

Rubagabaga Mini-Hydro Public-Private-Community Partnership Project: Baseline data analysis

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Smart Villages

We aim to provide policymakers, donors, and development agencies concerned with rural energy access with new insights on the real barriers to energy access in villages in developing countries technological, financial and political—and how they can be overcome. We have chosen to focus on remote off-grid villages, where local solutions (home- or institution-based systems and mini-grids) are both more realistic and cheaper than national grid extension. Our concern is to ensure that energy access results in development and the creation of 'smart villages' in which many of the benefits of life in modern societies are available to rural communities.

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INTRODUCTION

The Smart Villages Initiative is undertaking a set of rigorous impact evaluations to understand the relationship between modern energy access, its productive use, and rural development outcomes. Through building an evidence-base, the Smart Villages Initiative will help stimulate the investment of public and private sector resources in off-grid energy and rural development and ensure that effective policies are put in place to achieve modern energy access for all and its associated development outcomes. This technical report provides an analysis of baseline data collected in collaboration with Afritech Energy Ltd and Practical Action Consulting for the Rubagabaga Mini-Hydro Public-Private-Community-Partnership (PPCP) Project in Western Province, Rwanda. Section 1 provides an overview of the evaluation philosophy. Section 1 and 2 describe the Rubagabaga Mini-Hydro PPCP project and the study site. Section 3 details the baseline data collection and analysis process. Section 4 presents the results of the baseline data analysis.

1. EVALUATION APPROACH

The difference-in-differences approach is used in the evaluation of the Rubagabaga Mini-Hydro Public-Private-Community Partnership (PPCP) Project. The difference-in-differences approach is a cost-effective and powerful evaluation approach that allows for comparison of changes in outcomes between a treatment population and a control population over time by estimating the counterfactual for a change in outcome for the treatment population through calculating the change in outcome for the control population. A regression model is then estimated to quantify the development impacts of modern energy access to energy.

A baseline survey has been undertaken in both the treatment population (Rubagabaga village) and a control population (Gitwa village). An endline survey will be undertaken 12 months after construction of the mini-hydro plant to allow for the impact of the Rubagabaga Mini-Hydro PPCP Project to be quantified.



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2. RUBAGABAGA MINI-HYDRO PUBLIC-PRIVATE-COMMUNITY PARTNERSHIP PROJECT

The Rubagabaga Mini-Hydro Public-Private-Community Partnership (PPCP) Project aims to construct a run-of-the-river hydroplant on the northern bank of the Rubagabaga River in Jomba and Shyira Sectors, Nyabihu District, Western Province, Rwanda. The plant will utilize the water flow from both Rubagabaga River and its tributary, the Mbogo River. The plant will consist of two turbines: a 350kW turbine to supply the National Grid of Rwanda and a 50kW turbine to supply power to Rubagabaga village (see Figure 3). The 50kW turbine will power a local mini-grid that will service four types of customers: (1) new businesses to be established and managed by a community-based organisation; (2) existing and new private small businesses; (3) social and community institutions; (4) and households.

3. STUDY SITE

Rubagabaga is an energy poor, off-grid village located in Binana Cell, Matyazo Sector, Ngororero District, Western Province (see Figure 2). Established in 1930, the village is home to 314 households consisting of approximately 1,238 people. Rubagabaga is relatively isolated (see Table 1) and is vulnerable to flooding and mudslides during the rainy season. The main lighting technologies in the village are kerosene lamps and dry-cell battery torches/lamps. The main cooking fuels are firewood and charcoal. The dominant livelihood strategy in the village is farming. Crops include: bananas, beans, cassava, coffee, maize, potatoes, rice, sorghum, soya beans, sweet potatoes, tomatoes and yams. The only agricultural products processed in village are bananas, with the resulting banana beer being sold both within the village and at the nearest large market. Other livelihood activities include the rearing of livestock, collection of non-timber forest products, farm and non-farm employment, petty business, and public and private transfers (e.g. rental income, remittances). Like most Rwandan villagers, Rubagabaga's inhabitants regularly visit a nearby electrified market center and have a good grasp of electricity and its potential uses.





Figure 3: Mini-grid Architecture

Facility	Distance	Travel time by most common mode of transportation*
Market	1km	10 minutes
Bus stop	4km	15 minutes
Police station	20km	120 minutes
Primary school	2km	40 minutes
Secondary school	3km	60 minutes
Vocational school	6km	25 minutes
Church	2km	20 minutes
Health clinic	15km	120 minutes
Hospital	35km	90 minutes
Mill	1km	10 minutes
Farmers' cooperative	3km	20 minutes

* Modes of transportation include by foot, bicycle, motorbike and bus Source: Data obtained from authors' survey of village elders

 Table 1: Distance from Rubagabaga to nearest facilities

4. DATA COLLECTION AND ANALYSIS

Data were collected through a household survey. The household survey was based on the livelihoods framework (e.g. Scoones 2009) and the World Bank's Living Standards Measurement Surveys (LSMS) (e.g. O'Sullivan and Barnes 2007). The survey included questions on demographics, assets, disaggregated gross income, energy use for household-owned businesses, consumption, health, food security, education, energy access and use for lighting, cooking and other uses, willingness-to-pay for grid-electricity, and household priorities of services derived from modern energy access.

Design of the household survey was informed by a scoping trip to Rubagabaga village in March 2015 and a focus group discussion with village elders in May 2015. The survey was translated into the first language of the village population, Kinyarwanda, and field tested through a pilot study undertaken in nearby Sunzu village in May 2015. The survey was enumerated to 163 randomly selected households in June 2015 by four experienced enumerators and a supervisor. Data were coded and inputted into MS Excel datasheets before being cleaned and analysed using STATA/SE 11.2.

To better understand energy poverty at the household-level, we clustered households by a measure of socio-economic status (SES). We selected a hybrid asset- and income-based approach to calculate the socio-economic status index. This hybrid approach has advantages over a purely income-based measure due to income's transitory and seasonal nature (Collins et al. 2010). Our selection of household assets was informed by the livelihoods framework (Scoones 2009). Among the selected asset variables (see table s1) were three composite variables representing a household's housing situation, implements and financial assets. Formally, each composite index was defined as:

$$A_{i} = \sum_{k} f_{k} \frac{\left(a_{ik} - \overline{a}_{k}\right)}{s_{k}}$$

(1)

, where a_{ik} is the value of asset *k* for household *i*. a_k is the mean and $\overline{a_k}$ is the standard deviation. We then used principle component analysis to create uncorrelated components, with each component being a linear weighted combination derived from the initial variables. To create each index, the result was weighted by elements from the first eigenvector.

Following Adato et al. (2006) and Charlery and Walelign (2015), we calculated the assetand income-based index on the basis of the following regression model:

$$\frac{\mathbf{y}_{i}}{\mathbf{z}_{t}} = \sum_{j} \beta_{j} \left(\mathbf{A}_{ij} \right) + \beta_{h} \mathbf{H} + \varepsilon_{i}$$
(2)

, where y_i is gross income¹ for household *i* and z_i is the monetary poverty line². β_j represents the marginal contribution of asset *j* to the gross income of household *j*, and the vector of coefficients, β_h , represents household specific attributes (see Table S1). To allow for sufficient degrees of freedom within each group, we segmented households into asset- and income-based tertiles. This resulted in three groups: low socio-economic status households and high socio-economic status households.

¹ Gross income was used instead of net income due to the poor quality of data on total costs of income-generating activities. Gross income consists of three components: income from self-employment, wage income and transfers (Angelsen and Lund 2011).

² The monetary poverty line for Rwanda used was US\$ 162.12 (National Institute of Statistics of Rwanda 2012).

For our variables of interest (household energy use, willingness-to-pay, disaggregated gross income, education, health and food security) we tested differences between the mean household of each SES group for statistical significance. For continuous variables, a one way ANOVA test was run. Bartlett's test for equal variances, however, reported unequal variances in the sample for all continuous variables tested. To determine whether the one way ANOVA test was sufficiently robust to the

5. RESULTS

Demographics

The mean age of household heads in our sample was 45 years, with a standard deviation of 17. The majority of household heads were male (64%). 23% of male household heads had no formal education with 74% being educated to primary level and 3% having completed secondary education. 42% of female household heads had no formal education and 58% had completed primary education. The average household size was 5 members with the largest household consisting of 11 members.

Energy use

Household lighting and other electricity services

Households used four lighting technologies, with 34% of households having used more than one lighting technology. The dominant technologies for lighting were kerosene lamps and dry-cell battery driven torches/lamps, with a handful of households also making use of candles. Four households used pico-solar lighting systems¹. Three of these households were categorized as being of high socio-economic status (SES)

violation of the equal variances assumption, we used the pattern of sample sizes and standard deviation found in the sample to perform Monte Carlo simulations. We then compared the resultant simulation results to the nominal results allowing for variables that were likely to exhibit a higher or lower expected rate of type 1 error to be isolated. For these variables, we calculated and used the Brown-Forsythe F-start test statistic (see Table S2). For categorical variables, we used Fisher's exact test statistic.

and one household as medium SES. Two of the systems (both for high SES households) were capable of charging a mobile phone and cost the households approximately US\$28. The other two systems provided lighting only and cost the households US\$11. Notably, three of the four households continued to use one other source of lighting (kerosene lamps or dry-cell battery driven torches/lamps) in addition to their pico-solar lighting system.

With the exception of candles and pico-solar lighting systems, energy technology use was fairly uniform across the three SES groups. Low SES households spent the least in absolute terms (US\$6.79) on lighting per year but spent the most as a proportion of household gross income (6%). Medium SES households spent an average of US\$8.35 per year (4% of household gross income) and high SES households spent US\$14.63 per year (2% of household gross income). Mean household yearly expenditure on lighting was found to be statistically different among all three SES groups at the 1% significance level. As a proportion of gross income, expenditure on lighting was also statistically different among groups at the 10% level.

In addition to lighting, 93 (58% of) households powered radios and 89 (55% of) households charged their mobile phones. When breaking

¹ A pico-solar lighting system is defined as having a generation capacity of between 0.1 to 10W (Alstone et al. 2015).

	Low SES	Medium SES	High SES
Candles	US\$7.14 (n=2)		US\$15.12 (n=3)
Kerosene lamp	US\$7.74 (n=19)	US\$8.40 (n=23)	US\$10.89 (n=26)
Dry-cell battery powered	US\$4.16 (n=46)	US\$5.02 (n=48)	US\$9.30 (n=45)
Pico-solar lighting system	-	US\$3.66 (n=1)	US\$7.33 (n=3)
Lighting Total	US\$6.79 (6.00%)	US\$8.35 (3.90%)	US\$14.63 (2.14%)
Radio	US\$1.62 (n=14)	US\$2.05 (n=31)	US\$2.41 (n=39)
Mobile phone charging	US\$12.13 (n=6)	US\$10.92 (n=34)	US\$12.38 (n=40)
Other services total	US\$5.03 (3.70%)	US\$9.45 (3.37%)	US\$12.02 (1.94%)

Note: Pico-solar home system costs are calculated on the basis of an expected lifetime of 3 years. Numbers in parentheses for lighting total and other services total denote expenditure as a proportion of household gross income.

Table 2: Household yearly expenditure on lighting and other energy services

down radio and mobile phone ownership by SES group, however, notable differences arise. 30% of low SES households owned and powered radios compared with 59% of medium SES households and 83% of high SES households. Differences are even more striking for mobile phones, with only 11% of low SES households having owned and charged mobile phones compared to 63% of medium SES households and 91% of high SES households.

All sampled households powered their radios using dry-cell batteries. Two households charged mobile phones using their PLS and three households charged mobile phones using PLS purchased for their household's business enterprise. The remaining households charged their mobile phones at businesses in the village at a rate of approximately US\$0.14 per charge. For radio and mobile phone charging services, low SES households spent the least in absolute terms (US\$5.03) but spent the most as a proportion of gross income (4%). Medium SES households spent US\$9.45 (3%) and high SES households spent US\$12.02 (2%). Mean household spending on other services was statistically different among SES groups at the 1% level. As a proportion of household income, we found no statistically significant difference between the mean household of each SES group.

Household Cooking

We found that 113 (69%) households used traditional stoves and 50 (31%) households used improved mud-woodstoves that they had purchased. We found no significant difference in distribution of traditional and improved mud-woodstoves among the three SES groups. The main fuels used in Rubagabaga were firewood and charcoal. 87% of households collected firewood themselves and 13% only purchased either firewood or charcoal. 32% of households both regularly purchased and collected fuel with no significant difference in distribution among SES groups.

Low SES households spent the least (US\$30.83) on their main cooking fuel source but the most as a proportion of gross income (11%). Medium SES households spent US\$33.71 (10% of gross income) and high SES households spent US\$71.10 (9% of gross income) on their main cooking sources, respectively. We found no statistically significant differences between SES groups for expenditure on main cooking fuels. Medium SES households spent the most time collecting firewood (325 hours yearly), followed by high SES households (285 hours) and high SES households (284 hours). As shown in figure 2, the number of hours spent collecting firewood tends to increase as the number of household members increases for all three SES groups.

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	Low SES	Medium SES	High SES
Firewood (purchased)	US\$118.71 (n=13)	US\$70 (n=18)	US\$149.80 (n=16)
Firewood (collected)	284 hours (n=48)	325 hours (n=51)	285 hours (n=45)
Charcoal	US\$90.68 (n=1)	US\$140.14 (n=4)	US\$199.50 (n=5)
Cooking total	US\$30.83 (11 %)	US\$33.71 (10%)	US\$71.10 (9%)

* cooking total excludes firewood that is collected by households.

** numbers in parentheses for cooking total denote expenditure as a proportion of household gross income

Table 3: Household yearly expenditure on main cooking fuel source



Figure 4: Number of hours spent collecting firewood and number of household members

Energy use for business enterprises

16 households operated their own business enterprises (see Table 4). Six enterprises were bars serving locally-produced banana beer and alcoholic beverages purchased from the nearest market town. In addition to serving alcoholic beverages, three bars engaged in one or more of the following business activities: selling mobile airtime, charging mobile phones, and selling meat products. The primary energy source used by four of the bars was pico-solar lighting systems. Two of the systems were sufficient for lighting only. The remaining two systems were capable of charging mobile phones. In addition to using a PLS, one of the bars used candles as an additional lighting source. The two remaining bars used kerosene lamps, candles and firewood as their energy sources.

5 of the households operated restaurants. In addition to being restaurants, these restaurants all sold mobile airtime to customers. All five restaurants relied primarily on firewood for cooking, with one restaurant also using charcoal. For lighting, one restaurant used candles and three restaurants used kerosene lamps. One restaurant used both kerosene lamps and a pico-solar lighting system. Three households ran shops, with only one of these shops engaging in another business activity: charging mobile phones. For lighting, one shop used kerosene lamps and two shops used dry-cell battery powered torches/ lamps. Two households operated hair salons. One hair salon also charged mobile phones. Both hair salons relied primarily on lead-acid batteries. The hair salon that charged mobile phones also had a PLS capable of charging mobile phones.

When asked why they chose their bundle of energy sources for their business enterprises, respondents cited: easy availability (n=13); affordability (n=11); efficiency (n=2); a lack of alternative options (n=2). When asked what challenges their businesses faced as a result of not having reliable grid-level electricity, respondents responded with: security (e.g. thieves); a limited ability to work into the evening; not being able to provide entertainment (e.g. television) for customers in bars and restaurants; being unable to keep meat and vegetables fresh and to serve cold beverages; and the inability to grow existing business activities and diversity into new business opportunities. 14 out of 16 respondents said that they would expand their current business activities and/or move into new business opportunities with electricity. New business opportunities cited by respondents included welding, textiles, carpentry, and agricultural processing. One respondent, however, replied that she did not think that her business would increase with access to electricity. Instead, she cited that the main barrier to attracting more customers was poor infrastructure connecting households within the village and connecting Rubagabaga to other villages.

Main business activity	Other business activities	Energy sources used
Bar (n=6)	Airtime / Butcher / Charging mobile phones	Solar home system, Firewood, Kerosene, Candles
Restaurant (n=5)	Airtime	Firewood, Charcoal, Kerosene, Candles, Solar home system
Shop (n=3)	Charging mobile phones	Kerosene, Lead-acid batteries, Solar home system
Hair Salon (n=2)	Charging mobile phones	Lead-acid batteries, Solar home system

Table 4: Business enterprises

	Low SES	Medium SES	High SES	
Agriculture	US\$150.40 (55.63%)	US\$235.86 (54.80%)	US\$716.78 (53.17%)	
Non-timber forest products	US\$1.30 (0.10%)	US\$0.05 (0.02%)	US\$23.28 (1.04%)	
Livestock	US\$16.40 (3.44%)	US\$15.73 (2.30%)	US\$112.71 (5.94%)	
Farm employment	US\$51.53 (24.16%)	US\$47.11 (16.15%)	US\$106.04 (9.55%)	
Non-farm employment	US\$15.00 (4.60%)	US\$74.92 (10.40%)	US\$55.52 (5.28%)	
Own business activities	US\$49.78 (11.28%)	US\$112.77 (14.62%)	US\$519.46 (24.73%)	
Transfers	US\$1.56 (0.57%)	US\$3.82 (1.71%)	US\$7.73 (0.28%)	
Total	US\$285.96	US\$490.25	US\$1541.51	
Table 5: Disaggregated household gross income				

Livelihood outcomes

Disaggregated gross income

Table 5 presents the mean disaggregated household gross income for each SES group. For all three groups we found that agriculture was the livelihood strategy that contributed most to household gross income for all SES groups. For low SES households, we found that agriculture contributed over half of gross income (56%) of which 61% consisted of subsistence¹ agriculture products. Medium SES households earned 55% of their gross income from agriculture (45% of which was derived from subsistence agriculture) and high SES households earned 53% of their gross income from agriculture (45% from subsistence agriculture). We found a statistically significant difference for the mean contribution of agriculture to household gross income among SES groups at the 1% level and a statistically significant difference among SES groups regarding the proportion of agricultural income derived from subsistence agriculture at the 5% level.

Non-timber forest products, primarily edible wild mushrooms harvested from the forest, contributed US\$1.30 to low SES households (0.10%), US\$0.05 (0.02%) to medium SES households, and US\$23.28 to high SES households (1%). Low SES households derived US\$16.40 (3%) of their gross income from livestock with medium SES households having earned US\$15.73 (2%). High SES households earned US\$112.71 (6%) from livestock. We found that differences in the mean contributions for SES groups were statistically significant at the 10% level for non-timber forest products and at the 1% level for livestock.

Farm employment was the second most important contributor to the gross incomes of low SES households (24%) and medium SES households (16%). High SES households derived 10% of gross income from farm employment. For low SES households, 18% of income derived from farm employment was received through in-kind payments. In-kind payments constituted 10% and 5% of farm employment of income for medium SES and high SES households, respectively. We found the mean contribution of farm employment to gross income for the three SES groups to be significantly different at the 5% level. As a proportion of income, mean differences between the three SES groups were highly significant at the 1% level. For low SES

¹ Following Angelsen and Lund (2011), subsistence agriculture products were included in the accounting of gross income through using prices derived from the household or through village averages.

	Low SES	Medium SES	High SES
Total absences per month	2.288	1.762	1.460
Hours studied per weeknight	0.25	0.194	0.387

* Total absences is the measure of the average of the total number of absences for enrolled children per month weighted by the number of enrolled children in each household. Hours studied per weeknight is the average total number of hours studied per average school night for enrolled children, weighted by the number of enrolled children in each household per week.

Table 6: Education

households non-farm employment contributed US\$15 (5%) to household gross income, while the contribution for medium and high SES households was US\$74.92 (10%) and US\$55.52 (5%), respectively.

Own business activities was the second most important source of gross income for high SES households contributing US\$519.46 (25%) to household gross income, and the third most important source of income for low and medium SES households, contributing US\$49.78 (11%) and US\$112.77 (15%) respectively. For medium and high SES households, the production and sale of banana beer accounted for 72% and 66% of own business activity income, respectively. For the mean household, we found statistically significant differences among SES groups for the contribution of own business activities both in absolute terms and as a proportion of household income at the 1% significance level.

Low SES households earned US\$1.56 rental fees, remittances and public transfers. Medium SES and high SES households earned US\$3.82 and US\$7.73, respectively. This amounted to an average of less than 1% of gross income for low and high SES households and less than 2% for medium SES households.

Education

Out of a total of 287 school-aged children in surveyed households, 47 (16%) were unenrolled. Primary reasons for not being unenrolled cited by household survey respondents included: not being interested in school (n=17), no financial means to continue education² (n=6), failing the national exam (n=6), finding school too difficult (n=5), pregnancy (n=5), illness (n=3), taking care of siblings or ill parent(s) (n=3), and working for money (n=2).

On average, an enrolled child was absent from school for 2 days a month in low and medium SES households and for 1 day in high SES households. Reasons for enrolled children being absent from school included: illness (n=63), heavy rain (n=12), taking care of siblings (n=5), going to market (n=6), unavailability of school uniform on the day³ (n=5), not wanting to study (n=3), and working for money (n=2).

We found that enrolled low SES household children spent an average of 15 minutes studying per weeknight, with enrolled children at medium SES households studying for only 12 minutes per weeknight. Enrolled high SES children spent the most time studying each weeknight with an average of 23 minutes.

² Education in Rwanda is free and compulsory for six years.

³ Primary education in Rwanda is organised in two shifts. It is not uncommon for siblings to share school uniforms and stationery.

	Low SES	Medium SES	High SES
Days sick per month (adults)	10.920	8.302	9.728
Days very sick per month (adults)	8.360	5.606	6.466

* Days sick per month is the number of days in a month where at least one household member was sick, weighted by the total number of household members sick. Days very sick per month is the number of days in a month where at least one household member was unable to work or undertake normal activities, weighted by the total number of household members very sick.

Table 7: Health

Health

Among our surveyed households, we found a total of 18 children with long-term illnesses. These included: respiratory illness (n=4), parasites (n=2), physical disability (n=3) and malaria¹ (n=9). On average, adults in low SES households were sick for 11 days a month and very sick for 8 days a month. For medium SES households, adults were sick for 8 days a month and very sick for 6 days a month. For high SES households, adults were sick for 9 days a month and very sick for 7 days a month. Symptoms of illness reported by household members included: malaria/cold and flu (n=126), gastrointestinal problems (n=34), physical injury (n=21), tooth pain (n=7), parasites (n=6), chest pain (n=4), pregnancy-related (n=3), Hepatitis C-related (n=2), and HIV/AIDS-related (n=1).

From the sample, only 9.2% of respondents stated that using kerosene lamps negatively impacted the health of their household. Households who answered positively cited the smoke from kerosene lamps as having caused respiratory and eye problems. In addition to kerosene lamps, a point was made by some households that dry-cell battery torches/ lamps were detrimental to children's eyesight due to the poor quality of lighting. When asked if their main cooking fuel source negatively impacts the health of their household, 33% of households responded positively. Cited reasons included their main source of cooking fuel causing coughing, headaches, eye pain and breathing problems. Danger to children was also cited, both in terms of smoke being harmful to children and the danger facing children when collecting firewood from the forest. The risk of a house catching on fire was also mentioned.

Regarding drinking water, the majority of households (31%) of households relied on a tube well/borehole. Other sources of drinking water used by households were piped water (28%), protected wells (19%), unprotected springs (14%), unprotected wells (5%) and surface water channels (3%). When asked about how drinking water is treated before being consumed, the majority of households (52%) boiled their water. 25% of households used a water filter and 4% of households added bleach or chlorine tablets. 18% of households did not treat their water and 1% of households let the water stand and settle before drinking it. We did not find a statistically significant difference between treatment of drinking water among SES groups.

¹ Only includes cases where the child exhibited malaria symptoms at least 3 times in the past 12 months.

Food security

Figure 5 shows the proportion of households who had inadequate food to fulfil their household's nutritional needs. For all three SES groups, the two growing seasons (March-May and August-November) saw dramatic increases in the proportion of households with inadequate food supplies. We further measured food security by calculating an index (0-1) that accounted for monthly changes in food availability for each household. A household with a score of 1 was food secure throughout the entire year. Food security was lowest for low SES households (0.656). Medium SES households and high SES households scored 0.704 and 0.788 on the index, respectively. There were statistically significant differences among mean households in each of the SES groups regarding the food security index at the 1% level.

The primary reason given by households for not having enough food during the year was the need to buy food from the market during the growing seasons and the high market price of staple food (n=123). The inability of households to store enough food for the two growing seasons was reported by households to be a result of inadequate irrigation systems, having too little land to cultivate, using crops as seed inputs and inadequate storage capacity. Other reasons for not having enough food during the year given by households included being unable to find sufficient work to purchase food (n=9), being unable to work the land due to illness or old age (n=3), difficulty in getting to the market during growing seasons due to heavy rain (n=2), and a shortage of firewood (n=1).

Household priorities

Table 8 presents the aggregated ranking of household priorities of services derived from modern energy access by SES group. For all three SES groups, health and safety were ranked in the top two household priorities. Low and medium SES households ranked food security third. For high SES households, energy security was ranked third followed by food security. Children's education and income were middle-ranked with continuing education, comfort/saving time and connectivity coming in as relatively low priorities.

Rank	All households	Low SES households	Medium SES households	High SES households
1	Safety	Health	Safety	Safety
2	Health	Safety	Health	Health
3	Food security	Food security	Food security	Energy security
4	Income	Income	Children's education	Food security
5	Children's education	Children's education	Income	Children's education
6	Energy security	Energy security	Energy security	Income
7	Continuing education	Connectivity	Continuing education	Continuing education
8	Connectivity	Continuing education	Comfort/saving time	Comfort/saving time
9	Comfort/saving time	Comfort/saving time	Connectivity	Connectivity

Table 8: Aggregated ranking of household priorities

CONCLUSION

Analysis of baseline data revealed that households in Rubagabaga village exhibit the characteristics associated with energy poverty: they are income poor, and suffer from poor education, health and food security outcomes. Households use a variety of incumbent lighting technologies, with over one-third of households stacking technologies. Other electricity services were limited to radio and mobile phones. Households used either firewood or charcoal as their main source of fuel. Approximately one-third of all households both bought their main source of fuel and collected firewood from the nearby forests. Cooking was undertaken on either home-made 3-stone cookstoves or on uncertified improved mud-woodstoves. Business enterprises run by 16 of the households tended to stack lighting and cooking technologies on

the basis of availability, affordability, efficiency and a lack of alternative options. All business owners perceived notable challenges to their businesses due to energy poverty and 14 out of 16 expressed their ambition to expand and/or diversify their business activities with access to a reliable grid-electricity supply.

We found that household priorities overwhelmingly reflected basic human needs: health, safety and food security. This is consistent with the hierarchy of needs literature. Interestingly, high SES households ranked energy security above food security. This suggests that, within Rubagabaga, households pass a wealth threshold where they begin to highly prioritize the ability to benefit from an uninterrupted availability of energy sources at an affordable price.



Figure 5: Proportion of households with inadequate food supplies in Rubagabaga

ANNEX

Variables Description

Income variables

Agriculture	Household gross income derived from agriculture. Includes crops con- sumed for subsistence.
Non-timber forest products	Household gross income derived from non-timber forest products. Includes products consumed for subsistence.
Livestock	Household gross income derived from the sale of livestock and deriva- tive products.
Farm employment	Household gross income derived from employment in agriculture. Includes in-kind payment.
Non-farm employment	Household gross income derived from employment in non-farm eco- nomic activities.
Own business activities	Household gross income derived from own business activities.
Other	Household gross income derived from rental income, private transfers and public transfers.
Asset variables	
House (composite)	A composite indicator derived as per equation (1). Consisted of three binary variables: whether or not a household owned more than one house, the floor material of the house the household lives in, and the toilet walling material of the house the household lives in.
Implements (composite)	A composite indicator derived as per equation (1). Consisted of binary variables for whether or not a household owned one or more: bicycles, mattresses, tables, chairs, watch clocks, sofas, mobile phones, radios, and a binary variable denoting whether or not a household had a home-built or manufactured cookstove.
Agricultural land	Total agricultural land (in m ²) used by the household (includes both owned and rented land).
Agricultural land squared	Total agricultural land (in m ²) used by the household (includes both owned and rented land) squared.
Finance (composite)	A composite indicator derived as per equation (1). Consisted of: a binary variable denoting whether any member of the household had a bank account; a binary variable denoting whether any member of the household was a member of a savings group; a binary variable of whether or not the household was credit constrained.
Household head education	A categorical variable representing the highest level of education ob- tained by the household head.
Help from other households	A binary variable representing whether a household has either bor- rowed or lent money to at least one other household in the village.
Household attribute variab	les
Sex of household head	The sex of the household head.

Table S1: Variables used to calculate the asset- and income-based socio-economic status index

months a year.

The number of individuals resident in the household for more than 6

Household size

Variables	Nominal p value	Simulated p value	F-star p value
Household yearly expenditure on lighting	0.000	0.000	-
Household yearly expenditure on lighting as a proportion of gross income	0.048	0.067	0.051
Household yearly expenditure on other electricity services	0.000	0.000	-
Household yearly expenditure on other electricity services as a proportion of gross income	0.086	0.200	0.107
Willingness to pay for grid connection	0.001	0.003	-
Willingness to pay for grid connection as a proportion of gross income	0.105	0.119	-
Willingness to pay for monthly grid electricity fee	0.917	0.873	-
Willingness to pay for monthly grid electricity fee as a proportion of gross income	0.215	0.210	-
Household yearly expenditure on main cooking fuel	0.130	0.128	-
Household yearly expenditure on main cooking fuel as a proportion of gross income	0.857	0.856	-
Agriculture (gross income)	0.000	0.000	-
Agriculture (proportion of subsistence agriculture)	0.013	0.013	-
Agriculture (% of gross income)	0.835	0.828	-
Non-timber forest products (gross income)	0.085	0.117	0.067
Non-timber forest products (% of gross income)	0.151	0.170	-
Livestock (gross income)	0.000	0.004	-
Livestock (% of gross income)	0.087	0.099	-
Farm employment (gross income)	0.046	0.063	0.034
Farm employment (% of gross income)	0.000	0.001	-
Non-farm employment (gross income)	0.116	0.121	-
Non-farm employment (% of gross income)	0.102	0.108	-
Own business activities (gross income)	0.002	0.010	0.001
Own business activities (% of gross income)	0.000	0.000	-
Other (gross income)	0.416	0.394	-
Other (% of gross income)	0.571	0.489	-
Gross income	0.000	0.001	-
Total absences per month (enrolled children)	0.406	0.432	-
Hours studied per weeknight (enrolled children)	0.118	0.098	0.120
Days sick per month (adults)	0.296	0.302	-
Days very sick per month (adults)	0.164	0.161	-
Food security index	0.002	0.003	-

Table S2: ANOVA Results

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