10 years after: long term adoption of electricity in rural Rwanda

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Abstract

Universal access to energy has emerged as a major policy goal. Yet, in many areas served by the grid, uptake and electricity consumption remain low, at least in the short and medium run. This paper combines survey and utility data to document long-term connection rates and consumption patterns in rural Rwanda. Our analysis is based on a panel of 41 communities that were electrified up to 10 years ago. We find that connection rates for household living close the grid are high, though not high enough to achieve the universal access goal. At the community level, connection rates are low. Furthermore, among connected households, consumption levels and appliance usage are low, and do not grow much over time. This challenges the cost-effectiveness and economic sustainability of grid extension efforts.

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

Keywords: Energy Access, Energy Consumption, Energy use, Electricity, Sub-Saharan Africa

1. Introduction

733 million people worldwide do not have access to electricity. 4 out of 5 live in Sub-Saharan Africa, where over half of the population, mostly in rural areas, lack access (IEA et al., 2022). Based on the assumption that energy is a driver of economic development, universal access has emerged as an important policy goal, reflected by its inclusion in the United Nation's Sustainable Development Goals (United Nations, 2015). This resulted in major investments to increase electrification rates.

Yet, academic consensus on the socio-economic impacts of rural electrification is missing. The literature is divided, with a recent turn towards rather disappointing findings. Impact evaluations of grid extension studies in Sub-Saharan Africa document low adoption at the intensive and/or extensive margin (Bernard & Torero, 2015; Chaplin et al., 2017; Lee et al., 2020b; Lenz et al., 2017). However, one critique on these studies is the narrow time horizon. Assessing the impact in the short or medium term may be too narrow a focus (Burgess et al., 2020; Lee et al., 2020a; Peters & Sievert, 2016). Our paper follows up on Lenz et al. (2017, henceforth LMPS), who find that Rwanda's large-scale electrification program increased connection rates, but not electricity usage, up to 3.5 years after connection. We document connection rates and consumption patterns approximately one decade after electrification and thereby provide the longest term follow-up for an impact evaluation in this literature.

The few existing longer run studies point to postive effects of electrification. Lipscomb et al. (2013) document large impacts of electrification on household income, labor productivity and education over a 40-year period in Brazil. In India, Rud (2012) finds large increases in state manufacturing output in a 20-year panel and van de Walle et al. (2013) find positive effects of household electrification on consumption, labor supply and schooling in a 17-year panel. However, these studies rely on instrumental variable approaches which are not immune against exogeneity concerns (Bensch et al., 2021; Bensch & Peters, 2020; Lee et al., 2020a). Specifically in the context of large-scale infrastructure, instruments may also predict complementary investments, such as road availability (Bensch & Peters, 2020). Furthermore, these studies take place in contexts where electrification could have been the sole binding constraint. If other constraints exist, such as market access or availability of credit, we may not expect to see such positive results. In Sub-Saharan Africa, Peters et al. (2011) and Schmidt & Moradi (2022), follow-up 7 and 6 years after electrification respecitively.

Using a community panel dataset and prepaid electricity purchase data, we find that, approximately one decade after electrification, 82% of households living in the direct vicinity of the grid are connected. While this number is high, a non-neglegible share of households that can connect at low costs, does not. This is important for the universal access goal. Furthermore, there has been limited growth in connection rates since 2015, when the average connection rate was already at 78%. At the community level, 44% of households does not have access to any source of electricity, despite living in a connected community. These findings add to a thin literature showing that a significant share of households living within reach of the grid, remain unconnected (Blimpo et al., 2020; Blimpo & Cosgrove-Davies, 2019; Lee, Brewer, et al., 2016).

Furthermore, our data shows that, once connected, adoption of appliances and electricity usage is limited. Grid electricity is mainly used for lighting and phone charging. Only 43% of connected households purchase any other appliances and very few households use productive appliances. Electricity consumption levels are low and do not grow much over time. At the community level, businesses and public infrastructure acquire a connection, but we do not see large increases in enterprise creation. This poses a challenge for the financial sustainability of utilities.

This paper is set up as follows. Chapter 2 details the Rwandan context, our sample and data sources. Chapter 3 presents results and Chapter 4 concludes.

2. Context, sample and data

2.1 Rural electrification in Rwanda

The government of Rwanda aims to achieve universal access to electricity by 2024 through a combination of on-grid and off-grid technologies (Ministry of Infrastructure, 2018). Currently, 51% of the population is connected to the grid and 24% to off-grid sources, mainly solar energy (REG, 2022). To accelarate the electrification effort, the national utility launched the multi-donor Electricity Access Roll-out Program (EARP) in 2009. Through on-grid extension and grid densification activities, the EARP increased the electrification rate by 3.7 percentage points a year between 2010-2020, making Rwanda the fastest grower among the 20 least-electrified countries worldwide (IEA et al., 2022). In addition to supporting direct access, parts of the EARP funds were invested into the existing grid to ensure grid stability.

Over the years, REG addressed some of the major demand barriers for household electricity access. To address liquidity constraints and irregularity of income, connection costs are subsidized and can be paid in installments. A connection costs 56,000 FRW (67 USD in 2017) and since 2017, no upfront payments are required. To address poor housing quality, households receive a ready board upon connection. Electricity tariffs also altered over the years (Table 1**Error! Reference source not found.**). Between 2006 and 2015, tarrifs for residential consumers increased to cover the cost of service and increased generation costs, but since 2017, a block tariff is charged to increase affordability. In 2022, the prices are 89 FRW/kWh for the first 15 kWh consumed, 182 FRW/kWh for the next 35 KwH consumed and 210 FRW/kWh above 50 kWh consumed.

Table 1: Residential electricity tariffs in Rwanda

Year	Tariff (FRW/kWh)
2006	112
2012	134
2015	182
2017	0 – 15 kWh: 89 15-50 kWh: 182 > 50 kWh: 189
2018	0 – 15 kWh: 89 15-50 kWh: 182 > 50 kWh: 210

LMPS(2017) evaluate the impact of the first phase of EARP on different beneficiaries group. Using a difference-in-difference approach, the study compares communities that were connected to the grid between 2011 and 2013 with communities that were scheduled for connection after the endline survey. At the household level, EARP was successful in increasing electrification rates to 70% in newly connected areas, 3.5 years after community connection. While households increase lighting usage and obtain some new appliances, the quantity of electricity consumed remained low. Also, little appliances are used for productive purposes.

2.2 Sample

Our study revisits the 43 communities included in LMPS(2017). Communities are located in rural areas spread across Rwanda (Figure A1**Error! Reference source not found.**). The sample was selected by LMPS(2017) to be representative of communities scheduled for connection in the second stage of the EARP program. A random sample of then-treatment communities was chosen according to probability-proportional-to-size sampling from a list of communities scheduled for electrification between 2011 and 2012. Then-control communities were selected in the same region[1].

For the purpose of the study, a community is defined as a group of administrative settlements[2], clustered around basic infrastructure. The communities are relatively small, with an average population of 300 households in 2011. They are all located in rural areas, where the majority of the population relies on farming as their primary source of income. While some variation is present between communities, only few had a business center or substantial entrepreneurial activity before grid connection. Existing businesses mostly offered goods or services for local consumption. The

[1] For a detailed discussion of sample selection, see LMPS(2017).

[2] One community in our sample consists of 1-5 administrative village, called umudugudus.

majority of communities are accessible via dirt road only and apart from a primary school, only few communities have public facilities.

2.3 Survey data

In May and June 2022, a team of 30 enumerators visited each community as part of the baseline data collection for an ongoing impact evaluation. We interviewed 868 households, following the same sampling approach as LMPS(2017). The survey population consists of electrified and non-electrified households living under the grid[3], meaning that they live close enough to existing infrastructure to connect at a relatively low cost. The survey team identified a corridor of 50 meter along the distribution line[4]. Using a random walk approach, 30 randomly selected households were interviewed in 2011 and re-interviewed in 2013. In 2022, we interviewed a new random sample of 20 households in the 50 meter corridor. The survey was conducted with the household head or, if (s)he was unavailable, another knowledgeable household member.

We collected community level-data by surveying the leader of each administrative village and aggregating the data on the community-level. The community data covers the entire community and not only the under-grid population from which the households are sampled.

Our empirical strategy relies on comparing data over time where possible. We will compare key outcomes measured at the community level in June 2022 with the baseline survey, conducted between April and June 2011 and the follow-up survey conducted between May and July 2013. We pre-registered our theory of change and main outcome variables online[5] before the end of data collection and before analyzing any data. The variables of interest are either observed at the community level or averaged across households in the community.

2.4 CashPower data

To track electricity consumption over time, we rely on utility data shared by the national utility, the Rwanda Energy Group (REG). This dataset includes electricity meter numbers and purchases of all pre-paid tokens for 800.000 households in 15 out of 30 districts. The dataset covers the period from October 2012 to April 2020.

We collected meter IDs during the household interviews and then merged our survey data to the CashPower database. We were able to match 26% of the connected households in our sample. This results in a total 18,000 pre-paid purchases of electricity. Mismatches result from two sources; first,

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[3] This term is coined by Lee, Brewer, et al. (2016).
[4] According to REG, this was the distance at which households can connect without additional expenses for extending distribution lines in 2011.
[5] https://osf.io/7un39

the CashPower dataset contains an incomplete sample of consumers per district. Second, enumerators were either unable to collect a meter ID or collected a wrong ID.

The matched households may not be representative for the full household sample. We find evidence of selection on household observables, such as income levels and floor and roof quality, that may be correlated with consumption levels. We implement bias correction methods for the consumption data using inverse probability weighting.

3. Results

3.1 Theory of change

The focus of our paper is to assess the effects of electrification on household and community indicators. Rural electrification directly affects households if they connect, but also indirectly through community electrification. Once the grid reaches a community, households, enterprises, and social infrastructure can connect *(Section 4.2).* In most cases, a connection fee is charged to cover the extension costs and in-house wiring, so not necessarily all entities connect. Once connected electrification can affect household income through several channels *(Section 4.3)*. First, access to electricity may reduce the time spent on collecting traditional energy sources, if households use electricity for cooking. Second, the usage of electric lamps may affect wages if households offer more labor through extended working hours. Third, new, productivity-increasing appliances would need to be purchased for electrification to lead to higher incomes. This would then all lead to higher consumption of electricity *(Section 4.4).* At the community level, new firms that only operate through grid electricity would emerge and existing firms could benefit from efficiency improvements. For already existing businesses, access to electricity would lead to an increase in productivity, resulting from a decrease in input requirements or an increase in quality. Better lighting could increase operation hours and ownership of entertainment devices could attract new customers. For this to improve community welfare, employment would need to be created and connected businesses should not crowd out other businesses. This would result in a rise in business activities and a shift away from agricultural to non-agricultural activities *(Section 4.5).* This all hinges upon the reliability of supply *(Section 4.6).* In the light of the large number of new connections, capacity bottlenecks can be a major contraint that could affect the decision to connect and consume electricity in Sub-Saharan Africa (Blimpo & Cosgrove-Davies, 2019).

Impacts from electrification may differ in the long run. At the household level, adoption and usage could increase because it may take time for economic benefits to materialize due to liquidity constraints or learning effects. First, households and businesses may lack the resources to purchase electricity and appliances at the time of electrification. If liquidity constraints are only a barrier in the short run, broader knock-on effects on business creation and income growth would unfold over time. Second, it may take time for households to learn about the full potential of their connection. At the community level, employment effects may ensue as businesses adjust their production function. Over time, this may result in business creation. Yet, this optimistic view would require for electrification to be the only bottlenecks for rural development.

3.2 High but stagnating connection rates challenge universal access

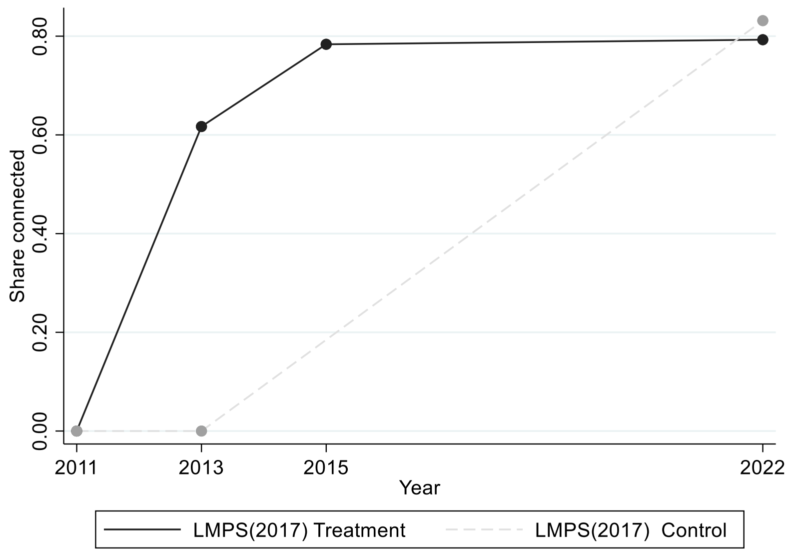
By 2022, REG installed low-voltage electricity lines in 41 out of the 43 study communities[6]. The two non-connected communities are dropped from our analysis in the remainder of the paper. Ten years after electrification[7], 82% of all households living in the direct proximity of the grid are connected. Figure 1 shows that the connection rate was already high in the first years after connection and barely increased between 2015 and 2022.

While the connection rate is high, 18% of all households in direct proximity of the grid still do not have a grid connection one decade after electrification. 3% does have access to electricity through a solar panel. Households that remain unconnected differ from connected households, as they have lower education, lower income and expenditures, lower access to credit and lower wealth (Table A 1).

[6] One of these communities was scheduled for connection between 2011-2013, but their connection got delayed. The other community was a control community. LMPS (2017) selected around half of the control communities from a list of EARP communities scheduled for connection after 2013 and half according to their comparability to the respective treatment communities regarding road access, community size, number and type of businesses, and prevailing agricultural activities.

[7] In 2022, the average community in the sample is connected in 2013.

Figure 1: Grid connection rate over time for households living within 50 meters of the low voltage lines



Note: Source: households survey. This figure shows the connection rate for households who live within 50 meters of the LV line. LMPS(2017) treatment communities connected between 2011 and 2013. LMPS(2017) control communities were connected between 2013 and 2020. To account for differences in sample size over time and across community, the overall connection rate is contructed as the average of all community connection rates. A household is considered as having a grid connection if they have a REG connection plus installation at their home, regardless of whether they consume any electricity. Following REG's definition, we do not count households who are connected through a neighbor. Connection rates in the table above differ slightly from LMPS2017, as they excluded connected households that do not consume. Other discrepancies are due to the two non-connected communities and one duplicate community were excluded from the current sample.

At the community level, considering all households living in a connected community, the average connection rate is only 51%. An additional 2% is connected through a neighbor and 3% has a solar panel. The remaining households either live out of reach of the existing network, are too poor to connect or do not desire a connection. For households living further away, connection fees increase as a function of distance to the LV line, which could be a barrier to connect.

Connection rates among businesses and public infrastructure are high (Table 2). 95% of the most common businesses in the average community are connected to the grid. Connectivity is lowest for carpenters (69%), tailors (81%) and mills (86%), indicating that some of these businesses still rely on mechanical or fuel-run appliances. Some electricity-reliant businesses, such as welders, copy shops and cinemas cannot operate without electricity. For other businesses, such as hairdressers, the cost of appliances is relatively low and the potential benefits large, making it more profitable to connect. Connection rates for public infrastructure are also high, though not univeral. Despite schools and health facilities being prioritized for connection, 16% of primary schools and 9% of health centers are not connected to the grid.

Table 2: Average electrification rates for the most common businesses and public infrastructure

	Percentage of communities with a […]	Average number of […] per community	Average share of […] connected to grid
Businesses			
All businesses	1	16.1	0.95
Small shops	.93	5.98	.96
Bar	.83	2.83	1
Hairdressers/beauty salons	.8	2.32	.99
Tailors	.56	1.63	.81
Mills	.46	1.05	.86
Restaurants	.44	.9	.97
Welder	.29	.51	1
Carpenter	.2	.32	.69
Copy shop	.12	.12	1
Phone shop	.1	.1	1
Public infrastructure			
Primary school	.46	.63	.84
Secondary school	.34	.34	1
Health center/clinic	.27	.27	.91
Local health unit	.17	.2	.86
Church	.88	1.98	.76
Mosque	.17	.17	.86
Cell office	.56	.66	.96
Sector office	.1	.1	1

Note: Source: village leader survey. Column 1 show the average prevalence of each business type or infrastructure, constructed from a dummy for whether the community has at least one. Column 2 reports the total average number per community. Column 3 reports the electrification rate per type of business or infrastructure, averaged over the community.

3.3 Low adoption at the intensive margin

3.3.1 Usage of electricity for cooking and lighting

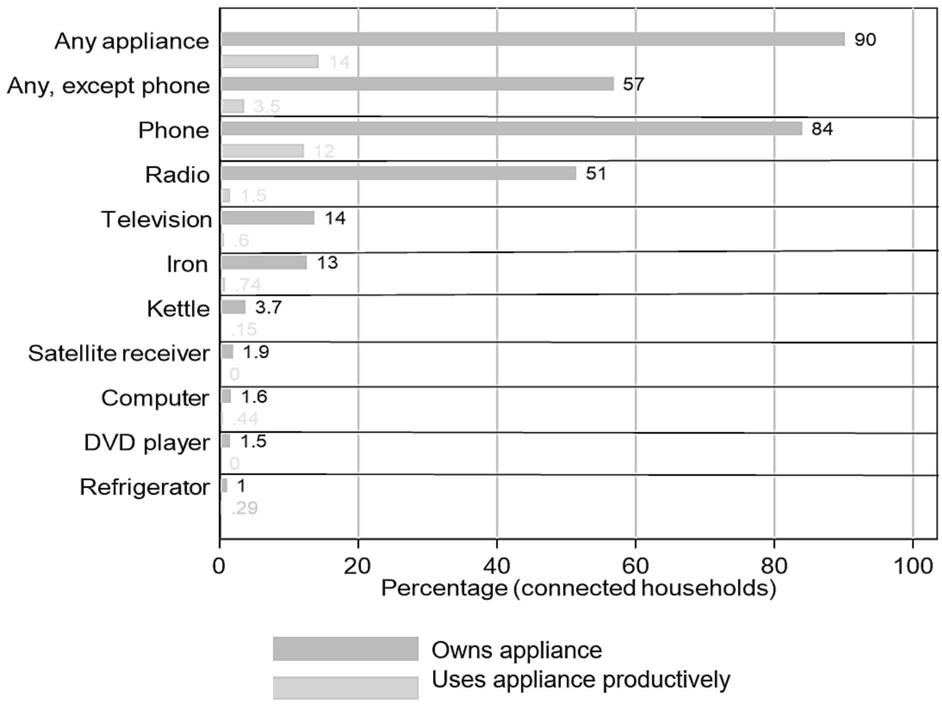
The use of traditional fuels for cooking remains common. Among the connected households. The majority of households rely on firewood (82%) and charcoal (20%) as their main source of energy for cooking. Less than 2% rely use electricity as main source of cooking.

96% of all households that are connected to the grid use electricity as their main source of lighting. Electric lamps, ordinary light bulbs or energy saver bulbs, have replaced kerosene lanterns and battery-run appliances almost entirely. 15% of all connected households do use candles occasionally, alongside electric lighting. Non-connected households mostly rely on battery-run torches, solar lamps or candles.

3.3.2 Appliance ownership

Figure 2 shows that connected households hardly use productive appliances, and rather entertainment devices. 43% of all connected households do not own any appliances except for lamps or mobile phones. The most common appliances are information and entertainment devices and very few households own appliances that require high Watt power and could not be provided by alternative energy sources. Productive use of appliances among connected households is not common. Only 3.5% of the connected households use any electric appliance to earn money.

Figure 2: Appliance ownership among connected households



Note: Source: household survey. This figure shows appliance ownership of common appliance averaged at the village level. The sample consists of households who have an electricity connection. Radio includes both bivalent (9%) and power radio (42%). Television includes color TV (12%) and black-and-white TV (2%)

Table 3 shows the average appliance ownership for grid connected households over time, for households living in communities that were electrified between 2011 and 2013. Apart from a shift from bivalent to line-powered radios, we see no increases in appliance ownership for none of the appliances among connected households.

Table 3: Appliance ownership in LMPS treatment villages over time

	2013 treat	2015 treat	2022 treat
Mobile phone	0.86	0.90	0.81
Radio	0.54	0.72	0.53
(battery only)	0.13	0.12	0.02
(bivalent)	0.43	0.29	0.08
(line powered)	0.19	0.35	0.44
Electric iron	0.09	0.13	0.14
TV (black and white)	0.02	0.02	0.02
TV (color)	0.27	0.21	0.15
Computer	0.04	0.02	0.04
Fridge	0.00	0.01	0.01

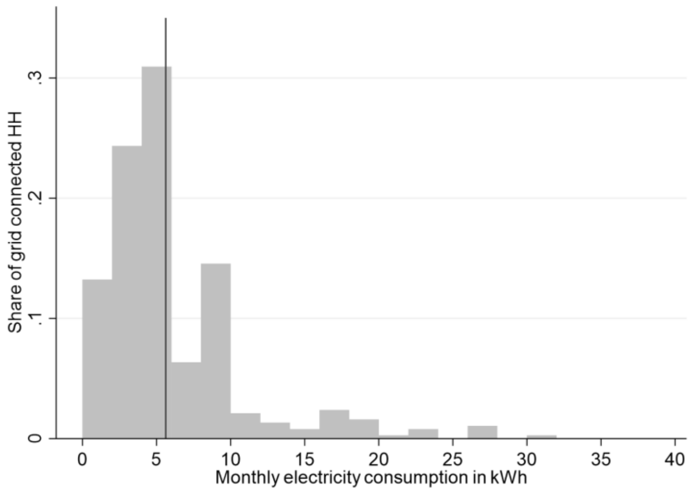
Note: Source: household survey. This table shows the average appliance ownership for connected households over time. The sample includes households who live in the 14 communities connected to the grid between 2011-2013. To account for differences in sample size over time and across communities, the shares are contructed as the average of the community averages.

3.4 Low and stagnant electricity consumption

Households purchase electricity on an as-needed basis and mostly recharge their prepaid meters frequently, for small amounts. This is most commonly done via phone or, alternatively, through an agent in a local shop. Over the period 2012-2020, the average household recharged their meter every 15 days, although large variations exists across households. The average purchase of electricity per recharge is 3.7 KwH, which is equivalent to 330 RWF (0,3 USD) under current electricity prices.

Figure 3 shows the self-reported average monthly consumption in kWh in 2022, up to 10 years after electrification. The average connected household consumed 6 kWh per month, and the median is 3 kWh. Under the current tariffs, the mean amount purchased per month is equivalent to 530 FRW (or 0,5 USD). This amount corresponds to 2% of the households' monthly food expenditures.

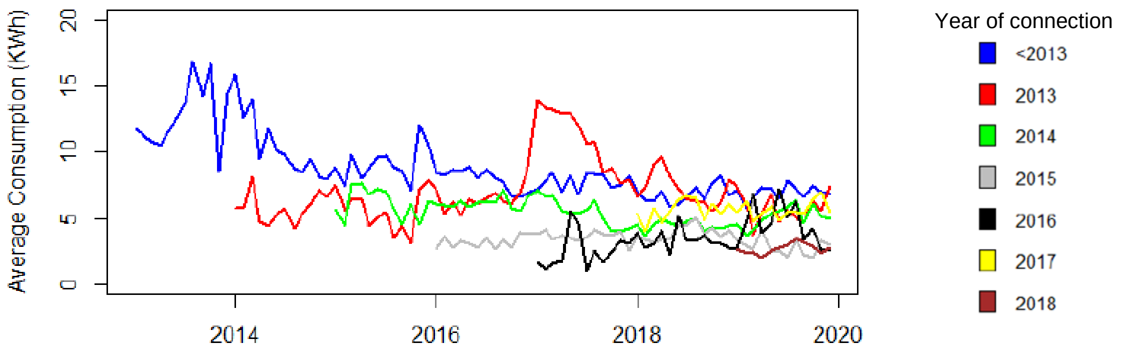
Figure 3: Self-reported monthly consumption in kWh (source: 2022 household interviews)



Note: Source: Household survey. This data is elicited through self-reports where we asked for the amount consumed over the last three bills and the frequency of recharging.The vertical line presents the mean monthly consumption.

Figure 4 shows CashPower data for the 180 matched households. We find that earlier connected households have higher average levels of consumption, which could be explained by richer households receiving a connection earlier. As grid extention efforts increase, poorer households are targeted. Second, we see no increase in consumption over time, for none of the connection years. There is a peak in consumption for the first years after electrification, which then tapers off. Furthermore, both the frequency of purchases and the quantity purchased, decline over time (see Appendix Table A2 and Table A3).

Figure 4: Consumption over time by year of connection (kWh)



3.5 Limited enterprise creation

In 2022, the average community has 16 businesses.**Error! Reference source not found.** The most c ommon enterprise is a shop selling small items like staple food or toiletries, usually for local demand. Bars and restaurants are also common in most villages. In the majority of these businesses, electricity is used for lighting. It is possible that access to electric lighting could inrease or shift operating hours, but it is unlikely to create a net income gain at the community level since products are produced and consumed locally in most cases. A minor share also uses eletricity for entertainment.

Millers, carpenters and tailors use grid electricity for operation of equipment, though many businesses also continue to work with manual machines, despite their grid connection. In these cases, it is possible that access to electricity leads to higher product quality, increased productivity, lower operating costs (especially when shifting from other sources of energy) and additional products that previously could not exist. This may lead to higher business income and additional employment.

Error! Reference source not found. shows that over time, electrification does not lead to massive e mergence of new business types in the community, apart from the emergence of a few businesses that could not exist without electricity, such as welders and copy shops. For most other businesses, the differences between 2013 and 2022 are minor, both in terms of prevalence (Table 4) and absolute number of businesses (Table A4).

Variable	Control 2011	Control 2013	Control 2022	Treatment 2011	Treatment 2013	Treatment 2022
small shops	.97	.9	.93	1	1	.93
bar	.55	.79	.81	.64	1	.86
hairdressers/beauty salons	.41	.66	.85	.64	.86	.71
tailors	.55	.83	.48	.5	.77	.71
carpenters	.41	.55	.19	.64	.79	.21
mills	0	.54	.56	0	.62	.29
welder	0	.03	.33	0	.5	.21
restaurants	.38	.48	.33	.43	.46	.64
copy shop	0	0	.11	0	.07	.14

Note: Source: EARP community data 2011-2013-2022. This table shows the share of communities with different types of enterprises per survey wave and per treatment group. Treatment communities are connected between 2011-2013 while control communities are connected after.

Table 4 shows the primary occupation of the household head over time. This table shows a decrease in subsistence farming, which is offset by an increase in commercial farming and wage employment. The majority of casual wage employees earn an income by offering labor in someone else's garden or childcare in someone's home. Salaried employment mostly consists of public sector employees (mainly teachers). We do not see any increase in self-employment, in line with the above findings on business creation.

Table 4: Primary occupation household head

Variable	2011	2013	2022
Head of household is …			
Subsistence farmer	.8	.71	.54
Commercial farmer	.	.	.06
Salaried or casual wage employee	.07	.11	.18
Self-employed	.1	.12	.11
Other	.03	.06	.09

Note: This table shows the different occupation in the community

3.6 Reliability of supply is unlikely to be a bottleneck

Supply side constraints are unlikely to be a bottleneck for household connection and consumption in Rwanda. Households report a limited number of blackouts and voltage fluctuations (for African comparisons). The average household experiences 2.6 blackouts last month. These last 3.6 hours on average. 41% of households wait for power to return, whereas the remainder relies an a back-up or traditional energy source. 22% of all households experienced voltage fluctuations. These usually occur once per month or less frequently. 19% of all households had an appliance damaged due to blackouts or voltage fluctuations, mostly light bulbs, radios or phones.

Grid connected households indicated to be satisfied with their connection. 80% of all households rate the quality of supply as good or excellent. Only 1% of households complained about poor quality of supply. Furthermore, 96% of all connected households state that the quality of supply has improved or stayed the same over the past 12 months. 95% of connected households considers the grid to be the safest source of electricity.

3.7 Our data is in line with what is being observed across the continent

We provide detailed data for what is being observed across Sub-Saharan Africa. In terms of connection, existing impact evaluations of grid extension studies in Sub-Saharan Africa report low adoption at the intensive and/or extensive margin in newly electrified villages. Despite the increasing extensiveness of the grid, a non-neglegible share of households living close to the grid remain unconnected. Across 20 countries in Sub-Saharan Africa, Blimpo & Cosgrove-Davies (2019) document a median connection rate of 57% for households living in an electrified area. In rural Kenya, Lee, Brewer, et al. (2016) find that 95% of households in their sample is not connected to the grid, up to five years after the infrastructure was installed. Half of these households live close to the grid and could connect at relatively low costs. In Tanzania, up to four years after connection, only 38% of households in connected villages use electricity despite high connection subsidies. This number increases to 57% for households living near the electricity lines (Bensch et al., 2019).

Furthermore, electricity consumption for residential users is very low and overall consumption growth has been limited in the region. In 2014, the average yearly consumption in Sub-Saharan Africa amounted to 483 kWhs, which is equivalent to powering a 50 watt light bulb for a year (Blimpo et al., 2020). Descriptive studies using national utilities' data for Kenya (Fobi et al., 2018; Taneja, 2018), Rwanda (Mugyenyi et al., forthcoming) and Togo (Boubakar et al., 2022), find low consumption growth over time. Consumers often experience some growth in electricity consumption in the first months after connection, but their consumption often tapers off after a while. Furthermore, the average consumption per household decreases as more low consumption users are connected to the grid.

Existing medium-run impact evaluations do not point toward growth effects of electrification either. In Western-Kenya, Lee, Brewer, et al. (2016) document low electrification rates for households in the vicinity of the grid, up to 5 years after building the infrastructure. They find very low average consumption among newly connected households and no meaningful impacts on economic and noneconomic outcomes, up to 32 months after electrification (Lee et al., 2020b). In Burkina Faso, Schmidt & Moradi (2022) look into the impacts of household electrification up to 6 years after connection and find that a plateau is reached in household connections and asset ownership after 3 years. One exception for Sub-Saharan Africa, is Ratledge et al. (2022) who estimate the impact of community-level electrification in Uganda over a 5-year period using satellite imagery and machine learning. They find an increase of 0.15 SD in households assets,mostly driven by home construction and appliances ownership (radio, TV, telephone and refrigerator)[8]. They also find some indication of treatment effects increasing over time.

4. Conclusion and discussion

The existing literature on the impact of rural electrification looks at the short to medium term and is broadly divided along two major lines. First, methodologically, impact evaluations more often document null results compared to quasi-experimental studies relying on instrumental variables or observational studies (Bayer et al., 2020; Jeuland et al., 2021; Lee et al., 2020a). Second, geographically, positive effects are more often found in Asia and Latin-America while there is little indication for effects on economic development and productive use in Sub-Saharan Africa (Bayer et al., 2020; Hamburger et al., 2019; Peters & Sievert, 2016).

Our paper provides evidence on the long-run impact of electrification in rural Rwanda. We compare connection rates and consumption patterns over time in 41 communities, 10 years after connection. We find high connection rates among households living in the proximity of the grid. However, in line with patterns observed across the continent, connection rates at the community level are lower and a large share of households within electrified communities remains unconnected. While connection increases substantially in the early years of electrification, we find no evidence of continued growth in later years. This threatens the universal access goal.

For households living near the existing grid, marginal connection costs are relatively low. The discrepancy between relatively high grid coverage rates and low connection rates, suggests that demand-side barriers may also play a role. Potential drivers of uptake identified in the literature are the connection fee, installation costs and price of electricity (Bensch et al., 2019; Golumbeanu & Barnes, 2013; Lee, Brewer, et al., 2016; Lee et al., 2020b), level of income and the regularity of income (Blimpo et al., 2020; Lee, Miguel, et al., 2016), quality of housing (Blimpo et al., 2020; Lee et al., 2020b), red tape and low grid reliability (Lee, Miguel, et al., 2016) and access to complementary infrastructure (Chaplin et al., 2017).

We also show that providing access does not automatically lead to consumption. On the one hand, this poses challenges for utilities' financial viability. In Rwanda, the ministry of instrastructure estimates that a consumer needs to purchase 130-140 kWh per month to cover the cost of their own connection,

[8] Their asset index includes appliances (radio, TV, telephone and refrigerator), means of transportation (motorcycle, car), primary floor, wall and roof materials, drinking water source, toilet types and people per room.

which is far below current consumption levels (Ministry of Infrastructure, 2018). On the other hand, this raises the question of whether a binary indicator of connection suffices to track energy access if the ultimate goal is to improve economic wellbeing.

Given these low levels of consumption, it is unlikely that household electrification strongly impacts household income. Yet, we do not rule out effects on other dimensions. For example, improved lighting could affect children's educational outcomes if they study more at home. Lighting could also affect comfort and convenience, and induce flexibility in time use. Radios or televisions could enable better access to knowledge and information, potentially affecting behaviour and attitudes. Impacts on health could occur but are likely to be small, given that air pollution primarily results from the usage of traditional cooking fuels, which are still used predominantly.

Our results highlight that most current energy needs at the household level can be covered by alternative, cheaper energy sources. Proponents of large infrastructure investments argue that grid extension efforts mediate better development potential and economic growth in the long run and a focus on small-scale off-grid energy may cap demand once income levels start to rise. While we cannot rule out that benefits would emerge at an even larger time horizon and with complementary investments, the question arises whether (very) long-term benefits justify today's high investment costs and significant opportunity costs. For sub-Saharan Africa, the IEA estimates that achieving universal access by 2030 and mainitaining it to 2040 will cost over USD 100 billion per year (IEA, 2019).

Finally, our findings suggest that electricity may not be the sole bottleneck holding back development of income generating activities. For already connected households, our study shows that without complementary programs that stimulate demand and support energy expenditures, the full potential of electrification is not exploited. Further research is needed to understand barriers to electricity adoption at the intensive margin and to understand the drivers of heterogeneity in impacts to better target investments.

References

Bayer, P., Kennedy, R., Yang, J., & Urpelainen, J. (2020). The need for impact evaluation in electricity access research. *Energy Policy*, *137*, 111099. https://doi.org/10.1016/j.enpol.2019.111099

Bensch, G., Cornelissen, W., Peters, J., Wagner, N., Reichert, J., & Stepanikova, V. (2019). *Electrifying Rural Tanzania. A Grid Extension and Reliability Improvement Intervention*. The Hague : Netherlands Enterprise Agency. http://hdl.handle.net/10419/222259

Bensch, G., & Peters, J. (2020). *Effects of Rural Electrification on Employment: A Comment on Dinkelman (2011)*. RWI. https://doi.org/10.4419/86788973

Bensch, G., Peters, J., & Vance, C. (2021). Development Effects of Electrification in Brazil – A Comment on Lipscomb et al. (2013). *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3980178

Bernard, T., & Torero, M. (2015). Social Interaction Effects and Connection to Electricity: Experimental Evidence from Rural Ethiopia. *Economic Development and Cultural Change*, *63*(3), 459–484. https://doi.org/10.1086/679746

Blimpo, M. P., & Cosgrove-Davies, M. (2019). *Electricity Access in Sub-Saharan Africa* (p. 167).

Blimpo, M. P., Postepska, A., & Xu, Y. (2020). Why is household electricity uptake low in Sub-Saharan Africa? *World Development*, *133*, 105002. https://doi.org/10.1016/j.worlddev.2020.105002

Boubakar, Z., Williams, N., Diallo, B. A. A., & Lare, Y. (2022). Geo-temporal analysis of electricity consumption growth in Togo. *2022 IEEE PES/IAS PowerAfrica*, 1–5. https://doi.org/10.1109/PowerAfrica53997.2022.9905243

Briggs, R. C. (2021). Power to which people? Explaining how electrification targets voters across party rotations in Ghana. *World Development*, *141*, 105391. https://doi.org/10.1016/j.worlddev.2021.105391

Burgess, R., Greenstone, M., Ryan, N., & Sudarshan, A. (2020). The Consequences of Treating Electricity as a Right. *Journal of Economic Perspectives*, *34*(1), 145–169. https://doi.org/10.1257/jep.34.1.145

Chaplin, D., Mamun, A., Protik, A., Schurrer, J., Vohra, D., Bos, K., Burak, H., Meyer, L., Dumitrescu, A., Ksoll, C., & Cook, T. (2017). *Grid Electricity Expansion in Tanzania by MCC: Findings from a Rigorous Impact Evaluation*. 368.

Fetter, R. T., & Usmani, F. (2020). *Fracking, Farmers, and Rural Electrification in India*. RWI. https://doi.org/10.4419/96973001

Fobi, S., Deshpande, V., Ondiek, S., Modi, V., & Taneja, J. (2018). A longitudinal study of electricity consumption growth in Kenya. *Energy Policy*, *123*, 569–578. https://doi.org/10.1016/j.enpol.2018.08.065

Golumbeanu, R., & Barnes, D. (2013). *Connection Charges and Electricity Access in Sub-Saharan Africa*. The World Bank. https://doi.org/10.1596/1813-9450-6511

Hamburger, D., Jaeger, J., Bayer, P., Kennedy, R., Yang, J., & Urpelainen, J. (2019). Shades of darkness or light? A systematic review of geographic bias in impact evaluations of electricity access. *Energy Research & Social Science*, *58*, 101236. https://doi.org/10.1016/j.erss.2019.101236

IEA. (2019). *Africa Energy Outlook 2019*.

IEA, IRENA, UNSD, World Bank, & WHO. (2022). *Tracking SDG 7: The Energy Progress Report*. World Bank, Washington DC. © World Bank.

Jeuland, M., Fetter, T. R., Li, Y., Pattanayak, S. K., Usmani, F., Bluffstone, R. A., Chávez, C., Girardeau, H., Hassen, S., Jagger, P., Jaime, M. M., Karumba, M., Köhlin, G., Lenz, L., Litzow, E. L., Masatsugu, L., Naranjo, M. A., Peters, J., Qin, P., … Toman, M. (2021). Is energy the golden thread? A systematic review of the impacts of modern and traditional energy use in low- and middle-income countries. *Renewable and Sustainable Energy Reviews*, *135*, 110406. https://doi.org/10.1016/j.rser.2020.110406

Lee, K., Brewer, E., Christiano, C., Meyo, F., Miguel, E., Podolsky, M., Rosa, J., & Wolfram, C. (2016). Electrification for "Under Grid" households in Rural Kenya. *Development Engineering*, *1*, 26–35. https://doi.org/10.1016/j.deveng.2015.12.001

Lee, K., Miguel, E., & Wolfram, C. (2016). Appliance Ownership and Aspirations among Electric Grid and Home Solar Households in Rural Kenya. *American Economic Review*, *106*(5), 89–94. https://doi.org/10.1257/aer.p20161097

Lee, K., Miguel, E., & Wolfram, C. (2020a). Does Household Electrification Supercharge Economic Development? *Journal of Economic Perspectives*, *34*(1), 122–144. https://doi.org/10.1257/jep.34.1.122

Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental Evidence on the Economics of Rural Electrification. *Journal of Political Economy*, *128*(4), 1523–1565. https://doi.org/10.1086/705417

Lenz, L., Munyehirwe, A., Peters, J., & Sievert, M. (2017). Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. *World Development*, *89*, 88–110. https://doi.org/10.1016/j.worlddev.2016.08.003

Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil. *American Economic Journal: Applied Economics*, *5*(2), 200–231. https://doi.org/10.1257/app.5.2.200

Ministry of Infrastructure. (2018). *Energy Sector Strategic Plan 2018-2024*.

Mugyenyi, J., Muhwezi, B., Fobi, S., Massa, C., Taneja, J., Williams, N. J., & Modi, V. (forthcoming). *A Data-driven Analysis of Electricity Consumption Growth & the Effects of Tariff Changes in Rwanda*. 12.

Peters, J., & Sievert, M. (2016). Impacts of rural electrification revisited – the African context. *Journal of Development Effectiveness*, *8*(3), 327–345. https://doi.org/10.1080/19439342.2016.1178320

Peters, J., Vance, C., & Harsdorff, M. (2011). Grid Extension in Rural Benin: Micro-Manufacturers and the Electrification Trap. *World Development*, *39*(5), 773–783. https://doi.org/10.1016/j.worlddev.2010.09.015

Ratledge, N., Cadamuro, G., de la Cuesta, B., Stigler, M., & Burke, M. (2022). Using machine learning to assess the livelihood impact of electricity access. *Nature*, *611*(7936), 491–495. https://doi.org/10.1038/s41586-022-05322-8

REG. (2022). *Rwanda Electricity Access Development Plan (2018-2024)*. https://www.reg.rw/fileadmin/user_upload/Rwanda_Electricity_Access_Development_Plan_2018-2024_updated_June_2022.pdf

Rud, J. P. (2012). Electricity provision and industrial development: Evidence from India. *Journal of Development Economics*, *97*(2), 352–367. https://doi.org/10.1016/j.jdeveco.2011.06.010

Schmidt, M., & Moradi, A. (2022). *Community Effects of Electrification: Evidence from Burkina Faso's grid extension*. 61.

Taneja, J. (2018). If You Build It, Will They Consume? Key Challenges for Universal, Reliable, and Low-Cost Electricity Delivery in Kenya. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3310479

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development* (Technical Report A/RES/70/1). United Nations General Assembly.

van de Walle, D., Ravallion, M., Mendiratta, V., & Koolwal, G. (2013). Long-Term Impacts of Household Electrification in Rural India. *World Bank Policy Research Paper*, *6527*. https://doi.org/10.1596/1813-9450-6527

Appendix

Figure A1: Map of study communities

Table A 1: comparison between connected and non-connected households in 2022

	Non-connected households			Connected households			
	n	mean	sd	n	mean	sd	Diff
HoH is female	139	0.34	0.47	681	0.23	0.42	-0.106**
							(0.044)
HoH age	139	46.05	16.54	668	46.91	14.44	0.858
							(1.627)
Respondent is married	139	0.68	0.47	681	0.77	0.42	0.089
							(0.056)
Number of household members	139	4.22	1.91	681	4.96	2.12	0.747***
							(0.181)
Share of HH members below 18	139	0.41	0.23	681	0.42	0.22	0.007
							(0.022)
Education level HoH: None	137	0.12	0.32	657	0.11	0.31	-0.007
							(0.031)
Education level HoH: Primary	137	0.23	0.42	657	0.21	0.41	-0.020
							(0.042)
Education level	137	0.04	0.19	657	0.05	0.21	0.009

HoH: Junior high							
							(0.016)
Education level HoH: Senior high	137	0.03	0.17	657	0.05	0.22	0.023
							(0.020)
Education level HoH: Vocational	137	0.01	0.09	657	0.00	0.00	-0.007
							(0.007)
Education level HoH: University	137	0.00	0.00	657	0.02	0.13	0.017***
							(0.005)
HH owns livestock	139	0.53	0.50	681	0.69	0.46	0.165***
							(0.055)
HH owns bicycle	139	0.17	0.37	681	0.25	0.43	0.084*
							(0.045)
HH owns motorcycle	139	0.00	0.00	681	0.03	0.18	0.034***
							(0.006)
HH owns bank account	139	0.16	0.37	681	0.27	0.45	0.116***
							(0.032)
Took loan last 5 years	139	0.09	0.29	677	0.25	0.43	0.152***
							(0.029)
Number of buildings	139	1.55	0.78	681	1.78	0.99	0.224**
							(0.106)
Number of separate rooms	139	3.32	1.09	681	4.02	1.22	0.698***
							(0.104)
Walls: Wood	139	0.16	0.37	681	0.11	0.31	-0.050
							(0.033)
Walls: Unburnt bricks	139	0.83	0.38	681	0.84	0.36	0.016
							(0.035)
Walls: Burnt bricks	139	0.01	0.08	681	0.03	0.18	0.027**
							(0.012)
Roof: Wood	139	0.06	0.23	681	0.05	0.21	-0.011
							(0.022)
Roof: Iron sheets	139	0.62	0.49	681	0.63	0.48	0.008
							(0.058)
Roof: Tiles	139	0.31	0.46	681	0.31	0.46	0.003
							(0.061)

Floor: Earth	139	0.77	0.42	681	0.43	0.50	-0.342***
							(0.043)
Floor: Concrete or cement	139	0.18	0.39	681	0.52	0.50	0.336***
							(0.040)
Floor: Ceramics	139	0.05	0.22	681	0.03	0.18	-0.018
							(0.016)
Probability to be below NPL (PPI)	139	0.36	0.23	681	0.19	0.15	-0.172***
							(0.022)
Household income last 4 weeks (w99)	133	12367.67	28151.52	600	26050.64	37861.59	13,682.967***
							(2,685.805)
Expenditures last year (w99)	139	361800.61	394005.15	671	590166.26	536119.41	228,365.646***
							(52,681.137)
Share of expenditures on food	126	0.58	0.24	645	0.51	0.24	-0.065**
							(0.029)

Table A2: number of days between prepaid electricity purchases over the year (days)

Year	Total Purchases	Mean	Median	St. Dev.	Min	Max
2012	289	7.36	3	10.25	1	71
2013	1281	12.39	4	22.99	1	324
2014	1499	9.89	4	18.12	1	220
2015	1517	12.55	6	26.68	1	619
2016	1575	10.45	6	20.48	1	634
2017	1146	15.40	7	33.69	1	1153
2018	970	18.83	10	36.96	1	1073
2019	1111	22.42	11	60.93	1	1641
2020	332	22.95	11	43.48	1	738

Note: Source: CashPower data.

Table A3: quantity purchased for each meter recharge (kWh)

Year	Purchases	Mean	Median	st. dev	Min	Max
2012	289	5.20	3.2	4.31	0.0	37.9
2013	1368	5.55	5.1	4.02	0.6	42.1
2014	1966	4.05	3.2	4.43	0.2	101.2
2015	2238	3.59	3.2	2.75	0.1	46.6
2016	2926	2.75	2.3	2.44	0.1	56.7
2017	2702	3.71	2.3	3.41	-6.7	35.0
2018	2685	3.56	2.2	3.77	-2.2	47.0
2019	2805	3.58	2.5	2.86	0	23.3
2020	982	3.50	2.5	2.94	0.1	15.1
Total	17961	3.69	2.5	3.42	-6.7	101.2

Note: Source: CashPower data.

Table A4: Average number of enterprises per community over time

Variable	Control 2011	Control 2013	Control 2022	Treatment 2011	Treatment 2013	Treatment 2022
small shop	16.37	11.31	6.11	17.77	18.46	5.71
bar	9.37	5.46	2.96	2	4.08	2.57
hairdressers/beauty salons	2.33	2.04	2.22	1.69	3.92	2.14
tailors	1.63	4.46	1.37	2.38	5	2.14
carpenters	1.54	1.38	.33	1.46	1.38	.29
restaurants	1.78	1.38	.52	2.31	1.69	1.64

Note: Source: EARP community data 2011-2013-2022. This table shows the average number of each business per survey wave and per treatment group. Treatment communities are connected between 2011-2013 while control communities are connected after.