Thinking Beyond The Connection: Mapping Electricity Tariffs Affordability in sub-Saharan Africa

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***Abstract*—A least cost basis approach to electrification considering a portfolio of technology options offers a promise to faster connections to achieve sustainable development goal seven (SDG7). But electricity access alone is not enough, affordability both in the short and long term needs to be sustained. Affordability of electricity tariffs is a key challenge for a lot of people in Sub Saharan Africa (SSA). In this study we use gross national income data and poverty data to assess affordability of electricity tariffs in 46 SSA countries and make recommendations on how to incorporate poverty data into electricity tariff setting. Our results show that tariffs are on average affordable in 26 countries, giving utilities some elasticity margins within which they could raise tariffs to improve cost recovery. Further, we show that to achieve energy equity it is important to consider the income levels of the people.**

***Index Terms*—electricity access, electricity tariffs, energy justice**

I. Introduction

Universal access to electricity, a major pillar of Sustainable Development Goal seven (SDG7), remains elusive for many countries in the Global South. In the period of 10 years from 2010 to 2020, the population without electricity access decreased from 1.2 billion to 733 million globally [1], or at an impressive average rate of 42.5 million per year. However, according to the Energy Sector Management Assistance Program (ESMAP)/World Bank *Tracking SDG 7* report of 2022 [1], to realize universal access by 2030, at least 100 million new connections have to be made annually. The International Energy Agency (IEA) projects, under the Stated Policies Scenario (STEPS) that 670 million people globally would still be without access to electricity in 2030, of whom close to 550 million (or 82%) would be in sub-Saharan Africa (SSA) [2]. This lack of access to electricity would disproportionately affect people in rural communities, with urban access expected to be nearly universal [1]. Worse still, for those who recently gained access to electricity, the future is not all bliss either, with the IEA estimating that about 75 million of them are likely to lose the ability to pay for it [2]. The plight of these vulnerable people brings about an important observation; electricity access alone is not enough and affordability both in the short and long term needs to be sustained.

A plethora of studies have been made on how to affordably extend electricity access to the hundreds of millions of people in SSA currently without access. The general consensus based on the least cost metric is that urban areas are better served through centralised grids while rural communities, because of their low population density and sparse spatial settlements, are better served via decentralized generation (DG) systems [3]–[6]. An holistic electrification strategy that considers the spatial distribution of costs for different choices of technology would result in a lower overall cost, and thus could lead to lower tariff. Despite this being the case, the share of DGs in the electrification of rural SSA remains low, with grid extension still a predominant mode. There could be a myriad of reasons DGs have not really taken off at the anticipated scale, but of notable mention are, according to the African Minigrid Developers Association (AMDA); the inappropriate regulations which hinder DGs deployment, dishonoring of concessional capital commitments and huge capital investments made towards publicly owned utilities instead of DGs [7]. The success or failure of electricity systems in meeting the objectives for which they are deployed must be defined and adjudicated from both the utilities' and consumers' perspectives. Unfortunately, these studies argue from the perspective of utilities, neglecting completely the consumer who is the most important party in the electricity supply value chain. Furthermore, there is a huge fixation on access provision as if it is the end goal, while it should only be the starting point in the fight to address the impending energy justice issues faced by the most vulnerable section of the world population today. From consumers' perspective, grid electricity is far more affordable compared to DGs' supplied electricity because it is heavily regulated and subsidized, while the mostly privately owned and run DGs have to charge cost-reflective tariffs [8].

Affordability, a key attribute in the multi-tier framework (MTF) for measuring access to electricity is a key challenge for the subset of the world population who reside in SSA. The World Bank data showed that in 2021 a staggering 53% of the SSA population was employed in agriculture which had a meagre 17.2% contribution towards the gross domestic product (GDP). In the same year, the fraction of the SSA population that lived in extreme poverty of less than $1.90 a day was 37.9% as reported by the United Nations (UN) *the sustainable*

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development goals report 2022 [9]. Thus, considering all these factors which obviously affect the bankability of electrification projects, policy makers need to think beyond providing access but also sustaining those connections.

In this study, we use gross national income (GNI) per capita data, the standard annual electricity consumption of 365 kWh per capita, current electricity tariffs and poverty data to assess the affordability of electricity in SSA countries and design tariffs. This research answers these questions: (1) in how many countries in SSA is electricity unaffordable (consumers overpay on average) and for how many is electricity affordable (pay below standard threshold)? and (2) how can we incorporate poverty data into electricity tariff setting? Through this study, we provide these contributions: (1) we develop a methodical framework to assess the affordability of electricity and (2) we present a methodology to incorporate poverty data into electricity price setting.

II. Data

To perform the analyses, we use freely available data from the World Bank database on development indicators. These data are on GNI, electricity tariffs and poverty. We describe these data in this section.

A. Electricity Tariffs and Gross National Income

We use the most recent electricity tariffs and GNI data sourced from the World Bank. These data are for the years 2017, 2018 and 2019. The Fig. 1 shows the scatter plot of the average tariffs against the GNI for SSA countries over the years of 2017 to 2019. At US\$240, Burundi has the lowest GNI per capita while Seychelles has the highest GNI per capita of US\$15,590. The most expensive electricity tariff is that of Liberia, at 44.5 US cents/kWh, and the lowest tariff is that of Ethiopia, standing at 3.87 US cents/kWh. The differences in electricity tariffs highlight the differences in the cost of generation. For countries like Ethiopia, Zambia, Sudan and Angola, the tariffs are low because their generation is heavily dominated by cheap to generate hydro-power.

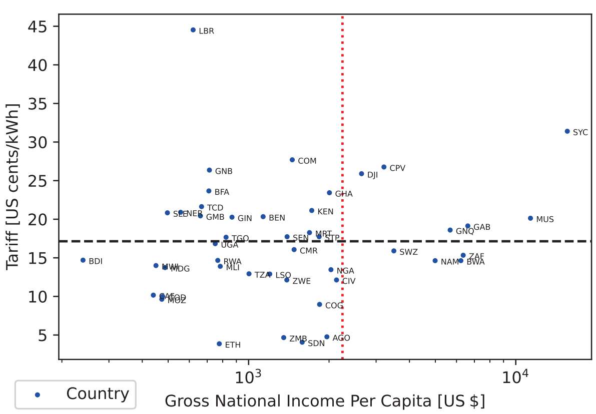

Fig. 1. Scatter plot of average tariffs and GNI per capita over the years 2017 to 2019 for Sub-Saharan Africa countries. The dashed black horizontal line shows the mean tariff across the countries, while the dashed red vertical line marks the mean GNI.

B. Poverty Data

We use the most recent poverty statistics from the World Bank. These data reports, for every country, the share of the total income that belongs to the highest 10%, highest 20%, lowest 20%, lowest 10%, and the middle 20th percentiles. These data are not reported every year, and there are different reporting years for different countries. Thus, we take average values on reported data for the years between 2010 and 2021. The Fig. 2 shows a stacked bar plot of the share by population percentiles of the total income over the years between 2010 and 2021 for SSA countries (there was no data availability in the same time frame for Central African Republic, Eritrea, Equatorial Guinea, Somalia and South Sudan). This figure shows glaring income disparities between the top 10, 20% and the bottom 10, 20%. For most of these countries, the top 20% account for nearly half of total income, and in some cases like South Africa the top 20% account for more than 60% of total income.

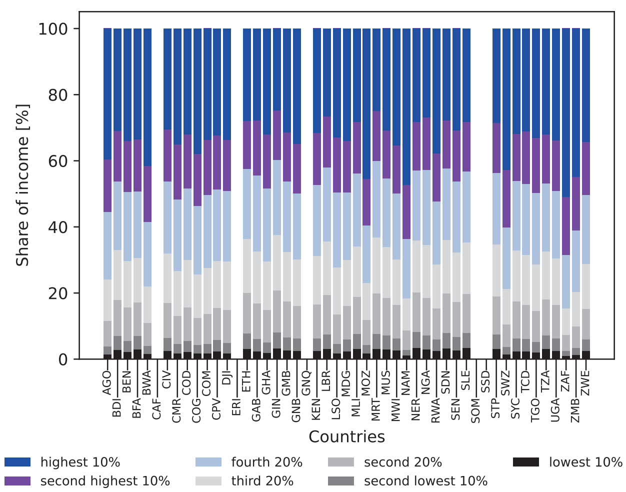

Fig. 2. Income share of different population sections for Sub Saharan Africa countries.

C. Electricity Consumption

While we do not explicitly use consumption data in this study, it is crucial to look at historical consumption to establish a solid perspective of how important this study is in not only advocating for energy equity, but also to bring to light the pressing energy poverty challenges across SSA. For reference, we use the most recent (2014) electricity consumption data from the World Bank. The Fig. 3 shows per capita electricity annual consumption for the year 2014. Out of the 25 countries for which data are available, only eight have average annual consumption greater that the standard 365 kWh. Ethiopia, which has the lowest tariff of all is among those with the lowest average annual consumption at approximately 68 kWh per capita, a number that pales in comparison to the standard consumption (it is a paltry 19% of standard consumption). This shows that electricity consumption may not necessarily be a function of only tariff or affluence, but of other factors like cultural norms and traditions. At the higher end of the consumption spectrum, with close to 4,000 kWh average annual consumption, South Africa is the highest electricity consuming SSA country.

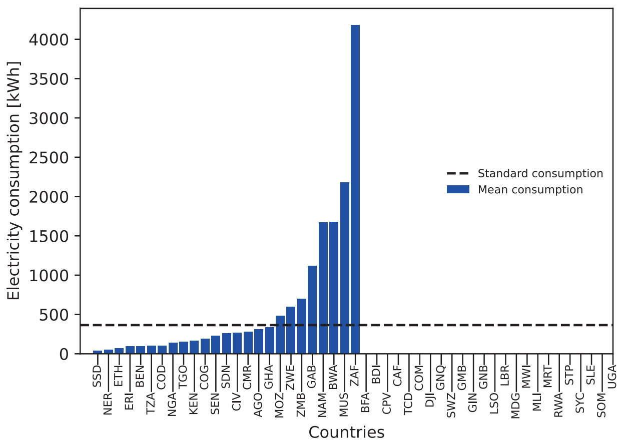

Fig. 3. Per capita annual electricity consumption for the year 2014. For the countries with zero values, it is an indication of a lack of data.

III. METHODS

In this section, we describe the methodology of assessing affordability and explain the model used to design tariff that promotes equity.

A. Affordability

The MTF for measuring access to electricity defines an annual per capita consumption of 365 kWh as *standard consumption* [10]. A person is categorized as being in the access tier 2 or below if their annual energy spend on this standard consumption exceeds 5% of their annual income, and is conversely categorized as falling in access tier 3 or above if their annual energy spend on standard consumption is less than 5% of their annual income. Based on this, we define a metric *standard tariff* denoted by Φ, which is the product of 5% of the country's per capita GNI divided by the standard consumption S_C. This is expressed formally in Eqn. 1.

$$\Phi = \frac{0.05 \times GNI}{S_C}. \tag{1}$$

In our analysis, we use the metric *affordability*, denoted by δ, which we define as the ratio of the difference and sum of the standard tariff and tariff Ω. This is expressed formally in Eqn. 2. Affordability takes values in the range [-1, +1], where the extreme ends of -1 and +1 indicate that the country has no (zero) GNI and electricity is free of charge. A value of zero for affordability is an indication that the tariff is equal to the standard tariff. Ideally, affordability must be greater than zero, and higher is desired.

$$\delta = \frac{\Phi - \Omega}{\Phi + \Omega}. \tag{2}$$

B. Tariff Design and Cross Subsidization

To promote equity in electricity tariff setting, we propose a price setting methodology that takes into consideration the income levels of the different income groups. The World Bank data on poverty provides the percentage share α of total income for five income groups consisting of 20% of the total population (i.e highest 20% to lowest 20%). Thus, for each income group ig, the respective standard tariff Φ_{ig} is given by Eqn. 3. The underlying assumption in Eqn. 3 is that the standard tariff is a weighted average of the individual income groups' standard tariffs.

$$\Phi_{ig} = 5 \times \Phi \times \alpha_{ig}. \tag{3}$$

The income groups that have higher standard tariffs effectively subsidize the income groups with lower standard tariffs. Tariff subsidy exists for an income group if its associated standard tariff is less than the average standard tariff. This is represented formally in Eqn. 4.

$$S_{ex,ig} = \begin{cases} 1 & if \quad \Phi > \Phi_{ig} \\ 0 & if \quad \Phi \leq \Phi_{ig} \end{cases} \tag{4}$$

IV. RESULTS AND DISCUSSIONS

A. Standard Tariffs

Using the GNI data and a per capita standard consumption of 365 kWh per annum, we evaluated the standard tariffs. The Fig. 4 shows the mapping of standard tariffs across SSA countries. The standard tariffs range from less than 10 US cents to a little over 200 US cents, depending on how high the GNI is.

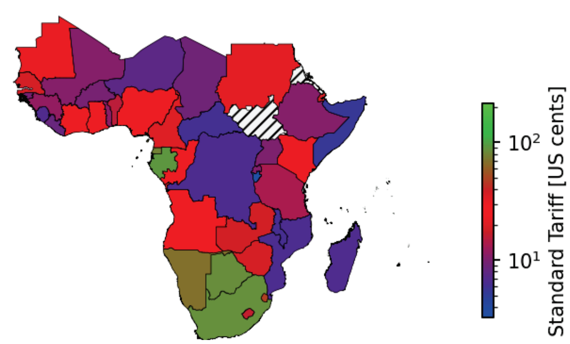

Fig. 4. Standard tariffs for SSA countries based on standard consumption of 350 kWh per annum and GNI per capita. The hatched countries signifies lack of data availability.

The Fig. 5 shows a scatter plot of the standard tariff against the actual tariffs. In the Fig. 5, the countries are clustered into two groups, marked by red and blue dots. A red dot indicates that a country's current average tariff is higher than the standard tariff, hence the tariff is unaffordable. Conversely, a blue dot indicates that a country's standard tariff is higher than the current average tariff, hence the tariff is affordable. Out of 46 countries for which data are available, 43.5 % of them have tariffs that are on average unaffordable.

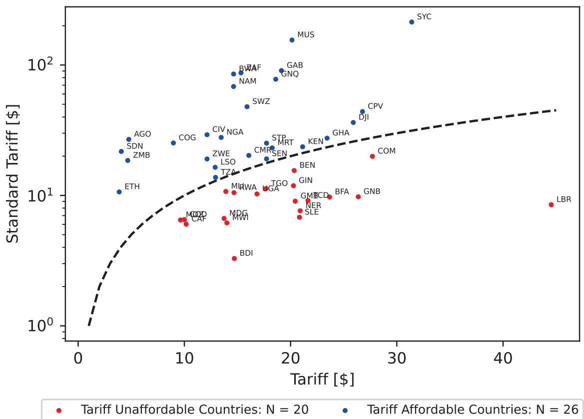

Fig. 5. Scatter plot of standard tariffs vs actual tariffs in SSA. Each dot represents a country: red means tariff is higher than standard tariff, and blue means standard tariff is lower compared to actual tariff. The dotted line is a parity line where standard tariff is equal to actual tariff. The dotted line is curved because the standard tariffs are plotted on a log scale, while tariffs are on a linear scale.

B. Affordability

We also evaluated affordability of tariffs across SSA. The Fig. 6 shows the map of affordability across SSA. In line with results in Fig. 5, the Fig. 6 shows a strong correlation between the position of a country relative to the parity line and affordability. A country with a higher standard tariff and lower tariff has a higher affordability value, while a country with lower standard tariff and a higher tariff has a lower affordability.

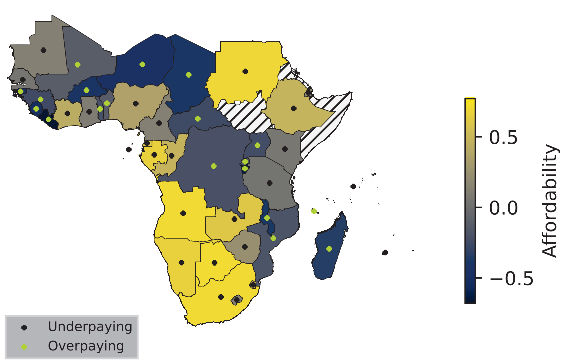

Fig. 6. Affordability map for SSA countries. The countries are marked with black and yellow markers. A black marker means the tariff is desirable (affordability is greater than zero), while a yellow marker means that the tariff is not affordable (affordability is negative).

We also evaluated the percentage tariff overpay and underpay for each country. An overpay is characterized by a tariff that is higher than the standard tariff, and an underpay is characterized by a tariff that is less than the standard tariff, as expressed in Eqn. 5.

$$t_{ou} = \begin{cases} \frac{\Phi - \Omega}{\Phi} \times 100 & if \quad \Phi > \Omega, \quad underpay \\ \frac{\Omega - \Phi}{\Omega} \times 100 & if \quad \Phi < \Omega, \quad overpay \end{cases} \tag{5}$$

The Fig. 7 shows percentage underpay, overpay, tariff and standard tariff. Liberia has the highest tariff relative to the GNI, with the difference between actual tariff and standard tariff being over 80%. Mauritius on the other hand has the lowest tariff relative to the GNI, with an average customer paying less than 20% of the standard tariff, or less than 1% of the GNI. For countries in which the tariff is higher than the standard tariff, an overpayment represents the average level of subsidy intervention necessary to bring the price to the standard 5% of the annual income. An underpayment represents the elastic margin within which utilities can increase prices before charging consumers more than the 5% of annual income.

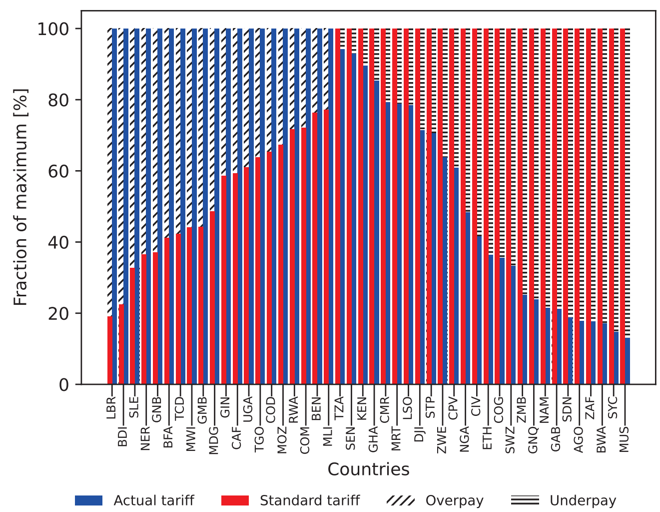

Fig. 7. Bar plot showing how much the countries overpay and underpay.

C. Tariff Design

We also did a what-if analysis based on standard tariffs of what equity scenario tariffs would be for each country. The Fig. 8 shows normalized (all tariffs are expressed as a percentage of the highest) plot of standard tariffs across SSA. For all the countries, the highest 20% income group would need to pay the highest tariff. The lowest 20% income group, the second 20% income group, and the third 20% income group would all have to pay tariffs that are below the average. This indicates that for all countries, the standard tariff based on the average GNI is unaffordable to at least 60% of the population. Thus, at least 60% of the population need tariff subsidy to afford the standard annual consumption of 365 kWh. These results reveal the enormous disparities in income levels. For some countries, 80% of the population would need tariff subsidy to afford the standard tariff.

D. Policy Implications and Recommendations

The results we have presented show that out of the 46 SSA countries analyzed, in 20 of them people cannot afford the standard consumption of 365 kWh yr^{-1}. Thus, for these countries it is necessary to have policy mechanisms in place to make up for the shortfall in affordability to meet the customers

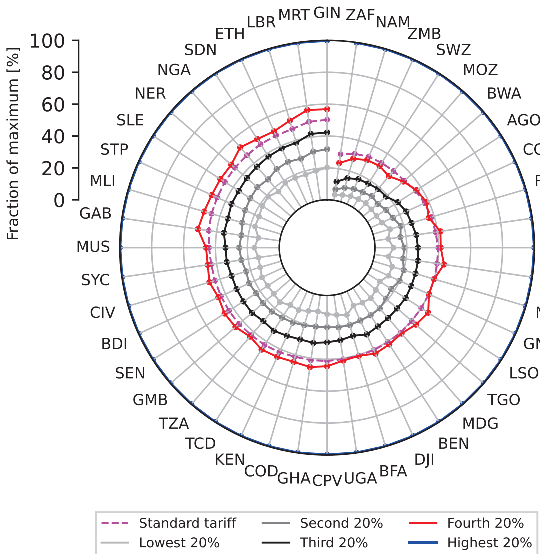

Fig. 8. Normalized equity scenario standard tariffs.

halfway to make the tariffs affordable. Trimble et al. [11] showed that for many utilities in SSA, cost recovery is a challenge, with only two utilities out of 39 being able to recover costs in 2014. In light of this, considering that for 26 of the 46 countries analyzed the tariffs are lower than the standard tariff, the utilities in these countries could increase tariffs (only within the elastic limits of the standard tariffs) to facilitate improved cost recovery and consequentially increase the return on investment (ROI). However, it is important to note that for the other 20 countries the tariffs are higher than the standard tariff, suggesting that tariffs need to be lowered to improve affordability. The knock on effect of reducing tariffs to improve affordability would unfortunately result in even lower ROI, thereby further worsening the financial sustainability of the utilities.

It was further shown that there are enormous income disparities between the top 20% earners and the rest of the population in all the countries we analyzed. In quest to promote equity in electricity tariff setting, the income levels of the people have to be taken into consideration, and policy to facilitate cross subsidization from high to low income earners must be implemented. While it is easier to conceptualize this sort of policy, practically it is complex to implement as it is difficult to know each household's income level. However, there could be ways around this, with one possible way to do it being to use tax filing records of the previous year as proxy to set current year tariffs. The likely result of this kind of policy intervention is increased consumption levels by the bottom 80%, hence a higher ROI overall.

V. Conclusions and Future Work

The objectives of this study were two-fold, (i) to assess affordability of tariffs in SSA countries and (ii) to provide a methodical framework to incorporate poverty data into electricity tariff setting. Our results have shown that out of 46 countries in SSA for which there was data availability, tariffs are on average affordable in 26 (or 56%). We have also proposed a methodology to incorporate poverty data into electricity tariffs setting. Using this methodology, the results have shown that to achieve energy equity, customers may need to be charged different tariffs in accordance to their income levels.

The results we have presented in this research are based on average, flat rate electricity tariffs. In reality, tariffs are seldom flat, with utilities employing varying types of block tariffs and time of use tariffs [12], [13]. Further, it was assumed in the analysis for this research that average electricity consumption is adequately represents typical consumption patterns of the entire country populations. In reality, consumption patterns vary widely across different geospatial locations and time of connection [14]. We plan to expand this work by incorporating the different types of tariff structures and different consumption levels driven by spatial heterogeneity and temporal differences pertaining to connections.

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