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Luciane Lenz, Anicet Munyehirwe, Jörg Peters, and Maximiliane Sievert[1]

# Does Large Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program

## Abstract

*The United Nations' objective to provide electricity to the 1.3 billion people without access in developing countries comes at high costs. Little evidence exists on socio-economic impacts of electrification. This paper rigorously investigates effects of a large grid extension program in Rwanda on all rural beneficiary groups: households, micro-enterprises, health centers, and schools. While the program has led to a tremendous increase of connections, appliance uptake and electricity consumption remain low. We find only weak evidence for impacts on classical poverty indicators. To inform future policy design, we call for thorough cost-benefit comparison between on-grid and off-grid solutions.*

*JEL Classification: O13, O18, Q41*

*Keywords: Energy access; difference-in-differences; electrification; mixed-methods; Sub-Saharan Africa*

*April 2015*

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## 1. Introduction

More than 1.3 billion people in developing countries lack access to electricity. Some 590 million of them live in Africa, where the rural electrification rate is particularly low at only 13 percent (IEA 2013). It is often hypothesized that lacking access to electricity hampers human development in many regards. The lack of access to modern lighting in households limits their possibilities to pursue productive activities after nightfall, but also educational and recreational activities. Likewise, enterprise development and the provision of public services like health care and schooling becomes more difficult.

Based on this assessment, the United Nations pursue universal access to electricity by 2030 via their initiative Sustainable Energy for All (SE4All, see also UN 2010). The investment requirements of electrification are enormous – IEA (2011) quantifies the additional needs to 640 billion USD if universal access to electricity should be achieved by 2030. For Sub-Sahara Africa alone, an annual amount of around 19 billion USD is required. For comparison, the total official development assistance influx to Sub-Sahara Africa is at 42 billion USD per year (World Development Indicators 2014).

In spite of these high costs, the investments into electrification have hardly been evaluated in terms of their genuine socio-economic impacts (BERNARD 2012, KÖHLIN et al. 2011). The present paper is the first to causally investigate the socio-economic effects of electrification in Africa using a comprehensive set of indicators on all rural beneficiary groups: households, firms, health centers, and schools. The electrification program under research, the Rwandan Electricity Access Role-Out Program, is one of the largest in the world and intends to leapfrog the electrification rate in the country from six percent in 2009 to 70 percent in 2017.

Only few studies exist that examine the causal relationship between electrification and indicators for household well-being. For Bangladesh, Vietnam and India, respectively, KHANDKER, BARNES, AND SAMAD (2012), KHANDKER, BARNES, AND SAMAD

(2013), and VAN DE WALLE et al. (2013) find evidence for positive effects on household income, educational performance, and job market indicators. GRIMM, SPARROW AND TASCIOTTI (2013) show that electrification contributes substantially to the fertility decline in Indonesia, PETERS AND VANCE (2011) find comparable evidence for Cote d'Ivoire. For effects on productivity, firm performance, and employment results in the literature are mixed with some very positive evidence from India, Nicaragua, and South Africa (RUD 2012, GROGAN AND SADANAND 2013, DINKELMAN 2011) and rather sobering findings from remoter areas in Africa (BERNARD 2012, PETERS, VANCE AND HARSDORFF 2011, NEELSEN AND PETERS 2011, GRIMM, HARTWIG AND LAY 2013). No evidence exists on the effects of electrification on schools or health centers.

Our analysis is based on different surveys, which we conducted between 2011 and 2014. The core is a two-period panel of 974 households and 44 communities in the rural target areas of EARP. In addition to this, we established a full census panel among all health centers in the country. These large quantitative surveys are complemented by qualitative surveys among households, micro-enterprises, schools, and health centers. Thereby, we draw a uniquely comprehensive picture of the various transmission channels via which socio-economic effects of electrification might unfold.

We first study the connection behavior and electricity consumption patterns of households. Using a difference-in-differences identification strategy we examine the socio-economic outcomes education, income, and health as indicators for human development. Second, based on our qualitative case study information from the micro-enterprise survey we explore the effects of electrification on appliance take-up and on productive processes in rural firms. Third, we examine effects of electrification on health centers and schools. The connection of health centers is one of EARP's key objectives. We therefore investigate the connection status of all health centers in the country and the extent to which connections have led to an uptake of electric appliances. In addition, we analyze open interview and case study information from our qualitative survey among a smaller number of health centers and schools.

## 2. Context

With 10.5 million inhabitants, Rwanda is the most densely populated country in Africa. After recovery from the genocide that devastated the country in 1994, Rwanda is now firmly on the path of resurgence and economic development. At current prices, per capita GDP in 2012 was USD 1,500 (PPP) and in recent years the country recorded an annual GDP growth rate between 7 and 8 percent (in real terms) against an annual population growth rate of around 2.6 percent.[1] Notwithstanding this recent growth performance, 44.5 percent of Rwandans were living on less than 2 USD a day in 2011 (World Development Indicators 2014).

The objective of the Rwandan Government is to transform the country into a middle income country and increase the GDP by the factor 4 until 2020 compared to 2000 based on a transition from subsistence farming to higher value added agriculture and non-farm activities. This ambitious goal is expected to be realized by promoting private sector development, infrastructure development, and the transformation from an agricultural based economy to a knowledge-based society.[2]

Before EARP started in 2009, only about 6 percent of all households and only one percent of rural households had had access to electricity making it a country with one of the lowest electrification rates in the world.[3] On the supply side, installed electricity generation capacity has increased from 69.5 MW in 2007 to 110 MW in 2012 (MININFRA 2011, GoR 2012). The country's own hydropower contributes 41.7 percent of the installed capacity, imported hydropower 15.7 percent, diesel and heavy oil generators around 38.7 percent, Kivu methane gas around 3.6 percent, and solar around 0.3 percent. A huge investment program shall lead to a further increase

[1] All figures from CIA World Factbook and the Rwanda 2012 Population and Housing Census

[2] See http://www.minecofin.gov.rw/index.php?id=81. Accessed on February 3, 2012.

[3] See http://mininfra.gov.rw/index.php?option=com_content&task=view&id=114&Itemid=142. Accessed on February 3, 2012.

of the installed capacity up to 563 MW in the coming years (GoR 2012), supported by an upgrade of the existing interconnections with the neighboring countries.[4]

The Electricity Access Roll-Out Program (EARP) is the central effort of the Government of Rwanda to combat low electrification rates. EARP is implemented by the national *Rwanda Energy Group* (REG) that is also responsible for the generation of electricity, its transmission, distribution, and the connection of customers.[5] EARP is supported by donors and endowed with a budget of USD 377 m for the first phase[6] and at least USD 300 m for the second phase.[7]

During EARP's first phase from 2009 to 2013 it aimed at an increase of electricity connections from around 110,000 in 2009 to 360,000 connections by May 2013, which corresponds to an increase in the national electrification rate from 6 percent to 16 percent in 2012. In mid-2013, 370,000 connections were reached. The EARP strategy put special emphasis on connecting social infrastructure: By 2012, all health stations, all administrative offices and 50 percent of schools were supposed to be electrified (Castalia 2009: 5ff). This objective was not fully achieved: By May 2013, 36 percent of schools, 56 percent of health facilities, and 58 percent of administrative offices were connected. In total, 170,000 km of transmission and distribution lines were constructed or rehabilitated by May 2013.[8]

These overall very successful results encouraged the GoR and several donors to

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[4] See http://www.afdb.org/en/projects-and-operations/project-portfolio/project/p-z1-fa0-032/

[5] See http://www.reg.rw for further information. The Rwanda Energy Group (REG) emerged from the former Electricity, Water and Sanitation Authority (EWSA), which was split up into into REG and the Water and Sanitation Corporation (WASAC) in July 2014.

[6] Involved donors are the World Bank, the Netherlands, Belgium, the European Union, the African Development Bank, the Japan International Cooperation Agency (JICA), OPEC Fund for International Development (OFID), and the Saudi Fund form part of the donor consortium (MININFRA 2011: 69). While the Word Bank, OFID, and part of the AfD contribution are concessional loans, JICA, Belgium, the European Union and the Netherlands provided grants. In addition, EWSA contributes 10 percent from its retained earnings. Customers contribute the remaining 10 percent through connection charges (World Bank 2009: 48).

[7] For the second phase, additional funds have been approved by several donors, including the European Union (USD 200 m) World Bank (USD 60 m) and the African Development Bank Group (USD 41 m). Further additional funding of USD 12 m was approved by DFID, and by the Netherlands (USD 4 m). BTC plans to provide EUR 17 m EUR for grid extension in the Eastern Province.

[8] The World Bank (Jul. 2013): "Implementation Status and Results – Rwanda Electricity Access Scale-up and Sector Wide Approach Development Project" , available at: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/AFR/2013/07/07/090224b081cf4e50/1_0/Rendered/PDF/Rwanda000Rwand0Report000Sequence007.pdf p. 01ff

extend the EARP activities to a second phase of the electrification program (EARP Phase II). The target has been lifted up to a national access rate of at least 70 percent by 2017, of which 45 percent should be connected to the national grid, while the remaining households will be served by off-grid solutions, mainly solar panels and micro-hydro mini-grids. Furthermore, all health centers, hospitals and administrative offices should be connected as well as at least 80 percent of schools.[9]

## 3. Evaluation Approach

### 3.1 Theory of Change

Electrification via the extension of the electricity grid can affect the welfare of people through various channels. If a community is newly connected, households, firms, and social institutions such as schools and health centers might obtain a connection. Since this is still associated with connection costs (fees plus in-house wiring), not all of them might do so. In a next step, the beneficiaries obtain appliances, beginning with electric lamps. Other typically bought household appliances in rural Africa are televisions, radios, and mobile phones. Firms might invest in machinery, refrigeration or entertainment appliances. Health centers might use lighting or simple appliances for diagnosis and treatment. Schools can use lighting for evening classes and computers in their schedule.[10]

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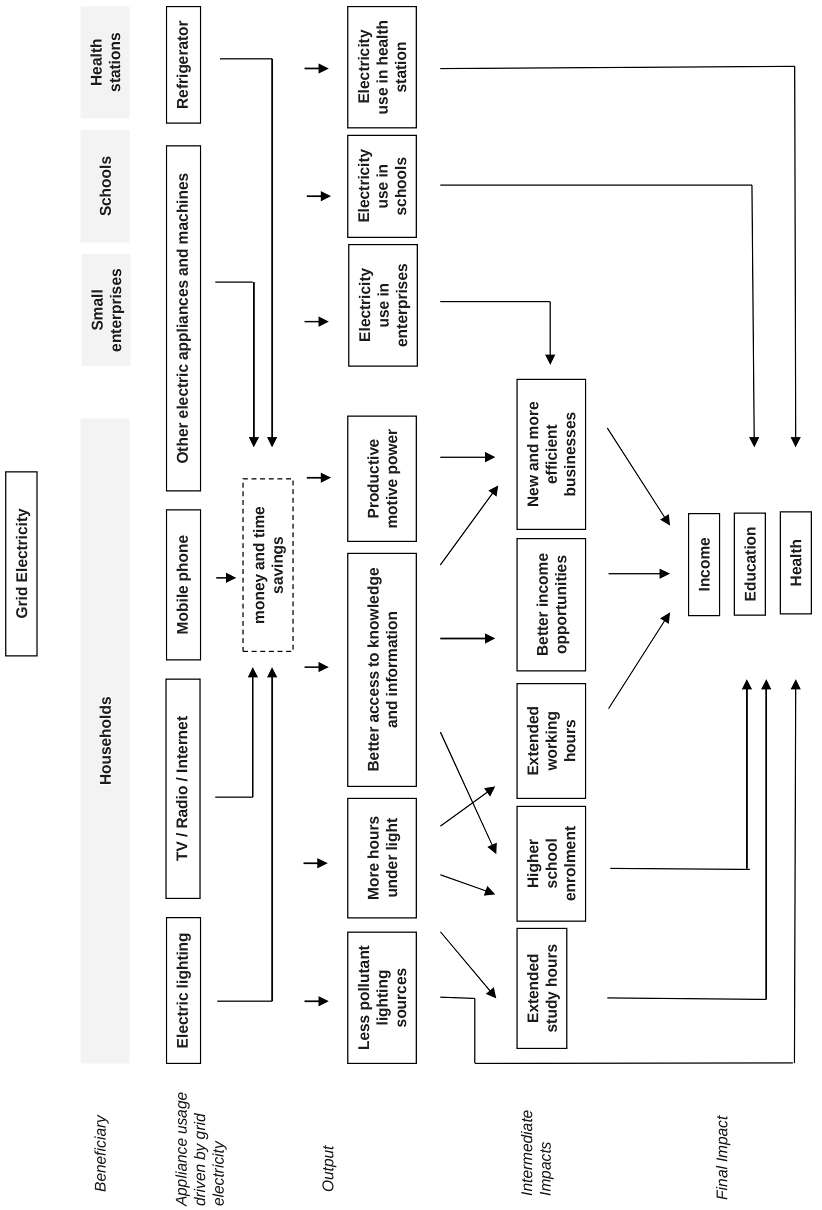
[9] The World Bank (Jan. 2013): "Project paper on a proposed additional credit in the amount of SDR 39.0 million to the Republic of Rwanda for an electricity access scale-up and sector-wide approach (SWAp) development project", available at http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/01/31/000356161_20130131152511/Rendered/PDF/741420PJPR0P120Official0Use0Only090.pdf p. 15

[10] Note that in principal all appliances can also be used in the absence of a grid connection using dry cell batteries, car batteries, generators, or solar systems. Potential impacts of a grid connection thus unfold via facilitating the usage of these energy services by bringing down the costs.

**Figure 1: Pathways from electricity access to socio-economic impacts (own representation, based on Khandker, Barnes and Samad 2013)**



These different beneficiaries can then use electricity for different activities, which in turn can improve their productivity and thereby increase income in the case of firms, improve health care services provided by health centers, and improve educational services for schools. Households' utility might benefit directly from, for example, improved lighting quality and access to information[11] or indirectly via the increased productivity of firms, health centers, and schools. Figure 1 summarizes these transmission channels from electrification to an increase in people's well-being in a stylized presentation.

### 3.2. Identification Strategy

Impacts among the different beneficiary groups are examined by different identification strategies. The focus of our paper is on assessing the program's effects on households. The major challenge in evaluating an on-grid electrification program like EARP is the selection into treatment that happens on two levels: First, on the community level where certain types of communities are given priority by EARP to be chosen as treatment community, for example those that exhibit better business opportunities over more remote communities without market access. Second, once the community is connected, households self-select into the treatment. Since households are not connected for free, certain types of households – the richer or the more modern – are more inclined to bring up the investment costs of the connection.

Methodologically the best way to handle this would be to assign the electrification treatment to communities in a randomized phasing-in design. This was not possible in the EARP set-up, because REG's effective roll-out was determined by many practical factors ranging from logistical issues to contractual matters with construction companies and it would have been impossible for them to stick to a controlled randomized schedule. The second-best option is to mimic a randomized phasing-in as a non-randomized difference-in-differences (DiD)

[11] See VAN DE WALLE et al. (2013) for a compelling theoretical framework of how electricity affects the household's utility function.

approach, which was pursued for this impact evaluation. The identification assumption to obtain unbiased impact estimates is that in the hypothetical absence of electrification, both groups of communities and households need to develop in a similar way in terms of the indicator under evaluation (parallel trend assumption). In other words, DiD controls for unobserved differences between the households and communities in the two groups as long as they are time invariant or change in the same way in both groups.

The virtue of our DiD design is the fact that we recruited both treatment and control communities from the population of EARP communities scheduled for connection between 2011 and 2013. Treatment communities are those scheduled for connection in 2011 or early 2012, control communities those to be connected in 2013. Hence, there is good reason to expect these communities to be quite similar. For some treatment communities, control communities scheduled to be connected in 2013 through EARP did not exist in the communities' proximity. As an alternative, we visited other potential control communities in the region, scrutinized them with regard to their similarity as compared to the respective treatment communities and picked the most comparable ones. The criteria were road access, community size, and income pattern (number and type of businesses, prevailing agricultural activities, etc.). Eventually, around half of the control communities were selected from the EARP list and the other half was picked from non-EARP communities according to the comparability criteria. To further reduce the risk of confounding factors, we balance the groups ex-post along a set of potential covariates.

As outlined above, not all households in a newly connected community will obtain a connection. Effectively, around 60 percent of the households within the access area of the grid got connected. Methodologically, this evokes the question of who is considered as treated: all households that are located in a connected community including non-connected households or only households that have a grid connection themselves. For most impact indicators we look at, effects can be expected to materialize only among connected households (and not among their maybe non-connected neighbors), so we chose the latter option.[12]

In order to compare connected households from the treatment community to similar, counterfactual households from the control communities, we identify those households in the control group that would be likely to connect if the grid was available. For this purpose, we first include only households from the treatment communities and regress the binary connection status of a household on a number of covariates. These covariates need to influence both the connection decision and the indicators under evaluation.[13] The coefficients from this probit model are used to predict the probability of getting connected for each household in the whole sample, including the control communities. These predicted propensity scores are then used to stratify the de facto non-connected control households into "hypothetically connected" and "hypothetically non-connected" households.[14]

For estimating the impacts on household level we compare only connected households in treatment communities to hypothetically connected households in control communities. Our estimation strategy relies on a community-level fixed effects model with robust standard errors clustered at the community level. Since our cluster sample size of 44 communities is rather small and since cluster-robust standard errors are consistent only if the number of clusters (i.e. communities in our case) is large, we test our results for robustness to finite sample problems. Using the wild bootstrap procedure proposed by CAMERON, GELBACH, AND MILLER (2008) we confirm all results.

For micro-enterprises and schools our methodological approach is to probe deeper into energy-related questions in semi-structured interviews, also owing to the smaller sample size. Here, the identification strategy is to establish the counterfactual

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[12] For results from estimations of the *intention to treat* (considering the whole village as treated) see PETERS et al. (2014).

[13] See AUGURZKY AND SCHMIDT (2001) and CALIENDO AND KOPEINIG (2008) for more details on the selection of covariates in matching approaches.

[14] In a cross-sectional set-up this approach was originally applied in BENSCH, KLUVE, AND PETERS (2011) and PETERS, VANCE, AND HARSDORFF (2011). Details on the probit estimation results and balancing of covariates can be found in Annex 1.

situation in every interview by eliciting information on the before situation (retrospectively) and by asking hypothetical questions ("What would have happened without electricity?").

Since health centers play an important role in the EARP, we apply an identification approach comparable to the one for households. We combine a qualitative in-depth interview approach with a quantitative approach based on a large sample size survey. The former is conducted in the 44 communities visited for our household survey. Here, we interviewed all health centers in the communities visited for the household survey or neighboring communities (26 health centers in total) by means of a semi-structured questionnaire.

For the latter we contacted all rural health centers in the country for a telephone interview. We elicited the connection status and the appliance take up of the health centers both at the time of the interview and, retrospectively, for the year 2009. Thereby, we established a retrospective panel for the period from 2009 (so before EARP started) until early 2014. We compare appliance endowment in health centers that got an electricity connection to the grid between 2009 and 2014 with health centers that in 2014 still do not have a grid connection, but use decentralized electricity sources instead. With this approach we are able to net out secular changes not related to the EARP intervention. For example, the public health budget might have been increased leading to appliance uptake.

### 3.3 Data Collection

We used different study modules to collect information on the transmission channels outlined in Section 3.1. summarized in Table 1. Except for the health center full census survey, all elicited information is coming from 44 communities that we surveyed in 2011 and 2013 (see Figure 2 for the regional distribution of the communities in the country). A two-stage random sampling was applied with the first stage at the community level and the second at the household level. In 2011, a random sample of 30 treatment communities was chosen according to probability-proportional-to-size sampling from communities identified for electrification in 2011 and 2012 by REG. REG provided us with lists that also contained information on the planned household connections for each community. We used this information to assign probabilities proportional to the number of envisaged household connections to each community to be selected for the survey.

**Table 1: Study Modules**

| Study module | Content | Sample Size | Interview Type |
|---|---|---|---|
| *Household study* | | | |
| Large household survey | Comprehensive socio-economic questionnaire covering most household characteristics (revenues, expenditures, education, health and, activities at night-time) with focus on energy and lighting usage. | 974 (baseline and follow-up) | Structured questionnaire |
| Qualitative household survey | Open discussions about intended and unintended effects of electrification. | 20 | Open interviews |
| *Micro-enterprise study* | | | |
| Qualitative micro-enterprise survey | Energy usage, bottlenecks of firm development and role of electricity. Customer basis and market access. | 83 | Semi-structured interviews |
| *Community study* | | | |
| Community chief survey | Connection rates, number of enterprises, community size, infrastructure and market access, availability of energy sources, major community particularities, etc. | 44 (baseline and follow-up) | Structured questionnaire |
| *Social infrastructure survey* | | | |
| Qualitative health center survey | Connection status, appliance usage, health care provision and role of electricity. | 16 (baseline)<br>26 (follow-up) | Semi-structured questionnaire |
| Qualitative school survey | Connection status, appliance usage, role of electricity in service provision. | 23 (baseline)<br>38 (follow-up) | Semi-structured questionnaire |
| Full census health center survey (via telephone) | Connection status, year of connection, appliance usage, fuel on which appliance runs. | 388 | Structured questionnaire (short) |

Additionally, 20 control group communities were selected from the remaining sub-population of EARP communities in the same region as the selected treatment communities that had been scheduled for connection after the follow-up survey in 2013. We chose a larger sample for the treatment group, since we expected delays and deviations from the foreseen schedule in the connection process so that some of the designated treatment communities would not be connected before the follow-up. In fact, eventually out of the 50 communities 15 were connected in 2011 or 2012. The non-connected former treatment communities were shifted to the control group. Yet, since obviously control communities were abundantly available in our sample we decided to randomly pick six communities from the eventual control communities and dropped them from the study given budget constraints for data collection.

The random selection of households within a community was implemented as follows: The survey team first identified the area to be covered by the future grid. A corridor of 50 meters was determined along the planned distribution line, in most cases along the main road. According to MININFRA and REG this is the area in which households will get connected at the normal connection fee (i.e. without extending the distribution line at their own expenses). The households within this corridor formed the population of the study from which the sample of 30 households per community was drawn using simple random sampling.

In total, 1,486 households were interviewed for the baseline survey. For the follow-up survey in 2013, 156 households in the purposefully excluded control communities were not visited again. Furthermore, we excluded 142 households that live in treatment communities, but outside the catchment area of the grid.[15] Attrition because of migration or unavailability at the time of the follow-up survey is modest at around 18 percent. Accordingly, 974 households have been interviewed during the follow-up.

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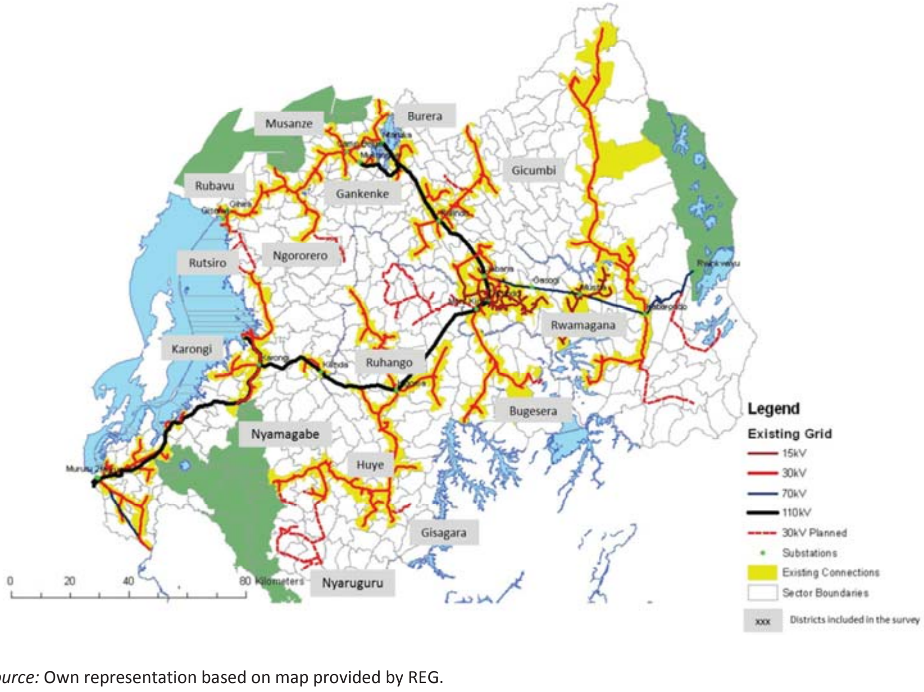
[15] In some cases, we noticed at the time of the follow-up survey that the low voltage lines had effectively been installed in a different part of the community than originally announced by EWSA branches, local authorities or predicted by community chiefs. Note that what we refer to as communities in Rwanda scattered settlements with small village centers only and the majority of households effectively being spread over a few kilometres.

For the micro-enterprise survey we sampled 83 enterprises from the 44 visited communities at the time of the follow-up survey. Different from the household survey we conducted a stratified sampling approach with firm types as stratification criterion, in order to ensure a comprehensive picture of firm activities.

For the health center full census we obtained a list of all health centers in the country from the Ministry of Health. By means of telephone interviews we administered a short questionnaire eliciting simple information on electricity and appliance usage between August 2013 and February 2014. We excluded seven health centers with very particular locations (e.g. in refugee camps). Out of the remaining 435 health centers, we reached 388. In addition to this telephone survey, we interviewed 26 health centers and 38 schools intensively using semi-structured questionnaire, all of them based in the 44 communities visited for the household survey.

**Figure 2: Map of Rwanda with surveyed districts**




*Source:* Own representation based on map provided by REG.

## 4. Socio-economic status in the region

This section presents the socio-economic living conditions of the EARP target population at the baseline stage. Thereby, we also scrutinize the balancing of the treatment and control group in terms of observable characteristics, which is the precondition for our major identification assumption to hold (see Section 3.3).

**Table 2: Infrastructure access and main source of income in sampled communities**

| Variable | | Control # | Control Share | Treatment # | Treatment Share |
|---|---|---|---|---|---|
| Number | | 29 | | 15 | |
| Distance to principal route (km) | | 10.95 | | 10.6 | |
| Accessibility of main road during rainy season | Good | 6 | 0.21 | 5 | 0.33 |
| | Average | 10 | 0.34 | 7 | 0.47 |
| | Possible with difficulties | 10 | 0.34 | 2 | 0.13 |
| | Hardly possible | 3 | 0.10 | 1 | 0.07 |
| No. of Communities with Schools | | 21 | 0.72 | 12 | 0.80 |
| No. of Communities with Health | | 13 | 0.45 | 5 | 0.33 |
| No. of Communities with Market | | 9 | 0.31 | 8 | 0.53 |
| Reception of Radio | | 29 | 1.00 | 14 | 0.93 |
| Reception of Mobile | | 29 | 1.00 | 15 | 1.00 |
| Reception of TV | | 16 | 0.55 | 10 | 0.67 |
| Internet Connection | | 7 | 0.24 | 3 | 0.20 |
| Main Income source | | | | | |
| Agricultural Activities | | 21 | 0.72 | 10 | 0.67 |
| Non-Agricultural Activities | | 4 | 0.14 | 2 | 0.13 |

*Source:* EARP baseline dataset 2011.

Table 2 summarizes major features of the 44 communities included in our survey with regards to infrastructure access and income sources. Most communities are accessible via dirt roads, some are connected to a tarmac main road. Most communities also host a school, mostly primary schools, but only a minority has a health center. Some communities are market centers. Reception of radio signal is good in virtually all communities, while television signal and in particular internet is more difficult. For the vast majority of communities, agricultural activities are the major source of income. From a methodological perspective, it is important to see that treatment and control communities are well balanced along these characteristics.

**Table 3: Household structure variables**

| Household's structure variables (baseline values) | Control | Treatment | | |
|---|---|---|---|---|
| | | all | p-value* | connected |
| *N* | *686* | *288* | | *180* |
| HH size | 4.98 | 5.24 | 0.062 | 5.8 |
| Share of HHs with female head of HH | 0.17 | 0.18 | 0.763 | 0.18 |
| **Household head's education** | | | | |
| Without formal education | 0.25 | 0.20 | 0.099 | 0.18 |
| Primary school | 0.56 | 0.58 | 0.614 | 0.56 |
| **Household's assets** | | | | |
| Share of HH cultivating land | 0.79 | 0.72 | 0.021 | 0.75 |
| Share of HH owning livestock | 0.67 | 0.62 | 0.135 | 0.64 |
| Share of households with bicycle | 0.26 | 0.22 | 0.110 | 0.26 |
| Share of households with motorcycle | 0.03 | 0.05 | 0.317 | 0.06 |
| **Expenditures** | | | | |
| Total annual household expenditure (in 1000 FRW) | 795 | 805 | 0.909 | 1016 |
| Share of expenditures spent on food | 0.38 | 0.36 | 0.211 | 0.33 |
| Share of expenditures spent on energy | 0.10 | 0.12 | 0.016 | 0.11 |
| **Household has pre-electrification source** | 0.04 | 0.04 | 0.895 | 0.06 |

*Note:* *p-value of *t*- and *chi-squared* tests on differences in means between the treatment and control group as a whole
*Source:* EARP baseline dataset 2011.

Table 3 displays some key socio-economic household characteristics in both groups. The treatment and control group samples are very much balanced. Most household heads have no education or primary education only. Since most households are farmers, cultivatable land and livestock are the major assets households possess. Vehicles are rare. Expenditure levels are low at around 800,000 FRW per year, which corresponds to about 1.90 USD (PPP adjusted) per person and day. The most important expenditure category is food. Expenditures for energy account for the second biggest part of expenditures. Electricity sources are very rare at the time of the baseline. Looking at households in the treatment group that later-on connected to the grid, we can observe that they are generally better off than the average household already at the baseline stage underpinning the necessity to combine the DiD approach with a matching method (see Section 3.3).

## 5. Results on household level

### 5.1 Do households connect to the electricity grid?

Between baseline and follow-up, REG installed low voltage electricity lines in all treatment communities. For a connection fee of 65,000 FRW (80 EUR), household in these communities can get connected to the electricity grid. At least 15,000 FRW have to be paid upfront and the rest can be paid in instalments over a one year period at a 10 percent interest rate. In-house installations have to be organized by the households themselves. In our sample, 60 percent of households living in the treatment communities got connected to the grid. On average, they have been connected for one year and five months at the time of the follow-up survey. Virtually all households who have not decided to connect say that connection fees are too high and impeded them from getting connected. Generally connected households are satisfied with their electricity connection and reliability is good. Although outages occur pretty frequently, on average 3.8 times per month, they only last a few minutes.

Table 4 shows energy usage patterns in the treatment and control group as well as regression results for the DiD estimation for effects on connected households as compared to hypothetically connected households in the control group (see Section 3.3). It is no surprise that electricity usage rates increase massively. In control communities, a small share of households also uses electricity (6 percent), mostly car batteries, Pico-PV kits, or solar panels. The share is slightly higher in 2013 than in 2011 when 4 percent of households used an electricity source due to an increase of Pico-PV kits from zero to two percent.

Batteries and kerosene, i.e. those energy sources that are used for energy services for which electricity can be used, are consumed significantly less in the treatment group. The share of households that uses candles increases, but the low consumption intensity (not displayed here) indicates that they are only used in case of blackouts. In line with intuition, firewood and charcoal consumption does not change, because electricity is not used for cooking.

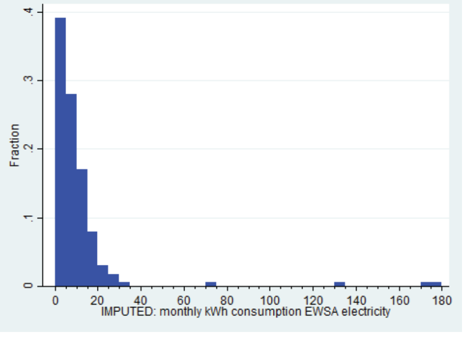
**Table 4: Percentage of households using energy sources (DiD and mean follow-up values)**

| Energy Source | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| Electricity | 0.94 | 0.000 | 0.06 | 0.63 |
| Batteries | -0.62 | 0.000 | 0.83 | 0.40 |
| Kerosene | -0.37 | 0.000 | 0.35 | 0.19 |
| Candles | 0.19 | 0.029 | 0.32 | 0.52 |
| Firewood | 0.01 | 0.671 | 0.86 | 0.89 |
| Charcoal | 0.09 | 0.273 | 0.12 | 0.22 |

*Note:* For the DiD household, we estimate a community level fixed effects Linear Probability Model comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_1 .
*Source:* EARP dataset 2011/2013.

On average, the surveyed connected households consume 11 kWh per month which is equivalent to expenditures of 1,500 FRW. The median electricity consumption is only 6 kWh, ten percent of the households do not even consume 1 kWh per month and three household have not consumed any electricity at all. The detailed distribution of electricity consumption can be observed in Figure 3. These low consumption patterns are in line with official data on consumption patterns of newly connected households in Rwanda. The official client database from REG specifies that among households connected between October 2009 and October 2011 (including urban and rural households) more than 2/3 of these households consume less than 20kWh/month and more than half use less than 15 kWh/month (EWSA 2012).

**Figure 3: Histogram of electricity consumption of REG clients**




*Source:* EARP dataset 2013

### 5.2 Do households adopt electric appliances?

All households that are connected to the REG grid use electricity for lighting.[16] Electric lighting devices, mostly energy savers, have mainly replaced wick and hurricane lamps, which are hardly used anymore in connected households. Half of connected households still use candles occasionally, probably in case of blackouts. To a smaller extent also mobile LED lamps and hand-crafted torches have been replaced. As can be seen in Table 5, access to electric lighting increases lighting consumption considerably, both in terms of mere lighting hours (the sum of usage time across all lamps in the household) and lumen hours. Apart from lighting, entertainment devices and mobile phones clearly dominate the electric appliances (see Table 5) for most frequently used appliance[17].

**Table 5: Usage of most important appliances (in % of total households; DiD and mean follow-up values)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| ***Lighting*** | | | | |
| Sum of lighting hours | 21.76 | 0.000 | 8.1 | 19.4 |
| Lumen hours | 28,239 | 0.000 | 526 | 17,473 |
| ***Appliances*** | | | | |
| Mobile phone | 0.08 | 0.056 | 0.71 | 0.75 |
| Radio | 0.01 | 0.742 | 0.73 | 0.69 |
| (bivalent) | 0.292 | 0.000 | 0.13 | 0.33 |
| (battery only) | -0.484 | 0.000 | 0.60 | 0.25 |
| (line power) | 0.238 | 0.000 | 0.01 | 0.15 |
| Cassette recorder | 0.058 | 0.049 | 0.03 | 0.06 |
| Electric iron | 0.11 | 0.000 | 0 | 0.08 |
| TV (color) | 0.219 | 0.000 | 0.01 | 0.18 |
| TV (black and white) | 0.041 | 0.014 | 0.01 | 0.02 |
| DVDs | 0.164 | 0.000 | 0.01 | 0.13 |
| Computers | 0.033 | 0.080 | 0.01 | 0.03 |

*Note:* For the DiD household, we estimate a community level fixed effects Linear Probability Model for binary outcomes and an community level fixed effects OLS model for continuous outcomes comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_3 and Table A2_4 .
*Source:* EARP dataset 2011/2013.

[16] An illustration of all lamp types and detailed estimations on lamp usage can be found in the electronic appendix, Figure A2_1 and Table A2_2.

[17] A comprehensive list of appliances can be found in Table A2_5 in the electronic appendix,.

### 5.3 Do households save money?

The average amount that connected households spend on REG electricity is 1,500 FRW[18]. Looking at the different components of energy expenditures (see Table 6) it can be seen that virtually all energy sources potentially to be replaced by electricity have changed significantly. Most importantly, kerosene, battery, and mobile phone charging expenditures have decreased significantly. Also the sum of all expenditure for energy excluding cooking energy[19] has decreased significantly. The effect of electrification on the share of energy expenditures in total expenditures is a three percent decrease, but only borderline significant.

**Table 6: Energy expenditures without cooking energy (DiD and mean follow-up values)**

| Expenditures on … | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| REG electricity [a] | 1,476 | 0.000 | 0 | 890 |
| Batteries | -1,457 | 0.009 | 1,331 | 291 |
| Kerosene | -1,163 | 0.007 | 899 | 167 |
| Mobile phone charging | -712 | 0.000 | 583 | 93 |
| Candles | -148 | 0.147 | 307 | 267 |
| Decentralized electricity sources | -214 | 0.285 | 59 | 15 |
| Gas | -0.58 | 0.324 | 36 | 0 |
| Monthly energy expenditures in FRW (without cooking energy) | -2107 | 0.003 | 3,431 | 1,117 |
| Share of energy in total expenditures | -0.029 | 0.154 | 0.10 | 0.11 |

*Note:* For the DiD household, we estimate a community-level fixed effects OLS model comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_6 . Investment costs for electricity sources are not included in the energy expenditures. a: DID estimation technically not feasible, we display differences in follow-up means instead.
*Source:* EARP dataset 2011/2013.

### 5.4. Does access to knowledge and information improve?

In order to see whether access to information and knowledge has improved, we analyze usage patterns of radio, TV, and mobile phones in the following (see Table 7). Mobile phones had already been used widely before electrification (more than 50

[18] The payment of electricity provided by REG works through a pre-paid metering system. This makes it more difficult to elicit electricity consumption and expenditures than in other cases in which households receive invoices on a regular basis. Only in few cases households had receipts of how much electricity they bought and they often found it difficult to recall the amount of kWh bought or money spent. Only around half of the REG clients were able to provide accurate consumption data. This is why we infer consumption data based on appliances usage and lighting consumption habits. For electric lighting, we can calculate exact electricity consumption, since we know the number of bulbs and usage hours for each household. For electric appliances we assume average usage times specified in Annex 3. For those households who gave information on consumption and expenditure for EWSA we can assess the quality of our inferred values by comparing actual and inferred consumption values. The comparison shows that the two values deviate on average by two percent. Hence, the inferred values appear to be quite accurate.

[19] In rural Rwanda, electricity is never used for cooking and thus no effect can be expected.

percent). While the share increased in both treatment and control communities to usage rates of more than 70 percent, the significant and positive DiD-estimate indicates that the increase among the connected households is above the general trend. Moreover, also the number of mobile phones per household and the usage intensity increases due to electricity. In principle, households do not need a grid connection to use a mobile phone, but it is the facilitation of phone charging that induces the increase in usage rates.

**Table 7: Mobile phone charging (DiD and mean follow-up values)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| HH has mobile phone | 0.07 | 0.056 | 0.71 | 0.75 |
| Number of mobile phones per household | 0.28 | 0.006 | 1.23 | 1.42 |
| Times phone used last week | | | | |
| more than 6 times | 0.05 | 0.486 | 0.67 | 0.69 |
| more than 21 times | 0.15 | 0.089 | 0.30 | 0.37 |

*Note:* For the DiD household, we estimate a community-level fixed effects Linear Probability Model for binary outcomes and an community-level fixed effects OLS model for continuous outcomes comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_7 .
*Source:* EARP dataset 2011/2013.

Most mobile phone owners use the phone on a daily basis. As can be seen in Table 8, all households use the mobile phone for calling people who live outside the province indicating that an increase in mobile phone usage also leads to an increase in connectivity of the users. Other common purposes are the usage of the mobile phone as a torch or as a radio and more than 50 percent of households use the mobile phone for money transfers. The share is significantly higher among treatment communities.

While television hardly exists in control communities, 20 percent of households in the treatment communities own a TV (Table 8). The usage rates are even higher. 24 percent of head of households in treatment communities watch TV regularly, which means that some of them watch TV in bars, at neighbors, or friends. Also spouses and small children exhibit high shares of TV usage.[20] All differences are statistically

[20] Households in treatment communities and in partiuclar connected households also increase the time they watch TV considerably. See electronic appendix for details .

significant.[21]

**Table 8: Mobile phone and TV usage (only follow-up values)**

| | Control | Treatment | p-value |
|---|---|---|---|
| *Purpose of mobile phone usage* | | | |
| Talking to people outside the province | 0.95 | 0.99 | 0.010 |
| Information on agricultural products | 0.26 | 0.29 | 0.502 |
| Money transfer | 0.51 | 0.67 | 0.000 |
| Listen to radio | 0.75 | 0.72 | 0.353 |
| Lighting | 0.91 | 0.94 | 0.135 |
| | | | |
| HH has TV at home | 0.02 | 0.20 | 0.000 |
| *[HH member]* watches regularly TV | | | |
| Head of HH | 0.08 | 0.24 | 0.000 |
| Spouse | 0.01 | 0.19 | 0.000 |
| Children | 0.01 | 0.14 | 0.000 |

*Note:* The asterisks refer to the significance level detected by *t-* and *chi-squared* tests on differences in means between the treatment and control group as a whole *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively.

*Source:* EARP dataset 2013.

While it is often claimed that people watch TV for entertainment reasons only, our data shows that news are very popular at least among head of households and their spouses (Table 9). The question was posed in an open way and did not propose any answer. In another open question respondents were asked for the main source of information, which is in both treatment and control communities mainly radio. For obvious reasons, television hardly plays a role as an information source in control communities, but becomes the main information source for around half of those households that use a TV set.

**Table 9: Preferred program (only TV owners)**

| Preferred program (follow-up values) | Head of HH | Spouse | Children 6-11 | Male 12-17 | Female 12-17 |
|---|---|---|---|---|---|
| News | 0.87 | 0.86 | 0.27 | 0.30 | 0.42 |
| Sport | 0.48 | 0.23 | 0.45 | 0.80 | 0.36 |
| Soap Operas | 0.45 | 0.53 | 0.22 | 0.17 | 0.49 |
| Music | 0.10 | 0.15 | 0.13 | 0.13 | 0.20 |
| African movies | 0.09 | 0.13 | 0.24 | 0.46 | 0.54 |
| Other movies | 0.17 | 0.24 | 0.42 | 0.51 | 0.68 |

*Source:* EARP dataset 2013.

[21] We are not able to calculate the DiD since TV watching has not been elicited on household member level during the baseline.

### 5.5. Does income generation potential increase?

The availability of electricity in the communities clearly has a significant effect on the daily routine of all household members. A first and evident effect is an extension of the time people are awake by on average 20 minutes per day, induced by better access to lighting and entertainment devices.[22] While it is sometimes hypothesized that this additional time can be used by newly electrified households to pursue income-generating activities, we do not observe much evidence for a change in income-generation patterns. The type of income-generating activities household members pursue is not influenced by electrification. The majority of household heads and their spouses are subsistence farmers both before and after electrification (see Table 10). Around five percent are public employees. Among head of households around ten percent engage in independent activities, seven percent in other dependent activities. These shares are substantially lower for spouses.

**Table 10: Income generating activity of household members, in percent (DiD and mean follow-up values)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| *Head of household is* | | | | |
| Subsistence farmer | -0.04 | 0.443 | 0.70 | 0.69 |
| Public employee | 0.02 | 0.511 | 0.05 | 0.06 |
| Independent activity | 0.03 | 0.487 | 0.12 | 0.11 |
| Other dependent activity | -0.01 | -0.843 | 0.07 | 0.07 |
| No income generating activity | 0.01 | 0.899 | 0.06 | 0.06 |
| *Spouse is* | | | | |
| Subsistence farmer | -0.07 | 0.075 | 85 | 84 |
| Public employee | 0.01 | 0.848 | 0.05 | 0.05 |
| Independent activity | 0.003 | 0.892 | 0.03 | 0.04 |
| Other dependent activity | -0.02 | 0.516 | 0.03 | 0.05 |
| No income generating activity | 0.075 | 0.029 | 0.03 | 0.04 |

*Note:* For the DiD household, we estimate a community-level fixed effects Linear Probability Model comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_8.
*Source:* EARP dataset 2011/2013.

Looking at the time the head of households and the spouses dedicate to income-generating activities either at home or outside we see no substantial changes (see Table 11).

[22] Table A2_8 in the electronic appendix shows detailed daily routines of all household member types.

**Table 11: Hours HH members spend on productive activities (including agriculture and livestock keeping)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| Head of household | -0h01 | 0.985 | 6h32 | 6h40 |
| Spouse | -0h08 | 0.811 | 6h17 | 6h06 |

*Note:* For the DiD household, we estimate a community-level fixed effects OLS Model comparing connected household to hypothetically connected households. Detailed results can be found in the electronic appendix, Table A2_9 .
*Source:* EARP dataset 2011/2013.

These findings are in line with our observations on the humble effect electricity has on micro-enterprises in the communities (see Section 5.1). Also examining appliance usage in households corroborates the finding of only very little effect on income-generating activities, as the share of households that use appliances productively is very low. Nonetheless, as can be seen in Table 12, on a low level, access to electricity seems to trigger some small-scale business activities among connected households. While in the control communities, only five percent of households use any appliance (electric or not) for productive purposes, the share is at more than 10 percent in treatment communities and even at 16 percent among connected treatment households. The DiD-estimate indicates that this increase is borderline significant with a p-value of 0.136.

Most of the productively used appliances are small electric appliances for communication and entertainment. Some households rent out their mobile phones to make calls on a fee basis, some use TVs and DVDs to operate small community cinemas in which they show films and football matches. Only very few devices are used for manufacturing or agricultural processing purposes, mostly sewing machines and mills. In both cases, the majority are mechanical and not electric.

**Table 12: Productive appliance usage (DiD and mean follow-up values)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| Share of HHs using appliances productively | 0.08 | 0.136 | 0.05 | 0.11 |
| Share of HHs using electric appliances productively | 0.07 | 0.136 | 0.04 | 0.11 |
| Productive usage of | | | | |
| Mobile phone | 0.06 | 0.375 | 0.03 | 0.05 |
| TV | 0.011 | 0.786 | 0.00 | 0.04 |
| DVD | 0.017 | 0.406 | 0.00 | 0.02 |
| Sewing machine | 0.012 | 0.207 | 0.01 | 0.02 |
| (in parentheses electric sewing machines) | (0.02) | (0.044) | (0) | (0.01) |
| Mills | 0.007 | 0.597 | 0.01 | 0.01 |
| (in parentheses electric mills) | (0.021) | (0.090) | (0) | (0.01) |

*Note:* For the DiD household, we estimate a community-level fixed effects Linear Probability Model comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_10 .
*Source:* EARP dataset 2011/2013.

### 5.6. Does investment in education increase?

Electricity access might improve people's education by influencing children's study behavior and school attendance. As depicted in the results chain in Section 3, electricity is expected to increase the time household members can spend under light. This gives greater freedom to organize the daily routines and might result in longer study hours of children. The greater flexibility might also translate into higher school attendance, since children can pursue activities in the evening that kept them from attending school. Also the parents' higher exposure to information through TV, radio, and mobile phone usage might increase school attendance rates.

However, the DiD-estimate indicates that the probability of households to send all their children to school does not increase (see Table 13). This is in line with qualitative interviews with teachers who do not observe any changes in school attendance. Yet, we find significant effects on study time after school. Depending on their age, children study between 20 and 37 minutes longer after nightfall. The total time children study does not increase significantly, though. Rather, children in households with electricity shift their study time from daytime to night-time. Effects are similar for girls and boys (not depicted in the table).

**Table 13: School attendance and study time (DiD and mean follow-up values)**

| | DiD household | p-value DiD | Control | Treatment |
|---|---|---|---|---|
| *Children between 6-11 years* | | | | |
| All children go to school | 0.10 | 0.308 | 0.47 | 0.50 |
| Study hours total | 0h36 | 0.142 | 0h16 | 0h32 |
| Study hours after nightfall | 0h20 | 0.017 | 0h19 | 0h35 |
| *Children between 12-17 years* | | | | |
| All children go to school | 0.07 | 0.580 | 0.37 | 0.54 |
| Study hours total | 0h01 | 0.986 | 0h31 | 0h31 |
| Study hours after nightfall | 0h37 | 0.001 | 0h33 | 0h60 |

*Note:* For the DiD household, we estimate a community-level fixed effects Linear Probability Model for binary outcomes and an community-level fixed effects OLS model for continuous outcomes comparing connected household to hypothetically connected households. Robust standard errors are clustered at the community level. Detailed results can be found in the electronic appendix, Table A2_10 and Table A2_11.
*Source:* EARP dataset 2011/2013.

### 5.7. Does electrification affect households' health and environmental hazards?

Electrification is often expected to improve households' health through reducing smoke emissions from kerosene usage. While the biggest share of air pollution in rural households is emitted by woodfuels for cooking, it is the immediate exposure of people sitting next to a wick lamp for a specific task (e.g. studying), that makes kerosene a substantial health threat (LAM et al. 2012). The substantial reduction in kerosene usage (see Section 4.3) can thus be expected to improve household air and people's health.

Measuring smoke emissions and exposure accurately was obviously beyond the scope of our study. Instead, we asked households in the follow-up for a subjective assessment of air quality. Around 40 percent of households in treatment communities indicate that the air quality has improved in the last two years. The share is significantly higher than among control households. Answering an open question on the reasons for the improvement, around 30 percent of treated households name the replacement of kerosene lamps as the major reason. Another 58 percent of the households say it is "due to electricity" without further specifying the exact transmission channel.

**Table 14: Subjective perception of HH air pollution**

| | Control | Treatment | p-value |
|---|---|---|---|
| *In comparison to two years ago, household air has…* | | | |
| Improved | 0.11 | 0.40 | 0.000 |
| Deteriorated | 0.01 | 0.01 | 0.550 |

*Source:* EARP dataset 2013.

In order to analyze whether this perceived air quality improvement also leads to an improvement in household members' health, we ask households whether any member suffers from respiratory diseases, eye diseases, or headaches. We do not observe a change in these indicators for connected households between baseline and follow up. It has to be noted, though, that smaller effects might exist but cannot be detected with the sample size at hand.

Next to air pollution induced by kerosene, dry-cell batteries used for LED-lamps and radios constitute a potential hazard to the immediate environment and eventually people's health. In fact, around 90 percent of the households in our sample throw used dry-cell batteries into their pit latrines (unprotected 3-4 meter holes in the backyards of the compounds), the remaining households either throw them into their garbage (which is disposed of simply in the bush) or directly into nature. In non-electrified areas, this will become even more dramatic in the coming years, since LED usage and dry-cell battery consumption are steadily increasing. While before electrification households consumed on average 5.5 batteries per household and month, in the follow-up households in control communities consume 9 batteries per month and household. This implies an annual increase of almost 30 percent. Among treatment communities the consumption of dry-cell batteries decreased significantly from 5.5 in 2011 to 2.5 batteries per household in 2013.

## 6. Electricity in micro-enterprises, health infrastructure and schools

### 6.1. Micro-enterprises

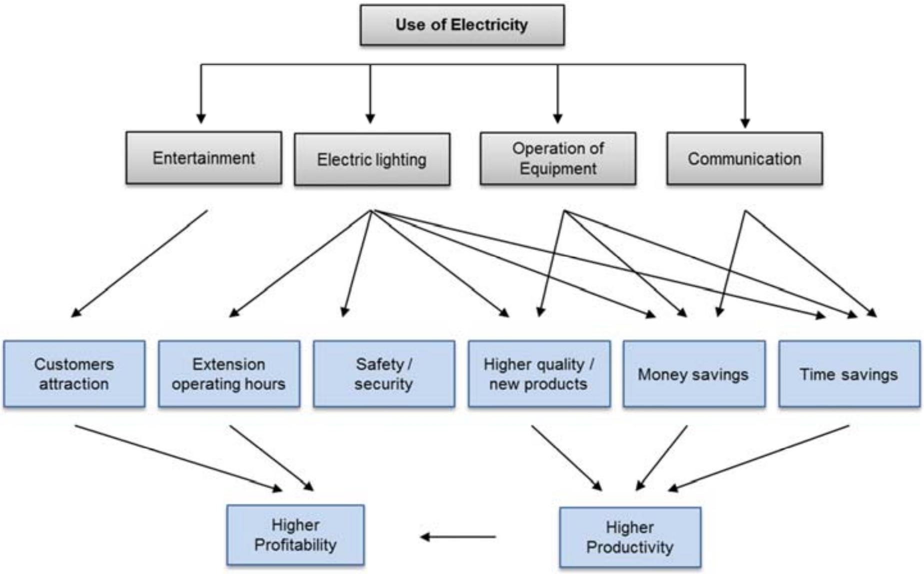
We analyze the effects of electrification on micro-enterprises on two levels. On the community level, we elicited information on existing and newly created firms in interviews with community chiefs. On the firm level, we conducted semi-structured interviews with 83 micro-enterprises during the follow-up. A list of interviews with basic information on business lines and electricity sources used, as well as detailed descriptions of effects for each business type can be found in Annex 2. This section summarizes general findings from these interviews.[23]

Positive impacts of electrification on the business environment are expected to be either the emergence of new businesses or the improvement of existing ones. For an already existing business, access to electricity is expected to lead to a decrease of input requirements or an increase in quality and thus, eventually, an increase in productivity (see Figure 4). In addition, the availability of better lighting and entertainment devices might enable longer operation hours or attract new customers.

Next to the availability of higher quality products, the most important expected impact on the community level is employment creation. Here, it has to be accounted for whether other locally produced goods are crowded out by the newly offered products. Strong positive net income effects on the community level can only materialize if products that used to be produced outside the community are now produced in the community or if local enterprises produce for markets outside the community.

[23] An extended version of findings from semi-structured interviews with small enterprise portraits can be found in PETERS et al. (2014).

**Figure 4: Pathways from electricity access to income generation in micro-enterprises**




The business environment before the grid connection differed strongly between the surveyed communities. One part of the communities in our sample are small business centers with vivid entrepreneurial activities. The majority of communities, though, do not have business centers and no or very little entrepreneurial activity. Based on interviews with community chiefs, Table 15 displays the most frequent enterprises in control and treatment communities and their connection status. The most common enterprise type is a small shop selling staple food, batteries, and toiletries. A similar business type is a bar selling sodas, locally brewed or bottled beer, and small snacks. Other very common businesses are tailor shops, mills, hairdressers, and carpentries. Technicians, mechanics, or bakeries often do not work following regular business hours and rather wait for customers to ask for their services. In the more developed communities, photocopy shops, welder shops, small cinemas, and pharmacies can furthermore be found.

The highest connection rates can be observed among mills, hairdressers, copy shops, and welding shops (see again Table 15). By contrast, tailors and carpenters only rarely connect to the grid.

**Table 15: Most frequent enterprise types in sampled communities**

| | Control 2009<br><br>Share with [*enterprise*] | Control 2013<br><br>Share with [*enterprise*] | Treatment 2009<br><br>Share with [*enterprise*] | Treatment 2013<br><br>Share with [*enterprise*] | Treatment 2013<br><br>Share of [*enterprise*] connected to REG |
|---|---|---|---|---|---|
| …small shops | 0.97 | 0.92 | 1.00 | 1.00 | 0.45 |
| …bar | 0.55 | 0.82 | 0.64 | 1.00 | 0.57 |
| …hairdressers | 0.41 | 0.68 | 0.64 | 0.86 | 0.96 |
| …tailors | 0.55 | 0.86 | 0.50 | 0.77 | 0.13 |
| …carpenters | 0.41 | 0.57 | 0.64 | 0.79 | 0.17 |
| …mills | 0.38 | 0.59 | 0.36 | 0.62 | 0.78 |
| …welding shop | 0 | 0 | 0 | 0.47 | 1.00 |
| …restaurants | 0.38 | 0.5 | 0.43 | 0.46 | 0.64 |
| …copy shops | 0 | 0 | 0 | 0.26 | 1.00 |

*Source:* EARP community data 2011/2013.

We generally observe a slight increase of business activities in connected communities. Some enterprises emerge and existing enterprises partly extend their operation hours or their range of offered products and services (see Table 16). Some enterprises can also be expected to increase net community income by attracting demand from outside the community or offering products locally that formerly had been imported from urban areas. Effects on business activities are most visible in communities that already had a vivid business center before electrification. The crucial factor for the development of all business activities is access to markets on which higher quantities or better quality can be sold. Communities without commercial centers are mostly lacking this access.

Mills are the main beneficiaries of electricity access. Most of the existing mills switch from diesel engines to electricity as soon as the community is connected to the grid and new mills emerge. This fact can be explained by a substantial productivity gain in the milling process induced by electricity. It makes milling faster, more profitable, and lower prices increases demand for milling services.

**Table 16: Effects of grid electricity on enterprise types**

| | Small shops, restaurants, bars | Hairdresser | Tailor | Carpenter | Mills |
|---|---|---|---|---|---|
| **Connection to electricity grid?** | Virtually all connected | Virtually all connected | Few | Few | Virtually all connected |
| **Additional usage of other electricity sources?** | no | no | No | no | Diesel (if no 3-phase power is available) |
| **Grid electricity used for** | | | | | |
| *…Electric Lighting* | Yes | Yes | Yes | Yes | Yes |
| *..Operation of Equipment* | Normally not. Very few radios, TVs, or refrigerators | Yes | Most firms still work with manual machines. | In few cases yes. In most cases, investment is not profitable. | Yes |
| *…Communication* | Only used for non-commercial purposes | Only used for non-commercial purposes | Only used for non-commercial purposes | Only used for non-commercial purposes | Only used for non-commercial purposes |
| **Impacts of grid connection** | | | | | |
| *Longer opening hours* | Yes | Yes | Demand is too low; shift to evening hours | No. Demand is too low | yes |
| *Safety / Security* | Yes. Less robberies and fights. | No | No | no | no |
| *Higher product quality / new products* | Exceptionally new products (ice-cream or cool drinks) | Yes | Only trough electric sewing machines (hardly used) | Yes | yes |
| *Money saving* | yes | Yes | yes | Yes | yes |
| *Time saving* | No | Yes | No | Yes | yes |
| *Employment creation* | No | Yes | No | No | yes |
| **Firm creation?** | Low | Yes | No | No | Yes |
| **Net effects on community level** | No net income generation on community level since virtually all products are sold and consumed locally No productivity gain. Net gains in community income can only be expected for communities next to a country road. | Yes, productivity gain leads to higher owner income and emergence of new and slightly bigger firms. Additional income, though, is mostly coming from the village. | No, all products are sold and consumed locally. | No, carpenters normally do not serve demand from outside the community. Demand is often too low to make investment into electric appliances profitable. Productivity gains often do not materialize. | Yes, some mills attract customers from outside the community. Productivity gains lead to higher owner income. |

*Source:* Semi-Structured Interviews with micro-enterprises in surveyed communities 2013.

Also hairdressing shops benefit substantially from grid-electricity since also in absence of grid-electricity they often possess a source of electricity, in most cases a car battery. This electricity source is used for razors and entertainment of clients with radios or TV sets. Often they additionally offer phone charging services. The connection to the electricity grid for them mainly has cost and convenience implications, as they save money and time to charge the car battery.

Small kiosks, bars, and restaurants, mostly use electricity for lighting and in few cases also for radio, TV, or refrigeration. Electricity mainly increases convenience and thereby often attracts more customers, for example through the replacement of dull candle light by electric lighting in a bar at night. For all these businesses – kiosks, bars, restaurants, mills, and hair dressers – the connection to the electricity grid can be expected to induce an increase in the owner' income. However, the increase in net community income is probably modest, since it is mostly local demand that is shifted from other purposes to these shops. Only in communities that are located next to country roads with people passing by from outside the region can the improved services and goods sold to these transit customers increase community income.

Carpenters and tailor shops do hardly connect to the grid, since – as expressed in their views – they do not necessarily need electricity to run their business and local demand is limited. Additional products cannot be sold.

We furthermore observe the emergence of copy and welding shops in the liveliest newly connected communities that do not exist in non-connected communities since these shops offer services and products that cannot be provided without electricity. Hence, people with demand for such goods had to travel to urban areas before and the newly offered services substitute for formerly imported goods.

To summarize, our qualitative and quantitative evidence shows that electrification leads to some changes in production processes and offered goods and services. In most cases, it is only local demand that can be served because access to supra-regional markets is limited. Electrification also induces the creation of new firms in occasional cases. While these findings suggest that the division of labor might improve and some productivity gains can be expected, the net gains in additional income will be rather small.

### 6.2.Health Infrastructure

One of EARP's major purposes is to connect rural health centers (HC). Health centers are the central point of reference for basic health care services for the rural population. Electricity in HC is frequently considered a prerequisite for an improved health care provision. HCs without grid electricity in Rwanda either have a solar panel or a generator. The effects we outline in the following describe hence a switch from an off-grid electricity source to on-grid electricity.

We assess the extent to which EARP has achieved its goal of pushing the connection rate of HCs and whether this can be expected to improve health care provision. For this purpose, we combine a qualitative survey based on semi-structured in-depth interviews that we conducted in 26 HCs with a full census survey of all HCs in the country via telephone. While the full census survey serves to determine the share of connected HCs in the country and whether a connection translates into higher appliance usage, the qualitative survey probes into the service facilitation following a grid connection in the day-to-day business of a HC.

The surveyed HCs are all open 24 hours and seven days a week. The HCs provide a catchment population of 25,600 on average, but the range is wide from 14,400 to 41,950 people. On average, 2,404 patients visit per month for treatment. The HCs have on average 14 employees, but no doctors. Rather, patients are treated by nurses.

The three most frequently treated diseases in the surveyed communities are respiratory infections, malaria, and parasitic worms. All three diseases vary strongly between regions with different climates and between seasons. An important service of HCs is delivery assistance.

### 6.2.1. What kind of electricity source do HC have and for which purposes is it used?

All surveyed HCs have an electricity source with 14 HCs being connected to the grid (eight have been connected by EARP i.e. 2009 or later) and twelve HCs possessing a solar panel or an individual generator or both. All HC recently connected to the grid say that their work has improved since electrification. According to an open question, the main purpose of grid electricity usage is lighting (100 percent) followed by the usage of medical machines (79 percent) and administrative tasks (43 percent), 28 percent explicitly name medicine storage and sterilizing. It is furthermore often mentioned that grid electricity facilitates the attraction of (trained) staff from urban areas to the community, not only as it improves working conditions, but also because electricity in their private houses increases their quality of life in the community. Problems to recruit skilled staff for HC in villages due to lack of electricity access is named as a major problem by all surveyed non-connected HCs.

The most important effect of having a grid connection is related to costs. The connected HCs unanimously paid 56,000 FRW for the connection and have monthly electricity bills of around 62,540 FRW. For comparison, the HCs using a generator, a solar panel or both face on average diesel costs of 205,000 FRW, i.e. three times more than what grid connected HCs pay.

In terms of reliability, 50 percent of grid electricity users report no or rare outages. The other 50 percent suffer from two to four mostly short outages per week. Some of the visited HCs have a generator or a solar panel as backup; others resort to candles, hurricane lantern, or torches.

### 6.2.2. Does grid connection translate into higher appliance ownership?

For the HC full census that was administered via telephone, we focused on simple to elicit indicators, like connection status, availability of other electricity sources, and the ownership of basic health care appliances.[24] It is important to note in this regard, that as in households or enterprises, most appliances can also be used without grid electricity, for example kerosene or LPG for fridges, but the access barrier decreases substantially, mostly due to lower operation costs.

Table 19 shows the share of HCs connected to the grid in August 2013 and the share of HCs connected to the grid in 2009 (i.e. before EARP started). In fact, the share is substantially higher now than it used to be, although it is far from being at 100 percent. Information on grid access and appliances in 2009 has been elicited by retrospective questions in 2013/14.

**Table 17: Electricity connection and appliances usage in HCs**

| ***Share of HC with …*** | |
|---|---|
| REG connection in 2013/14 | 0.68 |
| REG connection in 2009 | 0.30 |

*Source:* Health center telephone survey 2013/14.

It is furthermore striking to see that appliance usage rates in HCs connected by EARP are close to 100 percent for basic appliances like lighting, refrigerators, microscopes, centrifuges, or sterilizer (see Table 18). For other appliances like incubators, spectrophotometers or office equipment like photocopiers or scanners, usage rates are lower. In comparison to non-connected HCs, usage rates are higher only for some appliances (centrifuges, sterilizers, spectrometers, hematological analyzers, and photocopier). For the remaining appliances, we do not see any significant differences.

When comparing the development of appliance ownership between 2009 and 2014 of HCs that got connected to the grid and those HCs that are still non-connected in 2014, the mostly non-significant DiD-estimators (see Table 18) show that grid connection does not lead to higher appliance ownership. Both non-connected HCs and newly grid connected HCs got various types of appliances between 2009 and

[24] A list of most relevant health care appliances has been developed based on the most recent international tool to assess equipment in health facilities, the Service Availability and Readiness Assessment (Practical Action 2013). It combines and replaces the formerly used Service Provision Assessment by USAID and the Service Availability Mapping by the WHO.

2014.

This general increase in appliance usage can be explained by several reforms in the Rwandan health sector, which led to an increase in health expenditure per capita from 50 USD in 2005 to 144 USD in 2012 (World Development Indicators 2014). Only in the case of sterilizers, EARP connected HCs show a significantly higher increase in usage of sterilizers than non-connected HCs. In other words, the higher appliance usage rate among newly grid connected HC is not due to the connection, but had existed already before electrification in 2009.

This analysis does not account for the number of appliances used and it does not assess usage intensity. Yet, our respondents in qualitative interviews clearly stated that having grid electricity is highly valued by HC representatives. Grid electricity enables HCs to use several appliances simultaneously, uninterruptedly or for longer periods as compared to non-connected HCs. This, in turn, results in an increase in the number of patients that can be treated per day. HC representatives also highlight energy cost savings as an important gain that frees up budget for other quality enhancing expenditures.

It can hence be concluded that in spite of only insignificant effects on appliance endowment, grid electricity might improve the quality of health care provision in rural areas via other pathways. The effect, though, can be expected to be more subtle than suggested in frequently used examples in which a grid connection enables HCs to use appliances they could not use without.

**Table 18: Appliance endowment before and after electrification (share of health centers)**

| Appliance | DiD | p-value DiD | 2013/2014 | |
|---|---|---|---|---|
| | | | Health centers without REG connection | Health centers connected by EARP to REG grid |
| *N* | | | *118* | *144* |
| REG connection | | | 0 | 1 |
| Solar Panel | | | 0.3 | 0.2 |
| Generator | | | 0.19 | 0.32 |
| Solar Panel and Generator | | | 0.52 | 0.31 |
| Refrigerator | 0.069 | 0.265 | 0.99 | 1 |
| Microscope | 0.055 | 0.363 | 0.99 | 1 |
| Computer | 0.023 | 0.698 | 0.99 | 1 |
| Electric Lighting | 0.041 | 0.506 | 0.98 | 0.99 |
| Printer | 0.062 | 0.293 | 0.93 | 0.99 |
| Centrifuge | 0.047 | 0.502 | 0.86 | 0.94 |
| Sterilizer | 0.171 | 0.018 | 0.7 | 0.88 |
| Incubator | 0 | 0.996 | 0.85 | 0.87 |
| Spectrophotometer | 0.027 | 0.697 | 0.66 | 0.77 |
| Haematological analyser | 0.06 | 0.414 | 0.62 | 0.75 |
| Photocopier | 0.039 | 0.604 | 0.58 | 0.72 |
| Warmer lamp | 0.022 | 0.768 | 0.64 | 0.7 |
| Gynaecological lamp | -0.023 | 0.757 | 0.57 | 0.61 |
| Scanner | -0.008 | 0.9 | 0.35 | 0.34 |

*Note:* For the DiD, we estimate a Linear Probability Model comparing HCs that got an REG connection through EARP to HCs that are not connected to the REG grid in 2009 and 2013/14

*Source:* Health center telephone survey 2013/14.

## 6.3. Schools

EARP aims at providing at least 50 percent of all schools with electricity by 2013. In order to probe into whether and how electricity is used in rural schools, we conducted 38 semi-structured in-depth interviews with school principals, all located in the communities of our main survey or in their neighboring communities. Half of them are in connected communities, the other half in non-connected communities. 15 out of the 38 schools are connected to the grid, five have a generator or a solar panel or both. The remaining 20 schools have no electricity access. Most of the schools are primary schools (24), 12 are integrated primary and secondary schools, offering either nine or 12 years of education, and only two schools are pure secondary schools. Most surveyed schools are public (23), two are private and the remaining facilities are managed by (mainly catholic) churches.

It is frequently argued that electricity can be used to improve educational services of schools, for example by offering evening courses or employing computers in classes. As can be seen in Table 19, in connected schools, a higher availability of appliances and more diverse devices can be observed in comparison with the non-connected schools. Connected schools use computers, printers, and televisions. A few schools have purchased microscopes, a fridge, or a DVD player. Computers are rated as very important by all principals. Today, 100 percent of the connected schools own a computer, 64 percent of them did not have one before electrification. While most schools use computers mostly for administrative tasks, around 40 percent offer computer classes for students since electrification. While none of the unconnected schools (including those that have a generator or a solar panel) offer classes after 6.00 p.m., 33 percent of the connected surveyed schools give revision classes and computer classes after 6.00 pm.

**Table 19: Appliance usage in schools**

| Appliance | Number of connected schools (N=15) with [*appliances*] | Number of [*appliance*] purchased after electrification | Energy source used before electrification |
|---|---|---|---|
| Microscope | 4 | 3 | manually |
| Computer | 15 | 7 | solar panel, generator, charged elsewhere |
| Radio | 6 | 3 | solar panel, batteries |
| Radio cassette | 6 | 3 | solar panel, batteries |
| TV | 7 | 2 | generator, solar panel |
| Printer | 9 | 0 | generator, solar panel |

*Source:* Qualitative school survey 2013.

Schools that used to operate a generator before REG electrification highlight the cost savings due to electrification. Schools that used to have a solar panel report that they had problems due to the limited capacity of the solar panel and high maintenance costs.

Being asked for the three main purposes of electricity the principals unanimously report to have improved their work since electrification. The most frequently mentioned reason is electric lighting (73 percent) on par with the usage of computers and other electric devices for administrative purposes (73 percent). Exemplarily, one principal explains: “I am now able to write my reports much quicker; also I can print in the office, while before I had to travel for one hour to the closest copyshop and spent a lot of money for the transport”. One third of respondents furthermore state that the computer classes are very important and: “It opens students’ minds and shows them modern communication”.

With the same frequency, principals mention that the preparation of exams and classes and homework revision has become easier and has improved thanks to electric lighting, computer usage and printers. Some principals name an improved security situation, since the guards use lighting at night, some underline the usage of electronic teaching materials and some are relieved to be able to charge phones and radios at the schools (each 20 percent).

It can be summarized that electricity is mostly used to improve administrative processes, but a considerable share of schools has also improved the curriculum and extended the offered services by the integration of electric appliances and lighting.

## 7. Conclusion

This paper presented the results of an impact evaluation of Rwanda’s Electricity Access Roll-Out Program (EARP) on various user levels with a focus on households as the main beneficiaries. The basis of our analysis is a set of surveys we conducted between 2011 and 2014 among all rural target groups, i.e. households, micro-enterprises, health centers, and schools. The first result of this evaluation is that EARP – one of the largest ongoing national electrification programs in the world – is not only ambitious, but also effective in connecting households, health stations, and schools since 2009.

We administered a broad household questionnaire among 974 households in both grid-covered and non-covered areas before and after the electrification that enabled us to examine take-up of electricity and impacts on several dimensions of households' living conditions in a difference-in-differences approach. We found that take-up is high at around 60 percent of households in newly connected areas getting connected, but nonetheless leaving a considerable part of 40 percent of the population being unserved. The vast majority of the non-connected households are detained by affordability reasons related to the connection fees.

Connected households increase their lighting usage tremendously and obtain new appliances, mostly for consumptive purposes. Total energy expenditures are reduced due to substantial reductions in expenditures for kerosene, batteries, and mobile phone charging. The substantial reduction of dry-cell battery consumption after grid connection is another important impact, also from an environmental perspective. While among control households in our study, battery consumption has increased by almost 30 percent annually over the last two years, treatment households consume more than 50 percent less dry-cell batteries than before. This yields a net reduction of more than 70 percent.

Dry-cell battery consumption deserves special attention, as the majority of rural Rwandan dwellers remain unconnected for the years to come. Hence, battery consumption will probably further increase in the country with the vast majority of batteries not being disposed of properly. Households throw used batteries into their pit latrines, into their garbage or directly into nature. In all cases, the heavy metal content will end up in unprotected repositories. Environmental consequences have not yet been properly analyzed, but harmful effects via a contamination of ground water are likely. The establishment of a disposal system is extremely recommendable.

The availability of electricity in the communities clearly has a significant effect on the daily routine of rural dwellers. All household members in treatment communities are on average longer awake than household members in control communities. Children shift their study time from daytime to hours after nightfall, but do not increase their total study time. We furthermore observe a significant increase in TV as the main source of information.

In terms of productive take-up, very few households use any appliance for productive activities and if so, virtually only petty businesses like mobile phone charging. Also take-up in (non-home business) micro-enterprises is rather humble. Enterprises that have the highest connection rates and that are most positively affected by electrification are mills, hairdresser, copy shops, and welding shops. We generally observe a slight increase of business activities in connected communities. Some enterprises emerge and existing enterprises partly extend their operation hours, products, and services. In most of these cases, though, electrification of enterprises causes a redistribution of income, because demand is mostly coming from within the community or neighboring communities.

Only few enterprises also increase net community income by serving demand from outside the region or offering products and services locally that formerly had been imported from urban areas. Effects on business activities are considerably higher in well-connected communities that already had a vivid business center before electrification. The crucial limiting factor for the development of business activities is the lack of access to markets beyond the community. Additional production is simply not absorbed by the local markets on which micro-enterprises are offering their products.

The share of grid connected health centers has increased from 30 to 68 percent since the kick-off of EARP. While appliance usage increased considerably in connected health centers, a similar increase can also be observed among non-connected health centers. This shows that many of the appliances used for basic health care can also be run on other energy sources, solar panels, or generators, to which virtually all non-connected health centers have access to. Hence, the main effect of grid electricity on health care quality is the reduction in operation costs of appliances as well as higher convenience. Lower operation costs enable the health centers to operate appliances more intensively.

It is furthermore often mentioned that electricity facilitates the attraction of trained staff from urban areas to the community, not only as it improves working conditions, but also because electricity in their home places increases their quality of life. Also schools have mostly connected as soon as the grid became available. Here, electricity is mostly used for improving administrative processes in the school and also to improve the offered educational services.

Altogether, this paper has shown that EARP has reached its goals of substantially increasing the electrification rate in the country. It has furthermore provided new evidence for whether impact hopes associated with electrification are justified. In fact, we have found strong indication for broad effects on the living conditions of households, whose daily life is facilitated in many regards. Effects on income generation, however, are limited. Micro-enterprises seem to face other (or additional) bottlenecks than (only) a lack of access to electricity.

Putting the findings into the perspective of SE4All's global tracking framework (SE4All 2013), two aspects stand out. First, as in many other grid extension projects we found that a considerable share of the target population that in principle has access to the grid now does not connect (here: 40 percent), virtually all of them for cost reasons. Although some of these households might still obtain a connection in the years to come, this shows that in order to achieve access for all, additional measures need to be contemplated, since the poorer strata in rural Africa will not be able to bring up the connection fees (even if already pretty low as in the EARP case). Further specifically targeted subsidies might be required.

Second, as for SE4All's multi-tier access definition, EARP allows for Tier 4 access in terms of electricity supply. However, large parts of the target group reveal extremely low demand patterns that qualify at best for Tier 1 or 2, which could also be provided for example by solar home systems. This categorization is more than a technical question. It rather leads to the political question of whether the high investment costs of on grid electrification are justified compared to lower cost (and of course lower quality) off-grid solutions. A simple back-on-the-envelope calculation of dividing the EARP investment costs by the number of connected households suggests investment requirements of around 1,500 USD[25] per EARP-connection. A 50 Watt solar home system, which would fully suffice to satisfy the electricity demand of most rural households, is available at 200 to 300 USD on local markets. Hence, even if technical assistance and higher maintenance costs are added, at least four households could be provided with a solar home system at equivalent costs.

At the same time, as long as electricity supply problems in the Rwandan electricity grid are solved, the grid connection is a sustainable long-term solution to cover people's energy needs – in particular if these energy needs are increasing over time solar home systems have their limits. On that note, it is important to ponder the trade-off between long-term socio-economic development and the poverty reduction goals and energy access objectives of the international community, which are clearly of short-term nature.[26] Furthermore, households have a strong preference for grid electricity over off-grid electricity sources. Research on the willingness-to-pay of households for the different electrification options can help to examine whether the spread in investment costs is justifiable. Such evidence might help to inform a debate that is needed among energy access experts on the pros and cons of different energy access technologies in order to put the SE4All-movement on the right trajectory.

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[25] Cost estimations for infrastructure investment in the electricity sector compiled by the World Bank (AICD 2008) roughly confirm this value as representative for grid extension projects in Sub-Saharan Africa.

[26] See PETERS AND SIEVERT (2015) for a more extensive comparison of on-grid and off-grid electrification technologies.

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## Annex 1: Identification of hypothetically connected households

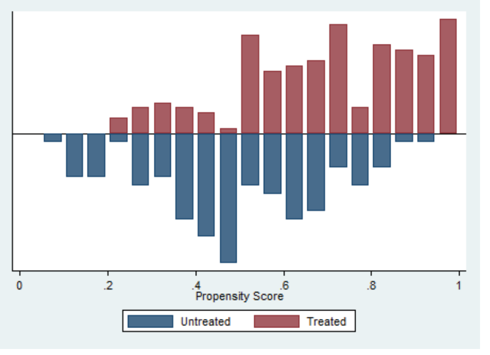
In the first step we estimate a probit model including only households from the treatment communities and regress the connection status of a household on a number of covariates. Results are displayed in the first column of Figure A1_1 below. In a second step, we use the coefficients from this regression to predict the probability to connect, both among the treatment communities and among the control communities (see Figure A1_2). These probabilities, also known as the propensity scores, are then used to stratify the households in control communities into those that are likely to connect and those are not likely to connect once electricity is available. We assume that those households with a propensity score larger than 0.5 are likely to connect. By examining the propensity scores of households in the treatment communities, we can assess the quality of our prediction. Effectively, we can predict correctly the decision to connect for 86 percent of the connected households and 44 percent for non-connected households. We refer to households in the control communities with a propensity score of more than 0.5 as the "hypothetically connected" households and use them as counterfactual for all difference in difference estimations.

**Figure A1_1: Probit estimations before and after matching**

| | Connected vs. non-connected in treatment communities | Connected vs. all HH in control communities | Connected vs. hypothetically connected HH in control communities |
|---|---|---|---|
| HH has bank account | 0.280 | 0.171 | -0.158 |
| | (1.539) | (1.488) | (1.246) |
| Head of HH is subsistence farmer | -0.296 | 0.084 | 0.122 |
| | (1.314) | (0.698) | (0.975) |
| Head of HH is female | 0.351 | 0.128 | -0.019 |
| | (1.544) | (0.941) | (0.128) |
| Distance to main road | -0.017 | -0.019 | -0.012 |
| | (2.363)** | (3.552)*** | (1.927)* |
| Consumed lighting hours | 0.141 | 0.012 | -0.012 |
| | (3.641)*** | (0.959) | (0.855) |
| HH size | 0.132 | 0.087 | 0.041 |
| | (2.967)*** | (3.494)*** | (1.505) |
| Living conditions deteriorated | -0.567 | -0.160 | 0.787 |
| | (1.266) | (0.459) | (1.343) |
| Head of HH has higher education | 0.031 | 0.145 | 0.069 |
| | (0.136) | (1.121) | (0.523) |
| Constant | -0.729 | -1.365 | -0.607 |
| | (2.193)** | (7.170)*** | (2.735)*** |
| LR chi2(8) | 68.72 | 45.95 | 12.41 |
| Pseudo R-Squared | 0.18 | 0.05 | 0.02 |
| Number of Observations | 286 | 841 | 607 |

*Note:* Control variables refer to baseline values.

**Figure A1_2: Distribution of propensity scores**




*Note:* "treated" refers to connected HH in treatment villages; "untreated" to all HH in control communities.

In order to assess whether the comparability of the groups has improved by identifying the hypothetically connected households, we look at differences in means on the covariates between the connected households and the control households. As can be seen in Figure A1_3, the difference between the groups to be compared becomes substantially smaller if we use the hypothetically connected households within the control communities as counterfactual instead of all households in the control communities. As a second way to test the quality of the matching process, we look at the pseudo-$R^2$ of the probit model, regressing the connection status on covariates used for the matching. First, we use all HH in the control communities as counterfactual (see Figure A1_1, column 2) and then we use only the hypothetically connected ones (Figure A1_1, column 3). The pseudo-$R^2$ is expected to fall if a balance improvement is achieved. This is what we see in our data: the pseudo-$R^2$ falls from 0.05 to 0.02. Furthermore, the respective chi-squared statistic shows a joint significant influence of the covariates in the non-matched case and no joint significant influence in the matched case.

**Figure A1_3: Balancing of covariates between treatment and control group**

| Difference in means of covariates | Connected vs. all HH in control communities | Connected vs. hypothetically connected HH in control communities |
|---|---|---|
| HH has bank account | 0.14*** | -0.04 |
| Head of HH is subsistence farmer | -0.01 | 0.06 |
| Head of HH is female | 0.01 | 0.01 |
| Distance to main road | -6*** | -3** |
| Consumed lighting hours | 1.05*** | -0.29 |
| HH size | 0.72*** | 0.25 |
| Living conditions deteriorated | -0.02 | 0.00 |
| Head of HH has higher education | 0.07** | -0.00 |

*Note:* The asterisks refer to the significance level detected by *t*- and *chi-squared* tests on differences in means between the treatment and control group. *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively. Control variables refer to baseline values.
*Source:* EARP dataset 2011/2013.

**Annex 2: Enterprise Interviews**

| Type of Enterprise | Treatment communities | | Control communities | |
|---|---|---|---|---|
| | # Interviews | # Connected to EWSA grid | # Interviews | # Other electricity source |
| Mill | 6 | 6 | 8 | 0 |
| Welder | 6 | 6 | 0 | 0 |
| Bar | 5 | 5 | 3 | 2 |
| Barber | 6 | 6 | 4 | 4 |
| Carpenter/Joiner | 4 | 3 | 5 | 1 |
| Photocopy | 4 | 4 | 0 | 0 |
| Tailor | 5 | 4 | 6 | 0 |
| Mechanic | 2 | 2 | 0 | 0 |
| Bakery | 2 | 2 | 0 | 0 |
| Coffee Processing | 1 | 1 | 0 | 0 |
| Small shop | 2 | 1 | 6 | 2 |
| Artisanal | 0 | 0 | 1 | 0 |
| Cooperative | 1 | 1 | 0 | 0 |
| Coffee washing station | 0 | 0 | 1 | 1 |
| Mining Company | 0 | 0 | 1 | 1 |
| Restaurant | 1 | 1 | 0 | 0 |
| Winemaker | 0 | 0 | 2 | 1 |
| Cinema | 1 | 1 | 0 | 0 |
| TOTAL | 46 | | 37 | |

*Source:* Qualitative micro-enterprise survey.

**Mills** exist in 62 percent of the electrified communities compared to 36 percent in communities without access to grid-electricity. Among these communities, the number of mills is higher in grid connected areas (2.1 mills vs. 1.4 mills per community). Millers typically switch from diesel engines to electricity as soon as the community is connected to the grid. In comparison to fuel-run mills, electric mills offer their services at substantially lower prices and increase the variety of offered milling services due to productivity gains in the production process. Productivity is higher because electric mills are able to grind flour finer and faster than fuel-run mills at substantially lower cost. Corn milling, for example, is virtually only offered by electric mills, since it is especially energy intensive. These productivity gains attract more customers; mostly from within but also from neighboring communities. Because of the lower prices, people that used to mill their crops by hand now start to use a mill and existing customers demand higher quantities than before. The price for grinding one kilogram of sorghum for example, declined on average from 22 to 15 FRW. Moreover, in some communities, demand that had been unmet before electrification can be satisfied since the electric milling process is faster. As a consequence, the income of mills in connected communities increases and new mills emerge.

Also **hairdressing shops** benefit substantially from grid-electricity since also in absence of grid-electricity they often possess a source of electricity, in most cases a car battery. This electricity source is used for shaving equipment and entertainment of the client with radios or TV sets. Often they additionally offer phone charging services. The connection to the electricity grid for them mainly has cost and convenience implications, as they save money and time to charge the car battery.

Small **kiosks, bars, and restaurants**, mostly use electricity for lighting and in few cases also for radio, TV, or refrigeration. For example, almost all connected bars use electricity for lighting, most of them have a radio, 23 percent have a fridge and 17 percent have a TV. Among small kiosks there is generally very little usage of electric machinery. Only few have a fridge or a TV in their shop or offer phone charging to their customers. Electricity mainly increases convenience and thereby often attracts more customers, for example through the replacement of dull candle light by electric lighting in a bar at night. For all these businesses – kiosks, bars, restaurants, mills, and hair dressers – the connection to the electricity grid can be expected to induce an increase in the owner' income. However, the increase in net community income is probably modest, since it is mostly local demand that is shifted from other purposes to these shops. Only in communities that are located next to country roads with people passing by from outside the region can the improved services and goods sold to these transit customers increase community income.

**Carpenters** and **tailor** shops do hardly connect to the grid, since – as expressed in their views – they do not necessarily need electricity to run their business. Tailors mostly keep their mechanic sewing machine – only 11 percent acquire electric machines after electrification. Although they could produce faster with an electric machine, local demand is limited and additional products cannot be sold. Among carpenters only few purchase an electric wood cutting machine or an electric sander. Some tailor or carpentry services can only be produced with electric machinery, for example embroiding or woodturning. However, local demand for such higher quality products is not sufficient to make the investment in such appliances profitable.

We furthermore observe the emergence of **copy** and **welding shops** in the liveliest newly connected communities that do not exist in non-connected communities. In one third of recently electrified communities two or three copy shops were opened. Welder shops emerged in 50 percent of the electrified communities, in many cases more than one. These shops offer services and products that cannot be provided without electricity and consequently had not existed in the communities before electrification. 44 percent of the entrepreneurs state that people formerly had to travel to urban areas to obtain the goods they are now producing. Hence, although to a limited extent, these services substitute for formerly imported goods.

**Annex 3: Electricity consumption of different appliances used for inference of electricity consumption**

| | Wattage | Source | Usage hours per day | kWh/month |
|---|---|---|---|---|
| Electric iron | 1100 | 1 | 0.05 | 1.54 |
| Electric fridge | 230 | 2 | 8 | 51.52 |
| Electric stove | 1200 | 1 | 0.5 | 16.8 |
| Ventilator | 100 | 1 | 1 | 2.8 |
| Mobile phone | 3 | 1 | | depending on charging behavior |
| Radio (bivalent) | 6 | 2 | 1 | 0.168 |
| Radio (line power) | 6 | 2 | 1 | 0.168 |
| Tape recorder | 18 | 2 | 0.5 | 0.252 |
| Stereo system | 20 | 1 | 0.5 | 0.28 |
| Cd/vcd player | 10 | 2 | 0.5 | 0.14 |
| TV (black and white) | 20 | 1 | 1 | 0.56 |
| TV (colour) | 70 | 1 | 1 | 1.96 |
| Video | 35 | 2 | 0.5 | 0.49 |
| DVD | 14 | 2 | 0.5 | 0.196 |
| Computer | 70 | 1 | 1 | 1.96 |
| Electric mill | 2000 | | 1 | 56 |
| Electric sewing machine | 100 | | 1 | 2.8 |

1 = http://www.wholesalesolar.com/StartHere/HowtoSaveEnergy/PowerTable.html

2 = http://mybroadband.co.za/vb/archive/index.php/t-102117.html