CROSSBOUNDARY

Study Design: Connecting Beyond the Meter
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Executive Summary

The Connecting Beyond the Meter prototype aims to deliver the full benefits of electrification to customers from day one. By the time a new mini-grid becomes operational, or an existing mini-grid is expanded, all households within reach have been connected to electricity and offered appliances for various household and productive uses, such as lighting their homes, keeping food cold, or milling maize.

This study tests whether mini-grids can reduce construction and customer engagement costs by proactively connecting all customers, and accelerate consumption, and thus revenue, growth by offering appliances simultaneously with power. This is the first of the Lab's prototypes to combine promising cost-reducing and revenue-generating innovations.

This prototype also draws on elements of the revenue generation model that has most recently worked for the solar home system (SHS) sector in Africa, but dates back to the early days of rural electrification in the United States. If this prototype is successful, it could point to a new model of financing appliances on mini-grids. Developers could include appliances in the capex of the mini-grid and finance them with the same long-term infrastructure capital. This study additionally tests whether there are added benefits to combining a revenue-generating scheme with a near proven cost-reducing scheme.

The primary objective of the study is:

1. Determine the impact of proactively installing full infrastructure to immediately connect all households reached by the distribution network *and* financing appliances for all customers as part of the grid's capex on:
    a. the economics of mini-grids, and grid utilization and load
    b. new customer acquisition

The study targets customers of currently operating or soon-to-be-constructed mini-grids in Africa. The study will be conducted on sites where connections are installed proactively *and* all households are offered appliances on set financing terms. Connections are installed proactively when 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 existing or planned distribution network are installed at the outset.

The study will assess the impact of proactively installing connections *and* financing appliances for all customers on three principal matters: (1) grid economics, (2) customer acquisition, and (3) grid utilization and load. Cost per connection, ARPU, and repayment rate, 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 sites will be used to compare changes observed at treatment sites.

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 two-year period, beginning [X 2020].

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 **Other 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: can the mini-grid sector improve profitability by mirroring parts of the solar home system business model?

This prototype is the first of the Innovation Lab's to simultaneously test a cost-reducing innovation alongside a revenue-generating innovation on the same site, to understand the full impact on mini-grid unit economics.

Through the Grid Densification prototype, the Lab has preliminarily found proactively designing distribution grids may reduce developers' capital expenditure, leading to improved grid economics. Specifically, unit economics appear to be optimized by proactively installing full infrastructure to immediately connect all households reached by the distribution network the developer would otherwise build ("Network Saturation" scenario). By building distribution grids proactively, rather than reactively, developers can maximize customer acquisition and reduce costly trips to site to connect new customers. One developer in Zambia has now adopted this as part of their standard operating model. According to the CEO, "We've decided to make [this] our standard deployment model and are now installing three new sites following this implementation strategy. It means these communities will receive electricity at least six weeks earlier and it will cost us 20% less."

To complement this cost reduction, the mini-grid sector can learn from the solar home system (SHS) revenue generation model. Within the off-grid energy market, solar home systems have scaled more quickly than mini-grids. In comparing the two models, the SHS operating model appears to have two clear advantages:

1. Solar home systems offer appliances to customers at the time of installation of the system and provision of power. This makes the value clear to customers, and means providers take the onus for customers' consumption.
2. Solar home systems offer a defined range of appliances. This allows SHS providers to monitor and enforce the energy efficiency of appliances, and ensure the loads are supported by the system.

By financing appliances for all customers as part of the mini-grid's capex, the mini-grid sector could draw on elements of the revenue generation model that has most recently worked for solar home systems in Africa. These learnings date back to the early days of rural electrification in the United States. Mini-grid operators can accelerate the typically slow ramp up in revenue by immediately providing customers with means to use electricity. Operators can additionally improve grid stability by better being able to predict customers' load profiles, encourage energy efficiency by offering a standard set of efficient appliances, and increase customer satisfaction by making the value clear to the customer upfront. If this prototype is successful, it could point to a new model of financing appliances on mini-grids. Developers could include appliances in the capex of the mini-grid and finance them with the same long-term infrastructure capital.

This study, therefore, seeks to:

1. Determine the impact of proactively installing full infrastructure to immediately connect all households reached by the distribution network *and* financing appliances for all customers as part of the grid's capex on:
    a. the economics of mini-grids, and grid utilization and load
    b. new customer acquisition

The study targets customers of currently operating or soon-to-be-constructed mini-grids in Africa. The study will be conducted on sites where connections are installed proactively *and* all

households are offered appliances on set financing terms. Connections are installed proactively when 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 existing or planned distribution network are installed at the outset.

Experimental Design

Hypotheses

The following table details the hypotheses the study will test and how each will be measured. **Treatment sites** are defined as sites where connections are installed proactively and appliances are offered to all customers; **control sites** are defined as sites where connections are installed reactively and no appliances offered to customers.

Hypothesis	Metric	Source
Grid Economics		
1. Cost per connection for treatment grids will be 10% lower than for control grids after one year.	• Cost per connection	• Developer data
2. ARPU at treatment sites will be 10% higher than at control sites after two years (after adjusting for baseline ARPU differential between sites).	• ARPU	• Smart meters
3. The additional revenue from increased consumption and interest payments on appliances will cover the total costs to the operator of managing the program, including all direct and indirect costs*. **Consists of: procuring appliances, delivering appliances, managing appliance payments, and repossessing appliances (as necessary)*	• Profit (or loss) of program	• Developer data
4. Historically higher-user customers will exhibit the highest repayment rates at treatment sites.	• Repayment rate, segmented by customer quartiles	• Developer data
Customer Acquisition		
5. Treatment grids will attract 20% more customers than control grids after one year.	• Number of connections	• Developer data

Hypothesis	Metric	Source
6. Treatment grids will serve 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	• Developer data
Grid Utilization and Load **7. 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
8. Solar mini-grids can sustain the load demanded when all customers are offered appliances.	• % of time there is a grid outage, as measured at the inverter • % of time voltage is within 10V of standard operating voltage, as measured at the smart meters	• 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

Treatment sites will be chosen according to where the Operator has current operations or plans to start new operations, and where offering at least some productive use appliances is feasible. Control sites will be chosen to resemble treatment sites as closely as possible, based on population, geography, profile and use of customers, and tariff structure.

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

- At least 100 customers

- Capability to automatically measure customer consumption and payment
- Sufficient generating capacity to sustain the use of household and productive use appliances

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

Participants are all households reached by the current or planned distribution network. All households reached by the distribution network will be given the opportunity to purchase appliances.

Duration

The study is expected to run two years, starting as soon as possible upon the signing of the Operator Agreement. The projected timeline of the study is [X] 2020 – [X] 2022. Early results will be analyzed after three months and quarterly thereafter.

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

Appliance Choice

Appliances offered to study participants will be chosen based on the following inputs:

- Customer demand
- Mini-grid sustainability
- Operator feasibility
- Availability from supplier

Appliance Pricing

Pricing for each appliance will be based on the wholesale cost of that appliance. Financing terms will be set to reflect commercial standards. Appliances may be bundled into the price of power or may be financed separately, according to the Operator's preference.

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

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: (1) the cost of procuring and distributing appliances to customers and (2) the cost of proactively installing connections to reach all households served by the current or planned distribution network, beyond those households expected to become customers. Specifically, suppose the Operator has, or plans to build, a distribution network to serve 100 households at a site. Suppose of those 100

households, the Operator expects 60 of those households to sign up as customers by day 1. This study would fund all costs associated with installing poles, low voltage lines, 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 [budget] 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 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 all households reached by the current or planned distribution network
- Procuring and distributing household and productive use appliances offered to study participants
- Managing study participants' appliance payments through Angaza's or another payment platform
- 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. geospatial data on household location).

Third Parties

This study will involve two types of third parties: (1) appliance suppliers and (2) Angaza or another payment technology.

The Operator will select the appliances to be deployed, and the supplier from whom to source those appliances. Appliance suppliers are responsible for supplying selected appliances to the Operator in the quantities ordered and offering post-purchase support for those appliances.

Angaza is a technology platform designed for product distributors in emerging markets, based in the United States. The selected payment technology is responsible for providing customer payment software to assist the Operator in managing customers' appliance payments.

Licenses and other Regulatory Approval

No licenses are required to implement this study, apart from the standard licenses required to 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 & Timing
(1) Remote Monitoring & Customer Data	**Customer consumption**	kWh	Twelve months' historical *(as available)*, prior to disbursement of funds + monthly for duration of study

Data Type	Metric	Unit	Frequency & Timing
	Customer electricity payment	Local currency	Twelve months' historical *(as available)*, prior to disbursement of funds + monthly for duration of study
	Meter numbers with customer information	Various	Once, prior to disbursement of funds
(2) Prototype-Specific Data	**Cost per connection**	Local currency	Quarterly throughout duration of study
	Total households in village	#	Once, at outset of study
	Total households connected	#	Once, at outset of study
	Customers signed up	#	Quarterly throughout duration of study
	Appliances procured	#	Once, at outset of study
	Appliances purchased with meter number, purchase date and price, and delivery date	Various	Monthly for duration of study
	Monthly customer appliance payment	Local currency	Monthly for duration of study
	Cost of running the program	Local currency	Quarterly for duration of study
	Theoretical maximum energy generation **a. Solar PV capacity** **b. Specific yield at site** **c. Internal losses**	kWh/kWp	Quarterly for duration of study
(3) Site Economic Data	**As shown in *Annex 1***	Various	Once, prior to disbursement of funds

Data Type	Metric	Unit	Frequency & Timing
(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
Delayed procurement, installation, or appliance distribution	Grid equipment or appliance procurement is delayed due to COVID-19 or other factors, or trips to site become infrequent given COVID-19 or other risks	High	• Work closely with Operator to resolve challenges as soon as they arise • Target procuring grid equipment and appliances locally, where possible
Customers dissatisfied with service or unable to afford power	Customers are dissatisfied with Operator's service provision or pricing experimentation, or are unable to afford power when bundled with the cost of an appliance	Low	• Work with Operator to set pricing structure and other terms for electricity services and appliance ownership, and encourage communication to customers • Adjust appliance repayment terms on a customer-by customer basis, as necessary to meet ability to pay • Ensure Operator has sufficient customer relationship managers in place to handle customer complaints and react quickly
Reliability of appliances	Some productive use appliances sourced in the past have proved unsuitable for local use (e.g. Chinese sourced mills unable to mill African maize as a result of its purported hardness and difficulty to grind)	Low	• Pre-test appliances in-country before deploying to customers • Work with partners to identify products best suited for mini-grid use and solve any performance issues related to appliances

Risk	Description	Probability	Mitigation
Customer acceptance of appliance and quality of product	Customers are particular about productive use appliance in particular, to meet the end customers' expectations (eg: the flour milled must be of specific fineness, the fish stored must be thoroughly frozen)	Medium	• Test appliances in-country with multiple configurations to ensure they are suitable to local realities (e.g. different cooling speeds for freezers, different sieve sizes for mills) • Offer appliances under a discounted tariff structure to optimize the business case for end-users
Increasing mini-grid capital and operational expenditure	At sites where a diesel generator supplements solar generation, increasing consumption on the mini-grid could raise opex due to increased diesel consumption by the genset; large increases in consumption could require capex expansion	Medium	• Instate time-of-use tariffs for productive use appliances to incentivize daytime consumption, drawing power primarily from solar rather than batteries or genset • In the case daytime loads increase dramatically, set the genset to run during peak load
Increased frequency of inverter overload events	Mini-grid inverters can be tripped by high inrush current of motored loads, increasing the frequency of grid-wide outages	Low	• Research motor starters for mitigating the inrush current • Instate time-of-use tariffs to discourage usage from residential customer at times of peak demand

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 also assess the impact of the prototype on customers' wellbeing and economic opportunities. 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

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].

Technical Design

The following details the technical design of the study with [developer] in [country].

Pricing and Loan Terms

The Operator will offer financing for the appliances over a 12-month period, requiring a deposit of 20% of the appliance's cash price and with monthly installments based on a 2.55% monthly interest rate. The following table details the implied deposits and monthly installments (to be converted into local currency).

Appliance	Cash Price (USD)	Deposit	Monthly Installment	Tenor

Additional appliances may be added following launch of the study.