CROSSBOUNDARY

Study Design: Grid Densification
2020

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Executive Summary

This study tests whether proactively installing distribution network infrastructure to connect a community to a mini-grid leads to higher project IRRs than installing the same infrastructure reactively. **Proactive installation** is defined as designing, building, and installing some amount of distribution infrastructure *prior* to community members making any financial commitment. This distribution infrastructure may range from low voltage lines and poles placed throughout a community, to droplines and smart meters placed directly in a home.

The primary objectives of the study are:

1. Determine what impact proactively installing distribution systems has on (1) the economics of mini-grids, (2) customer acquisition among rural households and businesses, and (3) utilization of mini-grids.
2. Determine whether mini-grid economics are optimized by proactively installing basic infrastructure throughout an entire community to later connect all households (**"Network Expansion" Scenario**) *or* proactively installing full infrastructure to immediately connect all households reached by the distribution network the Operator would otherwise build (**"Network Saturation" Scenario**).

The study targets customers of soon-to-be-constructed mini-grids in Africa. The study will be conducted on sites where the distribution grid is installed proactively, according to one of two scenarios:

1. **"Network Expansion" scenario:** Install overhead distribution (low voltage lines and poles) throughout the entire community. Customers requesting connection later on can be connected quickly and cheaply as they require only a dropline, smart meter, and in-home wiring.
2. **"Network Saturation" scenario:** Install all overhead distribution and customer connection accessories required (low voltage lines, poles, drop lines, smart meters, and in-home wiring) to connect *all* households reached by the distribution network the Operator would otherwise build.

Connections will be offered to all potential customers at a site, and allocated on a first-come, first-served basis.

The study will assess the impact of proactively building grids on three principal matters: (1) grid economics, (2) customer acquisition, and (3) grid utilization. Cost per connection, installation cost, and ARPU, among other metrics, will be used to analyze the impact on grid economics. Customer acquisition and grid utilization will be assessed by measuring customer sign-ups and energy delivered, respectively. Control grids will be used to compare changes observed in treatment grids.

The study will be delivered by the Operator, who will organize support from technical advisors and other third parties as necessary. The Study Partners will provide funding for the study, collect all relevant data, and analyze the results as they pertain to each hypothesis. The results will be made publicly available on an anonymized, aggregated basis. The study is expected to run over a three-year period, beginning [date].

Study Partners

The following table outlines the role of each partner involved in the study.

Partner	Role
Funder	• Provides funding • Offers strategic oversight for the study
CrossBoundary (CB)	• Manages all aspects of project • Leads study design • Disburses and monitors funds provided to Operator • Leads data collection, including surveying, and data cleaning • Leads analysis and communication of study results
Operator	• Provides insight into study design • Operates the mini-grids involved in the study and leads site implementation of study • Supplies data to CrossBoundary and other partners for analysis
Other partners	**Academic institutions:** • Supports study design • Supports analysis and communication of study results **Third parties (as identified):** • Supports Operator in site implementation of study

Introduction

Mini-grids are emerging as a viable technology to accelerate access to electricity in Sub-Saharan Africa. However, for mini-grids to become sustainable and scalable commercially, profitability must improve. This study seeks to improve grid economics by answering the question: what is the most efficient way to deploy a distribution grid? Does it make more economic sense for operators to deploy *reactively*, following customer interest, or *proactively*, with the expectation of attracting more customers? We define **proactive installation** as designing, building, and installing some amount of distribution infrastructure *prior* to community members making any financial commitment.

Currently, grids are often designed reactively based on where customers have communicated interest or made financial commitments. This strategy, however, implicitly limits customer acquisition as customers may be less likely to trust a mini-grid operator before a new grid has been built and limited customer liquidity may impact sign-ups. Proactively designing distribution grids may alleviate some of these issues while streamlining operators' capital expenditure, leading to improved grid economics. In-depth study of this topic may, further, inform tariff pricing by improving the sector's understanding of distribution costs at various population densities.

This study, therefore, seeks to:

1. Determine what impact proactively installing distribution systems has on (1) the economics of mini-grids, (2) customer acquisition among rural households and businesses, and (3) utilization of mini-grids.
2. Determine whether mini-grid economics are optimized by proactively installing basic infrastructure throughout an entire community to later connect all households (**"Network Expansion" scenario**) *or* proactively installing full infrastructure to immediately connect all households reached by the distribution network the Operator would otherwise build (**"Network Saturation" scenario**).

The study targets customers of soon-to-be-constructed mini-grids in Africa. The study will be conducted on sites where the distribution grid is installed proactively, according to one of two scenarios:

1. **"Network Expansion" scenario:** Install overhead distribution (low voltage lines and poles) throughout the entire community. Customers requesting connection later on can be connected quickly and cheaply as they require only a dropline, smart meter, and in-home wiring.
2. **"Network Saturation" scenario:** Install all overhead distribution and customer connection accessories required (low voltage lines, poles, drop lines, smart meters, and in-home wiring) to connect *all* households reached by the distribution network the Operator would otherwise build.

Experimental Design

Hypotheses

The following table details the hypotheses the study will test and how each will be measured. **Treatment grids** are defined as grids built proactively; **control grids** are defined as grids built reactively.

Hypothesis	Measurement	Source
Grid Economics		
1. Cost per connection for treatment grids will be 5% and 10% lower than for control grids after one year, for the "Network Expansion" and "Network Saturation" scenarios, respectively.	• Cost per connection	• Developer date
2. Installation costs for treatment grids will be 5% lower than for control grids after one year.	• Cost per square meter of grid	• Calculated from developer invoices and site plans
3. ARPU for treatment grids will be 5% lower than for control grids after one year.	• ARPU	• Smart meters
Customer Acquisition		
4. Treatment grids will attract 20% more customers than control grids after one year.	• Number of connections	• Developer data
5. Treatment grids will reach 10% more of the community than control grids after one year.	• Customers signed up as percentage of total potential customers (defined as number of households in village) • Customers signed up as percentage of households connected *(for "Network Saturation" scenario only)*	• Developer data
Grid Utilization		
6. Treatment grids will reach 20% higher utilization than control grids after one year.	• Energy delivered as % of maximum theoretical energy generated	• Smart meters • Developer data

At the end of the study, CrossBoundary will report how the observed changes in revenues and costs would impact IRR at a typical mini-grid.

Site and Participant Selection

Control sites will be chosen according to where the Operator has current operations. Treatment sites will be chosen to resemble control sites as closely as possible, based on population, geography, and profile of potential customers.

All sites are eligible to serve as treatment sites; however, priority will be given to those sites meeting the following criteria:

- At least 100 potential customers
- Capability to automatically measure customer consumption and payment

See *Annex 2* for Operator-specific site selection information.

For the "Network Expansion" Scenario, participants are all households considered members of the community or village.

For the "Network Saturation" Scenario, participants are all households reached by the distribution network the Operator would otherwise build who agree to have the meter installed at their home. Approval of meter installation will be tracked by an Operator site agent.

Duration

The study is expected to run three years, starting as soon as possible upon the signing of the Operator Agreement. The projected timeline of the study is [date] – [date]. Early results will be analyzed after one year, as detailed in the hypotheses.

The study's duration may be adjusted following initial results or any unforeseen circumstances, as mutually agreed upon by the Lab and the Operator.

Prototype-Specific Design Decisions

There are no prototype-specific design decisions involved in this study.

Budget and Disbursement of Funds

The Operator is responsible for providing a budget that accurately reflects the cost of running the study in excess of standard operations. For this study, that means the following.

Suppose the Operator plans to build a new mini-grid at a site with 200 households and plans to build a distribution network to serve 100 of those households. Under the "Network Expansion" scenario, this study would fund all costs associated with installing transmission lines to connect the remaining 100 households.

Suppose of those 100 households to be served by the Operator's planned distribution network, the Operator expects 60 of those households to sign up as customers by day 1. Under the

"Network Saturation" scenario, this study would fund all costs associated with installing drop lines, smart meters, and in-home wiring to connect the other 40 households not expected to sign up as customers by day 1.

See *Annex 2* for Operator-specific budget information.

Prior to receiving funds, the Operator must submit the following:

- Approved budget
- Signed Operator Agreement (consisting of the Grant Agreement and Study Design)
- Historical remote monitoring data, as available
- Site economic data

Funding of the budgeted amount to support the study will be disbursed by CrossBoundary to the Operator in a single payment upon submission of all required materials.

The Operator is required to maintain a record of all costs incurred in implementing and running the study and must provide receipts reflecting the totality of costs to CrossBoundary. The Operator agrees to use funds solely for the purposes of the study.

CrossBoundary is responsible for monitoring the use of funds for the purposes agreed with the Funder.

Implementation

Operator

The Operator is responsible for operating all sites involved in the study and implementing the prototype on selected treatment sites as agreed to in this Study Design. This involves but is not limited to the following:

- Installing overhead distribution (low voltage lines and poles) and any other equipment required to lay the basic infrastructure to later connect "Network Expansion" Scenario participants
- Installing all overhead distribution and customer connection accessories (low voltage lines, poles, drop lines, smart meters, and in-home wiring) and any other equipment required to fully and immediately connect "Network Saturation" Scenario participants
- Communicating all relevant information to study participants

The Operator will lead in engaging all third parties involved in the study and is responsible for thoroughly researching and proposing all third party collaborations. The Operator is also responsible for identifying and procuring any licenses or other regulatory approval required to implement the prototype. See *Annex 2* for Operator-specific implementation information.

The Operator agrees to inform CrossBoundary of any occurrences that may affect electricity consumption or other study results, and identify customers affected by such interventions (e.g.

changes in tariff or meter numbers). The Operator additionally agrees to disclose any other information pertinent to the study (e.g. GIS data).

Third Parties

There are no third parties involved in this study.

Licenses and other Regulatory Approval

No licenses are required to implement this study, apart from the standard licenses required to build and operate mini-grids in [country].

Data Collection

All data shared through execution of the study is protected by a direct Non-Disclosure Agreement with CrossBoundary. Data will only be shared with partners approved by the Operator as outlined in the Non-Disclosure Agreement on an aggregated and anonymized basis to protect customer information.

Through participation in this study, the Operator agrees to share three types of data: (1) remote monitoring and customer data, (2) prototype-specific data, and (3) site economic data. Additionally, the Operator agrees to allow CrossBoundary to collect survey data. The following table details the data the Operator is required to share, or allow CrossBoundary to collect, as part of the study.

Data Type	Metric	Unit	Frequency
(1) Remote Monitoring & Customer Data	**Customer consumption**	kWh	Twelve months' historical + monthly throughout duration of study
	Customer electricity payment	Local currency	Twelve months' historical + monthly throughout duration of study
(2) Prototype-Specific Data	**Cost per connection**	Local currency	Quarterly throughout duration of study
	Cost per square meter of grid	Local currency	Quarterly throughout duration of study
	Total households in village	#	Once, at outset of study
	Total households connected *(for "Network Saturation" scenario sites only)*	#	Once, at outset of study

Data Type	Metric	Unit	Frequency
	Customers signed up	#	Quarterly throughout duration of study
	Theoretical maximum energy generated, based on solar PV capacity, site yield, and internal losses	kWh	Quarterly throughout duration of study
(3) Site Economic Data	**As shown in *Annex 1***	Various	Once, prior to disbursement of funds
(4) Survey Data	**Various demographic, socioeconomic, and user experience data**	Various	Twice, prior to the prototype's launch and following the prototype's end

(1) Remote Monitoring and Customer Data

To evaluate the study's success, the Operator will share electricity consumption and payment data alongside smart meter numbers for all customers on control and treatment sites. This should take the form of raw smart meter data exhibiting the highest resolution available (e.g. individual payment records on a fifteen minute to hourly basis).

Historical consumption and payment data for the twelve months prior to the prototype's launch must be provided upon signing of the Operator Agreement, before disbursement of funds. In the case this data does not exist (e.g. a site involved in the study is newly constructed or yet to be built), the Operator will provide historical data for as many months prior to the prototype's launch as is available. Following the prototype's launch, consumption and payment data must be shared on a monthly basis for the duration of the study.

The Operator will share all consumption and payment data with CrossBoundary through the Lab's data platform, managed by Odyssey Energy Solutions, via API integration with the smart meter account. Should this not be feasible, the Operator will share all data as otherwise agreed to by both parties.

Additionally, to facilitate data analysis and survey conduction, the Operator will share a list of all meter numbers with customer name, customer ID, connection date, phone number, site, and site geographic coordinates. This information must be provided upon signing of the Operator Agreement, before disbursement of funds and may be uploaded to Odyssey.

(2) Prototype-Specific Data

Any prototype-specific data required to evaluate the study's success must be shared for control and treatment sites on a regular basis for the duration of the study. Data that will remain constant over time need only be shared once at the outset of the study. All customer-level data should be tagged by smart meter number. See the previous table for a schedule of the required prototype-specific data.

The Operator will share all data with CrossBoundary by uploading files to Odyssey.

(3) Site Economic Data

To assess the study's impact on mini-grid site economics, the Operator will share required site economic data for control and treatment sites. This data will be used to quantify the prototype's effects on Operator revenues, costs, and other important economic drivers.

Site economic data must be provided upon signing of the Operator Agreement, before disbursement of funds. The data should be shared by Operator's completion of the Excel table shown in *Annex 1*, which may be uploaded to Odyssey

(4) Survey Data

Surveys will be conducted to collect demographic, socioeconomic, and user experience data of study participants at control and treatment sites. Two surveys will be administered over the course of the study: (1) a baseline survey deployed prior to the prototype's launch and (2) an endline survey deployed following the prototype's end.

The surveys will measure asset ownership, current spending patterns, and current energy use patterns, among other metrics. This data will be analyzed to understand the prototype's impact on the socioeconomic status and well-being of participants.

The following table details the survey schedule for this prototype.

Survey	Audience	Format Administered
Baseline	Control and treatment sites, sample survey	Phone / In person
Endline	Control and treatment sites, sample survey	Phone / In person

CrossBoundary will deploy the surveys through Ipsos with funding from the Innovation Lab budget. The schedule, audience, and format of surveys may change given any updates to Lab funding or study needs (i.e. sample size).

Risks

The following table outlines the risks involved in the study.

Risk	Description	Probability	Mitigation
Funding used for other purposes	Funds not spent on installing or maintaining distribution grids	Low	• Agree with Operator on use of funds ahead of installation • Obtain quotes for cost of equipment and installation • Add contract clause requiring subsidy refund to E4I in case of non-compliance
Sample size not achieved	Fatal flaws found at proposed sites, preventing deployment	Low	• Expand number of sites • Expand to larger sites
Technical risk	Increased amount of equipment results in unsuccessful deployment or fatal technical flaws	Low	• Work with Operator to resolve technical issues
Logistics risk	Delayed procurement of equipment; high cost of transportation and installation at site	Low	• Operator investigates and vets reliable contractors prior to providing payment
Operational risk	Operator faces customer complaints and dissatisfaction due to service provision or pricing experimentation	Low	• Work with Operator to set terms and conditions for electricity services and encourage communication to customers • Ensure Operator has sufficient customer relationship managers in place to handle customer complaints and react quickly

Analysis and Evaluation

Full analysis and evaluation of the study's results will be performed by the Study Partners.

Analysis

Study Partners will thoroughly evaluate each hypothesis against the metrics outlined in this Study Design, both periodically throughout the study and at the study's end. Partners will, additionally, monitor and analyze the prototype's effects on customer behavior as well as its social and economic impact on treatment communities.

CrossBoundary will analyze to what extent the prototype improves the mini-grid business model and quantify the benefit or cost to developers of incorporating the prototype into their standard operations. CrossBoundary will do this by applying observed changes in revenues and costs to its proprietary financial model. The resulting impact on project IRRs and cash flows will be evaluated under different scenarios. CrossBoundary will then recommend improvements to the prototype's design and implementation, to be incorporated into a later study or taken up directly by developers.

Dissemination of Results

Regularly throughout the study, CrossBoundary will publish a brief report, or *Innovation Insight*, capturing the study's results against each hypothesis in an anonymized and aggregated form. At the end of the study, CrossBoundary will publish a complete report capturing the study's final results as well as the Lab's recommendations on scaling, further testing, or discarding of the prototype. For each report, all developers involved in the Lab will be given time to review the report for completeness and accuracy ahead of the report being published. The reports will be made publicly available and shared with stakeholders engaged in CrossBoundary's work, including but not limited to mini-grid operators, donors, investors, and government agencies. Findings may also be disseminated through sector events, such as conferences and workshops. Other Study Partners may publish anonymized and aggregated study results in peer-reviewed academic journals.

Annex 1: Site Economic Data

Key Project Economic Data
LC = Local Currency

Instructions: Please complete all cells colored blue. Note some rows are optional.

Input	Unit	Name of Site 1	Name of Site 2	Name of Site 3	Name of Site 4	Name of Site 5
Mini-Grid Sizing						
Number of Connections	#					
PV Generating Capacity	kW_p					
Battery Inverter size *(optional)*	*kVA*					
PV Inverter Size *(optional)*	*kVA*					
Diesel Generator Set *(optional)*	*kVA*					
Battery Storage *(optional)*	*kWh*					
Battery Regular Depth of Discharge Limit *(optional)*	*%*					
Number poles *(optional)*	*Poles per site*					
Diesel Use *(optional)*	*litre/month*					
kWh Produced from Diesel *(optional)*	*kWh/month*					
Diesel Cost *(optional)*	*LC/litre diesel*					
Diesel Expenditure *(optional)*	*LC/month expenditure*					
Night time consumption as % of total consumption *(optional)*	*%*					
Total CapEx						
Project Development Cost	*LC*					
Generation CapEx	*LC*					
Distribution CapEx	*LC*					
Labour CapEx	*LC*					
Logistics CapEx	*LC*					
OpEx						
Annual OpEx (historical)	*LC /site/year*					
Annual OpEx (projected)	*LC /site/year*					
Revenue						
Average tariff	*LC /kWh*					
Average consumption	*kWh/month/customer*					
15-year Consumption Forecast	*kWh/month/customer*	*See table below*	*See table below*	*See table below*	*See table below*	*See table below*
15-year ARPU Forecast	*LC /month/customer*	*See table below*	*See table below*	*See table below*	*See table below*	*See table below*

Consumption and Revenue ForecastDevelopers may specify assumptions rather than a specific consumption/revenue forecast e.g. annual escalation of 5%
Note: You may specify assumptions rather than a specific consumption/revenue forecast (e.g. annual escalation of 5%)

Year	***Unit***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Average Monthly Consumption Per Customer	*kWh/ month /customer*															
Average Monthly Revenue Per Customer	*LC / month /customer*															
Implied Tariff	*LC/kWh*	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check	Automatic formula for sense check

Annex 2: Operator-Specific Information

Site Selection

The following sites have been selected for execution of the study with [developer] in [country].

Site	Study Purpose	Households	Current Connections	Additional Information
[Site name]	Control / Treatment			

More sites may be added to the study pending initial results and Lab budget.

Budget

The following budget has been agreed to for execution of the study with [developer] in [country].

Implementation Plan

The following implementation plan has been agreed to for execution of the study with [developer] in [country].