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10 years after: Long-term adoption of electricity in rural Rwanda

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Lise Masselus
Jörg Ankel-Peters
Gabriel Gonzalez Sutil
Vijay Modi
Joel Mugyenyi
Anicet Munyehirwe
Nathan Williams
Maximiliane Sievert

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Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

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Abstract

Extending the power grid into hitherto unconnected areas is high on the policy agenda in Sub-Saharan Africa. Yet, connection rates and electricity consumption remain low in grid connected areas, at least in the short and medium run. This paper provides a long-term follow-up on an evaluation of a large-scale grid extension program in rural Rwanda. We study the adoption of grid electricity over time using a panel of 41 communities that were electrified up to ten years ago. We find that connection rates for households living near the grid increased from 62% in 2013 to 82% in 2022. At the wider community level, connection rates are much lower, at 51%. Furthermore, electricity consumption and appliance usage are low and did not grow over time. We corroborate these findings with administrative consumption data from the utility customer data base. Our findings suggest that investments into gridbased rural electrification cannot be justified by economic development impacts and cost-benefit considerations.

JEL-Codes: H54, L94, O12, O13, O18, Q41

Keywords: Energy access; energy consumption; energy use; electricity; Sub-Saharan Africa

June 2024

** Lise Masselus and Jörg Ankel-Peters, RWI and University of Passau; Gabriel Gonzalez Sutil, Vijay Modi and Joel Mugyenyi, Columbia University; Anicet Munyehirwe, IB&C Kigali; Nathan Williams, Rochester Institute of Technology; Maximiliane Sievert RWI.* *– We are grateful for comments received by participants at the Energy and Development seminar at Duke, the EAERE conference, the EfD annual conference and the LEADS conference. We thank Eugene Tan Perk Han and Courage Ekoh for providing input. We thank REG for providing electrification data and IB&C Rwanda for their excellent work in collecting survey data.* *– All correspondence to: Lise Masselus, RWI, Hohenzollernstraße 1-3, 45128 Essen, Germany, e-mail: masselus@rwi-essen.de*

1. Introduction

Based on the belief that energy is a driver of economic development, universal access has emerged as an important policy goal (United Nations, 2015). Yet, the literature on the socio-economic impacts of rural electrification is divided, with a recent turn towards rather disappointing findings (Bayer et al., 2020; Bos et al., 2018; Fetter & Usmani, 2024; Lee et al., 2020a; Peters & Sievert, 2016). In Sub-Saharan Africa (SSA), impact evaluations of grid extension studies document connection rates well below 100%, very low consumption levels among those who are connected, and, as a consequence, largely absent impacts on economic development (Bernard & Torero, 2015; Chaplin et al., 2017; Lee et al., 2020b; Lenz et al., 2017; Peters et al., 2011; Schmidt & Moradi, 2023). These impact evaluations typically examine adoption and impacts after two to three years, the longest after seven years. The question therefore arises as to whether it simply takes more time for utilization and thus also the impacts to materialize.

This paper examines the long-term adoption of grid electricity in rural Rwanda, up to ten years after the communities were connected to the grid. We follow up on Lenz et al. (2017), who evaluate the impacts of the Electricity Access Roll-out Program (henceforth EARP), Rwanda's grid expansion initiative, one of the biggest of its kind worldwide. EARP notably increased electrification from a very low rate of 6% in 2009 to 54% in 2023 (Rwanda Energy Group, 2023), making Rwanda one of the fastest-electrifying countries over the last decade (IEA et al., 2023). Lenz et al. (2017) evaluate the first phase of EARP, 3.5 years after connection. They document noteworthy usage patterns in households such as lighting, partly for studying purposes, entertainment devices and phone charging. Yet consumption levels in terms of kWh are extremely low, also in connected enterprises, which hardly use electric appliances at all beyond lighting. Hence, there is no indication for the economic development effects of electrification that are typically assumed in cost-beneft considerations of donor agencies.

We revisit the same communities up to ten years after they were connected to the grid and thereby provide the longest-term follow-up for an impact evaluation in an African context.[1] Our analysis is based on two data sources with complementary virtues: four waves of survey

[1] The average community was connected eight to nine years ago. Out of the 41 communities, 28 communities were connected nine years ago or longer. Only four communities were connected less than five years ago.

data and administrative consumption data. The survey data comprises detailed energy usage data from 820 households in 41 rural communities. The administrative consumption dataset covers all pre-paid purchases for 147,074 rural households in the country between 2012 and 2020, among them 174 households in our sample.

EARP succesfully connected 41 and hence all but two communities in our sample to the grid. We find that in the connected communities, a notable share of households remains unconnected. Connected households mainly use electricity for lighting and phone charging, with only 58% of households owning electric appliances other than lamps or a phone. Very few households use appliances productively. Consequently, electricity consumption levels in 2022 remain at similarly low levels as in 2013. At the community level, enterprises acquire a connection, but there is no evidence of large increases in enterprise creation.

Our paper addresses one critique on the aforementioned studies with disappointed findings: adoption and hence also impacts might need more time to unfold (Burgess et al., 2020; Lee et al., 2020a; Peters & Sievert, 2016). The few existing longer run studies in the United States, Asia and Latin America observe large effects of electrification (Lewis & Severnini, 2020; Lipscomb et al., 2013; Nag & Stern, 2023; Rud, 2012; van de Walle et al., 2013), but the extent to which these findings are transferrable to contexts in SSA remains an open question (Lee et al., 2020a; Peters & Sievert, 2016).

2. Results

2.1 Data

Our analysis relies on two data sources. First, we collected four waves of a community panel dataset from 41 communities in 2011, 2013, 2015 and 2022. The communities are representative for communities scheduled to be electrified during EARP's first phase between 2009 and 2013.[2] In fact, all but two communities got connected by 2022. These two non-connected communities are dropped from our analysis because we deem those to be a sample too small to use it for any further comparison. We conducted surveys with households living close to the low-voltage line (50 meters maximum) that can connect at the lowest fee of 93 USD[3],

[2] See Appendix A.1 for more context on rural electrification in Rwanda and Appendix A.2 for more details on sample selection and the definition of a community.

[3] This connection fee can be paid in instalments and, since 2017, has been abolished completely for the poorest households. See Appendix A.1 for more details. We use the 2011 conversion rate of 600 RWF to 1 USD throughout.

henceforth "under-grid" households.[4] We used a random walk approach to select a sample representative of all under-grid households in the community. We interviewed 30 households per community in 2011 and again in 2013. A subsample was also interviewed in 2015. In 2022, we selected a new random sample of twenty under-grid households per community. Tracking the same households as in the previous waves turned out to be too complicated because family compositions, locations and phone numbers have changed. Also, for our research question a household level panel dimension is not crucial. Additionally, we interviewed community leaders to elicit information about the entire community, that is, including households living beyond the under-grid corridor.

Our second data source is an administrative consumption dataset covering all pre-paid purchases from October 2012 to April 2020 for 800,000 consumers of the national utility Rwanda Energy Group (REG).[5] We used a unique meter ID to identify households that occur in both datasets, and were able to match 26% of the connected households in our surveyed sample. Unmatched households probably stem from incomplete administrative consumption data and difficulties collecting accurate meter IDs.[6] Yet, despite the distorted matching process, the matched households provide valuable insights. First, they confirm the consumption measurement in our survey data (based on self-reported recall questions, see Appendix A.3). Second, the matched data is crucial to check for a potential negative effect of COVID-19 on electricity consumption. We can rule out that the pandemic explains the low consumption rates in 2022 since also in the years prior to the survey in 2022, the administrative consumption data document similarly low consumption levels for the matched households.

2.2 Household adoption

We use two data sources to examine household consumption, our survey data and the administrative consumption data. Looking at our survey data, Figure 1 shows household connection rates (Panel A) and appliance ownership (Panel B) over time. Despite living in a connected community, not all households connect. In 2022, up to ten years after community

[4] "Under-grid" households live within a 50-meter corridor along the LV line. This benchmark was determined by the national utility in 2011. See Appendix A.1.

[5] Mugyenyi et al. (2024) use this dataset to analyse how electricity consumption patterns evolve and how changing tariffs affect consumption and utility revenue across the country.

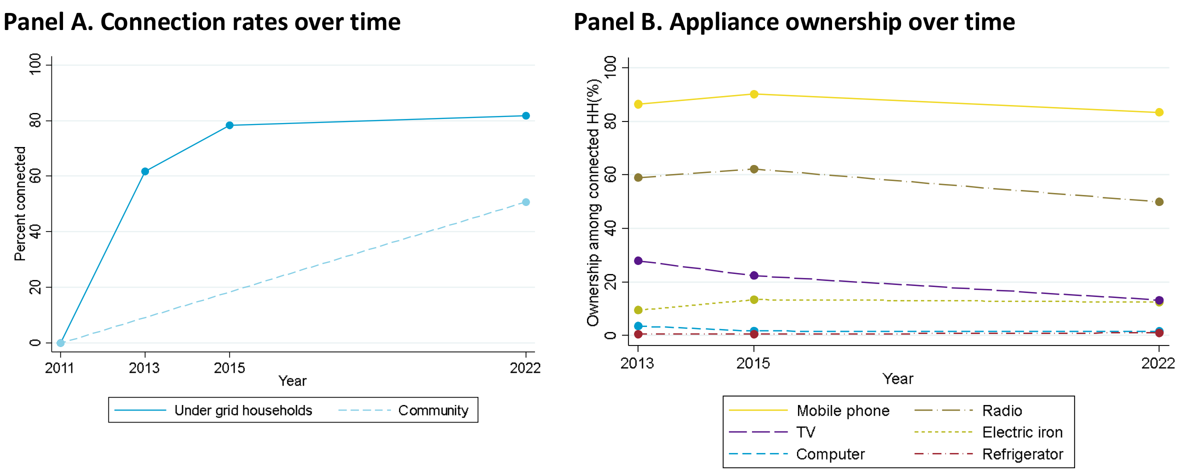
[6] In Appendix A.4, we implement a bias correction and find that the matched households are likely to present an upper bound for the entire survey sample.

connection, 82% of the under-grid households are connected. This connection rate was already high in the first years after connection and hardly increased since. At the wider community level, so including households that live further away from the grid, only 51% are connected in 2022.

Adoption of electric appliances among connected under-grid households is low. In 2022, nearly all connected households use electric lamps and 84% own mobile phones, but only 58% own another appliance (radios and televisions in most cases). Productive use of appliances among connected households is not common, as only 4.5% of the connected households use electric appliances to earn money. These appliances are radios (10 respondents), irons (5), televisions (4), computers (3), refrigerators (2), a kettle (1) and a mill (1). They are all used in self-employed enterprises or farming activities. Panel B shows ownership of the most common appliances, mostly information and entertainment devices, over time. There is no indication of increased appliance adoption over time.

In 2022, electric light bulbs or energy saver bulbs have replaced kerosene lanterns and battery-run appliances almost entirely among connected households; only 15% use candles occasionally. Households not connected to the grid mostly rely on battery-run LED torches, solar lamps or candles. Like in most other countries in SSA, electricity is not used for cooking (IEA et al., 2022).

Figure 1: Electricity adoption over time

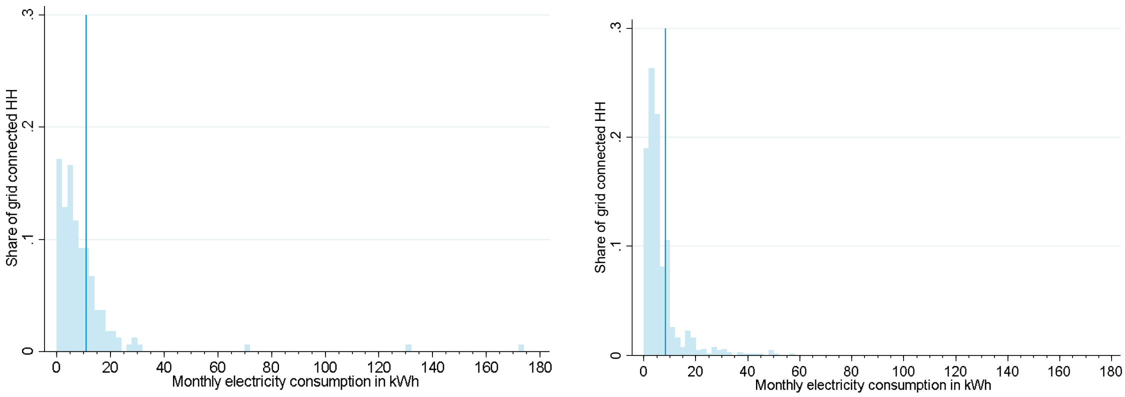


Note: Source: Household and community survey. A household is considered as having a grid connection if they have a connection plus installation in their home, regardless of whether they consume any electricity. Following REG's definition, we do not count households that are connected through a neighbour. In contrast to other countries in the region, such illegal connections are very rare in Rwanda. The sample for this figure consists of 13 connected communities in 2013 and 2015 and 41 connected communities in 2022.

Figure 2 shows the self-reported average monthly consumption in kWh. The left panel shows the 2013 consumption levels for connected households in those communities that were connected by 2013. The right panel shows consumption levels in 2022 for connected households in all communities.[7] Up to ten years after electrification, the average connected household consumed 8.3 kWh per month, and the median is 4 kWh. Under the current tariffs, the mean amount purchased per month is 740 RWF, equivalent to 2% of the median households' expenditures.

Figure 2: Self-reported monthly consumption in kWh for connected households

Panel A. 2013 (treatment communities) **Panel B. 2022 (all communities)**



Note: Source: Household survey. Consumption is trimmed at the 99th percentile for graphical presentation. The vertical line presents the mean monthly consumption. The 2013 data is calculated based on appliance ownership and usage patterns. The 2022 data is based on electricity bills imputed with information on appliance ownership and usage. The approach is discussed in Appendix A.3.

Figure 3, Panel A shows the administrative consumption data for the 174 matched households in our sample. The figure shows that earlier connected households initially have higher average levels of consumption, which could be explained by richer households receiving their connection earlier, because better-off communities are connected first or because better-off households within connected communities connect first, or both. Additionally, we see no increase in consumption over time, for any of the connection years. On the contrary, the data shows a peak in consumption for the first years after electrification, which then tapers off. Both the frequency of purchases as well as the quantity purchased decline over time. We find similar trends for the highest 10% of consumers in our sample, indicating that there even for the top-consumers in our sample, there is no indication of consumption growth over time (See Figure A3).

[7] When looking only at communities already connected by 2013, the mean consumption in 2022 is 9.1 kWh per month. This indicates that the consumption in the entire sample is not pulled down by the more recent connected communities.

2.3 Enterprise Adoption

We elicited information from the community leaders about the enterprises in their villages. In 2022, the average community has sixteen enterprises, most of them connected to the grid, and all of them micro-enterprises without or with very few employees. We do not find evidence that electrification leads to perceivable emergence of new types of enterprises in the community, apart from a few enterprises that can only operate with electricity (through the grid or a generator), such as welders and copy shops.

Most enterprises provide basic services to the local population, like small shops, bars and restaurants, and hairdressers. Only half of the communities have manufacturing firms like tailors, welders, or carpenters. Most enterprises use electricity for lighting. Small shops, which usually sell small items like staple food or toiletries for local consumption, bars, and restaurants sometimes obtain electric appliances after electrification. Among all small shops, 22% have a radio, 12% a TV, and only 2% a refrigerator. Bars and restaurants often have a radio (50% and 22% respectively), or a TV (35% and 22% respectively). 17% of all bars and 14% of all restaurants have a refrigerator. Additionally, many shops, bars and restaurants offer phone charging services. Hairdressers and beauty salons commonly own electric razors (93% of all hairdressers), a radio (44%) or a TV (14%). Millers, carpenters, and tailors use grid electricity for operation of equipment, though many enterprises also continue to work with mechanical or diesel-run appliances, despite their grid connection. Only 9% of all tailors have an electrical sewing machine and 31% all carpenters have an electric wood cutting machine.

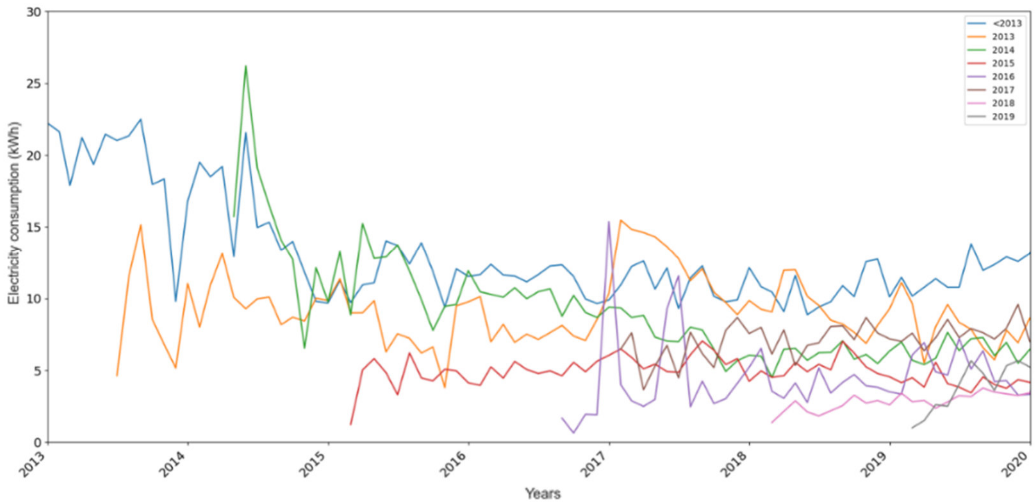
2.4 Comparison across Sub-Saharan Africa

In Figure 3, Panel B, we compare the consumption levels in our survey communities to the average consumption in rural communities, using the administrative consumption dataset. In line with our findings, the average consumption per rural household is low, and does not seem to increase over time. It has to be noted, though, that we have no information how the administrative sample was selected by the utility and hence about the representativeness, but we also have no reason to believe it is distorted in a way that affects our interpretation. The total dataset we received from the utility covers about 800,000 consumers out of a universe of about 1,300,000 consumers, from 15 out of 30 districts in the country. Within this dataset, only about half of the consumers are geolocated, allowing us to identify them as "rural" or "urban".

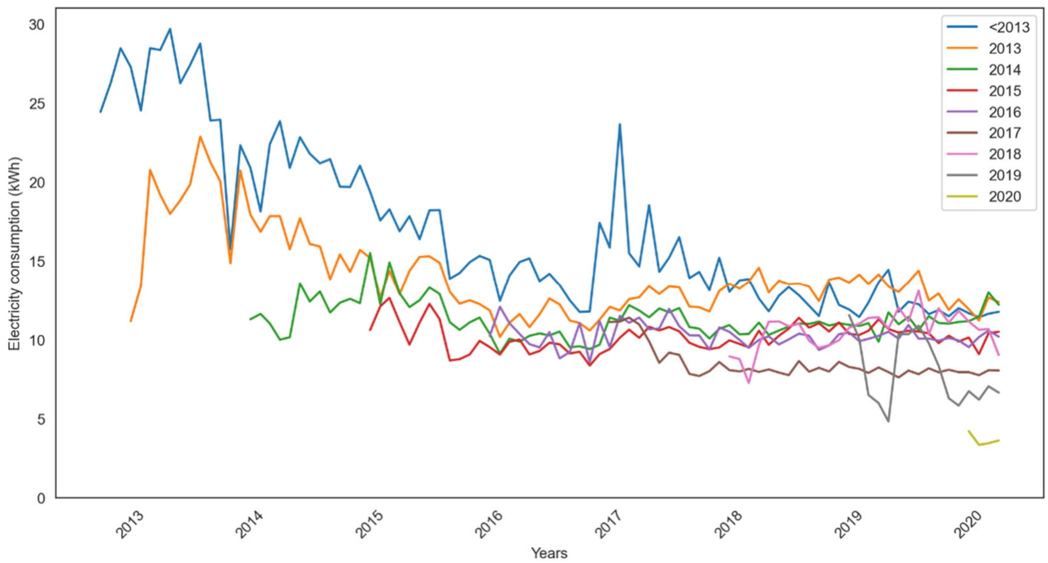
We included only the rural households, giving us the 147,000 households depicted in Figure 3, Panel B. The matched households are rather from the better-off stratum in our survey communities, so if anything their consumption levels are upward biased, which would imply they represent the upper bound of all rural consumers.

Figure 3: Consumption over time (kWh) by year of connection

Panel A. 174 matched households



Panel B. 147,000 rural households



Note: Source: Administrative consumption data. The dataset for this figure contains all pre-paid purchases and geolocations for 400,000 households. Panel A shows the data for the 174 matched households in our sample. Panel B shows the data for 147,000 rural households. We use village boundaries provided by the World Bank and the definition of rural areas provided by the European Commission to identify rural customers.

In a next step, we discuss in how far our findings generalize beyond rural Rwanda. We compare our estimates with connection rates and consumption levels documented in other studies in SSA, which mainly use utility data or nationally representative socio-economic datasets. Blimpo & Cosgrove-Davies (2019) report connection rates for households under the grid to vary substantially across SSA. Using data from the Demographic and Health Surveys, they calculate grid connection rates of between 13% and 81% - yet including urban areas. The median connection rate is 46%, with Rwanda slightly below average at 40%.[8] No information is available for how long the areas have already been electrified. In rural Kenya, Lee et al. (2016) find that 95% of households in their sample are not connected, up to five years after the grid was installed. Half of them live close to the grid and can connect at the lowest cost of USD 412. In Tanzania, according to Bensch et al. (2019), up to four years after connection, only 38% of households in connected villages use electricity despite high connection subsidies and 57% of under-grid households are connected. Also in Tanzania, Chaplin et al. (2017) document an increase in connection rates from 11 to 21%, 2 to 3 years after a line extension intervention. In Burkina Faso, Schmidt & Moradi (2023) find that household connection rates stagnate around 8-10%, three years after community electrification. These findings suggest that our diagnosis of low connection rates appears to be relevant for several SSA countries. The innovative insight we add is the long-term perspective.

On electricity consumption, Blimpo & Cosgrove-Davies (2019) report overall low consumption across SSA of on average 483 kWhs per year in 2014. This is very low and equivalent of powering only a 50 Watt light bulb for a year, but still four times the amount we measure among our Rwanda sample. Descriptive studies using national utilities' data for Kenya (Fobi et al., 2018; Taneja, 2018) and Togo (Boubakar et al., 2022) document similar consumption pattern as in our study: overall low consumption and limited consumption growth over time. In Kenya, the median yearly consumption among rural consumers ranges between 200-400 kWh in 2015, with later connections consuming less. In Togo, the average yearly consumption for rural consumers is around 600 kWh in 2020. The observed pattern is one of modest electricity consumption growth in the first months after connection, that then tapers off after a while. Furthermore, the average consumption per household decreases as more low consumption users connect.

[8] These estimates are only approximations since the definition of an electricity connection (e.g. ongrid vs. offgrid) is not consistent across countries and the authors have to rely on assumptions for defining households "under the grid". The authors have to assume that as soon as one household reports an electricity connection, the whole enumeration areas has access to electricity.

3. Discussion

We address an important policy question: what is the electricity adoption trajectory over time? We do not observe a decline in connection rates and appliance usage over time, and this may not be taken for granted in the aftermath of the COVID-pandemic. We therefore expect the positive short-term impacts on household wellbeing observed in Lenz et al. (2017) to sustain. Yet, we also confirm Lenz et al. (2017)'s short term diagnosis of no noteworthy economic development effects, now in the long term. What is more, connection rates stagnate way below 100% in grid connected communities. It can hence not be expected that the universal access goal is achieved in the long term – even in grid connected areas and despite connection fees for households living near the grid that are comparatively low in Rwanda (Blimpo & Cosgrove-Davies, 2019; Golumbeanu & Barnes, 2013). Note that in contrast to some other countries in SSA, electricity supply is stable in rural Rwanda. Most grid connected households report to be satisfied with their connection. Although blackouts and voltage fluctuations occur, they are infrequent.

For those households that do connect, consumption does not ensue automatically. Households own few productive appliances, but rather entertainment devices, and have low average levels of consumption. There is no indication for enterprise creation or for existing enterprises starting to use electricity productively. This challenges the narrative of electrification as a panacea for poverty reduction and raises concerns about the financial sustainability of utilities. In Rwanda, the ministry of infrastructure estimates that a consumer needs to purchase 130-140 kWh per month to cover the cost of their own connection (Ministry of Infrastructure, 2018), which is far above current consumption levels.

In fact, extending the grid requires enormous upfront investments. For SSA, the IEA estimates that achieving universal access by 2030 and maintaining it to 2040 will cost over USD 100 billion per year. The cumulative investments amount to 2.7% of the regional GDP (IEA, 2019). For our sample of rural Rwandan households, most current household energy needs could be covered by alternative, cheaper energy sources. Proponents of large infrastructure investments argue that in the long run, grid extension moderates better development potentials once economic growth and productive demand occur endogenously[9] and a focus on small-scale decentralized energy instead of the grid may cap that demand increase. Our findings suggest that even this more patient prior, based on long-term expectation, needs to be updated towards a much longer period that is needed. The question hence arises whether such potential benefits justify today's high investment costs and significant opportunity costs, given that it will probably take even longer than previously hoped. A careful case-by-case consideration of different energy sources for different locations seems to be warranted to improve the cost-effectiveness of scarce resources for universal access purposes (Agutu et al., 2022; Egli et al., 2023; Maqelepo et al., 2022). Yet, with respect to decentralized electrification, our findings are also of utmost importance for the mini-grid sector, in which oftentimes ex-ante assessments of financial sustainability are based on increasing electricity adoption and demand over time (Duthie et al., 2024; Egli et al., 2023; Peters et al., 2019).

Major donors and development banks conduct cost-benefit analyses to justify their investments. An assessment of the World Bank's cost-benefit analyses reveals that the economic rate of return is frequently overly optimistic (IEG, 2010). This optimism stems from the fact that benefits are rarely verified beyond the initial seven to ten years, whereas the calculations include benefits over a 25 to 30-year time period (IEG, 2010). The Millenium Challenge Corporation employs a 20-year horizon for its cost-benefit calculations, though assessments typically occur two to five years after project closure (MCC, 2024). The projected benefits can either be constant or growing over time. Our findings show that while impact and adoption are sustainable after ten years, they do not increase and even stagnate on a low level. Based on our findings, it is unlikely that impacts will begin to materialize within a 10 to 15-year timeframe without an external growth stimulus. The positive impacts on household wellbeing alone are insufficient to justify the high investment costs – not least since they can also be generated by off-grid technologies (see Grimm et al. (2020)). Despite the evidence provided in our paper, donors are free to assume demand increases in the medium to long term, but such assumptions should be labelled as optimistic scenarios.

[9] For northwestern India, Fetter & Usmani (2024) observe that electrification does lead to economic development only in communities that are simultaneously exposed to a positive exogenous price shock for agricultural products produced in some of the newly electrified communities but not in others.

Meanwhile, there are other reasons beyond economic ones that justify rural electrification. Many people and also governments in SSA perceive electricity and other infrastructure as a right that is derived from normative principles and not from cost-benefit considerations (Ankel-Peters & Schmidt, 2023; Madon et al., 2023; Rao & Min, 2018). From this rights-based perspective, our findings are not disappointing since they confirm sustainable uptake of electricity. Our paper does not question this account of infrastructure policy. It only casts doubt on the narrative that this whatever-it-takes approach is backed by a positive cost-benefit analysis.

Appendix

A.1 Rural electrification in Rwanda

The cornerstone of Rwanda's electrification endeavor is the EARP, nowadays run by the national utility Rwanda Energy Group (REG, previously the Energy, Water and Sanitation Authority or EWSA), which extends the grid through rural areas. This paper focusses on the grid extension and grid densification activities carried out by EARP.[10] Grid extension activities expand access to unconnected communities far from the existing grid by building new Medium Voltage (MV) lines to communities, where power is transformed to Low Voltage (LV) distribution lines. Grid densification activities connect communities and households closer to the grid by installing transformers from existing MV lines and extending LV lines.

Once the grid reaches a community, households, enterprises, and social infrastructure can request a connection with REG. Connection fees are subsidized and determined by the distance to the grid. For households living within a 37 meter corridor[11] along the LV line, the connection fee is 56,000 RWF (93 USD). Following Lee, Brewer, et al. (2016), we call these "under-grid" households throughout the paper. For households living outside this corridor, connection fees increase as a function of distance to the existing LV line, to cover the increasing cost of extending the distribution lines. For all households, connection fees can be paid in installments, which are added to each electricity bill. Since 2017, upfront payments are abolished for the poorest households. Most households receive a so-called ready board, a connection point ready for household use with two sockets and two light bulbs.

Households use a pre-paid meter to purchase electricity. These meters are recharged with tokens, unique numbers that can be purchased using mobile money or through a commissioned REG agent in a local shop. Most households in rural areas recharge their prepaid meters frequently, on an as-needed basis and for small amounts.

Electricity tariffs per kilowatt hour (kWh) have changed over the years. Between 2006 and 2015, tariffs for residential consumers increased from 112 kWh to 182 kWh to cover the cost of

[10] In addition to supporting direct access, parts of the EARP funds were invested into extending transmission (or High Voltage (HV)) lines and improving grid stability.

[11] According to conversations with REG in 2011, the distance where households can connect without additional expenses for extending distribution lines was 50 meters. For consistency of the sampling approach, we employ the 50 meters distance to determine the connection corridor.

service and increased generation costs. Since 2017, tariffs for the lowest consumers have decreased by half to increase affordability for the poor. A block tariff is charged, where the first 15 kWh each month costs 89 RWF/kWh, the next 35 kWh costs 182 RWF/kWh and any kWh above 50 is charged at the highest prices of 210 RWF/kWh (Mugyenyi et al., 2024).

In light of the large number of new connections, capacity bottlenecks can be a major constraint that could affect the decision to connect and consume electricity (Blimpo & Cosgrove-Davies, 2019; Meeks et al., 2023). In Rwanda, grid connected households report to be satisfied with their connection. 79% of all households rate the quality of supply as good or excellent and only 1% rate the quality of supply as poor. Furthermore, 91% of all connected households state that the quality of supply has improved or stayed the same over the past twelve months. Among connected households, 90% consider the grid to be the safest source of electricity.

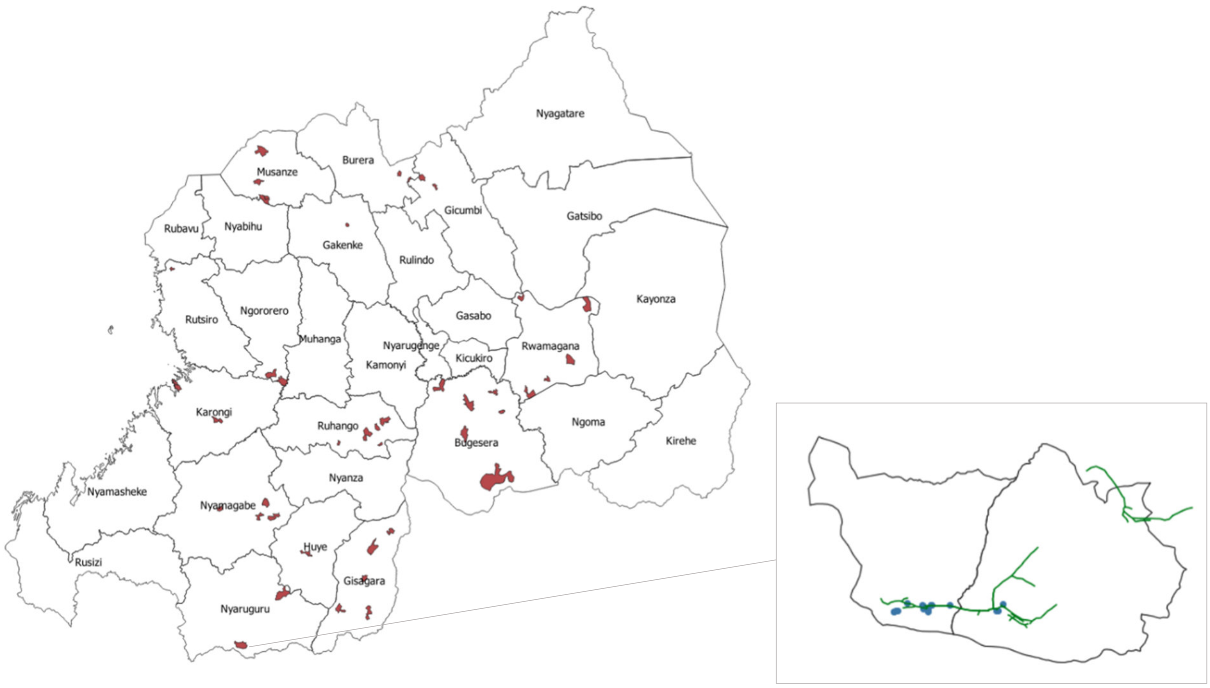
Blackouts and voltage fluctuations occur, but relatively infrequently compared to other SSA countries (Blimpo & Cosgrove-Davies, 2019). In the month prior to the survey, 58% of connected households report to have experienced blackouts, which occur once per week on average. Blackouts last 3.6 hours on average. 21% of all connected households reported that they had noticed voltage fluctuations, which occur only once per month or less in 70% of the cases. Blimpo & Cosgrove-Davies (2019) document for eleven countries, including neighboring countries Burundi, Tanzania and Uganda, that over 40% of the connected households experience outages for over half of the time. In Kenya, approximately one fourth of connected households have outages for over half of the time. Bensch et al. (2017), study the service quality in two grid connected towns in rural Tanzania. Blackouts are reported by 88% of all connected households, occur twice per week and last two to eight hours on average.

A.2 Sample selection

A representative random sample of then-treatment communities was chosen by Lenz et al. (2017) according to probability-proportional-to-size sampling from a list of communities scheduled for electrification between 2011 and 2012. Then-control communities were partly selected from a list of EARP communities scheduled for connection after 2013, and partly according to their comparability to the respective treatment communities regarding road access, community size, number and type of enterprises, and prevailing agricultural activities. See Lenz et al. (2017) for a more detailed discussion of sample selection.

The study communities are located across rural Rwanda (Figure A1, left). For the purpose of the study, a community is defined as a group of households, clustered around basic infrastructure, and often covers multiple administrative settlements, so-called umudugudus. Figure A1 (right) shows a detail of one study community that consists of two umudugudus, illustrated by the black borders. The lines represent the LV lines, which run in the center of the community, often alongside the main road. The dots represent under-grid households.

Figure A1: Map of study communities and detail of study community



In 2011, the average population is 300 households per community. All communities are located in rural areas, where the majority of the population relies on farming as their primary source of income. Only few communities had a business center or substantial entrepreneurial activity before grid connection. Existing enterprises mostly offered goods or services for local consumption, such as shops, hairdressers, bars, carpenters and tailors. The majority of communities are accessible via dirt road only, and only one is accessible via an asphalted road. Few communities have public facilities, apart from a primary school.

A.3 Electricity consumption

Eliciting electricity consumption through recall in household surveys is challenging as households recharge their pre-paid meters on an as-needed basis and few households keep receipts. We elicit electricity consumption in two ways. First, we ask households for the amount (in kWh or RWF) consumed on the last three bills, the dates of recharge, and the average frequency of recharge. Second, we elicit ownership of appliances and lighting devices, and their average usage hours in each household. We use this data, and the average kWh per appliance to infer monthly consumption.

Our preferred metric (as reported in Figure 2) consists of a combination of these different variables. We use prepaid electricity bills for households that are able to provide them, and appliance and lighting usage for all other households. 77 households are able to provide us with the exact date and recharge amount for at least two of their last three bills. For an additional 321 households, we use the average frequency of recharge. For the remaining 272 households, we only have appliance ownership, so we estimate electricity consumption based on appliance ownership and self-reported average usage hours.

The average consumption level for the different measures range between 6.1 kWh and 11.7 kWh per month. We assess the quality of our inferred values by comparing the values from bill dates and the inferred comsumption values, for households for which we have two or more metrics. The Pearson correlations coefficients, reported in Table A1, are moderate to high.

Table A1: Pearson's correlation coefficients for different electricity consumption metrics

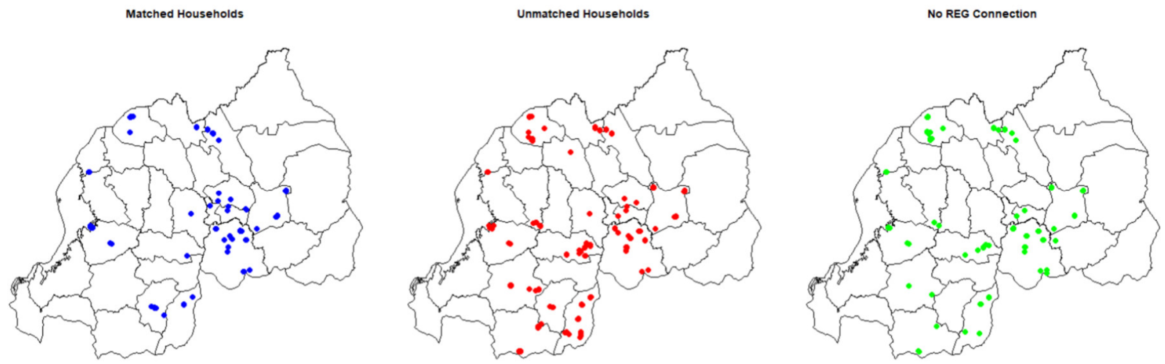
	Bills and date	Bills and frequency	Appliances and light
Bills and date	1		
Bills and frequency	0.45	1	
Appliances and light	0.12	0.48	1

The administrative consumption data also has similar levels of consumption. We compare the 2019 data from the administrative consumption data with our preferred combined consumption metric, described above. The average difference in electricity consumption for matched households in the two datasets is 4 kWh. The Pearson correlation coefficient is moderately high, at 0.29.

A.4 Bias correction

We were able to match 26% of the connected households in our sample with the administrative consumption data. Figure A2 below shows the distribution of households across the country.

Figure A2: Geographic distribution of matched and unmatched households



Using our 2022 level survey data and a tobit model, we analyse which communities have the largest share of matched households. We find that the share of matched households is larger in communities with better road quality, a higher number of enterprises and in earlier electrified communities. In addition, at the household level, higher-income households with better housing quality are more likely to be matched. This means that the matching is imperfect and results in the systematic exclusion of some households.

To address this distorted matching, we formally implement a bias correction for the administrative consumption data using inverse probability weighting. We first estimate a probit regression which includes both household- and community-level covariates, such as demographic characteristics of the head of household (gender, age, education), household characteristics (number of members and their age), type of electricity access, dwelling characteristics (type of walls, windows, floors, and roofs), and community indicators. We use the fitted model to predict the probability to be matched, and then weight the observation by the inverse of the predicted probability.

Table A2 shows the descriptive statistics for yearly consumption from the administrative consumption data. The unweighted yearly averages are slightly higher than the yearly averages using inverse probability weighting, with 2014 and 2015 as exception. This indicates that the matched administrative consumption data presented in the paper rather presents an upper bound for the entire survey sample.

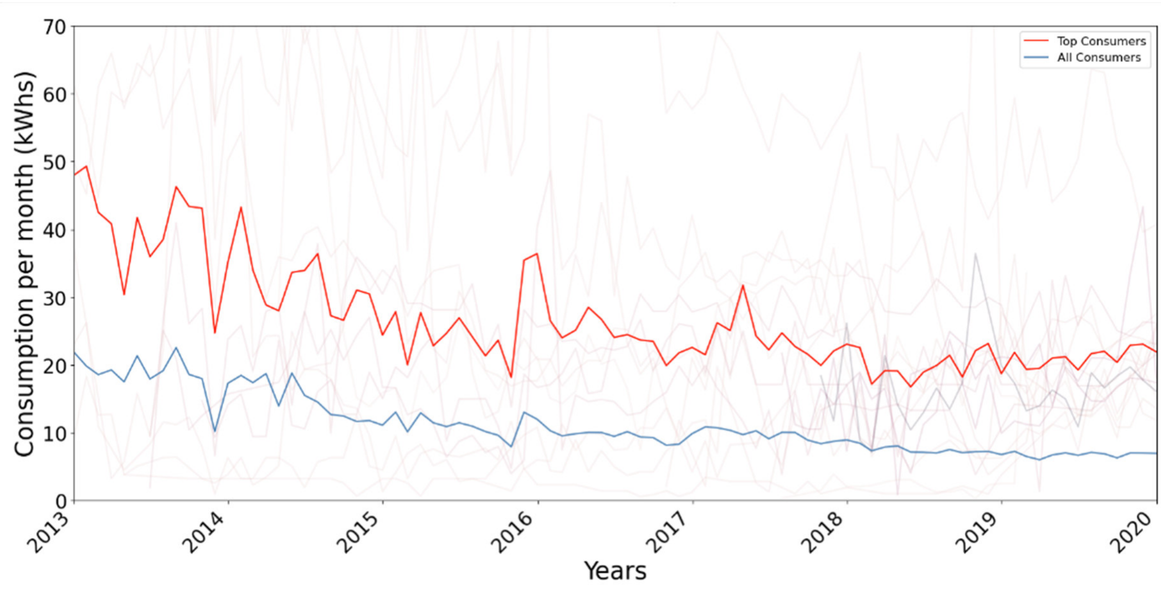
Table A2: unweighted and weighted yearly average consumption

Year	On-grid*	Not Weighted					Inverse Probability Weighting				
		Mean	Median	St. Dev.	Min.	Max.	Mean	Median	St. Dev.	Min.	Max.
2013	47	148.37	72.20	196.97	0.00	968.00	142.85	52.20	194.25	0.00	968.00
2014	66	107.55	55.70	146.76	0.00	770.90	112.61	59.65	145.64	0.00	770.90
2015	82	89.09	40.80	123.61	0.00	600.60	94.70	45.65	121.50	0.00	600.60
2016	102	75.21	42.00	114.59	0.00	923.50	71.51	39.85	96.42	0.00	923.50
2017	107	84.14	47.50	138.33	0.00	1079.80	77.44	46.70	122.64	0.00	1079.80
2018	130	68.22	40.35	90.25	0.00	603.70	61.56	35.05	80.98	0.00	603.70
2019	165	58.39	32.40	76.80	0.00	610.00	52.21	27.25	69.14	0.00	610.00
Total	165	80.91	39.40	120.71	0.00	1079.80	74.69	36.35	108.83	0.00	1079.80

Note: Source: Administrative consumption data. Values for consumption are in kWh.* On-grid are the number of meters at the beginning of the year. Nine households are excluded from this table as they connected during 2019/2020.

A.5 Tables and figures

Figure A3: Consumption over time (kWh) for matched households



Note: Source: Administrative consumption data.

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