CROSSBOUNDARY

Study Design: Modular Grids Increasing Capacity

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Executive Summary

This study tests whether building and expanding grids modularly improves profitability for mini-grid developers, by reducing the cost of adding generation and storage capacity at sites where demand is greater than generation.

Currently, developers rely on their own predictions of consumption for a given community to size the generating capacity for a new mini-grid. Size it too big and developers are left with capital expenditure costs unmatched by revenue. Size it too small and developers can't meet demand, and thus miss out on potential revenue.

New smart inverter technology has come onto the market that allows developers to easily, and modularly, add capacity to a mini-grid. Developers can add modular capacity in two principal ways:

1. Add additional generation units with smart inverters, shared across multiple generating units, to serve excess demand.
2. Install larger powerhouses or containerized generation units at the start with extra space reserved for adding additional PV, inverters, and non-lead acid batteries[1] as demand grows.

Over the lifetime of a mini-grid, these solutions could improve mini-grid returns through:

- Cost savings for developers who currently have to replace entire generation systems to add capacity
- Matching the timing of capital expenditure to revenue growth
- Allowing developers to continually expand capacity to meet customer demand, thus never missing out on potential revenue

The primary objective of the study is:

1. Determine what impact building and expanding grids modularly has on (1) the economics of mini-grids, specifically capital expenditure costs and revenues.

The study will be conducted on currently operating mini-grid site(s) in Africa where demand is greater than generation. The Operator will install new generation capacity over time through deploying either (1) smart inverter technology or (2) larger powerhouses or containers combined with battery technology that allow incremental expansion of generation and storage capacity.

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[1] Lead acid batteries cannot be added incrementally to a power system since voltage characteristics of the batteries degrade with time, making it uneconomical to connect battery banks of different ages.

The study will assess the impact of building and expanding grids modularly on one principal matter: (1) grid economics. The cost of incrementally adding capacity and the expected cost of total replacement otherwise required will be used to analyze the impact on capital expenditure. The impact on revenue will be assessed by measuring the increase in total revenue and unmet demand.

The study will be delivered by the Operator, who will organize support from technical advisors and other third parties as necessary. The Operator will test a smart inverter technology or other solution designed to incrementally increase generation and storage capacity.

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 January 2020.

Study Partners

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

Partner	Role
Funder (The Rockefeller Foundation / DFID)	• 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: can developers reduce capital expenditure by building and expanding grids modularly?

Currently, developers rely on their own predictions of consumption for a given community to size the generating capacity for a new mini-grid. Size it too big and developers are left with capital expenditure costs unmatched by revenue. Size it too small and developers can't meet demand, and thus miss out on potential revenue. If a 30 kW mini-grid which achieves a 12.5% Internal Rate of Return (IRR) when capacity perfectly matches demand, when *oversized* by 50% IRR drops to 9.2%, and when *oversized* by 100% IRR drops to just 6.1%.

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2. Install larger powerhouses or containerized generation units at the start with extra space reserved for adding additional PV, inverters, and non-lead acid batteries[2] as demand grows.

Over the lifetime of a mini-grid, these solutions could improve mini-grid returns through:

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[2] Lead acid batteries cannot be added incrementally to a power system since voltage characteristics of the batteries degrade with time, making it uneconomical to connect battery banks of different ages.

Experimental Design

Hypotheses

The following table details the hypotheses the study will test and how each will be measured.

Hypothesis	Metric	Source
Grid Economics 1. **Adding capacity gradually over three years to match demand is more profitable than building a grid with capacity to match projected year 3 demand upfront.**	• Monthly revenue as % of capex • Consumption as % of generation	• Developer data
2. **The cost of incrementally adding capacity, including increased installation costs, at treatment sites will be less than the expected cost of any replacement of the generation unit required after three years.**	• Cost of incrementally adding capacity • Expected cost of any replacement of the generation unit otherwise required	• Developer data
3. **Consumption and revenue will be 20% higher at treatment sites one year following prototype launch as compared to before prototype launch** a. **Number of connections will be 10% higher at treatment sites one year following prototype launch as compared to before prototype launch**	• Consumption • Revenue • Number of connections	• Smart meters

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.

The study's hypotheses may be subject to change following any changes to the prototype's design.

Site and Participant Selection

Treatment sites will be chosen according to where the Operator has current operations. There are no control sites for this study.

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

- Significant excess demand compared to grid generation or storage capacity

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

Participants are all households considered members of the community or village.

Duration

The study is expected to run for 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 three months and quarterly thereafter.

The study's duration may be adjusted following initial results or any unforeseen circumstances.

Prototype-Specific Design Decisions

The Operator is responsible for proposing the technology or other solution designed to incrementally increase generation and storage capacity at selected site(s).

For each way of adding modular capacity:

1. Two smart inverters have been researched and proposed by a community of developers interested in deploying this study:
    - Studer Innotec's Xtender Inverter
    - ZOLA Electric's INFINITY Integrated Power System
2. Developers may propose technology solutions for expanding larger powerhouses or containerized generation units at the start with extra space reserved for adding additional PV, inverters, and non-lead acid batteries as demand grows.

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 represents the cost of procuring, installing, and maintaining the smart inverter technology or other identified solution on grids at all treatment sites, and any associated costs incurred in deploying the solution to increase capacity. 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)
- 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:

- Procuring, installing, and maintaining the smart inverter or other technology on grids at all treatment sites
- 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 study results. The Operator additionally agrees to disclose any other information pertinent to the study (e.g. GIS data).

Third Parties

This study will involve one third party: (1) the supplier of the identified technology or solution designed to incrementally increase generation and store capacity. The supplier is responsible for providing the product to the Operator.

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 data, (2) prototype-specific data, and (3) site economic data. No surveys will be conducted for this study. The following table details the data the Operator is required to share as part of the study.

Data Type	Metric	Unit	Frequency & Timing
(1) Remote Monitoring Data	**Customer consumption**	kWh	Twelve months' historical *(as available)*, prior to disbursement of funds + monthly for duration of study
	Customer electricity payment	Local currency	Twelve months' historical *(as available)*, prior to disbursement of funds + monthly for duration of study
(2) Prototype-Specific Data	**Total generation**	kWh	Monthly for duration of study
	Cost of incrementally adding capacity	Local currency	Quarterly for duration of study
	Expected cost of any replacement of the generation unit otherwise required	Local currency	Quarterly for duration of study
	Number of connections	Number	Quarterly for duration of study
(3) Site Economic Data	**As shown in *Annex 1***	Various	Once, prior to disbursement of funds

The data collected may be subject to change following any changes to the prototype's hypotheses.

(1) Remote Monitoring Data

To evaluate the study's success, the Operator will share electricity consumption data alongside smart meter numbers for all customers on 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 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 data must be shared on a monthly basis for the duration of the study.

The Operator will share all consumption 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.

(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.

Risks

The following table outlines the risks involved in the study.

Risk	Description	Probability	Mitigation
Smart inverters have long procurement timelines	Procuring the smart inverters requires considerable lead time, thus delaying the results of the study	Medium	• Prioritize ordering smart inverters at the start of the study • Maintain close contact with suppliers to resolve issues as soon as they arise

Risk	Description	Probability	Mitigation
Smart inverters do not function as expected	Smart inverters do not properly communicate between generation sources, or cause issues with other elements of system	Medium	• Have dedicated customer support representative for each smart inverter technology • Communicate issues as soon as they arise
Smart inverter technology becomes obsolete or unavailable	Smart inverter companies cease production of the technology required to incrementally add capacity	Low	• Require smart inverter companies to retain inventory or provide replacements for obsolete products in contracts
Customers develop unrealistic expectations for connection timelines	Customers realize Operator can more immediately add capacity to connect new customers, and develop unrealistic expectations for the time it will take to get connected once requested	Low	• Support Operator in communicating clear connection timelines with all potential customers

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.

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

Quarterly 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. 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].