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Smart metering and energy access programs: an approach to energy poverty reduction in sub-Saharan Africa

Bennour Bacar
EECE Department
Cape Peninsula University of Technology
Cape Town, South Africa
221601430@mycput.ac.za

Ali Almaktoof
EECE Department
Cape Peninsula University of Technology
Cape Town, South Africa
almaktoofa@cput.ac.za

Abdurazag M. Khalat
EEE Department
Sabratha University
Sabratha, Libya
a.khalat@sabu.edu.ly

Mohamed K. Elmezughi
EECE Department
University of KwaZulu-Natal
Durban, South Africa
m.k.elmezughi@gmail.com

***Abstract*—Access to electricity is a global challenge, with more than half of the energy-poor population located in sub-Saharan Africa alone. By considering energy access frameworks designed for the planning of energy systems for these environments, such as the Sustainable Energy Access Planning (SEAP), this study aims to analyse and evaluate the applicability of smart metering (SM) technologies and actual energy data to this framework. Data applicability to each SEAP assessment component and for monitoring is investigated. For a specific sub-Saharan country, secondary energy data is collected to define an energy profile used as input to the SM experiment to generate new, simulated data. The analysis then focuses on how this primary energy data applies to the different SEAP framework components, and as input to related applications for renewable energy system analysis and load forecasting. Current results show how usage patterns can be identified from interval-based consumption data to define energy demand, cost, and affordability, while also used to derive environmental data towards the benefit and sustainability aspects of the energy system to be implemented; moreover, network quality and energy system status is measured with real-time usage and alarm data.**

Keywords*— *energy access, energy poverty, smart metering, sub-Saharan Africa

I. INTRODUCTION

In 2019, near 761 million people in the world had no access to electricity, with over 53% in sub-Saharan Africa (SSA). Despite overall economic growth, the impact is more significant within the rural population, with only 28% being able to use electricity [1].

Access to electricity is essential for human and economic growth; in this context, global access to modern energy services was made a universal 2030 goal by the UN, with the Global Tracking Framework (GTF) of the Sustainable Energy for All (SE4ALL) initiative setting a common outline that defines access to electricity as "availability of an electricity connection at home or the use of electricity as the primary source for lighting" [2], [3]. In particular, the Sustainable Energy Access Planning (SEAP) framework, released by the Asian Development Bank, aims to address the energy access challenge by creating an energy supply system that is socially inclusive and provides sustainable access to a minimum amount of energy for the basic needs, for both poor and non-poor households [3]. In this framework, assessments are conducted on energy poverty, energy demand, energy resources, cost, benefits, sustainability, and affordability; furthermore, the SEAP elements indicated include key measures in common: electricity consumption, demand profile, usage patterns, as well as aspects of modern energy supply services such as availability (can be used), reliability (available most of the time), affordability (non-prohibitive cost), quality (e.g., level of voltage), and convenience (safe and available when needed) [3].

The energy data required for energy access pre-implementation planning requirements and post-implementation monitoring and tracking of energy systems are often acquired from surveys and historical data, which could be missing, estimated, non-contextual, old, or insufficient. This paper, therefore, aims to analyse the use of smart metering technologies to collect household energy data, with emphasis on the applicability of real data to different components of the energy access framework. In contrast with other studies that have evaluated smart metering and energy access either separately, or from a developed country perspective, the proposed approach analyses the data-acquisition features of smart metering technology to the framework of an EAP, to aid energy planners in effectively extracting, interpreting, and use the data that derives from all the features a smart meter and applications can provide, adding value not only to the EAP itself but ultimately and most importantly, to those who need access to modern energy in sub-Saharan Africa.

The paper is structured as follows. Section II provides an overview of the literature for the two main components of this study, i.e., smart metering and the SEAP framework. The data acquisition methodology follows in section III. The experiment is presented in section IV, with the results and discussion provided in section V. In Section IV finally, a conclusion is given in the form of significance and contributions.

II. LITERATURE OVERVIEW

A. Smart Metering

With the continuous advancements in technology SM has, as shown in Fig. 1, evolved from just essential manual meter readings to integrating modern smart grids with

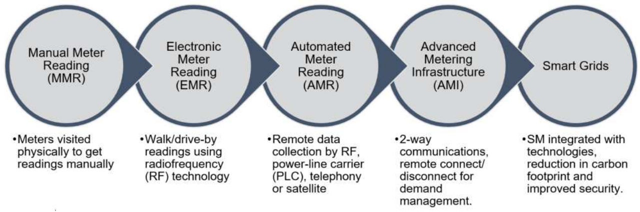


Fig. 1. Smart metering evolution [4].

elements such as distributed generation, prosuming, and electric vehicle charging stations while playing a more active role in reducing carbon footprint [4].

A typical SM system can be described by Fig. 2, as one consisting of smart meters, control devices, appliances, a communication link, and a control centre [5]; in some cases also includes energy measurement taken at a point of distribution for an area [6].

According to [7], further to improving utilities' operation efficiency and quality of supply (QoS), SM systems lead to increased consumer satisfaction and participation; moreover, key benefits include:

1) Utilities: Reduction in aggregated technical and commercial losses (AT&C), Lower costs of labour, purchasing power, and connection/disconnection, improved power quality, asset management, and generation cash flow, enhanced anomaly detection and overall grid visibility, integration with renewable energies, and demand management.

2) Consumers: accurate bills, ability to monitor electricity consumption and to control and manage home/office appliances, and electricity bill savings through the implementation of time-of-use (ToU) tariffs.

3) General: ability to introduce value-added services, and reduced carbon footprint by minimizing physical presence for meter readings.

The smart meter stands as the central element of the SM system, as the device with energy metering and intelligence combined [5] to record energy data from an endpoint (e.g. a household) and send it to the software application (middleware) remotely over communication mediums that include Global Systems for Mobile Communications (GSM), General Packet Radio Service (GPRS), Power Line

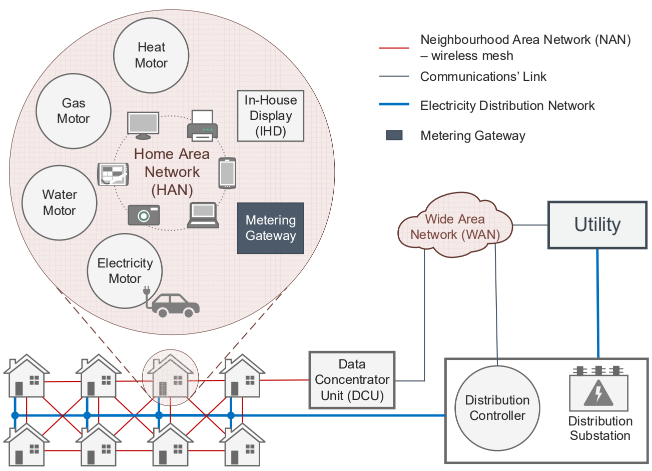


Fig. 2. Smart metering system components, based on [4].

Carrier (PLC), Radio Frequency RF, among others [8]; or if required, locally via interfaces such as an infra-red (IR) optical probe [9].

On a more recent note, since the emergence of COVID-19 and the periods of lockdown, information and communication technologies (ICT) were key in mitigating the impact of the pandemic on day-to-day activities; remote meter readings via smart metering systems reduced the exposure of personnel to COVID allowing utilities to still be able to timely and accurately bill consumers [10], while energy usage data collected from the meters pre-, during and post-COVID allowed for further analysis into consumer behaviour during these 3 periods, as studied by [11].

B. Energy Access Programs: The SEAP Framework

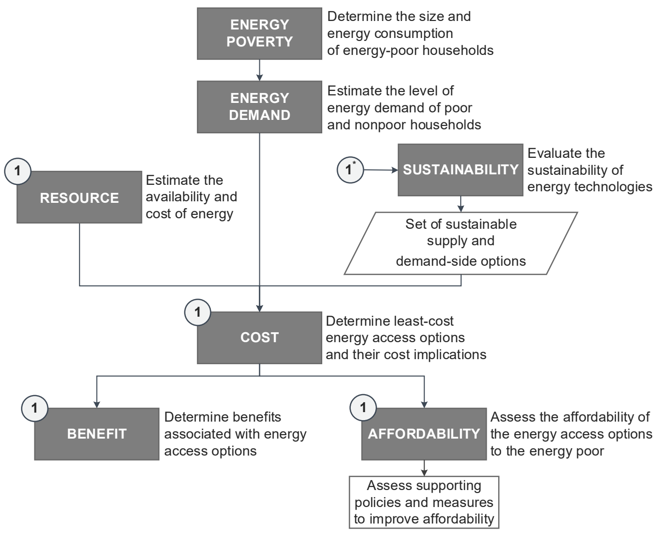
A key component in planning out the ideal solution for an EAP, the sustainable energy access planning (SEAP) is a framework that aims to identify technologies and resources which are sustainable and cost-effective, toward "providing universal access to basic energy services and to assess the affordability of cleaner-energy service options to energy-poor households" [3]; it stands out from conventional energy and electricity planning frameworks through the following features, in particular for developing countries in the Middle East and sub-Saharan Africa regions:

1) Oriented to social inclusiveness: considers the poorest households (HHs) in terms of access to electricity and other cleaner energies for necessities such as lighting, heating, and cooking.

2) Approaches both poor and non-poor HHs: contemplating the minimum acceptable level of essential energy services for the earlier, while considering energy demand access through econometrics and other conventional approaches for the latter.

3) Affordability: evaluates the economic implications of even the more cost-effective options in the supply of electricity and other clean energies to the poor.

4) Safeguards EAPs' quality and sustainability: locally analyzes acceptable, reliable, and sustainable cleaner energy options.



*The resource, cost, benefit and affordability assessments are also inputs to sustainability.

Fig. 3. Flow diagram of the SEAP framework assessments [3].

5) Generates key data: on requirements for investment, along with EAP benefits concerning the reduction of energy inequality and greenhouse gases (GHGs), as well as improving environmental quality and social well-being.

6) Sustainability and reliability: ensures EAP continuity by analyzing how acceptable, reliable, and sustainable the options of clean-energy services are.

Seven assessments establish the SEAP framework. As illustrated in Fig. 3, the links between each assessment are vertical, sequential, and horizontal as the resource, cost, benefit, and affordability assessments provide inputs required for the sustainability assessment.

C. Considerations

Smart metering and energy access have been addressed separately in literature; a particular study by [12] analysed a smart meter's capability to address energy poverty within the context of a developed world HH, with data provided by the utility. This study takes an approach to energy poverty for the least developed and developing countries in SSA by directly using the smart metering system (meter, communications, software) to record and collect low-tier (Table IV) energy consumption data and then explore its applicability to an energy access framework that is relevant to those countries.

III. Data Acquisition Methodology

The following segments describe the methodology proposed for the research, explaining the research design, sampling method, data collection, data analysis, and ethical considerations.

A. Research design

This study involves primary and secondary data generated from the smart meter and on existing databases from countries, implemented EAPs, and a quantitative research method has been used. The data is primarily on energy consumption over time and other related variables. [13] indicates that any data collection or data analysis procedure that produces or utilizes numerical data defines as quantitative; moreover, stating primary as new, purpose-specific data, and secondary as previously collected data for other purposes, but both significant towards answering the research questions. Fig. 4 shows the components of the experiment, as secondary data provides the energy profile to render detailed energy data scenarios on the smart meter using a variable load, resulting in new primary data for further analysis (which still includes secondary data).

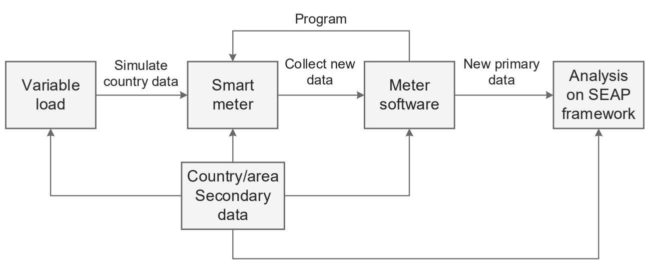


Fig. 4. Steps of the proposed method to collect and analyse the data on SEAP.

B. Sampling method

Decreasing the amount of data by collecting it from a smaller group, instead of all probable cases (Table I), is achieved by implementing sampling techniques; furthermore, sampling allows for improved accuracy compared to a census [13]. Simple random probability sampling has been used in this research, based on the criteria described by [8, pp. 216-218], with the resulting random numbering removing the bias factor from the data.

TABLE I. Selecting Samples

Sampling frame	Country or country area in sub-Saharan Africa
Selection criteria for country	Availability and detail of secondary data, energy poverty severity
Case or element	Region/area within the country
Sample size	278 – 370, based on a population range of 1000 – 10 000 and within a 5% margin of error [13]. The specific size depends on the availability and detail of EAP and other relevant data necessary for the energy profile.

C. Data collection

Collected secondary data is derived from multiple sources, based on area and time series, such as government publications, books, journals, and industry statistics [13]. Some sources would include organizations such as the country's local website and statistics, The World Bank, International Energy Agency, International Renewable Energy Agency, and others. Primary data is acquired from an experiment based on examining energy profile data collected from the secondary data over a period of 1 to 3 months; this data includes variables such as, but not limited to:

1) Energy data: interval consumption profile per household, supplied electricity, quality of supply and renewable energy data.

2) Demographic data: population, number of households, electricity access, and energy poverty.

In [13], it was stated that the experiment is a research method related to the natural sciences; and that it is often carried out in laboratories instead of in the field, allowing greater control over elements of the research process such

TABLE II. Quantitative Analysis Approach, Based On [13]

Analysis component	**Approach**
Data preparation, input, and verification	*Data type*: quantifiable and categorical, sub-categories applicable based on the country data and metering data available.
	Data layout: mostly tabular (data matrix), in software-compatible formats such as CSV, XLS, and XLSX. Other less common forms may include PBI (Power BI) and IPYNB (Python).
Exploring and presenting data	*Exploration*: Variable statistics, such as maximum, minimum, median, average, standard deviation, distributions.
	Presentation: Tabular, histogram, box plot, bar, line, or pie charts, based on the data type.
Describe data applying statistics	*Relationships*: Scatter chart, correlation, related to possible regression analysis on energy data
Examining differences, trends, and relationships by applying statistics	*Predict values*: Regression analysis on energy data provided by the smart meter (benefit highlight).

as the selection of samples and the experiment occurrence context.

D. Data analysis

Quantitative analysis is applied for both primary and secondary data in this study, using statistical methods and tools such as, but not limited to, Excel, Python, Jupyter, Power BI, and Azure ML, as indicated in Table II. The analysis included the country/area data, the simulated data from the smart meter experiment, and the mapping/relationship with the SEAP framework components.

IV. Experimentation

A. Secondary data: analysis

Located in Western Africa, with a population close to 24 million [14] and the third-lowest electric energy consumption per capita in the world [15], Niger was the country selected to acquire secondary data, summarized in Table III.

According to the multi-tier framework (MTF) for electricity access based on minimum thresholds for energy services (Table IV), the average household in Niger would fall under tier 2. However, seeing that only 7.72 percent of the rural population, which is the majority in the country at nearly 84 percent of the total population, has access to electricity [17], consideration has to be given to the lower tiers. This is corroborated by the fact that not only the rural areas lack access to modern energy services, but the urban areas with possible connectivity also face challenges with unreliable and poor access [18]; moreover, [2] indicates that elements like the variety of appliances and energy efficiency would not accurately be reflected by a kilowatt-hour based indicator, with some household-level MTF as a key measure to get data on electricity access progress. This is where technology such as smart metering would aid with data collection and a more accurate energy profile.

TABLE III. Niger Energy And Household Data For 2014

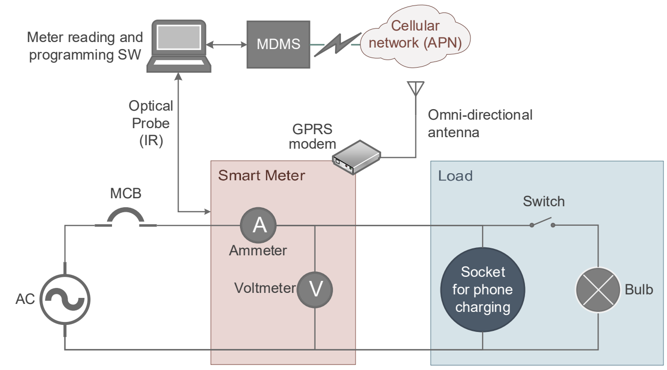
Indicator	Value	Unit	Source
Access to electricity: total population	15.77	% of population	[1]
Average household (HH) size	6	Member/HH	[16]
Electricity consumption per HH	307.14	kWh	[15], [16]

TABLE IV. Multi-Tier Matrix Of Access To Electricity Services And Consumption For A Household, Based On [19]

Tier	Electricity services	Annual consumption (kWh)
0	-	< 4.5
1	Task lighting + Phone charging	≥ 4.5
2	General lighting + Phone charging + TV + Fan	≥ 73
3	Tier 2 + any medium-power appliances	≥ 365
4	Tier 3 + any high-power appliances	≥ 1 250
5	Tier 4 + any very high-power appliances	≥ 3 000

B. Primary data: simulation

Based on the country profile collected, the system illustrated in Fig. 5 was built to simulate data for a household, with the following main components:



*AC = Alternate Current, APN = Access Point Name, MCB = Miniature Circuit Breaker, MDMS = Meter Data Management System, SW = Software.

Fig. 5. Designed system to simulate tier 1 data for a household.

1) *Smart meter:* a three-phase, direct connection meter of accuracy class 1 that measures bi-directional active and reactive power, load profile, billing and demand registers, network monitoring, among others; and this data can be accessed locally via Liquid Crystal Display (LCD) screen, optical probe (infrared port) and serial (RS232 or RS485 type ports), or remotely via GSM*/GPRS*/ Ethernet modem.

2) *The load:* based on MTF's tier 1 for a household, it includes a bulb (initially a 60W incandescent, then replaced by a 9W LED) and a socket to charge a mobile phone. These elements are used randomly during the day, based on the need for lighting or charging.

3) *MDMS*:* set up on a daily schedule to remotely collect meter data via GPRS modem.

4) *Computer (PC):* used to access the data via MDMS and to locally/remotely program and read the meter (for more detailed data) via meter configuration SW.

V. Results And Discussion

A. Local access: meter SW and optical probe

Using the meter SW, as indicated in Table V, the load (LED bulb rating), the energy register count (for consumption), and meter status could be verified and monitored. For a measurement-transformer-connected meter, parameters such as the current transformer (CT) and voltage transformer (VT) ratios would've also been included.

Event data is key to monitoring the network for factors such as QoS. Fig. 6 shows a detailed case of a power cut, accurately logged on from the time when the alarm was raised for a phase-cut, then a power cut, to restoration; from this data it could be deduced that the power cut lasted for exactly 6 minutes and 58 seconds. These are important measures to the SEAP framework as they define and track factors such as reliability, convenience, and adequacy of supply to a household.

TABLE V. USAGE READINGS AND METER STATUS

Parameter	Value/message	Observation
Real-time: Import active power, P+	8 W	Only the 9W LED bulb was on (no phone charging).
Real-time: Export active power, P-	0 W	No exported quantities, only imported from the grid.
Real-time: Import reactive power, Q+	0 var	No reactive quantities, despite LED bulb.
Real-time: Export reactive power, Q-	2 var	No exported quantities, only imported from the grid.
Real-time: Power factor	1.0	No reactive quantities, despite LED bulb.
Register: Import active energy, A+	2899 Wh	Energy register count since the start of measurement
Register: Export active energy, A-	0 Wh	No exported quantities, only imported from the grid. No reactive quantities, despite LED bulb.
Register: Import reactive energy, R+	0 VArh	No reactive quantities, despite LED bulb.
Register: Export reactive energy, R-	0 VArh	No exported quantities, only imported from the grid. No reactive quantities, despite LED bulb.
Date and time: meter	2022/02/14 20:40:00	Synchronized, otherwise it would result in inaccurate data.
Date and time: PC	2022/02/14 20:40:11	The PC's time was used to synchronize the meter time.
Alarms: Fatal		Not present. A fatal alarm indicates a severe problem with the meter, requiring removal and testing.
Alarms: Non-fatal	• Network voltage unbalance detected. • Voltage cut detected in phase 2. • Voltage cut detected in phase 3.	Only 1 phase is being used, hence the absence of voltage in the remaining phases.

Type	Setting	ID	Date	Time
Register data saved in Flas	SAVE POWER UP	762	Sunday, 13 February	19:22:49
AC fail signal disappearanc	PRESENCE PHASE	761	Sunday, 13 February	19:22:46
Non fatal alarm disappeara	Alarm Type : VOLTAGE CUT PHA	760	Sunday, 13 February	19:22:46
Power up		759	Sunday, 13 February	19:22:46
Power fail signal raised		758	Sunday, 13 February	19:15:48
AC Fail signal raised	PHASE CUT	757	Sunday, 13 February	19:15:48
Non fatal alarm raised	Alarm Type : VOLTAGE CUT PHA	756	Sunday, 13 February	19:15:48
Non fatal alarm raised	Alarm Type : VOLTAGE SAG PHA	755	Sunday, 13 February	19:15:48

Fig. 6. Network monitoring through event data.

B. *Remote access: MDMS via GPRS*

The MDMS provided different types of reports and views for the data analysis. The graph in Fig. 7 showed some of the insights based on collected load profile data so far, with three load scenarios and related events:

1) The initial load from 17/01/2022: a 60 W, 548 lumens (lm) incandescent bulb applied.

2) An increase in usage from 29/01/2022: introduction of phone charging.

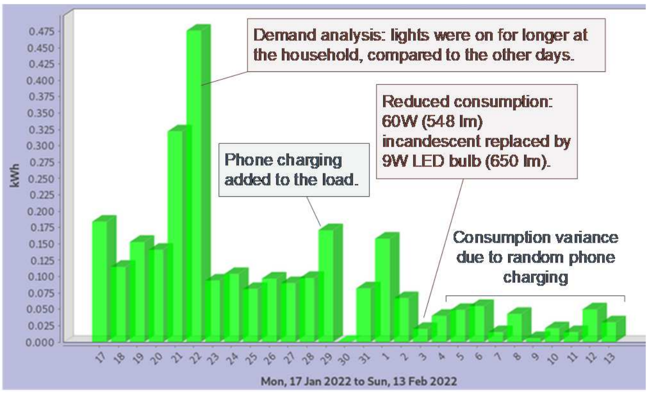


Fig. 7. Daily consumption analysis (kWh per day).

3) A decrease in usage from 03/02/2022: incandescent bulb replaced by a 9W, 650 lumens Light Emitting Diode (LED).

The data from the last scenario measures and highlights the use of efficient options for demand-side technology in the SEAP framework [20]: at a consumption 6 times lower (9 W) while providing more light, the LED lamp is more efficient and cost-effective [21], addressing important factors of affordability (for both lamp and electricity bill) and adequacy (low power rating).

Observing the load profile further to a higher data resolution (every few hours to an hour, to half an hour), consumption patterns were identified; Fig. 8 shows a demand higher for both charging and lighting occurring in the evening, as well as a stable voltage level. This level of granularity would assist in addressing the affordability issue by implementing improved electricity tariffs [20] that benefit the energy-poor while optimizing the tariffs for the non-energy poor.

The United Nations refers to the importance of providing, where viable, energy access from low GHG emission sources [3]; besides just energy, the data acquired from the smart metering system can also be used as an input to generate environmental data. Applicable to the sustainability factor, such is the case of the environmental impact report on Table VI generated from the MDMS that shows, based on constants set out by the local utility and the specified consumption period, the emission and utilization

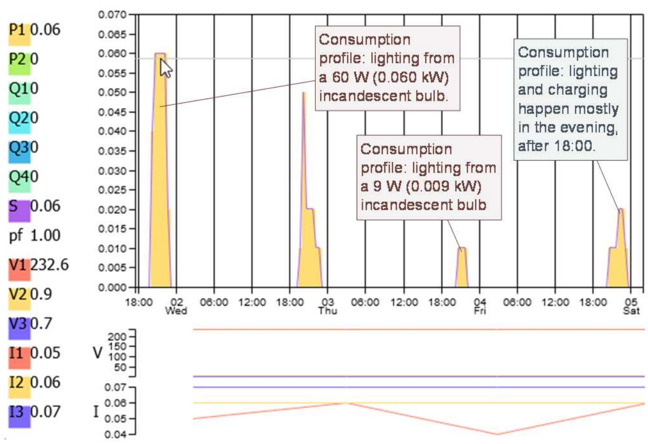


Fig. 8. Half-hourly usage analysis.

TABLE VI. ENVIRONMENTAL IMPACT (BASED ON SOUTH AFRICA).

Implication	2022-01-17 16:00 to 2022-02-13 20:30	Daily Average	Monthly Average
Ash produced	0.427954 kg	0.015740 kg	0.479112 kg
CO2 emissions	2.733389 kg	0.100538 kg	3.060140 kg
Coal use	1.463329 kg	0.053823 kg	1.638256 kg
NOx emissions	0.011540 kg	4.244958 kg	0.012920 kg
Particulate emissions	9.111299 kg	3.351282 kg	0.001020 kg
SO2 emissions	0.021397 kg	7.870436 kg	0.023955 kg
Water use	0.003865 kl	1.421756 kl	0.4327

values for the different compounds; if taking 2 elements of the report, for the nearly 27 days of household consumption, close to 3 kg of CO_2 was released and 4 litres of water were used to generate the required electricity.

VI. CONCLUSION

Energy poverty is a reality in many of the least developed and developing countries in SSA. The data collected and analysed through the SEAP framework in this RiP highlighted, so far: (i) demand, affordability and cost: interval-based consumption data identified usage patterns that could be used to make electricity more affordable through improved tariffs or home appliances/devices (efficiency); (ii) benefit and sustainability: environmental data derived from energy data quantified the impact of energy technologies to the environment; (iii) monitoring and sustainability: real-time usage (such as power) and alarms (e.g., voltage cuts per phase) provided readings and events that could not only measure QoS but also aid in identifying and taking preventive action on issues with the implemented energy system. This paper coupled the data-acquisition features of smart metering technologies with energy access methods, contributing to energy planners in effectively extracting, interpreting, and using real energy data towards implementing and sustaining an optimal energy system for the energy-poor. It is a ripple effect that will be valuable to the EAP, implementation, tracking, but ultimately and most importantly, to those who need access to modern energy. While continuous and accurate data collection will help build a database for reference and forecasting, technology limitations such as communications, as well as the local know-how to use and maintain such technologies are challenges to take into consideration. As the research continues, further applications of household energy data collected from a smart meter will be explored to include load forecasting and renewable energy elements.

REFERENCES

[1] The World Bank, "Access to electricity (% of population)," 2021. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=ZG (accessed Jan. 24, 2022).

[2] International Energy Agency & The World Bank, "Sustainable Energy for All 2013-2014: Global Tracking Framework Report," Washington, DC, 2014.

[3] R. M. Shrestha and J. S. Acharya, *Sustainable Energy Access Planning: A Framework*. Manila: Asian Development Bank, 2015.

[4] N. S. Živi, O. Ur-rehman, C. Ruland, S. Member, A. M. Meter, and R. Mmr, "Evolution of Smart Metering Systems," pp. 635–638, 2015.

[5] K. S. K. Weranga, S. Kumarawadu, and D. P. Chandima, *Smart Metering Design and Applications*. Singapore: Springer, 2014.

[6] H. Sun, N. Hatziargyriou, H. V. Poor, L. Carpanini, and M. A. S. Fornié, *Smarter Energy: From Smart Metering to the Smart Grid*. London: The Institution of Engineering and Technology, 2016.

[7] Asian Development Bank, "Smart Metering Roadmap For Nepal," Asian Development Bank, Manila, 2018. doi: 10.1201/b11300-4.

[8] F. Toledo, *Smart Metering Handbook*. Tulsa: PennWell, 2013.

[9] M. Bajer, "Building Advanced Metering Infrastructure using Elasticsearch database and IEC 62056-21 protocol," no. August, 2019.

[10] ADD Grup, "COVID-19 a trigger for smart metering rollouts," 2020. https://www.smart-energy.com/industry-sectors/smart-meters/covid-19-a-trigger-for-smart-metering-rollouts/.

[11] S. García, A. Parejo, E. Personal, J. I. Guerrero, F. Biscarri, and C. Léon, "A retrospective analysis of the impact of the COVID-19 restrictions on energy consumption at a disaggregated level," 2021, [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7843085/.

[12] L. C. Casals, S. T. Herrero, M. Barbero, and C. Corchero, "Smart meters tackling energy poverty mitigation: Uses, risks and approaches," *2020 IEEE Electr. Power Energy Conf. EPEC 2020*, vol. 3, 2020, doi: 10.1109/EPEC48502.2020.9320062.

[13] M. Saunders, P. Lewis, and A. Thornhill, *Research Methods for Business Students*, 4th ed. Harlow: Pearson, 2007.

[14] Central Intelligence Agency, "The World Factbook," 2022. https://www.cia.gov/the-world-factbook/countries/niger/#geography (accessed Feb. 13, 2022).

[15] The World Bank, "Electric power consumption (kWh per capita) - Sub-Saharan Africa (excluding high income)," 2022. https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2014&locations=ZF&start=1971&type=shaded&view=map (accessed Feb. 13, 2022).

[16] The United Nations, "Household Size and Composition," 2019. https://population.un.org/Household/index.html#/countries/562 (accessed Feb. 13, 2022).

[17] The World Bank, "Access to electricity, rural (% of rural population) - Niger," 2022. https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=NE&type=shaded&year=2014 (accessed Feb. 14, 2022).

[18] The World Bank, "International Development Association Project Paper on a Proposed Additional Credit in The Amount of Eur 48.0 Million (US$56 Million Equivalent) and a Proposed Additional Grant in The Amount of SDR 9.9 Million (US$14 Million Equivalent) to the Republic of," 2018.

[19] The World Bank, "Beyond Connections: Energy Access Redefined," pp. 1–244, 2015.

[20] Asian Development Bank, *Sustainable Energy Access Planning: A Case Study*, no. August. Manila: Asian Development Bank, 2018.

[21] S. Desai, *Handbook of Energy Audit*. New Delhi: McGraw Hill Education, 2015.