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10 Years After: Long-term Adoption of Electricity in Rural Rwanda

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Power grid extension into hitherto unconnected areas is high on the policy agenda in Sub-Saharan Africa. Yet, connection rates and electricity consumption remain low in rural grid-covered areas, at least in the short and medium run. This paper provides a long-term follow-up on an evaluation of a large 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 triangulate our own survey data with administrative consumption data. We find that in connected communities, almost half of the households remain unconnected. Electricity consumption and appliance use are low and did not grow over time. It is therefore difficult to justify investments into grid-based rural electrification by economic development impacts and cost-benefit considerations. Rights-based arguments rooted in equity and fairness considerations may provide a more compelling yet controversial justification for such investments.

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

Keywords: SDG 7, Energy Access, Energy Consumption, Electrification, Sub-Saharan Africa

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1. Introduction

Based on the belief that energy is a driver of economic development, universal access emerged as an important policy objective and a Sustainable Development Goal (United Nations, 2015; SDG 7). 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 consequently, 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 studies typically examine adoption and impacts after two to three years, the longest after seven. The question therefore arises if it simply takes more time for adoption and 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 Rwanda's Electricity Access Roll-out Program (EARP), one of the biggest grid expansion initiatives worldwide. EARP increased electrification from a very low rate of 6% in 2009 to 54% in 2023 (Rwanda Energy Group, 2023), making Rwanda the second fastest-electrifying country in SSA (after Kenya) in the last decade (IEA et al., 2023). Lenz et al. (2017) evaluate adoption and impacts in communities connected in the first phase of EARP, 3.5 years after connection. They document noteworthy usage patterns in households such as lighting, for studying and other household chores, entertainment devices and phone charging. Yet consumption levels were extremely low, also in connected enterprises, which hardly use electric appliances beyond lighting. Hence, there was no indication for the economic development effects of electrification that are typically assumed in cost-benefit considerations of donor agencies.

We revisit the same communities up to ten years after grid-connection and thereby provide an unusual long-term follow-up.[1] Our analysis is based on two data sources with complementary virtues: four waves of survey data and administrative consumption data. The survey data comprises detailed energy usage data from 820 households in 41 rural communities. The

[1] The average community in our sample was connected eight to nine years ago; 28 communities were connected more than eight years ago. Only four communities were connected less than five years ago.

administrative consumption dataset covers all pre-paid purchases for 147,074 rural Rwandan households between 2012 and 2020, among them 174 households in our sample.

EARP succesfully connected 41 and hence all but two communities of the Lenz et al. (2017) sample to the grid. We find that in connected communities, a notable share of households remains unconnected. Electricity consumption in 2022 remains at similarly low levels as in 2013. Connected households mainly use electricity for lighting and phone charging, with only 23% owning electric appliances other than a lamp, phone, or radio (mostly television). Few households use appliances productively. Most enterprises acquire a connection, but there is no indication for noteworthy enterprise creation.

Our paper responds to the legitimate criticism that the lack of impacts measured in previous impact evaluations could be explained by the fact that adoption, and therefore economic development effects, might need 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 diagnose large effects (Lewis & Severnini, 2020; Lipscomb et al., 2013; Nag & Stern, 2023; Rud, 2012; van de Walle et al., 2013). Our paper confirms concerns about the transferability of these findings to contexts in SSA (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.[2] We dropped two non-connected communities from our analysis because this sample is too small to use it for further comparison. We conducted surveys with households living within a 50 meters corridor on both sides of the low-voltage line that can connect at the lowest fee of 93 USD, henceforth "under-grid" households.[3] We used a random walk approach to select a sample representative of all under-grid households in the community. Per community, we interviewed 30 households in 2011 and 2013. A subsample was also interviewed in 2015. In 2022, we selected a new random sample of twenty under-grid households. Tracking the same households as in the previous waves was too complicated because family compositions, locations, and phone numbers changed. Also, for our research question a household-level panel dimension is not

[2] See Appendices A.1 and A.2, details on sample selection and the definition of a community.
[3] We use the 2011 conversion rate of 600 RWF to 1 USD throughout.

crucial. Additionally, we interviewed community leaders to elicit information about the entire community, that is, including households living beyond the under-grid corridor as well as information about the enterprises.

Our second dataset consists of administrative consumption data covering all pre-paid purchases from October 2012 to April 2020 for 800,000 consumers of the national utility Rwanda Energy Group (REG, out of a universe of 1,300,000 consumers in total), from 15 out of 30 districts in the country.[4] We are interested in rural customers, but only about half of the consumers in the administrative data are geolocated, allowing us to identify them as "rural" or "urban". From the geolocated data, we include only the 147,074 rural households. We use this administrative dataset to scrutinize the external validity of our survey findings, by comparing them to the rest of the country. The underlying assumption is that the administrative data is suffciently representative despite the selection process that is not entirely traceable. Furthermore, we use the administrative data to corroborate our survey consumption data. For this, we use a unique meter ID to identify households that occur in both datasets, and could match 26% of the connected households in our surveyed sample.[5]

2.2 Household adoption

We examine household consumption with 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 connection, 82% of the under-grid households are connected. This connection rate was already high 3.5 years after connection and hardly increased since. Between 2011 and 2022 REG might have extended distribution lines in some communities, and thus the 2022 under-grid corridor, which we use here, is different from the 2011 under-grid corridor. The implication would be that we underestimate what we consider the long-term under-grid connection rate, because in the 2011 corridor the connection rate could be higher than 82%. At the wider community level, so including households that live further away from the grid, only 51% are connected.

[4] While the dataset covers purchases of electricity, we deem this a good proxy for consumption in Rwanda. Customers usually recharge their meters for small amounts and on an as-needed basis.

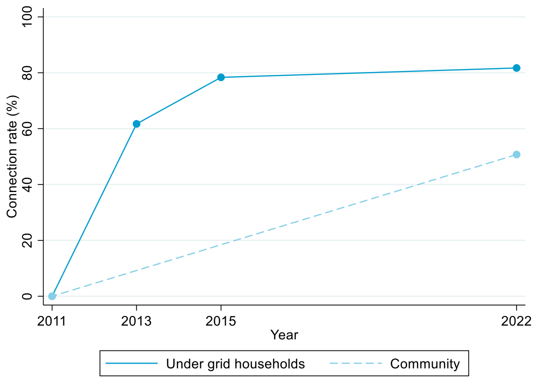
[5] We implement a bias correction and find that the matched households are likely to represent the upper bound of the consumption distribution in our survey sample (Appendix A.4).

Adoption of electric appliances among connected under-grid households is low. In 2022, nearly all connected households use electric lamps, 84% own mobile phones, and 50% own electric radios. Only 23% own other appliances (mostly televisions). Productive use of appliances is not common: 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. There is no indication of increased appliance adoption over time.

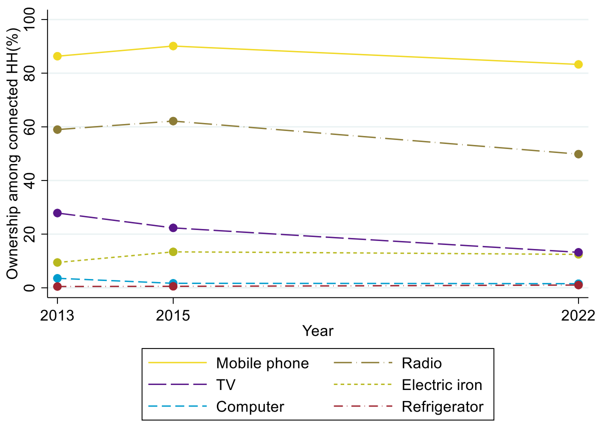
In 2022, electric light bulbs have replaced kerosene lanterns and battery-run appliances almost entirely among connected households; only 14% use candles occasionally. Households not connected to the grid rely on battery-run LED torches, solar lamps, or candles. Like in most other countries in SSA, electricity is not used for cooking (IEA et al., 2022).

Figure 1: Electricity adoption over time

Panel A. Connection rates



Panel B. Appliance ownership



Note: Source: Household and community survey. A household is considered as grid-connected 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 extremely rare in Rwanda. The sample for this figure consists of thirteen connected communities in 2013 and 2015 and 41 connected communities in 2022.

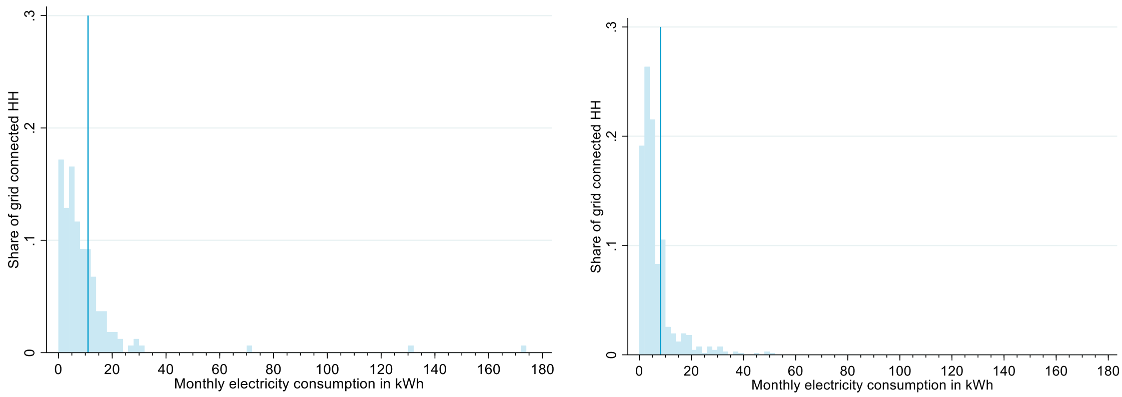
Figure 2 shows the self-reported average monthly consumption in kWh. The left panel shows the 2013 consumption levels for connected households in those communities that were connected by 2013. The right panel shows consumption levels in 2022 for connected households in all communities.[6] Up to ten years after electrification, the average connected

[6] When looking only at communities already connected by 2013, the mean consumption in 2022 is 8.5 kWh/month. This indicates that the consumption in the entire sample is not pulled down by the more recently connected communities.

household consumes 8.1 kWh per month, and the median is 4 kWh. Under current tariffs, the mean amount purchased per month is 720 RWF, equivalent to 2% of the median households' expenditures.

Figure 2: Self-reported monthly electricity consumption for connected households

Panel A. 2013 **Panel B. 2022**



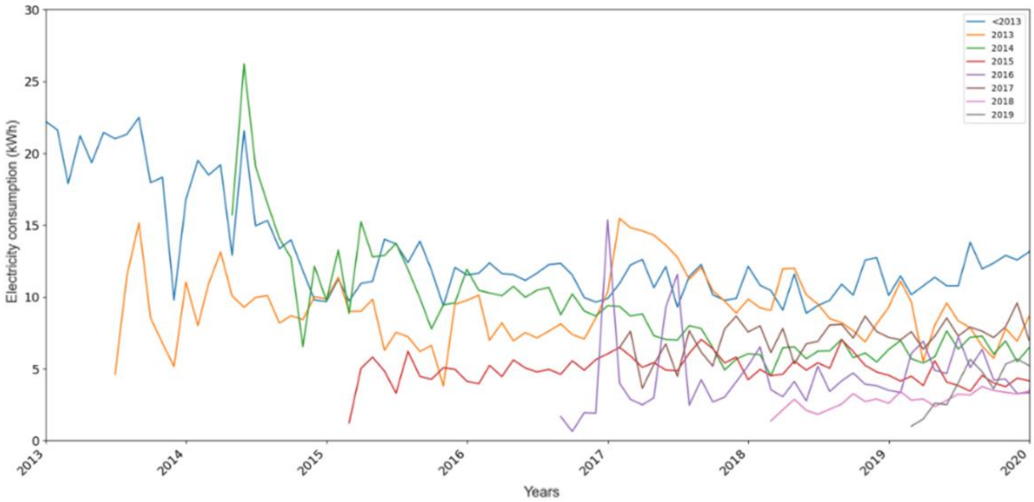
Note: Source: Household survey. The sample for this figure consists of thirteen connected communities in 2013 (panel A) and 41 connected communities in 2022 (panel B). See Lenz et al. (2017) for more details. Consumption is trimmed at the 99th percentile for graphical presentation. The vertical line presents the mean monthly consumption (untrimmed). 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. Earlier connected households initially have higher average levels of consumption, which could be explained by better-off communities being connected first, or better-off households within connected communities being connected 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 and the purchased quantity decline over time. We find similar trends for the highest 10% of consumers in our sample (Figure A.3), indicating that even for the top-consumers, there is no indication of consumption growth over time.

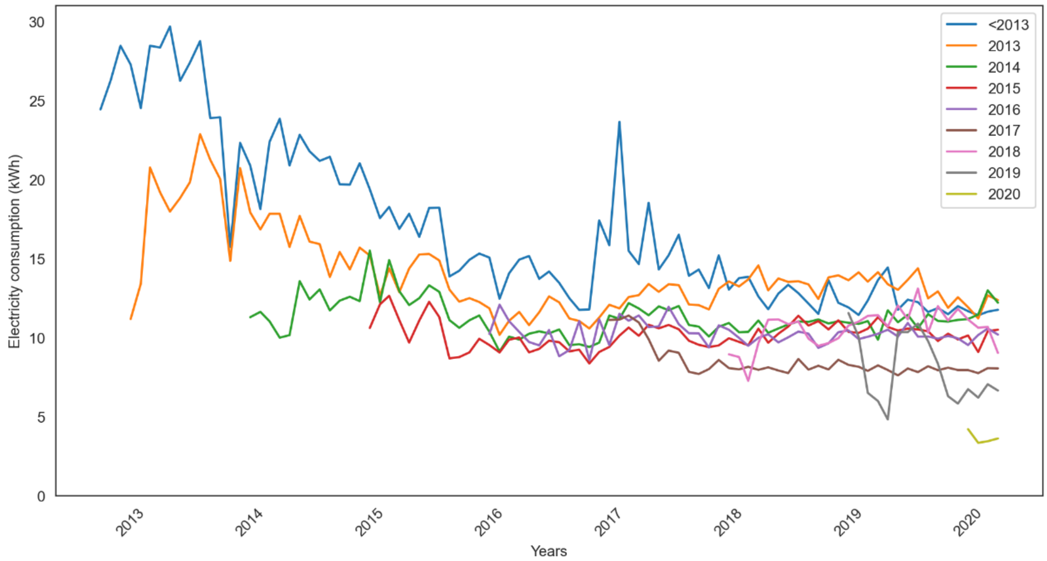
The administrative consumption data also corroborates our survey data results. The matched households have similar consumption levels in both the administrative consumption data and in the survey data, which gives confidence in the accuracy of the self-reported survey data (see Appendix A.3). Additionally, the administrative consumption data shows that the low consumption levels in 2022 cannot be attributed to the COVID-pandemic, as consumption levels have already been similarly low before the pandemic.

Figure 3: Consumption over time by year of connection

Panel A. 174 matched households in survey communities



Panel B. 147,074 rural households across the country



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 147,074 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.

2.3 Enterprise adoption

We elicited information from the community leaders about the enterprises in their community. In 2022, the average community has sixteen enterprises, most of them grid-connected, and all of them micro-enterprises with no or very few employees. We find no evidence that electrification leads to substantial creation of new types of enterprises, although we do observe a few new enterprises that rely on electricity (like welders in 29% of the communities and copy shops in 12%) and that might not have been created in absence of grid-electricity (using a generator).

In general, enterprises in the communities provide basic services to the local population, like small shops, bars, restaurants, and hairdressers. Only half of the communities have any manufacturing firms like tailors, welders, or carpenters. Most enterprises use electricity for lighting. Small shops, selling items like staple food or toiletries for local consumption, as well as bars and restaurants sometimes obtain electric appliances after electrification. Among small shops, 22% have a radio, 12% a TV, and 2% a refrigerator. Bars and restaurants often have a radio (50% and 22% respectively), or a TV (35% and 22%). 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 electric sewing machine and 31% of all carpenters have some kind of electric wood processing machine.

2.4 Generalizability across Rwanda and Sub-Saharan Africa

In Figure 3, Panel B, we compare consumption levels in our sample to the average in rural communities, using the administrative consumption dataset. In line with our findings, the average consumption per rural household beyond our sample is also low, and does not increase over time.

Next, we discuss the generalizability of our findings beyond rural Rwanda. We compare our estimates with connection rates and consumption levels from other studies in SSA, which mainly use utility data or nationally representative socio-economic datasets. Blimpo & Cosgrove-Davies (2019) report that connection rates for under-grid households vary substantially across SSA. Using Demographic and Health Survey data, 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%.[7] No information is available for how long the areas have been electrified. In rural Kenya, Lee et al. (2016) find that only 5% of

[7] 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.

households in their sample are connected, up to five years after community connection. Half of the non-connected households 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 are grid-connected 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%, two to three years after a grid extension program. In Burkina Faso, Schmidt & Moradi (2023) find that household connection rates stagnate around 8-10%, three years after community connection. These findings suggest that our diagnosis of low connection rates appears 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 kWh/year in 2014. This is equivalent to powering only a 50-Watt light bulb for a year, but still four times the amount we measure in rural Rwanda. Descriptive studies using national utilities' data for Kenya (Fobi et al., 2018; Taneja, 2018) and Togo (Boubakar et al., 2022) document similar consumption patterns: overall low consumption and limited consumption growth over time. In Kenya, the median consumption among rural consumers ranges between 200-400 kWh/year in 2015. In Togo, the average consumption for rural consumers is around 600 kWh/year in 2020. In the first months after connection, electricity consumption grows modestly, but later tapers off. Similar to our findings in Rwanda, later connections consume less electricity.

3. Discussion

We address important policy questions: what is the electricity adoption trajectory over time and will economic development impacts unfold in the long-run? We do not observe a decline in connection rates and appliance usage over time. This, as well as the sustaining positive short-term impacts on household wellbeing observed in Lenz et al. (2017), cannot be taken for granted in the aftermath of the COVID-pandemic. 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 well below 100% in grid-connected communities. Hence, it cannot be expected that the universal access goal is achieved in the long term – even in grid-connected areas and despite connection fees for under-grid households 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 (see Appendix A.1 for more details).

For connected households, consumption remains very low. Households own virtually no productive appliances, but rather use lighting and entertainment devices only. There is no indication for noteworthy 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 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 electricity usage could be covered by alternative, cheaper electricity sources – for example decentralized off-grid solar. Proponents of large infrastructure investments argue that in the long run, grid extension enables better development potential once economic growth and productive demand occur endogenously. A focus on small-scale decentralized electricity instead may cap that demand increase and hamper endogenous economic growth. Our findings suggest that even this more patient prior, based on long-term expectations, needs to be updated towards a much longer period than most donor agencies and governments might have hoped. The question hence arises whether such potential benefits in the far-away future justify today's high investment and opportunity costs. A careful case-by-case consideration of different electricity 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; Trotter et al., 2019; Trotter et al., 2017). 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 demand over time (Duthie et al., 2024; Egli et al., 2023; Peters et al., 2019).

Large 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, as 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 twenty-year horizon for its calculations, though assessments typically occur two to five years after project closure (MCC, 2024). 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 ten to fifteen year timeframe without an external growth stimulus.[8] Donors might nevertheless assume demand increases in the medium to long term, but our findings strongly suggest that such assumptions should be labelled as optimistic scenarios. From a cost-effectiveness perspective, it should also be noted that the non-negligible positive impacts on household wellbeing can also be generated by off-grid technologies, at much lower investment costs (Grimm et al., 2020).

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 vantage point, our findings are not disappointing since they confirm sustainable uptake of electricity – but measures need to be taken to address stagnating connection rates and ensure all households under the grid are connected.

[8] 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.

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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.[9] 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 close to the LV line[10] , the connection fee is 56,000 RWF (93 USD). Following Lee 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

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[9] 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.

[10] Currently, distances below 37 meters from the LV line pay lower fees. 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.

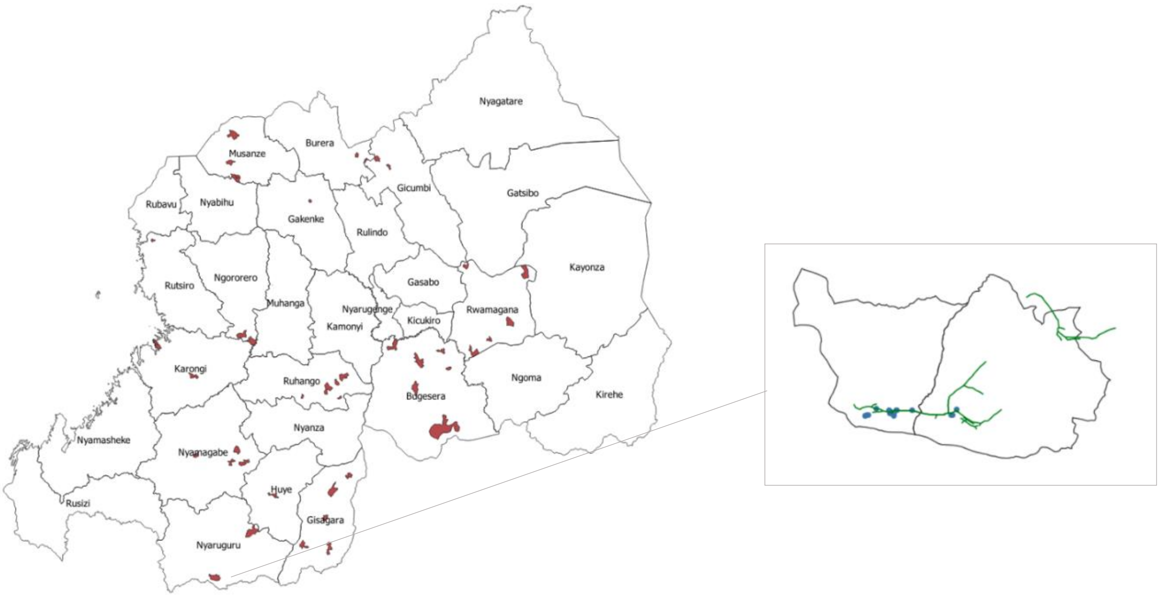
Blackouts and voltage fluctuations occur, but relatively infrequently compared to other SSA countries (Blimpo & Cosgrove-Davies, 2019). In the month prior to our 2022 survey, 61% of connected households report to have experienced blackouts, which occur once per week on average. Blackouts last 3.6 hours 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

The communities in our sample are representative for communities scheduled to be electrified during EARP's first phase between 2009 and 2013. 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 treatment communities regarding road access, community size, number and type of enterprises, and prevailing agricultural activities.

The study communities are located across rural Rwanda (Figure A.1, left). We define a community as a group of households, clustered around basic infrastructure. One community often covers multiple administrative settlements, so-called umudugudus. Figure A.1 (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 A.1: 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 consumed on the last three bills (in kWh or RWF), 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 data on appliance ownership, so we estimate electricity consumption based on appliance ownership and self-reported average usage hours.

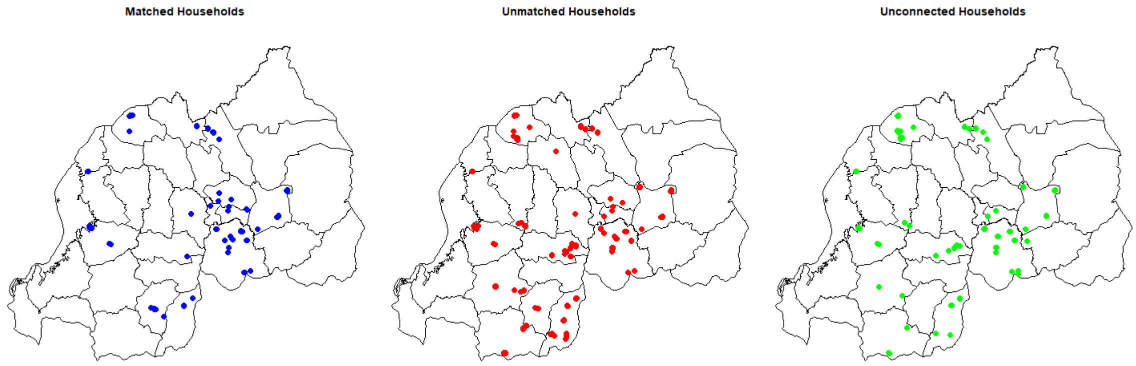
The average consumption level for the different measures ranges between 6.1 kWh and 11.7 kWh per month. We assess the quality of our inferred values by comparing the values from bill dates and the inferred comsumption values, for households for which we have two or more metrics. The Pearson correlation coefficients range between 0.14 and 0.48, which is moderate to high.

The administrative consumption data also shows similar levels of consumption for the matched households. 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 A.2 shows the distribution of households across the country.

Figure A.2: 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 A.1 shows the descriptive statistics for yearly consumption from the administrative consumption data. The unweighted yearly mean and median is slightly higher than the yearly mean and median using inverse probability weighting, with 2014 and 2015 as exception. This indicates that the matched administrative consumption data used in the paper rather presents an upper bound for the entire survey sample.

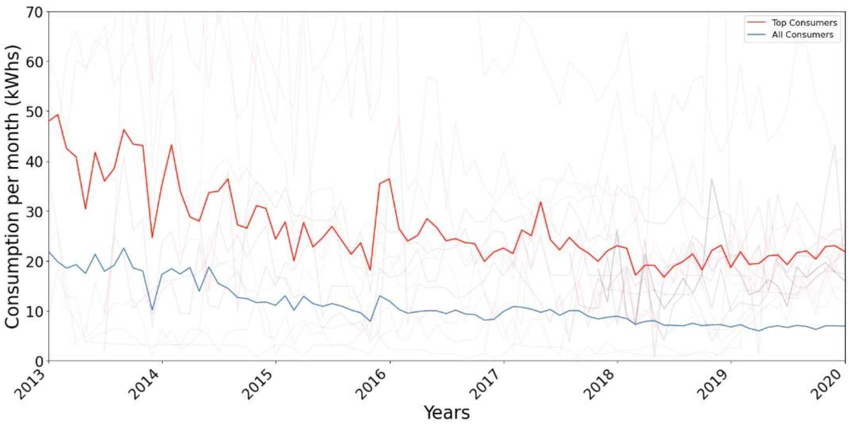
Table A.1: Unweighted and weighted yearly average consumption

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. Nine households are excluded from this table as they connected during 2019/2020. * On-grid are the number of meters at the beginning of the year.

A.5 Adoption among top consumers

Figure A.3: Electricity consumption over time (kWh) for matched households



Note: Source: Administrative consumption data. “Top consumers” indicate the highest 10% of consumers in our matched sample.

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