High-Resolution Real-World Electricity Data from Three Microgrids in the Global South

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ABSTRACT

Microgrids are a promising solution for providing renewable electricity access to rural populations in the Global South. To ensure such renewable microgrids are affordable, careful planning and dimensioning are required. High-resolution data on electricity generation and consumption is necessary for optimal design. Unfortunately, real-world electricity data for microgrids in the Global South is scarce, and the little data that is available has a low temporal resolution. Therefore, in this paper, we introduce a unique high-resolution real-world electricity data set from three microgrids in the Democratic Republic of the Congo, Rwanda, and Haiti. The data has a temporal resolution of up to five seconds and focuses on microgrids with renewable generation from either hydropower or photovoltaic systems. Furthermore, we include data from both residential and industrial microgrids. We describe the recorded data and highlight the advantages of the high resolution. We demonstrate how this resolution offers insight into consumption patterns and enables the analysis of grid voltage and frequency, which is highly relevant for the planning and dimensioning of affordable renewable microgrids in the Global South.

CCS CONCEPTS

• **Applied computing**; • **Hardware → Power and energy**;

KEYWORDS

microgrid, energy time series, electricity data, load profile, electricity demand, high-resolution data, Global South, SDG7, Hydropower, PV, off-grid system, Africa, DR Congo, Rwanda, Haiti

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1 INTRODUCTION

In 2019, approximately 800 million people worldwide were without access to electricity with 74% of this population living in rural areas, especially in the Global South[1] [26]. Connecting this rural population to a public power grid is often complex and expensive [26] and thus, decentralised microgrids are an affordable alternative [11]. Therefore, it is expected that these decentralised microgrids will play a major role in expanding energy access in the Global South [11, 27]. These microgrids not only provide economic and social benefits to the consumers but also allow for the replacement of traditional fossil-based generators, e.g. diesel, with sustainable renewable generators, such as solar, hydroelectric, and wind power [6, 27, 34].

Given the potential for microgrids in the Global South to enable electricity access in a sustainable manner, developing methods to accurately plan and dimension affordable and renewable microgrids is crucial [7, 12]. Numerous tools for planning and dimensioning microgrids exist [13, 15, 23–25, 34, 38, 43], which all rely on modelling generation and load profiles and the related assumptions about the pattern and volume of electricity generation and consumption. Many tools utilise hourly resolved profiles due to data availability and simplicity, which is often sufficient, especially for grids with dispatchable power plants such as diesel generators. However, for microgrids with a high share of renewables, electricity data with a higher temporal resolution, i.e. one minute or higher, can be useful. For example, short term phenomena, such as short term power peaks and their effects on voltage and frequency stability can be investigated. The high-resolution data sets could also be used as input for simulations, for example, to design microgrids with tools

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[1] In this paper, we use the terminology "Global North" and "Global South" common to the development literature, cf. [31].

such as Offgridders [23] or to improve and validate inverter control algorithms. For tasks such as dimensioning the photovoltaic (PV) or battery inverter capacity, power lines, measurement equipment, and fuses or circuit breakers, high temporal resolution data is important as well, since hourly averaged power profiles underestimate short term power peaks.

Unfortunately, microgrid electricity data for the Global South is scarce, and the limited available data, e.g. [49, 50], only focuses on average hourly consumption patterns. Furthermore, existing electricity data focuses purely on residential microgrids, despite the importance of industrial consumers for microgrids in the Global South. Through the productive use of energy, industrial and commercial consumers often have the opportunity to refinance or even expand the microgrid and thus ensure a positive impact for the region in the long term [10, 29]. Another motivation for collecting real-world high-resolution electricity data is that if these industrial consumers see and understand when and how much energy they consume, they could significantly reduce the cost of the grid by adjusting their consumption behaviour to electricity generation through demand side management (DSM).

Although load profile modelling tools could provide a viable alternative to real data, these tools, e.g. [22, 36], also offer a low temporal resolution and focus almost exclusively on residential load profiles as well.

The present paper introduces high-resolution real-world electricity data from three microgrids in the Global South. From data loggers installed in microgrids located in the Democratic Republic of the Congo (DRC), Rwanda, and Haiti, we present open-source data[2] recorded with a resolution of either five seconds (DRC), or one minute (Rwanda and Haiti). The microgrid electricity data includes not only two residential microgrids in Rwanda and Haiti but also an industrial campus in DRC. The microgrids incorporate various renewable energy sources, such as hydropower in DRC and Rwanda, and photovoltaic generation in Haiti. We describe and analyse the characteristics of the recorded electricity data before highlighting the benefit of the high temporal resolution. We demonstrate that this high resolution offers more insight into consumption patterns, allows for an analysis of the voltage and frequency stability, and, as a result, is useful for the planning and dimensioning of affordable renewable-based microgrids in the Global South.

The remainder of the paper is structured as follows. In Section 2, we provide an overview of existing electricity data from the Global South detailing both load profile modelling tools and real recorded data. Section 3 then describes the design of the considered microgrids and how data is collected. In Section 4, we describe the recorded electricity data, consider power consumption characteristics, analyse variations in power, frequency, and voltage, and highlight the benefits of the high temporal resolution. Finally, we summarise our findings and discuss future work in Section 5.

2 EXISTING ELECTRICITY DATA FROM THE GLOBAL SOUTH

Currently, microgrid planning and dimensioning are based on either synthetically-generated load profiles or real measured data. In this section, we provide overviews of both load-profile modelling techniques and real-world electricity data from Global South microgrids.

Load Profile Modelling. There are numerous approaches to modelling microgrid load profiles, however, most of them are based on residential households in developed countries [37], or require extensive training data [5, 14, 33]. In the Global South, extensive training data is not available and whilst the consumption patterns of the high-income bracket mirror those of the standard residential household in a developed country [2], the patterns of typical households differ based on their socioeconomic status [3]. Therefore, alternative approaches with a focus on the Global South are required.

A summary of load profiling models focusing on the Global South is presented in Table 4 in Appendix A. Whilst numerous models exist, we observe that they all have a low temporal resolution of one hour, do not usually focus on microgrids, and almost always consider residential load. A detailed analysis of the identified load profile models can also be found in Appendix A.

Real-World Electricity Data. Whilst modelled load profiles can assist with microgrid planning and dimensioning, these are usually not given in a high temporal resolution necessary for renewable microgrids. Furthermore, real data contains anomalies and uncertainties [48] not accounted for in modelled load profiles, which may be important for the planning process. Therefore, ideally, real data should also be considered when planning and dimensioning a microgrid in the Global South.

In developed countries, there is a wide range of recorded consumption and generation data that can be used in the planning process [40, 42, 46], however, such data is scarce for the Global South. Table 1 presents an overview of the small number of identified real-world data sets focusing on the Global South. The temporal resolution of almost all data sets is hourly or lower with only Toussaint and Dekenah [47] considering a higher temporal resolution of five minutes. Further, only Williams et al. [49, 50] consider microgrid data, with the other data sets focusing on minigrids[3] [4, 41], or the main electrical grid for the country or region [17, 19, 21, 47]. Furthermore, all data sets focus solely on residential load profiles, and only Banerjee et al. [4] and Giles et al. [21] include solar generation profiles.

A key observation is that only Toussaint and Dekenah [47] provide raw data, although this data is only available with a data access agreement. All other data sets consist of average load profiles calculated on all available data [4, 21, 41, 49, 50], or all the data in a predetermined group of villages [17, 19]. From these load profiles, only Williams et al. [49, 50] and Scott and Coley [41] provide their data in an open-source format, whilst Dominguez [17] and Dominguez et al. [19] provide open-source metadata but not the recorded data.

We conclude that although real-world data focusing on electricity data for the Global South does exist, none of the identified data sets consists of openly accessible, measured data from a microgrid with a high temporal resolution.

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[2] The data is freely available at KITopenData under the DOI 10.5445/IR/1000143466 (DOI active after acceptance)

[3] In the present paper, we consider a microgrid as a grid with a capacity of 3 to 200 kW. On the other hand, a minigrid has a larger capacity and is also capable of connecting to the central grid to exchange power when not operating independently.

Table 1: An overview of real-world data sets concerning consumption and generation data for the Global South.

Paper	Location	Temp. Res.	Grid Type	Load Type	Averaging Performed	Load Profile	Gen. Profile	Raw Data	Open Source	Notes
[50] [49]	East Africa	Hourly	Micro	Residential	All data	✓	✗	✗	(✓)[1]	11 Microgrids. Tabular presentation. Variance according to season and day of week analysed in paper.
[41]	Tanzania	Hourly	Mini	Residential	All data	✓	✗	✗	✓	Data from two PV diesel hybrid mini-grids.
[4]	Koury, Mali	Hourly	Mini	Residential	All data	✓	Solar	✗	✗	Graphical representation. 556 households, average consumption level of 24 kWh per month.
[21]	Various[2]	Hourly-Monthly	Main	Residential	All data	✓	Solar	✗	✗	Monthly solar profile for USA and Bangladesh. Load profiles for a single house[3], small community, and village.
[17] [19]	Kenya	Hourly	Main	Residential	Each group	✓	✗	✗	✓	17 Rural villages in Kenya classified into four groups. Only survey metadata available.
[47]	South Africa	Five minute	Main	Residential	None	✗	✗	✓	(✓)[4]	Electrified houses with a focus on low-income households.

[1] Only with IEEE Xplore access, available through many tertiary institutes.

[2] Dominican Republic, Bangladesh, USA, India, Mexico, Philippines.

[3] The house was built for the purposes of the study and designed to replicate a typical load profile. However, it was the only household with a TV in the village leading to higher energy consumption than typical for the other houses in the village and is therefore not representative.

[4] Data (CC-BY-NC) may be available after conclusion of a data access agreement. Requirements for a successful data access agreement unclear.

3 MICROGRID DESIGN AND DATA COLLECTION

In the present paper, we introduce a sample of data collected from three real-world microgrids in the Global South. This data is, however, only useful when coupled with a description of the microgrids and knowledge of the data recording mechanism. Therefore, we introduce the considered microgrids and explain where and how the data loggers were used.

3.1 Design of the Microgrids

The first microgrid is an industrial campus in the Democratic Republic of the Congo (DRC), which is powered by a micro-hydropower plant (MHP) and alternatively a backup diesel generator (DG). The second microgrid is an MHP in Rwanda that provides electricity to households in a village community, and the third grid is a stand-alone PV system with battery storage that supplies an orphanage with electricity. In this section, we describe the design and layout of these three microgrids.

3.1.1 Industrial Campus with MHP+DG in DR Congo. The industrial campus is located in Kalenge, on the eastern coast of Idjwi Island in Lake Kivu in DR Congo, close to the border to Rwanda[4]. The campus is operated by the local development organisation PROLASA to offer apprenticeships, create jobs and improve the local value chain. The island has about 290,000 inhabitants [28] but is not connected to the public electricity grid of the mainland, partly due to its remote location. In the past, PROLASA has built a hydroelectric power plant[5] for the campus with an estimated capacity of 20 kW, however, this has not yet been sufficient to power all activities on the campus satisfactorily. A diesel generator with a capacity of 200 kW can alternatively supply the campus when energy-intensive processes that cover the cost of diesel consumption are carried out.

Several facilities are accommodated on the campus, including a wood and a metal workshop, a beverage production (including water purification, juice manufacturing and a PET blowing machine), a fish farm, two corn mills, a chicken farm with two hatcheries, and a coffee cooperative that processes coffee beans. In addition, there are approximately ten residential buildings as well as a guest house on the campus. The topology of the hydropower plant and the microgrid is shown in Figure 5 in Appendix B.

Most of the facilities on the campus are operated by PROLASA itself. The power of the installed equipment and machines exceeds the hydropower capacity by far. Therefore, it is not uncommon that consumption is adapted to the available electricity generation, for example, by coordinating the shifts of different facilities with each other. When energy-intensive tasks are performed, the diesel generator is used, which can supply the industrial grid instead of the hydroelectric power plant. This is done by turning a load switch at the feed-in point of the main distribution station, causing the grid to have a power outage for a few seconds to minutes. Electronic load controllers (ELC) with heating resistors ensure that the grid frequency does not exceed the nominal frequency of 50 Hz when the run-of-river hydropower plant (using a Bánki-Michell turbine), generates more power than is consumed. During the period of data collection, one or more ELCs were defective, which is why the grid frequency is often far above the nominal frequency.

3.1.2 Residential electricity supply with MHP in Rwanda. This microgrid in Nyakiramba in the eastern part of the Muhanga district in Rwanda is only fed by a small hydropower plant[6]. It is estimated to supply between 200 and 300 private households with electricity.

The local operating company, consisting of a technician, a hydraulic engineer and an accountant, offers different monthly tariffs

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[4] GPS coordinates: -2.0864, 29.0712

[5] GPS coordinates: -2.0925, 29.0689

[6] GPS Coordinates: -1.8811, 29.6804

for the surrounding households depending on the connection capacity (1 A, 2 A or 6 A). By far most households use the smallest connection, which is sufficient to power light bulbs and smaller devices such as cell phone chargers; some households also own television sets.

The MHP used to generate about 11 kW of electricity according to the operators, however, the generator was impaired in operation during the measurement campaign because two of its three-phase windings were defective. Provisionally, all three phases of the power grid were connected to one phase of the generator, so that they operate without a phase offset. During the measurement, about 3 to 4 kW were available. In addition, the ELC was broken in this microgrid as well, so that the grid frequency can exceed 50 Hz. However, since the power grid is relatively overloaded most of the time, the frequency is typically in the range of 30 to 50 Hz. The grid topology is shown in Figure 6 in Appendix B.

3.1.3 *Orphanage powered by PV + battery in Haiti.*

The third microgrid is a stand-alone PV system in Beaumont, Haiti. It provides electricity to an orphanage with approximately 35 children, a medical station and a canteen.

The system consists of 28 PV modules (4s7p) with a nominal power of 200 Wp each. Since the modules are already aged, in total only about 4.5 to 5 kWp are available instead of the nominal 5.6 kWp. A DC charge controller is used to charge wet lead-acid battery cells in an 8s2p configuration with a nominal voltage of 6 V and a nominal capacity of 428 Ah (in total 48 V / 856 Ah / 41.1 kWh). The usable net capacity of the cells is limited to 50 %. An inverter with a continuous power rating of 3.0 kVA (3.3 kVA for 30 min, 4.8 kVA for 5 seconds) powers the single-phase grid with a nominal voltage of 230 to 235 V and a nominal frequency of 50 Hz.

The electrical devices used on-site are two laptops, a fridge (for medication), a medical ultrasonography device, a medical steriliser (with a peak power of up to 2 kW), a water pump for the freshwater supply of the houses (550 W nominal), multiple LED light bulbs and mobile phone chargers. During the first twelve days of data logging (until the end of November), small electrical construction equipment and tools were used as well. The topology of the system is shown in Figure 7 in Appendix B.

3.2 Data Collection

To record the microgrid data we used two different types of data logging systems. The first type was only installed in the DRC industrial campus, the second type in both Rwanda and Haiti.

3.2.1 *DRC industrial campus.*

All measured electricity values (such as power, voltage, frequency, also see Table 5 in Appendix C) are recorded in the main distribution station every 5 seconds. The overall electricity demand of the campus supplied either by the hydropower plant or the diesel generator is recorded by a Schneider Electric PM5310 power meter at the feed-in point of the main distribution station. The outgoing power lines to the corn mill and the coffee factory are connected via Schneider Electric PM3250 power meters. All other outputs (metal workshop, wood workshop, fish farm, sub-distributions 1-3) are connected via Schneider Electric iEM3350 energy meters.

All data is read out via Modbus RTU from an Accuenergy AcuLink 810-868 Data Acquisition Server, which is connected to the WLAN of a GSM router, and sends the data to a remote server. On the server, the data is unpacked, processed and stored in a database, after which it can be visualised in a Grafana web interface.

3.2.2 *Microgrids in Rwanda and Haiti.*

At the other sites, enerserve SmartPi 2.0 are used, which log all measured values every minute. In Rwanda, two devices are used to measure the generation (between the generator and the load controller) and the consumption of all grid users (behind the load controller, out to the power line). However, due to the malfunctioning ELC, the measurements in generation and consumption are almost identical. In Haiti, only one device measures the consumption of all connected consumers at the output of the inverter. Via GSM routers the data is sent to the previously mentioned server as well.

4 MICROGRID DATA DESCRIPTION AND DISCUSSION

The high-resolution real-world electricity data introduced in this paper is available at KITopenData.[7] In this section, we describe and analyse this data.[8] Firstly we briefly describe the collected data, illustrating its key properties. In a second step, we analyse how variations in power consumption affect voltage and frequency stability. We then discuss the effect of the data resolution before presenting some of the challenges we encountered during the microgrid electricity data measurement campaign.

4.1 Data Description

Due to the differing capabilities of the different measurement devices, the limited data transmission rates between measurement devices and gateway, and to reduce data usage for cellular data transmission, not all measurement variables were recorded for each measurement point (see Table 5 in Appendix C). All locations include phase voltage (V_{ph}) and current (I) as well as active power (P) measurements. For three-phase grids, line-to-line voltages (V_{L-L}) are measured as well. For large consumers in DRC, the reactive (Q) and apparent power (S) is recorded, for all others only, the power factor ($P.F.$) is given. At least once per grid, the frequency (f) is acquired. The main distribution station in DRC also includes measurements of the total demand distortion (TDD), total harmonic distortion (THD) and harmonics ($H_{1/2/3/5/7/9}$).

Due to various factors, discussed in Section 4.5, all data sets contain periods during which no grid data could be collected. The duration and data availability is summarised in Table 2.

4.2 Power consumption

Table 3 summarises the properties of mean and peak power as well as daily energy consumption and variability for different days.

In the industrial DR Congo microgrid, the time step variability is comparatively low and the mean power is similar for weekdays and weekends. This is probably due to large consumers that draw

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[7] The data is freely available at KITopenData under the DOI 10.5445/IR/1000143466 (DOI active after acceptance)

[8] The data analysis code is available at https://git.scc.kit.edu/migs/microgrid-electricity-data-analysis.

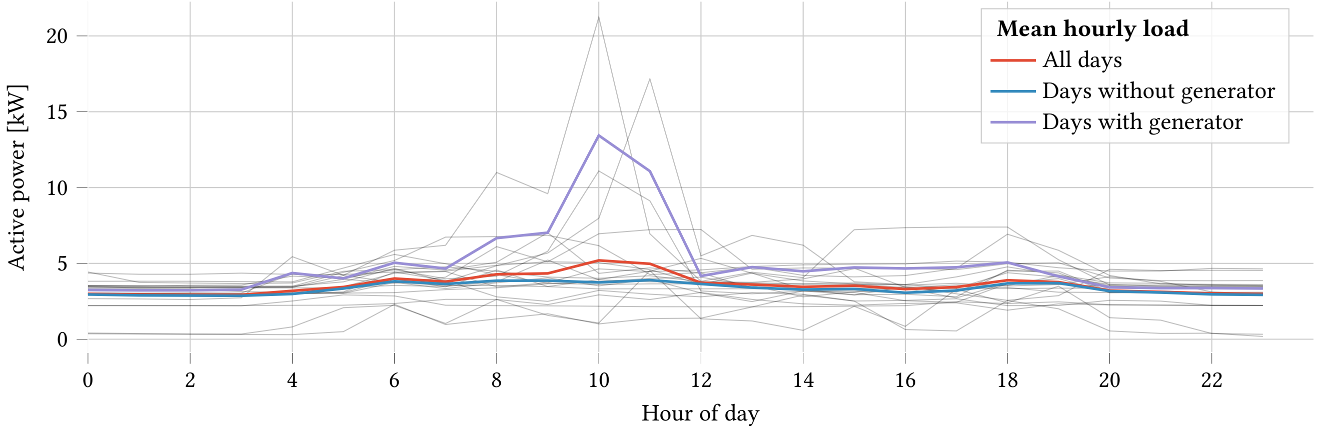

Figure 1: Overlay of daily power curves with hourly resolution (grey) and mean values of all days (red), days without diesel generator usage (blue) and with generator usage (purple) as representative load profiles

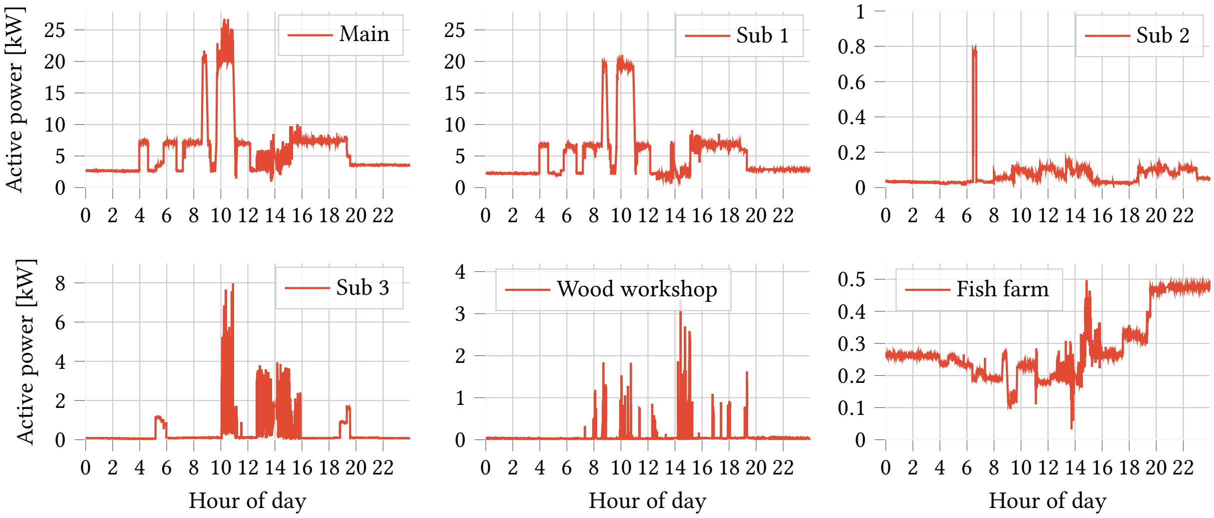

Figure 2: Active power consumption for all consumers (Main) and breakdown for the individual consumers (Wed, 9 Feb 2022)

Table 2: Properties of the data sets

	Duration	Entries	Availability	Resolution
DRC	35.6 days	399 620	64.94 %	5 s
Rwanda	17.8 days	24 856	97.19 %	60 s
Haiti	31.3 days	44 928	99.76 %	60 s

a relatively constant power over several hours or even days (especially the chicken hatchery). However, the peak power is higher on weekdays, because multiple facilities work in parallel. Some businesses are off on Saturdays, some on Sundays, and some on both days. The day-to-day variability is quite high. On some days the power consumption is significantly higher and for this purpose, the diesel generator is used, because the power of the MHP is not sufficient for some applications.

Demand curves of all days with hourly resolution can be seen in Figure 1. In Figure 2, both the overall active power demand in the main distribution station as well as the demand of individual consumers that were active at the time are shown for one specific day with the highest available resolution. Sub-distribution station 1 has the highest demand: We suppose that the chicken hatchery was running the whole day with relatively constant power and the water, juice and bottle production was active during the daytime. Over longer periods of time, short but quite high power peaks can be seen at distribution station 3 due to welding work. A similar pattern with lower peak powers is present for the wood workshop.

In the residential microgrid in Rwanda, the total power consumption is extremely uniform at about 3.1 kW almost all the time. We suspect that the reason for this is not on the demand side, but because the hydropower plant cannot produce more electricity, and the power demand would actually be much higher if more power was available. Consequently, the data from Rwanda presented in this paper are not very useful to generate load profiles.

Consumption in Haiti differs only slightly on weekends and weekdays, possibly because there are always children and staff in the orphanage consuming electricity. The high load peaks resulted from construction work that took place on the orphanage campus in the first weeks of data acquisition. After construction was completed at the end of November, the highest power peaks at minute resolution are at around 1 kW. They occur only on a few days and last only 1-3 minutes.

Table 3: Power and energy demand characteristics

		DRC	Rwanda	Haiti
Mean power $[kW]$	Mon-Fri	3.708	3.094	0.127
	Sat	3.244	3.081	0.132
	Sun	3.383	3.193	0.121
	All	3.590	3.106	0.127
Peak power $[kW]$	Mon-Fri	26.753	3.493	1.819
	Sat	6.142	3.602	2.354
	Sun	12.164	3.496	0.968
	All	26.753	3.602	2.354
Mean daily energy consumption $[kWh]$	Mon-Fri	88.994	74.253	3.051
	Sat	77.845	73.943	3.177
	Sun	81.187	76.635	2.911
	All	86.163	74.541	3.053
Day-to-day variability		31.26 %	4.19 %	21.78 %
Time step variability		17.35 %	1.91 %	57.02 %

4.3 Power, frequency and voltage variations

In Figure 3 and Appendix D, power, frequency and voltage curves of representative days of the three microgrids are shown. All grids are nominally 50 Hz and 230 V. Since the electronic load controllers of the hydropower plant in DRC are out of order, but the MHP provides sufficient power most of the time, the frequency in the grid is very high, often between 50 and 70 Hz (the electricity meter limits the measured frequency to 40 - 70 Hz even if the real frequency is outside of this range). The voltage is usually in the range of 200 to 250 V, but is often well below that at 170 V, transiently even well below 100 V. Frequency changes of more than 10 Hz over a time frame of 20 seconds as well as voltage drops and surges of 60 V and changes of power of 8 kW per 5 second time step can occur in the grid. In the wood workshop and for welding work (sub-distribution 3) the power fluctuates often by 1 - 4 kW per time step. When the diesel generator is used instead of the hydroelectric power plant, the voltage is stable at about 230 V and the frequency between 50 and 51 Hz.

The MHP in Rwanda supplies a large number of private consumers (about 200-300 households), each with a very small individual power (e.g. for light and for charging cell phone batteries). Due to the law of large numbers and the proportionally small contribution of most of the individual consumers, almost no abrupt changes in power, frequency and voltage occur (see Figure 8 in the appendix). However, there are large but smooth fluctuations: Especially in the evening hours between 6 and 10 PM, frequency and voltage drop significantly. This can be explained by the increased demand for electricity for lighting and charging cell phones. Since the entire available power plant capacity is used and there is no storage, the generated and thus also overall consumed power P_{tot} barely changes, only the distribution between the individual consumers is shifted (compare P_1 and P_2 in Figure 8). As mentioned before, the measured power does not represent the desired consumption but rather the maximum available power generation at any given time. The grid voltage measured at the MHP is usually very high (around 270 to 290 V) to compensate for the large voltage drop on the power line to the consumers.

In comparison, the voltage and frequency curves from the PV system in Haiti are comparable to an interconnected grid. The voltage varies only minimally between 230 and 235 V and the frequency is extremely smooth at about 49.995 ±0.002 Hz. This is because the PV system is completely sufficient for the current expansion of the campus, including its electrical consumers. With the aid of the battery and fast-acting power electronics, the inverter can regulate the frequency much faster and more precisely than the two hydroelectric power plants, which react mainly mechanically to power changes due to the missing electrical load regulators.

4.4 Advantages of the high data resolution

In Figure 4, we compare different temporal resolutions of the overall active power demand measurement of a typical weekday in the DRC grid. Power fluctuations due to large changes in consumption can hardly be detected in hourly resolved data, which also underestimates the magnitude of power peaks. This is also evident in the frequency (not shown): averaging underestimates short-term fluctuations, which are unfavourable for many industrial consumers. The same comparison for the Rwanda and Haiti grids can be found in figures 10 and 11 in Appendix E. As previously mentioned, there are no rapid changes in the power demand. Consequently, the resolution doesn't often play a large role in these grids.

4.5 Challenges of the data logging project

We encountered numerous difficulties during the installation and operation of the data loggers, and believe it worthwhile to record here the salient points for future projects and new energy metering equipment for microgrids.

We had intended to install more data loggers than the three documented here. However, without contact persons or intermediaries in the respective countries and regions, it is difficult to locate microgrids and establish contact with the operators. Furthermore, microgrids are mainly used in remote regions. Since it is often impossible to clarify all details of the grid, the generators, and distribution stations with the operators in advance and further, since it is often difficult to obtain components and tools in these regions, all steps and contingencies for installation of the equipment must be planned thoroughly.

Although some PV inverters offer the possibility to read out many grid parameters or, for example, the battery state of charge, this is often done via proprietary interfaces and cannot be integrated into the data acquisition with little effort, especially not when visiting new microgrids without much preparation and testing.

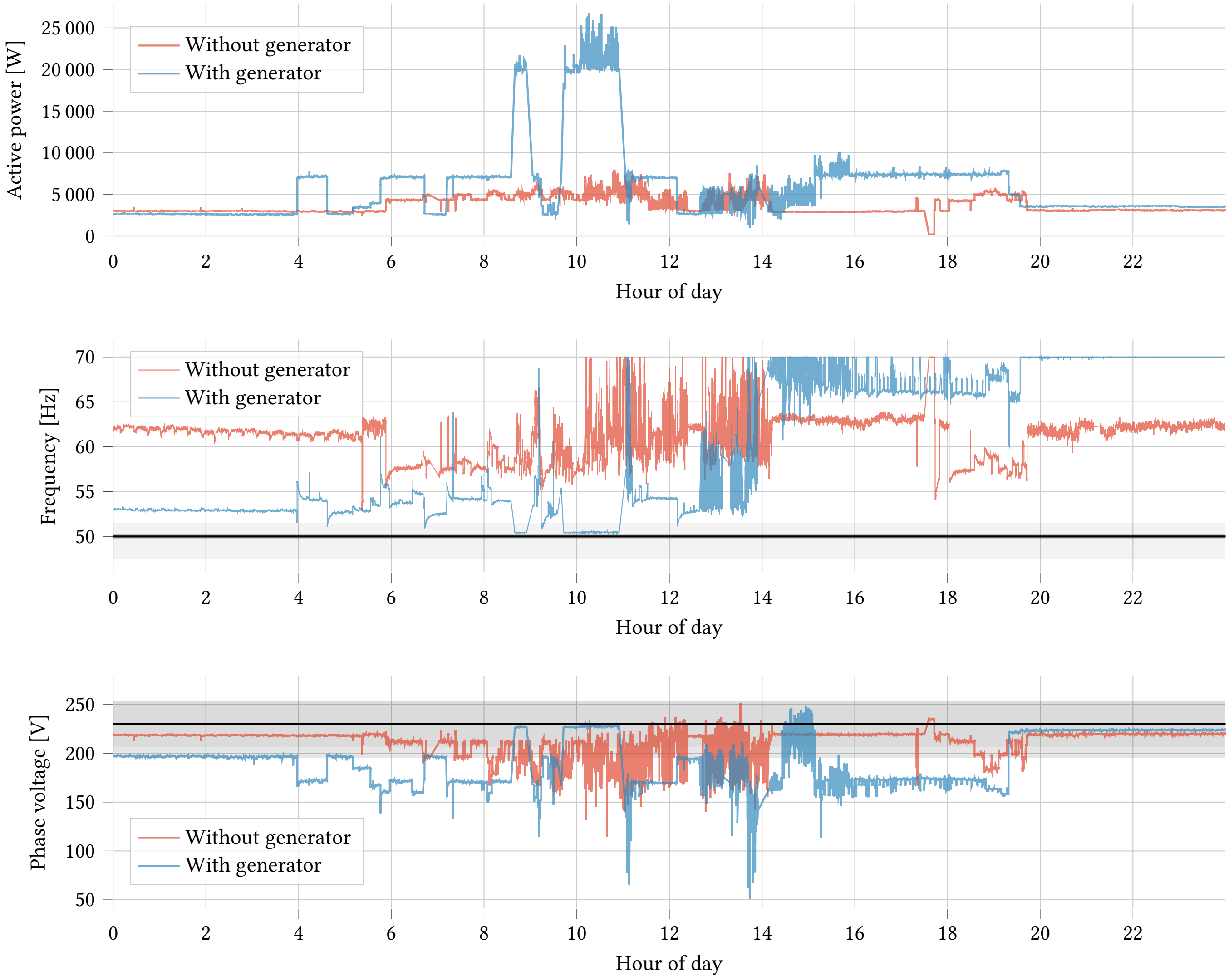

Figure 3: Voltage and frequency variations in the DRC microgrid on a day without diesel generator usage (Wed, 2 Feb 2022) and with generator usage at around 9 AM and 10-11 AM (Wed, 9 Feb 2022). For comparison, regular and irregular limits of frequency (49.8 to 50.2 Hz and 47.5 to 51.5 Hz) and voltage (−10 % or −15 % to 10 %) of the European integrated grid are marked semi-transparently in grey (see [20]).

Although many of the manufacturers of the measurement data acquisition equipment state that the devices work reliably, we found the user interface of one tested commercial device underdeveloped and experienced numerous bugs and sporadic outages despite many updates. In case of doubt, the selected equipment should be tested extensively well in advance before scheduling it for installation.

As described earlier, very high voltage and frequency fluctuations appear in some microgrids (especially in grids with small micro-hydropower plants). It may occur that these power plants are operated far outside usual grid specifications, either temporarily (e.g. in case of defects) or more or less intentionally (e.g. due to lack of available budget for repairs or better power lines and long delivery times for spare parts). Thus, the measuring instruments, as well as the power supplies, should be robust against very low and high voltages (e.g. 60 - 480 V) and also be able to measure atypical grid frequencies (e.g. 15 - 85 Hz). In the case of the microgrid in Rwanda, the GSM router power supply was damaged twice due to an overvoltage.

If data transmission via GSM is envisaged, it should be noted that mobile data tariffs with automatic renewal (i.e. without physical access to the SIM card) are not easy to obtain in every country or are only available to residents. In any case, it is extremely beneficial (or even a precondition for success) if there is a known local contact person in the grid (e.g. the grid operator or a technician) who has an intrinsic interest in data collection, e.g. for billing purposes or to better assess the condition of the grid.

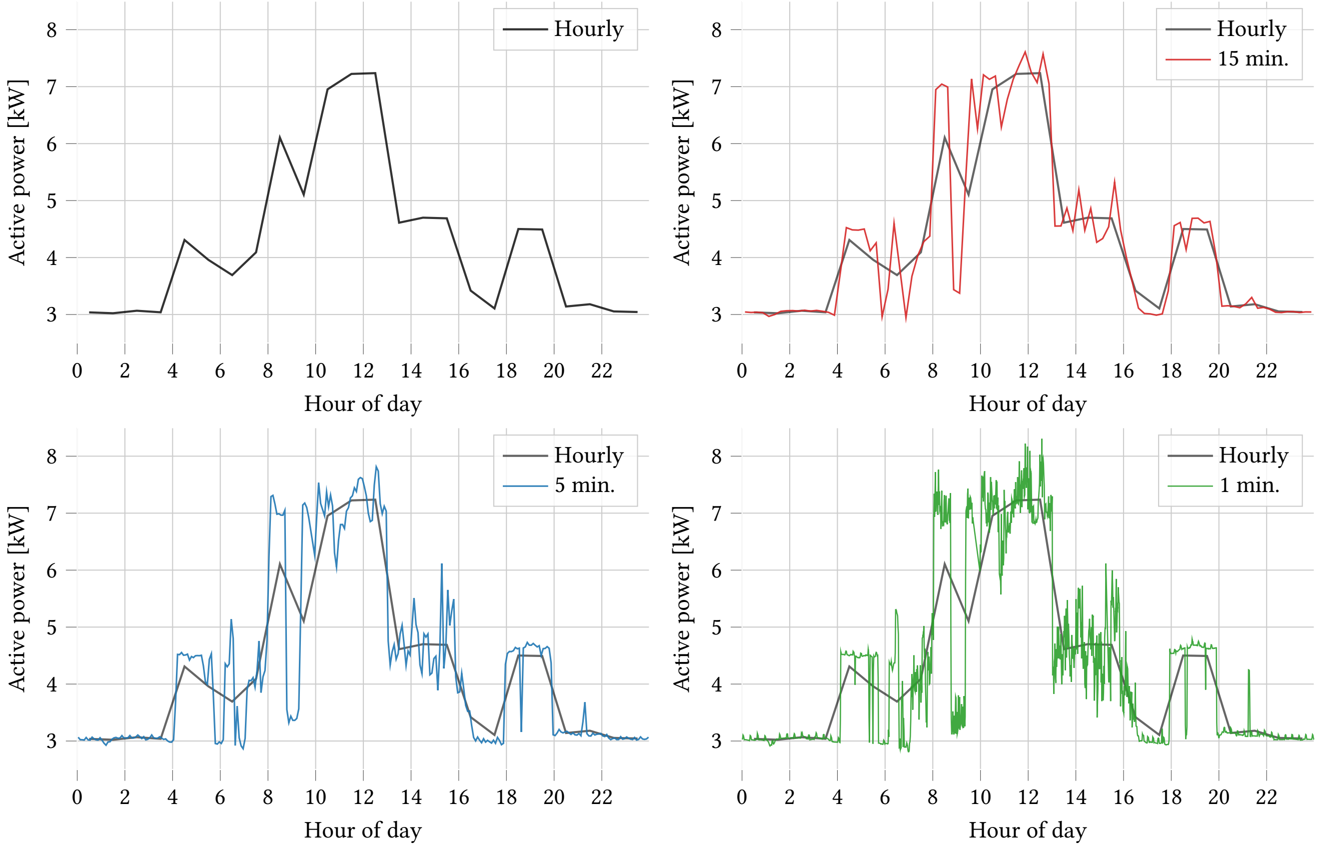

Figure 4: Comparison of the temporal resolution of the power demand in the DR Congo microgrid on Tuesday, 15 Feb 2022.

5 CONCLUSION

To assist with the planning and dimensioning of affordable renewable microgrids in the Global South, this paper introduces high-resolution real-world electricity data from three microgrids in the Global South. This data, with a temporal resolution of up to five seconds, is from an industrial campus in the Democratic Republic of Congo and two residential microgrids in Rwanda and Haiti. All three grids include renewable generation from hydropower or photovoltaic arrays. We describe and analyse the characteristics of the recorded microgrid electricity data and show benefits of the high temporal resolution. We demonstrate how this resolution offers extra insight into consumption patterns, allows for an analysis of the voltage and frequency, and, as a result, is useful for the planning, dimensioning and demand-side management of, and research into, affordable renewable-based microgrids in the Global South.

We believe the presented electricity data will be a valuable tool for microgrid planners now and in the future. Nevertheless, our data set is only a small step in the process of enabling the widespread development of affordable and effective microgrids in the Global South. To fully enable this development, a much broader data basis with electricity data from numerous diverse microgrids and covering a greater period of time is required. Although we hope to install further data loggers and collect more electricity data from microgrids in the future, we strongly encourage fellow researchers to publish any data they may have collected from microgrids, especially data from the Global South. We believe that access to electricity can only be increased in an affordable and sustainable manner if there is a concentrated joint effort in the research community to grow the open-source basis for data, software and information.

ACKNOWLEDGMENTS

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ACRONYMS

DG	Diesel Generator
DRC	Democratic Republic of the Congo
DSM	Demand Side Management
ELC	Electronic load controllers
MHP	Micro-Hydropower Plant
PV	Photovoltaic
SDG	Sustainable Development Goal
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
UN	United Nations

REFERENCES

[1] Omotola Adeoye and Catalina Spataru. 2019. Modelling and forecasting hourly electricity demand in West African countries. *Applied Energy* 242 (2019), 311–333. https://doi.org/10.1016/j.apenergy.2019.03.057

[2] Dilip Ahuja and Marika Tatsutani. 2009. Sustainable energy for developing countries. *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society* 2, 1 (2009). http://journals.openedition.org/sapiens/823

[3] Valeriya Azarova, Dominik Engel, Cornelia Ferner, Andrea Kollmann, and Johannes Reichl. 2018. Exploring the impact of network tariffs on household electricity expenditures using load profiles and socio-economic characteristics. *Nature Energy* 3, 4 (2018), 317–325. https://doi.org/10.1038/s41560-018-0105-4

[4] Sudeshna Ghosh Banerjee, Kabir Malik, Andrew Tipping, Juliette Besnard, and John Nash. 2017. Double Dividend - Power and Agriculture Nexus in Sub-Saharan Africa. (2017). https://openknowledge.worldbank.org/handle/10986/26383

[5] Christian Behm, Lars Nolting, and Aaron Praktiknjo. 2020. How to model European electricity load profiles using artificial neural networks. *Applied Energy* 277 (2020), 115564. https://doi.org/10.1016/j.apenergy.2020.115564

[6] Philipp Blechinger, Michel Köhler, Clara Jütte, Sarah Berendes, and Christine Nettersheim. 2020. Off-Grid Renewable Energies to achieve SDG-7 and SDG-13: Cheaper, Cleaner and Smarter. (2020). https://www.ruralelec.org/sites/default/files/Digital.pdf

[7] Philipp Blechinger, Elisa Papadis, Martin Baart, Pierre Telep, and Florian Simonsen. 2016. What size shall it be? A guide to mini-grid sizing and demand forecasting. (2016).

[8] Peter Boait, Varun Advani, and Rupert Gammon. 2015. Estimation of demand diversity and daily demand profile for off-grid electrification in developing countries. *Energy for Sustainable Development* 29 (2015), 135–141. https://doi.org/10.1016/j.esd.2015.10.009

[9] Gilbert Bokanga, Atanda Raji, and Mohammed Kahn. 2014. Design of a low voltage DC microgrid system for rural electrification in South Africa. *Journal of Energy in Southern Africa* 25, 2 (2014), 9–14. https://doi.org/10.17159/2413-3051/2014/v25i2a2664

[10] Samuel Booth, Xiangkun Li, Ian Baring-Gould, Diana Kollanyi, Abishek Bharadwaj, and Peter Weston. 2018. Productive Use of Energy in African Micro-Grids: Technical and Business Considerations. https://www.osti.gov/biblio/1465661

[11] Catherina Cader. 2015. Is a grid connection the best solution? Frequently overlooked arguments assessing centralized electrification pathways. Micro perspectives for decentralized energy supply (MES), Bangalore, India, 137–141. https://core.ac.uk/download/pdf/129975756.pdf

[12] Abhi Chatterjee, Daniel Burmester, Alan Brent, and Ramesh Rayudu. 2019. Research Insights and Knowledge Headways for Developing Remote, Off-Grid Microgrids in Developing Countries. *Energies* 12, 10 (2019). https://doi.org/10.3390/en12102008

[13] Pedro Ciller, Douglas Ellman, Claudio Vergara, Andres Gonzalez-Garcia, Stephen Lee, Cailinn Drouin, Matthew Brusnahan, Yael Borofsky, Carlos Mateo, Reja Amatya, Rafael Palacios, Robert Stoner, Fernando de Cuadra, and Ignacio Perez-Arriaga. 2019. Optimal Electrification Planning Incorporating On- and Off-Grid Technologies: The Reference Electrification Model (REM). *Proceedings of the IEEE* 107, 9 (2019), 1872–1905. https://doi.org/10.1109/JPROC.2019.2922543

[14] Adam J Collin, George Tsagarakis, Aristides E Kiprakis, and Stephen McLaughlin. 2014. Development of low-voltage load models for the residential load sector. *IEEE Transactions on Power Systems* 29, 5 (2014), 2180–2188. https://doi.org/10.1109/TPWRS.2014.2301949

[15] Nicholas Deforest, Goncalo Cardoso, and Thomas Brouhard. 2018. Distributed Energy Resources Customer Adoption Model (DER-CAM) v5.9. https://doi.org/10.11578/dc.20181016.2

[16] Marcus Dekenah and Schalk Heunis. 2019. Distribution Pre-Electrification Tool. https://doi.org/10.25375/UCT.7246673.V1

[17] Cristina Dominguez. 2020. Energy consumption patterns of rural households in Kenya. https://doi.org/10.3929/ETHZ-B-000455732

[18] Cristina Dominguez, Kristina Orehounig, and Jan Carmeliet. 2021. Estimating hourly lighting load profiles of rural households in East Africa applying a data-driven characterization of occupant behavior and lighting devices ownership. *Development Engineering* 6 (2021), 100073. https://doi.org/10.1016/j.deveng.2021.100073

[19] Cristina Dominguez, Kristina Orehounig, and Jan Carmeliet. 2021. Understanding the path towards a clean energy transition and post-electrification patterns of rural households. *Energy for Sustainable Development* 61 (2021), 46–64. https://doi.org/10.1016/j.esd.2021.01.002

[20] European Network of Transmission System Operators for Electricity (ENTSO-E). 2012. Network code for requirements for grid connection applicable to all generators – Requirements in the context of present practices. https://extranet.acer.europa.eu/Media/News/Documents/120626%20-%20NC%20RfG%20-%20Requirements%20in%20the%20context%20of%20present%20practices.pdf

[21] Brent Giles, Edward Skolnik, Brian Marchionini, and Ndeye Khota Fall. 2007. Remote Area Power Supply (RAPS) load and resource profiles. Sandia National Laboratories.

[22] S Heunis and M Dekenah. 2014. A load profile prediction model for residential consumers in South Africa. In *Twenty-Second Domestic Use of Energy*. IEEE. https://doi.org/10.1109/due.2014.6827763

[23] Martha Hoffmann and Reiner Lemoine Institut (RLI). 2022. Offgridders. https://offgridders.readthedocs.io/. https://offgridders.readthedocs.io/ Accessed: 2022-02-02.

[24] HOMER Energy. 2022. HOMER Pro. https://www.homerenergy.com/products/pro Accessed: 2022-02-02.

[25] Shamina Hossain-McKenzie, Matthew Reno, Johan Eddy, and Kevin Schneider. 2019. Assessment of Existing Capabilities and Future Needs for Designing Networked Microgrids. (2019). https://www.osti.gov/servlets/purl/1761847

[26] IIEA, IRENA, UNSD, World Bank, WHO. 2021. Tracking SDG 7: The Energy Progress Report. https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

[27] International Energy Agency. 2017. Energy Access Outlook 2017: From Poverty to Prosperity. (2017). https://doi.org/10.1787/9789264285569

[28] Ruben Jimenez-Redal, Germán Arana-Landín, Beñat Landeta, and Jaime Larumbe. 2021. Willingness to Pay for Improved Operations and Maintenance Services of Gravity-Fed Water Schemes in Idjwi Island (Democratic Republic of the Congo). *Water* 13, 8 (2021), 1050. https://doi.org/10.3390/w13081050

[29] Kathinka Kurz. 2014. The ABC-Modell: Anchor customers as core clients for mini-grids in emerging economies. https://www.german-energy-solutions.de/GES/Redaktion/DE/Publikationen/Praesentationen/2015/2015-03-19-iv-mini-grids-05-giz.pdf

[30] Nipon Ketjoy. 2005. *Photovoltaic hybrid systems for rural electrification in the Mekong countries*. Ph.D. Dissertation.

[31] Nicholas Lees. 2021. The Brandt Line after forty years: The more North–South relations change, the more they stay the same? *Review of International Studies* 47, 1 (2021), 85–106. https://doi.org/10.1017/S026021052000039X

[32] Xiangkun Li, James Salasovich, and Tim Reber. 2018. Microgrid Load and LCOE Modelling Results. National Renewable Energy Laboratory.

[33] Karen Byskov Lindberg, Steffen J Bakker, and Igor Sartori. 2019. Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts. *Utilities Policy* 58 (2019), 63–88. https://doi.org/10.1016/j.jup.2019.03.004

[34] Stefano Mandelli, Jacopo Barbieri, Riccardo Mereu, and Emanuela Colombo. 2016. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. *Renewable and Sustainable Energy Reviews* 58 (2016), 1621–1646. https://doi.org/10.1016/j.rser.2015.12.338

[35] Stefano Mandelli, Marco Merlo, and Emanuela Colombo. 2016. Novel procedure to formulate load profiles for off-grid rural areas. *Energy for Sustainable Development* 31 (2016), 130–142. https://doi.org/10.1016/j.esd.2016.01.005

[36] Gerro Johannes Prinsloo. 2016. Scoping exercise to determine load profile archetype reference shapes for solar co-generation models in isolated off-grid rural African villages. *Journal of Energy in Southern Africa* 27, 3 (2016), 11. https://doi.org/10.17159/2413-3051/2016/v27i3a1375

[37] Elisavet Proedrou. 2021. A comprehensive review of residential electricity load profile models. *IEEE Access* 9 (2021), 12114–12133. https://doi.org/10.1109/ACCESS.2021.3050074

[38] Mina Rahimian, Lisa D. Iulo, and Jose M. Pinto Duarte. 2018. A Review of Predictive Software for the Design of Community Microgrids. *Journal of Engineering* (2018). https://doi.org/10.1155/2018/5350981

[39] Marlon Schlemminger, Raphael Niepelt, and Rolf Brendel. 2021. A Cross-Country Model for End-Use Specific Aggregated Household Load Profiles. *Energies* 14, 8 (2021), 2167. https://doi.org/10.3390/en14082167

[40] Marlon Schlemminger, Tobias Ohrdes, Elisabeth Schneider, and Michael Knoop. 2022. Dataset on electrical single-family house and heat pump load profiles in Germany. *Scientific Data* 9, 1 (2022), 1–11. https://doi.org/10.1038/s41597-022-01156-1

[41] Nigel Scott and William Coley. 2021. Understanding Load Profiles of Mini-Grid Customers in Tanzania. *Energies* 14, 14 (2021). https://doi.org/10.3390/en14144207

[42] Stephan Seim, Paul Verwiebe, Katharina Blech, Christoph Gerwin, and Joachim Müller-Kirchenbauer. 2019. *Die Datenlandschaft der deutschen Energiewirtschaft.*

[43] Travis Simpkins, Dylan Cutler, Kate Anderson, Dan Olis, Emma Elgqvist, Michael Callahan, and Andy Walker. [n.d.]. REopt: A Platform for Energy System Integration and Optimization. In *8th Intl. Conf. on Energy Sustainability / 12th Intl. Conf. on Fuel Cell Science, Engineering & Technology*. American Society of Mechanical Engineers (ASME).

[44] Frances Sprei. 2002. Characterization of power system loads in rural Uganda.

[45] David Tinarwo. 2009. *Design of village power and micro-grids for rural areas of Zimbabwe with specific attention to voltage regulation on low voltage meshed distribution grids*. Kassel University Press GmbH.

[46] T Tjaden, J Bergner, J Weniger, and V Quaschning. 2015. Repräsentative elektrische Lastprofile für Einfamilienhäuser in Deutschland auf 1-sekündiger Datenbasis. *HTW Berlin* (2015).

[47] Wiebke Toussaint and Marcus Dekenah. 2019. Domestic Electrical Load Metering, Hourly Data 1994-2014. https://doi.org/10.25828/56NH-FW77

[48] Long Wang, Yong Ding, Till Riedel, Andrei Miclaus, and Michael Beigl. 2017. Data analysis on building load profiles: A stepping stone to future campus. In *Proc. 2017 International Smart Cities Conference (ISC2 2017)*. https://doi.org/10.1109/ISC2.2017.8090823

[49] Nathaniel J. Williams, Paulina Jaramillo, Kieran Campbell, Brian Musanga, and Isaiah Lyons-Galante. 2018. Electricity Consumption and Load Profile Segmentation Analysis for Rural Micro Grid Customers in Tanzania. In *2018 IEEE PES/IAS PowerAfrica*. IEEE. https://doi.org/10.1109/powerafrica.2018.8521099

[50] Nathaniel J. Williams, Paulina Jaramillo, Benjamin Cornell, Isaiah Lyons-Galante, and Ella Wynn. 2017. Load characteristics of East African microgrids. In *2017 IEEE PES PowerAfrica*. IEEE. https://doi.org/10.1109/powerafrica.2017.7991230

A OVERVIEW OF LOAD MODELLING TOOLS

In this section, we provide a more detailed analysis of the identified load modelling tools. We firstly observe that the majority of the identified methods are based on mathematical models aiming to recreate the load profile with simple equations. Another approach is to model load profiles with simple regression methods [22]. Both the mathematical models and regression approaches do not require large amounts of data. On the other hand, machine learning approaches do require more data, such as presented by Schlemminger et al. [39], where these methods are used to generate synthetic regional or national load profiles, and Dominguez et al. [18], where multiple data sources are collated to develop synthetic residential lighting load profiles. These two approaches however either use European data for training [39] or rely on the assumption that lighting load is an accurate proxy for electricity load [18].

All identified tools for load profile modelling focusing on the Global South work with an hourly temporal resolution, which, as pointed out in the introduction, is rather low for the planning and dimensioning of renewable microgrids.

With regards to the load type, Table 4 shows that the majority of the considered load profile modelling tools focus on residential houses [8, 18, 22, 32], or aggregated regional or national load [1, 39]. In comparison, Mandelli et al. [35] designed a synthetic load profile for a college in a rural village in Cameroon, and Prinsloo [36] focuses on synthetic models for aggregated village load. Such aggregated village loads are possibly the best representation for a microgrid; however, the model presented by Prinsloo [36] is not open-source, and although it is based on observations and analysis from existing data [9, 30, 44, 45], this existing data is either not publicly available or is data obtained from simulated systems.

In summary, we see that whilst some load profile modelling tools with a focus on the Global South do exist, they all have a low temporal resolution. Furthermore, they do not usually focus on microgrids, and almost always consider only residential load.

Table 4: An overview of load profile modelling tools focusing on the Global South.

Paper	Target Region	Model Type	Temporal Resolution	Load Type	Generation Profile	Open Source	Notes
[36]	Africa	Mathematical	Hourly	Aggregated village load	✗	✗	Based on observations in [9, 30, 44, 45].
[22]	South Africa	Regression	Hourly	Residential houses	✗	✓	Model implemented in the Distribution Pre-Electrification Tool [16].
[8]	Minigrid, rural	Mathematical	Hourly	Residential	✗	✓	Designed for integration with HOMER. Includes seasonal variations.
[32]	Sub-Saharan Africa	Mathematical	Hourly	Residential	✗	✓	Various income levels possible. Distributed as an Excel worksheet.
[35]	Rural off-grid	Mathematical	Hourly	College	✗	✓[1]	Bottom-up stochastic based approach. Verified at a college in Cameroon.
[1]	Western Africa	Mathematical	Hourly	Aggregated national load	✗	✗	Electricity demand model. Neither model nor verification data publicly available.
[39]	Multiple	Machine Learning	Hourly	Regional or National	✗	✓[2]	Focus on European countries.
[18]	East Africa	Machine Learning	Hourly	Residential lighting load	✗	✓	Assumes that lightning accounts for almost all electricity needs.

[1] Code is open-source, however, requires Matlab to run.

[2] The resulting load profiles for European countries are distributed, however, the model itself is not.

B GRID TOPOLOGY

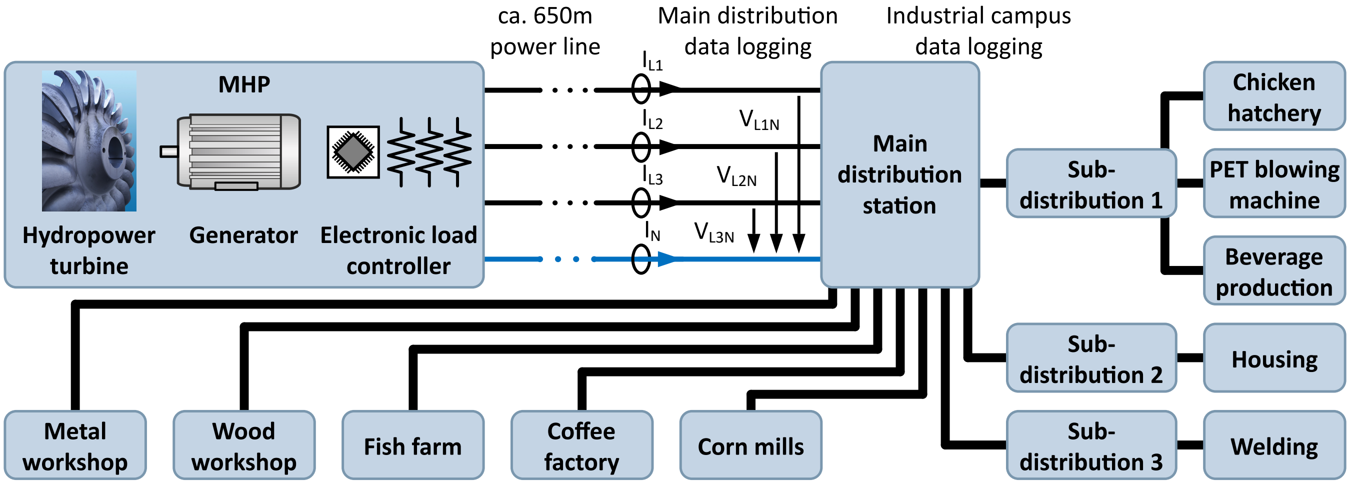


Figure 5: Grid topology of the industrial campus in DR Congo supplied by a micro-hydropower plant and a diesel generator

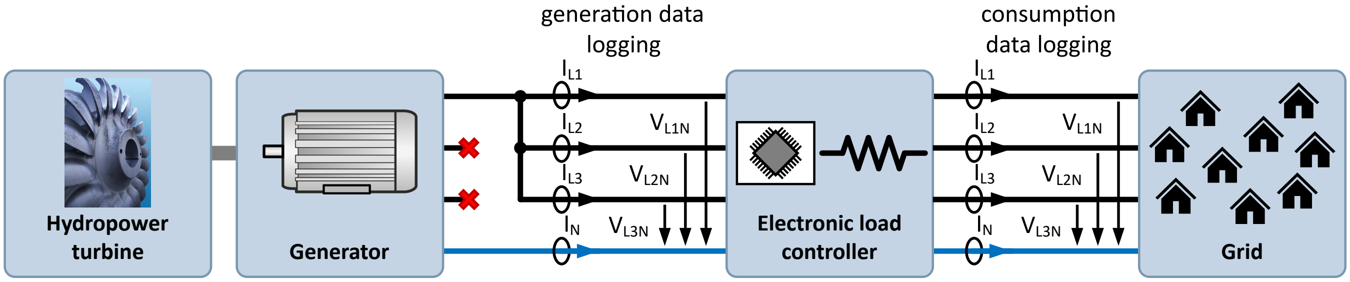


Figure 6: Grid topology of the residential microgrid in Rwanda supplied by a micro-hydropower plant

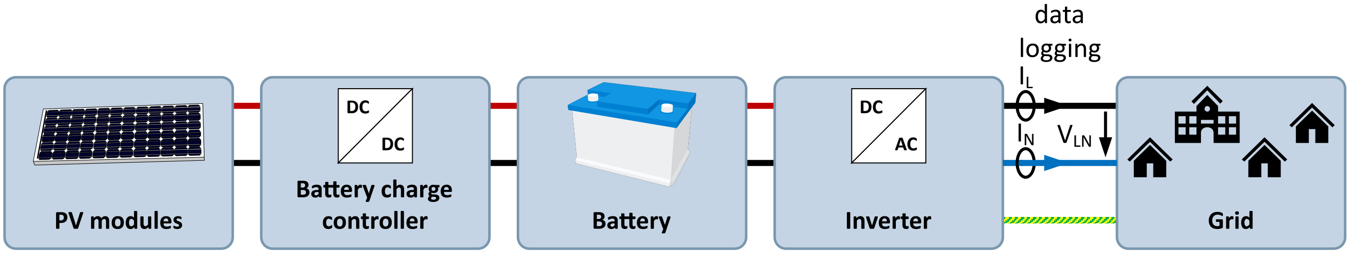


Figure 7: Grid topology of the PV system of the orphanage in Haiti

C ACQUIRED MEASUREMENT DATA

Table 5: Overview of acquired measurements

Location	V_{ph}	V_{L-L}	I	P	Q	S	$P.F.$	f	TDD	THD	$Harmonics$
DRC											
Main distribution	✓	✓	1/2/3/N	1/2/3/tot.	1/2/3/tot.	1/2/3/tot.		✓	✓	✓(V+I)	✓(V+I)
Corn mills[1]	✓	✓	1/2/3/N	1/2/3	1/2/3	1/2/3					
Coffee processing[1]	✓	✓	1/2/3/N	1/2/3	1/2/3	1/2/3					
Sub-distribution 1	✓	✓	1/2/3	1/2/3			avg.				
Sub-distribution 2	✓	✓	1/2/3	1/2/3			avg.				
Sub-distribution 3	✓	✓	1/2/3	1/2/3			avg.				
Fish farm	✓	✓	1/2/3	1/2/3			avg.				
Metal workshop	✓	✓	1/2/3	1/2/3			avg.				
Wood workshop	✓	✓	1/2/3	1/2/3			avg.				
Unused connection[1]	✓	✓	1/2/3	1/2/3			avg.				
Rwanda											
Generation[2]	✓		1/2/3	1/2/3			1/2/3	✓			
Demand[2]	✓		1/2/3	1/2/3			1/2/3	✓			
Haiti											
Demand	✓		1	1			1/2/3	✓			

[1] Unfortunately, these consumers were not used during the recording (no power consumption).

[2] Since the electronic load controllers in Rwanda are out of service, generation and demand data approximately look the same.

Sub-distribution 1: Beverage production (juice/water), PET bottle production, chicken incubator, storage rooms, residential housing
Sub-distribution 2: Residential housing
Sub-distribution 3: Outdoor power plug (mostly used for welding)

D FREQUENCY AND VOLTAGE VARIATIONS

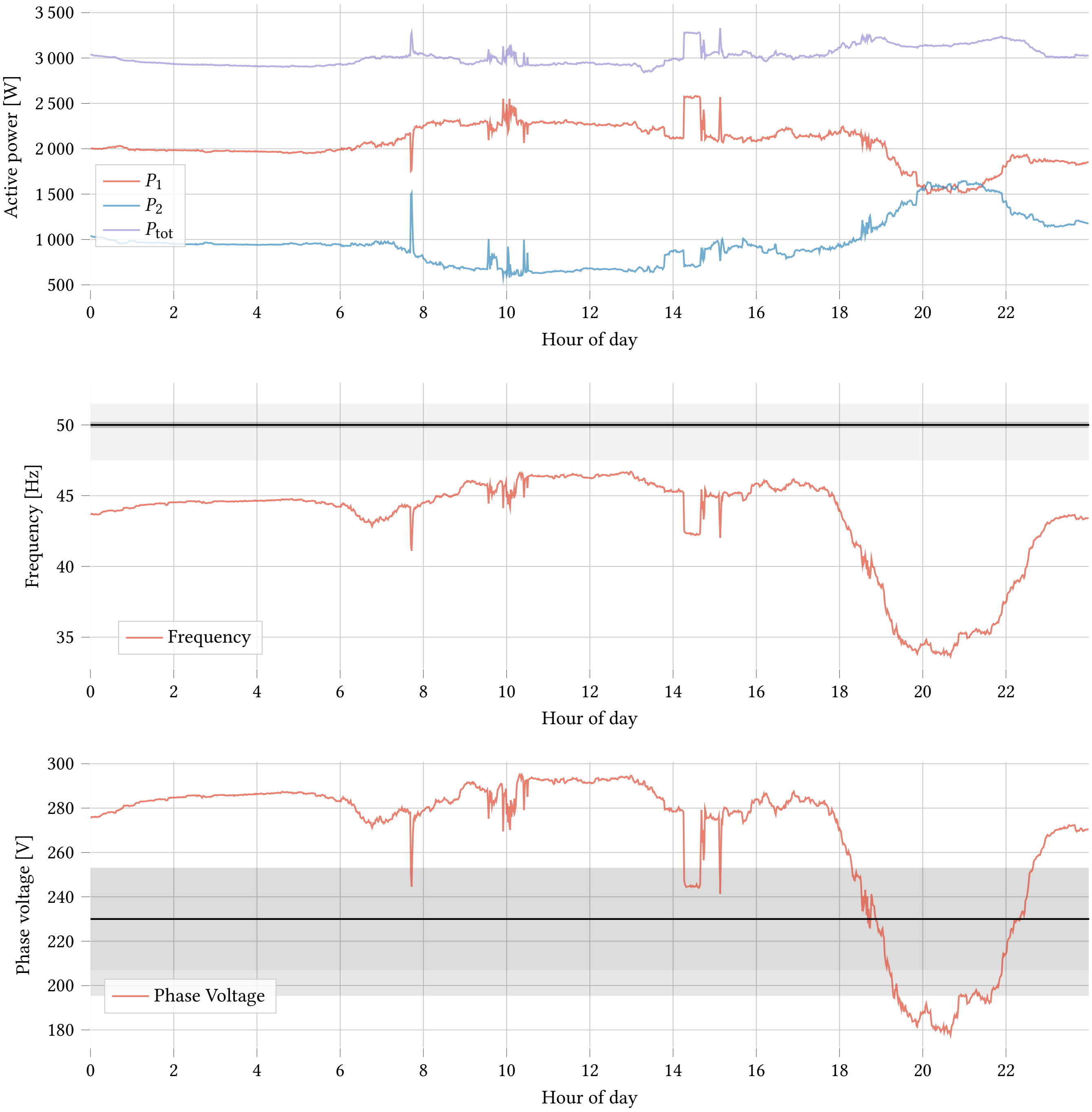


Figure 8: Voltage and frequency variations in the Rwanda microgrid (Thu, 25 Nov 2021). Since the total power consumption P_{tot} is limited by the generated power of about 3 kW, the powers P_1 and P_2 of the two sub-grids are also plotted to show indications of changes in power demand.

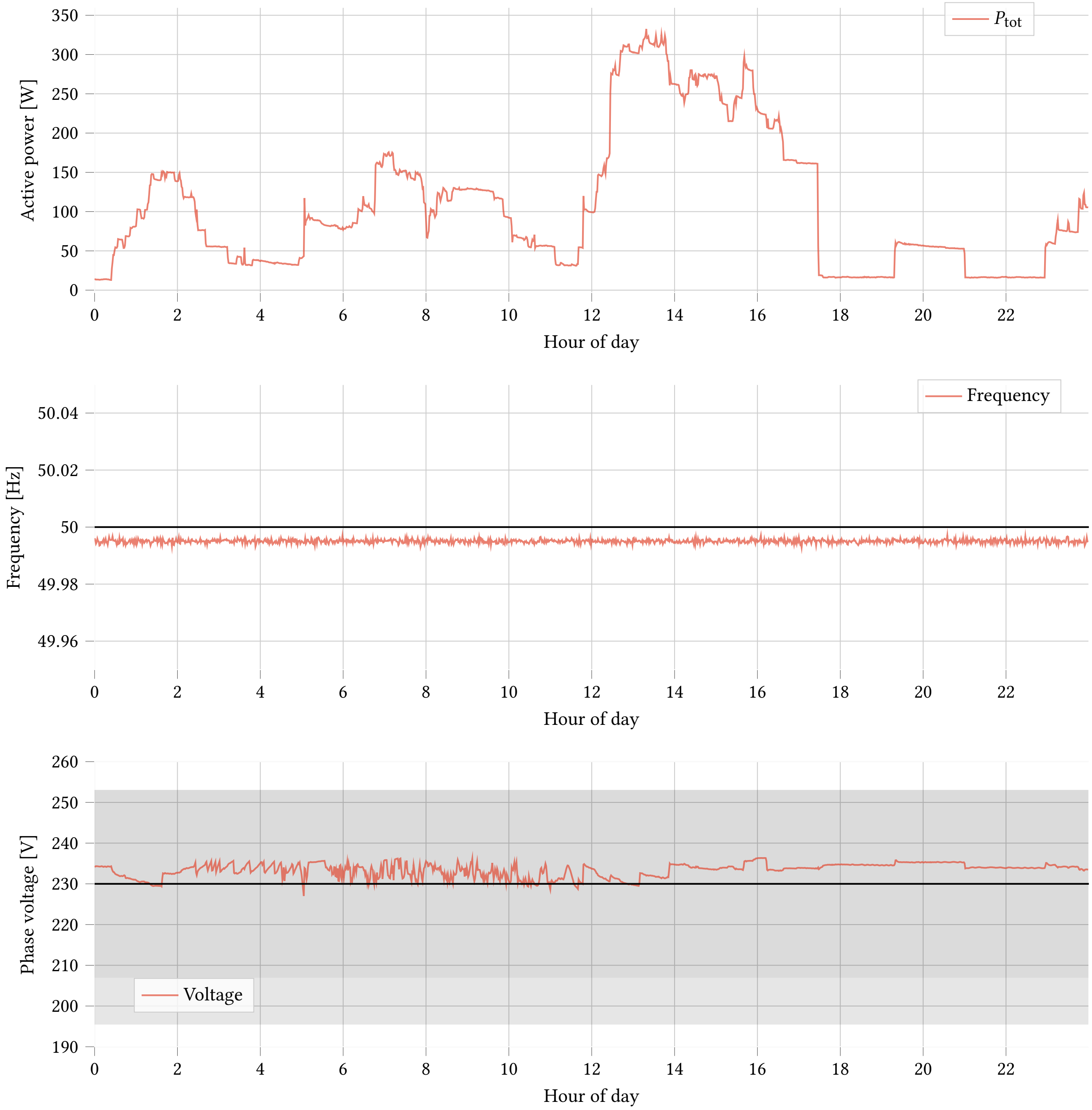


Figure 9: Voltage and frequency variations in the Haiti microgrid (Tue, 14 Dec 2021)

E TEMPORAL RESOLUTION OF POWER MEASUREMENTS

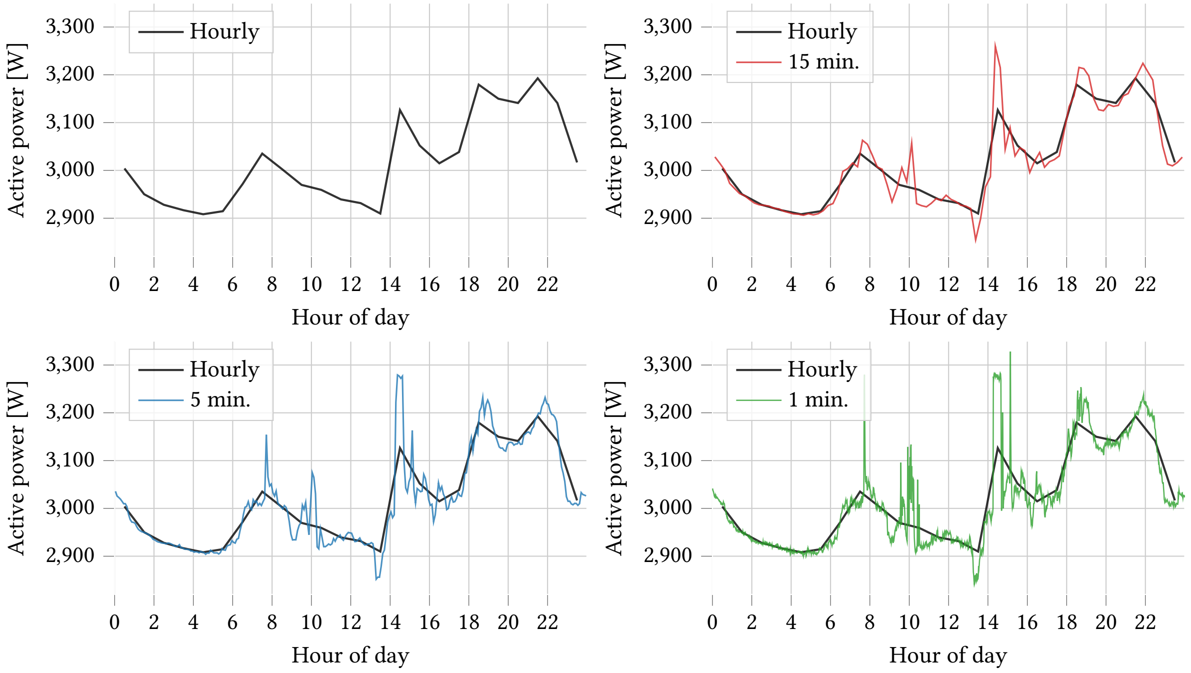


Figure 10: Comparison of the temporal resolution of the power demand in the Rwanda microgrid on Thursday, 25 Nov 2021

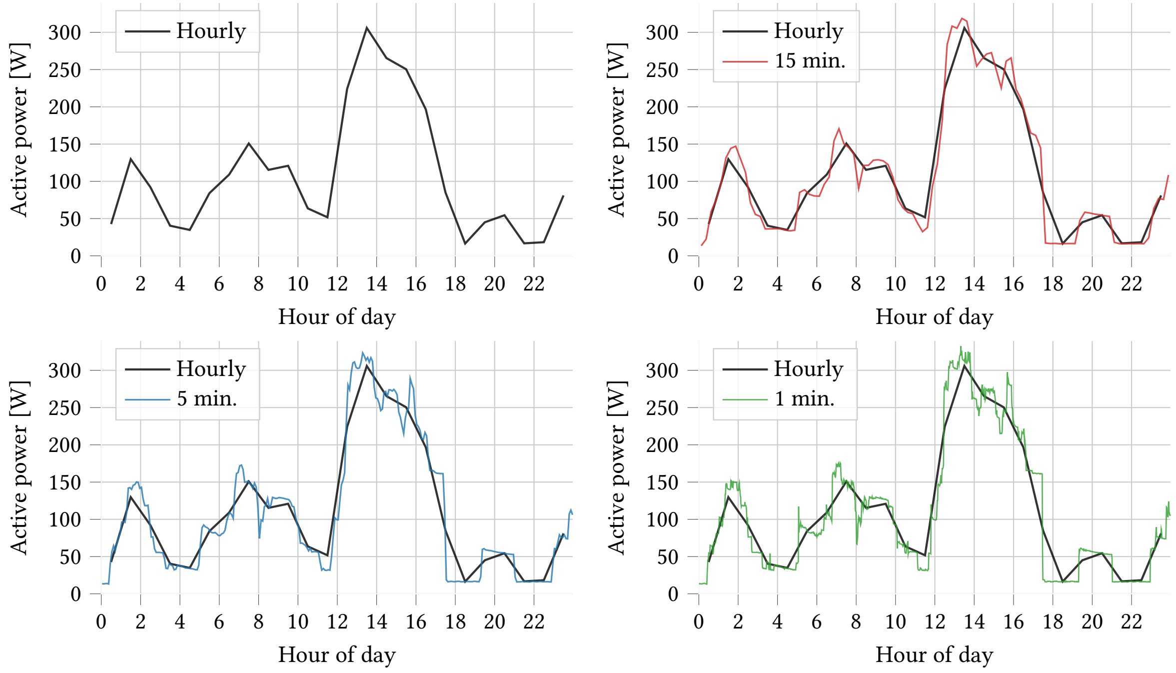
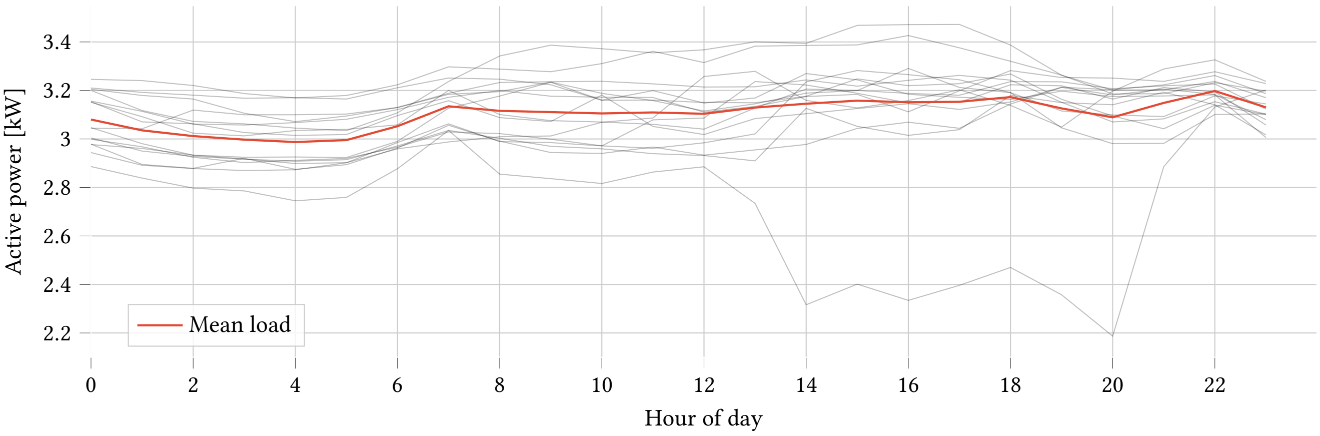
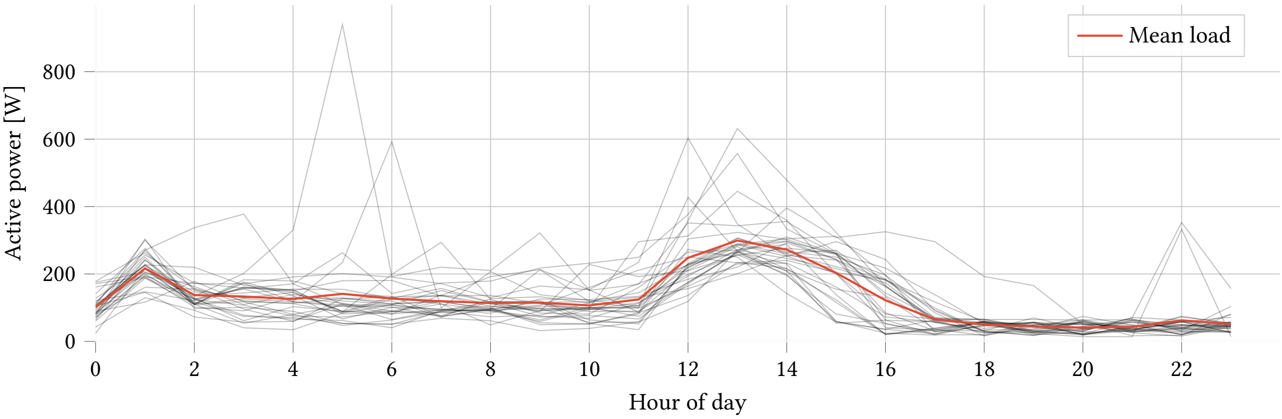


Figure 11: Comparison of the temporal resolution of the power demand in the Haiti microgrid on Tuesday, 14 Dec 2021

F DAILY LOAD OVERLAYS



(a) Rwanda



(b) Haiti

Figure 12: Overlay of daily power curves of the DR Congo microgrid with hourly resolution (grey) and mean values (red) as a representative load profile

Table 6: Derived load profiles of the three microgrids in kW.

Hour		DRC		Haiti	Rwanda
	All	Without generator	With generator		
0	2.994	2.950	3.247	0.101	3.080
1	2.940	2.890	3.221	0.217	3.035
2	2.931	2.879	3.225	0.138	3.012
3	2.926	2.866	3.267	0.133	2.997
4	3.191	2.984	4.366	0.126	2.987
5	3.443	3.343	4.009	0.141	2.995
6	4.003	3.819	5.045	0.127	3.053
7	3.795	3.642	4.660	0.119	3.135
8	4.280	3.859	6.666	0.114	3.116
9	4.339	3.865	7.026	0.115	3.111
10	5.198	3.744	13.436	0.107	3.105
11	4.975	3.898	11.080	0.124	3.109
12	3.723	3.644	4.168	0.248	3.104
13	3.607	3.404	4.754	0.299	3.130
14	3.454	3.274	4.477	0.272	3.145
15	3.530	3.318	4.733	0.203	3.158
16	3.305	3.065	4.666	0.122	3.151
17	3.440	3.210	4.741	0.065	3.153
18	3.888	3.681	5.064	0.050	3.173
19	3.767	3.701	4.143	0.044	3.126
20	3.210	3.172	3.424	0.041	3.089
21	3.123	3.079	3.370	0.043	3.149
22	3.020	2.958	3.372	0.062	3.198
23	2.987	2.924	3.345	0.051	3.130