SURVEY USE IN MICRO-GRID LOAD PREDICTION, PROJECT DEVELOPMENT, AND OPERATIONS

Review and Best Practices

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List of Acronyms

GIS	geographic information system
HH	household
LASSO	Least Absolute Shrinkage and Selection Operator
M&E	monitoring and evaluation
NREL	National Renewable Energy Laboratory
SHS	solar home system
SMS	Short Message Service
TSH	Tanzanian shilling
USD	United States dollar

Executive Summary

Micro-grids are proliferating in East Africa as alternatives to grid extension in communities far from existing grid infrastructure. Although many studies have found micro-grids to be cost-effective choices compared with the grid in remote areas (Moksnes et al. 2017; Moner-Girona et al. 2017; Nerini et al. 2016; Szabó 2011), micro-grid developers face unique challenges. The Quality Assurance Framework for Mini-Grids (Baring-Gould et al. 2016) was developed to address many of those challenges, and this report builds on the Quality Assurance Framework.

Because micro-grids must meet local electrical loads with local generation, accurate community-level electrical load forecasts are critical to proper system design and financial modeling. Further, because these systems are largely operated by private, for-profit companies that generally do not benefit from the same subsidies as the main electricity grid, it is crucial to select micro-grid sites that will consume sufficient electricity to make the micro-grids financially sustainable. To learn more about prospective communities and customers, micro-grid developers often deploy surveys before selecting sites and building new micro-grids. Although it is known that micro-grid developers use survey tools, these activities are often developed and implemented internally. The current state of practice regarding the use of surveys to estimate market opportunities and electrical loads for remote communities is not well understood.

This study was undertaken to identify current practices within the sector involving the use of surveys and their ability to accurately predict customer demand once connected to a micro-grid. Further, best practices are identified for survey use during micro-grid development and operation. This includes:

- Survey objectives
- Type of information collected
- Data collection and storage techniques
- Analysis methods.

To better understand current practices, eight micro-grid developers operating in sub-Saharan Africa were interviewed about their use of surveys. The developers were chosen to represent a diversity of geographies, technical approaches, and business models. Although the depth and approach to conducting surveys differed among developers, all of them conducted surveys as a normal part of doing business. This assessment also determined that, although there are no defined standard practices around survey techniques across the sector, a similar category of studies with like objectives is typically undertaken. These include surveys for:

- Market research
- Site selection
- Customer applications
- Customer satisfaction
- Socioeconomic monitoring and evaluation.

Using data from more than 1,000 micro-grid customers in Tanzania, several statistical methods are examined to determine which survey questions will better predict actual customer electrical loads after initial connection. This study identifies the following questions that seem to best indicate potential future energy use:

- Customer class (Home, Business, Home/Business, Public Premises)
- Nature of business
- Employment status
- Current source of energy and uses
- Current mode of transport
- Appliances owned before micro-grid connection
- Building construction materials
- Mobile phone airtime spending

The data generated by answers to these questions were then analyzed using three methods, including correlation to actual energy usage, a Least Absolute Shrinkage and Selection Operator regression, and a random forest model. The correlation to actual energy usage is illustrated in Figure ES-1. A positive coefficient means that the variable is positively correlated with electricity demand, whereas a negative coefficient shows negative correlation. Energy sources, transport modes, pre-electrification appliance ownership, building type, connection class, and business type feature strongly.

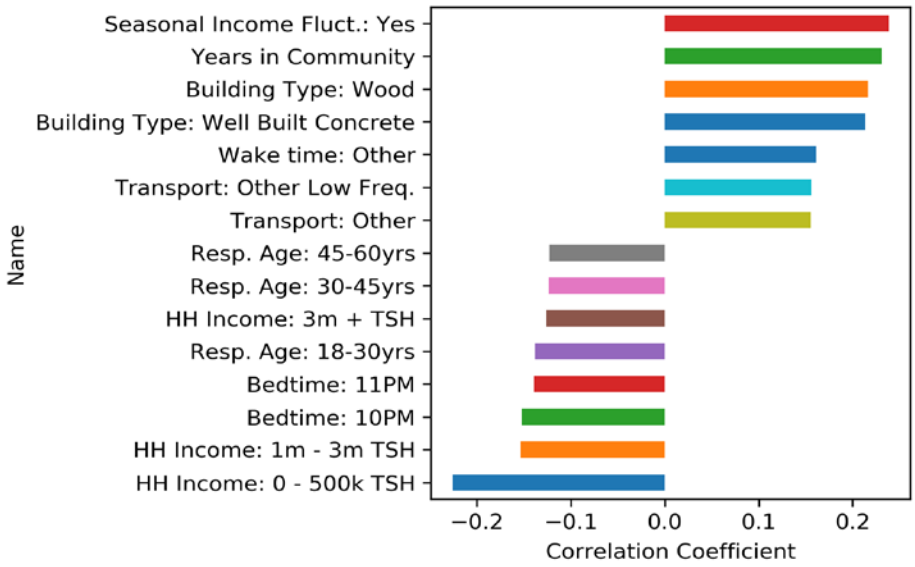

Figure ES-1. Correlation coefficients between survey variables and daily electricity consumption in first 90 days since connection to the micro-grid.[1]

Note: Household (HH) income is for households only (1 United States dollar [USD] ≈ 2,250 Tanzanian shilling [TSH]).

It should be noted however, that there appears to be a difference in opinion and approach among developers with regards to predicting electrical load. On one end of the spectrum, developers allocate significant resources to collecting data on customers and applying sophisticated quantitative models to forecast electrical load in order to optimize system design and project revenue. On the other end of the

[1] The names shown in Figure-ES-1 correspond to the survey response options given to customers. See Section 3 and the report Appendix for more details and explanation of the chart and the names. For example, building type refers to the construction material of residential homes and wake time: other refers to customers that wake up at a time other those specified in the survey.

spectrum, some developers are skeptical that forecasting load is feasible and rather deploy modular systems that can exert more control over consumption. We are unable to draw conclusions on the relative performance of these approaches due to limited data and a small sample.

The objectives of using surveys to predict demand are twofold. Developers seek to identify the most financially viable micro-grid sites which is in large part a function of electricity demand. This information is also required to design systems that meet customer demand at minimum cost. The timing of these surveys introduces a trade-off. Surveys provide valuable information on the basis of which developers select micro-grid sites but are expensive to run. If surveys are conducted before site selection decisions, additional expense will be incurred for unselected sites. However, if surveys are completed only after site selection, good sites may be overlooked. A middle ground is to conduct surveys on a sample of potential customers during initial site visits prior to site selection.

Drawing on experience from a range of eight sub-Saharan African micro-grid developers, the second main outcome of this work is a set of best practices for the use of surveys at different stages of micro-grid development and operations. These best practices include:

- The level of data collection needed to meet specific business or national energy access goals should be defined early and well understood.
- Develop surveys using standard or accepted survey techniques.
- Survey questions should be pretested to ensure that they are interpreted accurately and consistently by respondents.
- Surveys to estimate expected energy consumption should use questions that have been identified as important predictors of consumption, such as those identified in this study.
- Because estimates of income can be difficult to obtain and subject to bias, proxies of wealth may be better methods to determine eventual energy usage than income estimates.
- Surveys should be conducted using mobile device-based assessment tools using clear survey instruments.
- Well-trained and experienced survey enumerators who are fluent in the local language, have experience in energy issues, and understand potential cultural sensitivities should be used.
- Incorporating a set of standard questions in all surveys to allow comparison across projects and over time will be valuable.

Finally, we propose a set of standard survey tools that can act as a core set of questions that micro-grid developers can use in creating their own surveys.

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1 Introduction

Micro-grids are proliferating in Africa as an alternative to waiting for grid extension in communities far from existing grid infrastructure. Many studies have found micro-grids to be cost-effective choices compared with the grid in remote areas (Moksnes et al. 2017; Moner-Girona et al. 2017; Nerini et al. 2016; Szabó 2011).

Carnegie Mellon University and the National Renewable Energy Laboratory (NREL) authored this report with support from Power Africa and USAID. It is a resource for developers, policymakers, regulators, and other stakeholders to better understand how to use surveys to support electricity load prediction, project development, and operations for micro-grids. Improved customer demand/usage production, site selection, and micro-grid development and operation will help developers scale micro-grids faster.

NREL and the U.S. Department of Energy have developed a Quality Assurance Framework for Mini-Grids (Baring-Gould et al. 2016). This framework, developed with the intent of fostering mini-grid growth and rural electrification, has the dual goals of:

1. Defining a range of service levels that ensure safe, quality, and affordable delivery of electricity.
2. Providing an accountability framework that can be used to determine whether an agreed-upon service level has been delivered.

This report focuses on smaller micro-grids with a capacity less than 1,000 kilowatts located in sub-Saharan Africa and is a companion document to the Quality Assurance Framework.[2]

1.1 Objectives of Study

The objectives of this study are threefold:

1. Identify common pre-project survey types, objectives, characteristics, tactics, and practices employed by micro-grid developers with direct experience in sub-Saharan Africa.
2. Identify survey questions which are most useful in accurately predicting customer demand once connected to a micro-grid.
3. Use input from the first two sections to develop best practices advice for micro-grid developers.

Combined, this information can serve as a guide for a range of users, including micro-grid developers, government officials, regulators, policymakers, and other stakeholders.

Many micro-grid developers, because of size, experience, and financial resources, rely on some internal or informal survey tools and practices to learn more about the potential markets where they are considering developing new micro-grid projects. The first objective of this study is to identify current practices within the sector involving the use of surveys. This includes survey objectives, the type of information collected, data collection and storage techniques, and analysis methods.

The second objective is to identify survey questions which are most useful in accurately predicting customer demand once connected to the micro-grid using two statistical approaches that attempt to relate

[2]The terms “mini-grid” and “micro-grid” do not have clear or consistent internationally recognized definitions and are used somewhat interchangeably by many industry stakeholders and practitioners. In this report, the single term “micro-grid” is used for simplicity with no attempt to distinguish it from the term “mini-grid,” which could also apply in most instances.

customer characteristics with electricity demand/consumption. This work is based on actual customer electricity consumption and survey data for more than 1,000 micro-grid customers in East Africa.

Third, drawing on experience from a range of micro-grid developers, a set of best practices will be identified for the use of surveys at different stages of micro-grid development and operations. Additionally, several standard survey tools will be proposed that can act as a core framework with appropriate questions that micro-grid developers can use in creating their own surveys. Developing a standard set of data to be collected across the sector will help facilitate more equitable monitoring and evaluation of micro-grids by regulators, financiers and investors, and other industry stakeholders. Such standardized data collection will also allow for expanded learning about regional and national energy use assessments and predictions. The resulting data sets may help open the door to standardized project assessment methods that could streamline regulation and investment across the sector, resulting in lower transaction costs, more investment, and increased electrification.

1.2 Role of Surveys in Micro-Grid Development

While it is known that micro-grid developers use survey tools, these activities are often developed and implemented internally. Current practices on the use of surveys are not well understood or documented. Micro-grid developers face unique challenges such as accurately forecasting future electricity demand in their micro-grids.

Electrical load forecasts are key in planning the central power system, although the total electrical load in any particular community is less critical, because both temporal and spatial variability are smoothed through aggregation and averaging energy usage. Because micro-grids must meet local electrical loads with local generation, accurate community-level electrical load forecasts are critical to effective system design and financial modeling. Further, because these systems are largely operated by private, for-profit companies that generally do not benefit from the same subsidies as the main electricity grid, it is crucial to select micro-grid sites that will demand sufficient power to make the micro-grids financially sustainable. To learn more about prospective communities and customers, micro-grid developers often deploy surveys prior to selecting and building new micro-grids.

Furthermore, micro-grid operators are often very customer-centric enterprises and engage with their customers during operations to gauge customer satisfaction, respond to evolving customer needs, identify opportunities to offer new services, and support growth in demand for electricity. There is also interest among the larger set of stakeholders in monitoring and evaluating the socioeconomic impacts of micro-grids on the communities they serve. Therefore, operators also conduct surveys to improve customer service, estimate the need for expanded supply, and measure the impacts of their activities.

1.3 Interview Method

This study relies on data collected during semi-structured interviews with micro-grid companies that actively develop and operate micro-grids in Africa. Participants were provided a list of questions before the interview that were used to guide the discussions. To allow a free-flowing conversation and identify pertinent information that the questions may not address, the questions were not posed sequentially. One interview was carried out in person, with the balance of the oral exchange conducted telephonically. On average, the interviews lasted approximately 1 hour. One developer provided a written response to the survey questions before the interview.

The framework of the questions that formed the basis of the interviews was divided into four categories: (1) questions about the surveys themselves, (2) questions about the analysis carried out using the survey data, (3) a set of questions specifically about the micro-grid site and customer selection, and (4) questions about survey use for monitoring and evaluation. A summary of the interview questions is in Table 1.

Eight micro-grid developers were interviewed. Efforts were made to capture a breadth of experience, geography, and approach from the population of developers in Africa. Geographically, the developers interviewed operate in East, West, and Southern Africa. In terms of experience, developers range from those operating a single site to those with more than 20. Most of the micro-grids charge customers per unit of energy consumed; however, some of the operators charge based on duration of energy or appliances used. Most of the developers have built and operate alternating current networks, though two of the developers have built primarily direct current grids.

Table 1. Summary of Interview Questions

Questions on Surveys
Do you use surveys as part of your micro-grid development and/or operations processes?
What are the objectives of your surveys?
Whom do your surveys target? Do you have different surveys for different customer segments? If so, how do you segment your customers?
How do you collect the survey data (e.g., in person on paper, in person via tablet/phone)? Is there a particular software you use in conducting surveys (e.g., smartphone apps, etc.)?
What data do you collect? Can you share your survey?
Are there certain questions that respondents have difficulty answering or for which you question the accuracy of their response? Are there types of questions that you find respondents are uncomfortable answering or you suspect are likely to be untruthful answering?
How do you store the data? Do you use particular formats in storage?
At what stage(s) in the micro-grid development process do you conduct the surveys?
What is the cost of running the surveys?
How long do the surveys take to conduct?
How large is your survey team? Does it operate full time or as needed? Is it in house or from an external organization?
Do you use your surveys to estimate willingness/ability to pay? What methods do you use in surveys for estimating willingness to pay? Do you use this information when setting tariffs?
Questions on Survey Data Analysis
What analysis do you perform on the survey data? Who does this analysis?
Do you use surveys to estimate electricity demand before construction? If so, how?
Historically, how accurate and useful have these estimates been?
What other methods do you use to estimate electrical demand for sizing your systems?
How do you assess/estimate load growth over time and incorporate growth into system design? Do surveys play a role in this?
What else do you use your survey data for (e.g., marketing of appliances to customers)?
Other Load- and Site-Related Questions
What criteria do you apply when selecting micro-grid sites? Is there a minimum load density or other criteria you look for?
Do you use particular software in conducting these analyses? If so, what software do you use?
Do you target anchor loads? If so, what kind of anchors and why? Have these anchors led to successful micro-grid development? (Anchor loads are large electricity consumers that provide a reliable source of revenue)

Table 1. Summary of Interview Questions
What criteria do you apply in selecting which customers to connect to your system?
Ongoing Monitoring and Evaluation
What data do you monitor on an ongoing basis during operation? How frequently do you collect each type of data?
Do you use the same survey(s) and approach for ongoing monitoring as you do for the survey(s) during the development process? If not, how do the two approaches differ (e.g., intent, questions asked, equipment used for survey, cost, size of team)?
What, if any, indicators of household and community impacts of your systems can you monitor using these surveys (e.g., impacts on quality of life, gender equity, community social infrastructure, health, education and literacy, income-generating, and entrepreneurship opportunities)?
Do your investors or other external stakeholders have reporting requirements that necessitate survey work (e.g., determining or quantifying social and economic impacts)? If so, what metrics are required, and are the current surveying techniques adequate for this?
Do you use any other data collection methods to validate or add to surveys (e.g., expert interviews, focus group discussions)?
Are the current survey content and methods adequate for your requirements? What else, if anything, is needed? What could be improved?

2 Findings

All micro-grid companies interviewed performed some form of survey. These surveys span the life cycle of the micro-grid. Practices and attitudes toward surveys vary widely, though survey types can generally be placed into the following categories:

- Market research
- Site selection
- Customer applications
- Customer satisfaction
- Monitoring and evaluation.

The use of site selection surveys is universal, though the approach to these surveys ranges from very structured (with formal survey questionnaires and data collection) to informal site visits and open-ended interviews. One developer performed a large-scale market research study before market entry and later used the data from it for site selection purposes. Customer-level surveys, generally conducted after a site has been selected, are common, though less universal. These surveys are typically used to estimate electricity demand, screen customers, and collect data about the location of customers to aid in system design.

There appear to be two attitudes toward using customer surveys for demand estimation. One group uses customer surveys to estimate the electricity load profile before system deployment and designs a system accordingly. The level of detail and structure of these surveys varies widely, as do analysis methods. The second group is skeptical about the feasibility of estimating electricity demand with any accuracy before having electricity available and therefore does not invest heavily in customer-level surveys before construction. These developers tend to have standardized technology solutions that seek to exert more control over how customers use energy. These systems incorporate an ability to scale up generation, if necessary, once actual system loads can be observed. This is a way of mitigating the risks associated with oversizing systems resulting in capital expenditure for underused capacity that does not generate revenue.

During operations, most micro-grid operators collect information from their customers about their satisfaction with the services provided. Several developers have also conducted ad hoc surveys for specific purposes, such as trying to understand what electrical appliances customers are interested in obtaining. Most of these customer satisfaction surveys are conducted irregularly and often in an unstructured way. A minority of developers conduct regular, structured surveys either in person, over the phone, or by phone-based Short Message Service (SMS). Operators are customer-centric and focused on improving their services for their customers. Most operators expressed interest in monitoring the socioeconomic impacts micro-grids have on their customers' households and businesses, but very little rigorous project specific socio-economic monitoring and evaluation is occurring primarily because of focus on primary business operations. Developers report little pressure from funders to provide socioeconomic impact data and therefore have little incentive to pursue rigorous monitoring and evaluation. In these eight cases, the monitoring seems to focus on finding anecdotal evidence from discussions with customers about how electricity services have facilitated growth in businesses and incomes or improved lifestyles.

In all phases of the micro-grid life cycle, survey methods were observed to be prone to several common sources of bias, including:

- Social desirability bias: This form of bias occurs when respondents seek to paint themselves in a socially desirable light.
- Acquiescence response bias: Survey respondents tend to reply positively to questions requesting confirmation (e.g., questions with yes/no or agree/disagree responses).
- Primacy/recency: In closed-ended questions, respondents tend to select the first response option in a written survey and the last response option they hear in an oral survey.
- Question order effects: The ordering of questions can affect the way respondents answer questions.
- Misreporting: Misreporting can occur both intentionally and unintentionally, either in an attempt to manipulate survey results or because respondents simply do not know the answer to the question but are compelled to provide a response. This may also be related to social desirability bias or demand characteristics.

Overall, micro-grid companies seem to have similar objectives in carrying out surveys, but there is little consistency in approach. All study participants had reasons for approaching surveys in the manner they did and have accumulated valuable insights and experience that are useful to the sector. The remainder of this section will detail these insights and experience by survey type.

2.1 Market Research Surveys

Only one participant indicated carrying out a large-scale market research study before market entry. There was not a specific question about large-scale market research studies in the interview, so it is not clear how many other developers may have carried out similar exercises. This developer secured external funding to visit and survey 30 communities across 22 counties in an East African country. Data were collected via unstructured interviews with various local government and community stakeholders. Information was recorded manually on paper, along with audio recordings and photographs. This approach was taken to put respondents at ease and build a rapport and relationship with the communities. There was concern that formal, structured interviews were too impersonal and would make people uncomfortable. They also observed that many communities had experience with various groups passing through, asking questions, and raising expectations that electricity would be provided, only to be disappointed when electricity did not arrive, further compounding the problem of trust.

The objectives of the surveys were stated broadly to "better understand local communities and potential end users of micro-grid power, build relationships with government entities, and understand regulatory frameworks." It was also seen as a way to demonstrate to government that they were serious about entering the market. Developing a strong understanding of the local context was viewed as essential by the microgrid companies to ensuring that local needs were affordably met. These surveys also served as site identification surveys, which are practiced universally in some manner.

2.2 Site Identification Surveys

Identifying communities capable of supporting a commercial micro-grid is critical to developing financially viable micro-grids, so all participants carry out some form of site survey to assist in site selection.

2.2.1 Data Collected

There are many commonalities in criteria applied for site selection between developers and therefore the data collected tend to be similar as well. Many developers first short-list sites for on-the-ground surveys using geographic information system (GIS) tools to identify areas with high population density located far from the existing electricity grid with reasonable road access and cellular coverage. These tools include GIS mapping software and applications that provide satellite imagery, such as Google Earth. Where

available, national electrification plans are also consulted to minimize the risk of near-term grid encroachment.

Before completing surveys in a community, many developers have established procedures for approaching regional and local authorities to present their company and development objectives and request an introduction or authorization to approach community leaders. This usually starts at higher-level local or regional government and progresses to lower-level local authorities. Other local stakeholders, such as utilities, may be engaged as well. These processes seem to be based both on country-specific regulations and local customs, which vary by jurisdiction.

Most developers reported that on-site survey teams look for several primary site factors, including densely populated village centers; evidence of high levels of economic activity and opportunities for productive electricity use; distance from the electricity grid; and practical considerations, such as road accessibility. Because many micro-grids use Global System for Mobile Communications-enabled smart meters, the quality of a mobile network is also frequently measured, sometimes using a smartphone app. The presence of local mobile money agents is also noted. Some developers reported taking coordinates of key locations, such as potential institutional and productive loads, and infrastructure, such as the nearest tarmac road and power line. Local leaders are commonly engaged to gauge political support for a micro-grid.

Other data frequently collected include: the type and quantity of other energy technologies used in the community, such as diesel generators and solar home systems; proxies for wealth and income, such as the quality of construction of local buildings; asset ownership, such as vehicles and livestock; and factors affecting temporal variation in electricity demand patterns, such as the number and timing of agricultural seasons and, on a shorter timescale, frequency of market days. Table 2 summarizes categories of commonly collected data. Many developers have minimum criteria that a community must satisfy to be short-listed for micro-grid deployment.

Table 2. Categories of Frequently Collected Data during Site Selection Surveys

Criteria	Criteria Range and Context	Rationale
Distance to electricity grid	5–20 kilometers or more and an understanding of grid electrification plans	Grid encroachment is a risk and further distance from the grid lowers this risk. Also, there is a lack of clear policy in most locations regarding what might happen to the micro-grid assets and customers if the grid did arrive.
Population density	Higher population density is better	Higher population density enables more potential connections within proximity to generation sources.
Community demographics	Number and proportion of households and businesses, vehicles, livestock, building construction quality, and electrical appliance ownership	These data can help inform the potential for initial electricity demand and the potential for growth.
Evidence of economic activity	Local industries, number of businesses, and commercial activity	The greater the economic activity, the greater the need for electricity and likelihood for sustainable demand over time.
Number of potential connections	More connections are better as are more connections within a fixed distance to town center	Developers have their own metrics, but a common aim is meeting a minimum number of connections within proximity to generation sources.
Cellular network	High cellular signal strength and existing mobile money vendors	Developers rely on cellular communication for metering and collecting payments (facilitated by mobile money vendors) and it can also foster increased economic growth.

Table 2. Categories of Frequently Collected Data during Site Selection Surveys		
Site accessibility	Transportation infrastructure and public transit options	Good transport options often foster increased commerce and economic productivity, leading to increased electricity use. Good roads and year-round access are also necessary for construction and regular maintenance.
Current energy technology use	Diesel generators, solar home systems (SHS's), solar lanterns, batteries, kerosene	Generators, batteries, and kerosene use suggest existing energy users that could readily switch to electricity if there were economic advantages. SHS's represent both competition and an opportunity to distribute excess solar to other loads periodically.
Potential for seasonal load demand	Seasonality of income related to agriculture	Understanding seasonal load variation and causes can inform system design and impact revenue consistency.
Productive loads	More productive loads are better and can improve the overall business model of the micro-grid	Many productive loads will benefit from local electricity availability. Productive loads are high consumers of electricity and will also increase the disposable income in the community to enable further electricity use.

2.2.2 Collection Methods

Although there is some consistency in the type of data collected during site surveys, the method of collection and whom the data are collected from varies significantly. Two general approaches to collection emerged from the interviews with developers, and their characteristics are summarized in Table 3. Some developers have a formal, consistent set of questions that are collected on all sites - while others take a more informal approach. The informal approach may lead to respondents feeling more at ease and thus providing more information than they might otherwise, including information that might not be easily captured in a structured survey. However, this approach comes with the caveat that the collected data may not be so readily comparable between different communities. Both approaches have their own merits, and most developers incorporated some elements of each.

Table 3. Collection Methods		
Type	**Method**	**Rationale**
Formal survey: consistent set questions for every respondent	Smartphone or tablet: collect photos and videos, upload to cloud, sort data	Efficient, consistent data for subsequent analyses and comparison while providing coordinates, cell strength, and photos
	Manual notes or audio recordings, collect photos and videos	Consistent data for subsequent analyses and comparison
Informal survey: one-on-one, free-flowing conversation	Manual notes or audio recordings, collect photos and videos	Likely to keep respondents at ease but can result in different types of information or data; not necessarily readily analyzable

Only one of the developers has a full-time dedicated survey team. Most developers conduct surveys using employees whose primary responsibilities lie elsewhere. Some hire freelance surveyors to assist employees in conducting surveys. Multiple developers cited concerns relating to surveyors. The cultural and linguistic diversity found in many African countries presents challenges, particularly when surveyors are not familiar with the cultural context and do not speak the local language. This can lead to misunderstood questions and answers or to questions phrased or posed in ways that make respondents uncomfortable. Several forms of bias can occur in survey data, which can be exacerbated by untrained enumerators. Some of the pitfalls observed in collecting survey data are presented in the section on Lessons Learned under Customer Application Surveys. These include biases related to social desirability

(when respondents provide answers they view as socially desirable, such as exaggerating one's education in the presence of peers), electricity demand characteristics (when respondents infer the purpose of questions and answer in a way they believe will benefit them such as answering questions in a way they believe will increase their likelihood of receiving an electricity connection), and acquiescence (when respondents tend to agree with statements from the interviewer). One developer expressed strong concerns about interviewer bias related to acquiescence. Well-designed surveys and trained enumerators can help mitigate these effects.

2.2.3 Logistic and Financial Considerations

Running surveys in remote, often poorly accessible villages in regions with diverse cultural and linguistic communities can be costly and complex. There are often several layers of stakeholders that need to be consulted before entering a community to administer surveys. As an example, several developers described first having to approach regional government officials to obtain permission to engage with district officials who were also gatekeepers to approaching village leaders. These cost and logistical factors influence how developers approach surveys.

2.2.3.1 Cost of Running Surveys

Not all developers track the cost of running their surveys and, due to the informal and opportunistic approach that some developers take, it may be difficult to allocate costs specifically to survey activities. However, participants with more structured and formal survey programs were able to provide some cost estimates. Developers report that the majority of costs associated with running surveys are related to logistics, particularly transportation. The cost of labor is a relatively small portion of the total cost.

One of the developers in East Africa with a more sophisticated survey program has a dedicated survey team. The cost of a site survey was reported to be approximately $100-$150 per site. This cost reflects the practice of using a vehicle and driver to transport the survey team because site surveys are shorter in duration than customer surveys.

Other developers reported using private transportation for surveys, with one developer using air travel in some instances. Few developers have dedicated survey teams, while some rely on part-time contract workers who are not employees. Most developers are still small, lean organizations; and therefore, employees conducting surveys don't have specialized training.

2.2.3.2 Time Required for Surveys

The time required to complete site surveys varies depending on remoteness of the site and travel time. Most developers describe surveying several communities in a region at the same time to reduce the travel time per site. Before surveying communities, local government and other stakeholders at a regional level should be consulted. This regional work does not need to be completed by a full survey team, but it still increases the amount of time required overall to complete site surveys. Once on the ground, developers report surveying 1–3 sites per day, with those conducting more detailed surveys or samples of customer surveys taking longer to complete.

2.2.3.3 Whom Do Surveys Target?

Site surveys tend to target community leaders and, at times, a representative sample of the general population within the community. Surveys may also target potential productive users of electricity. Developers differed in how they target potential customers to survey during site surveys. Most developers who also interview individual customers take a two-phased approach. They conduct site surveys first, and they do not return to the site to interview individual potential customers until after they create a short list to identify the most promising sites. One developer stated that, for particularly promising sites, customer surveys could take place at the same time as the site visit, though this is not the standard practice. A

couple of developers stated that they perform customer surveys for a sample of about 10% of the population during the site survey with the intent that it is roughly representative of the population.

2.2.3.4 Timing in Development Process

Analysis of GIS data to identify promising regions and communities is typically the initial step in site identification. The GIS screening narrows the list of potential sites. Site surveys are often the next step in the development process and contacting people in the community to conduct the survey connects the developer to the community.

2.2.4 Analysis Techniques

The initial GIS data combined with site survey data, whether obtained via formal survey or informal conversation, provide developers with critical pieces of necessary information to determine if a site should be developed. None of the developers pointed to a formal analysis technique to make final siting decisions. All pointed to combining the collected data with more subjective data and their experienced judgment to arrive at decisions to move forward at particular sites.

The collected site information combined with other development information obtained through discussion with government officials, regulators, investors, financiers, and other stakeholders enables the experienced developer to analyze and weigh the potential suitability of one site compared with another. Some of the collected data will have minimum thresholds for a developer, but there will also be subjective weighting assigned to numerous factors, such as comparing sites based on their perceived level of and potential for economic activity, which is assumed to be tied to electricity consumption and ability to pay for energy services. Final siting decisions are made combining the more objective data collected with the more subjective developer experience and intuition.

2.2.5 Lessons Learned

There is not a large enough sample of micro-grid sites with available site survey and assessment data to be able to draw firm conclusions on the relative performance of different approaches to identifying successful sites. However, each developer established their respective site survey methods based on their own rationale and micro-grid development experience. Approaches span a spectrum from very formal and structured to informal and unstructured. Reasons for taking a less formal approach include skepticism in the accuracy of survey data, resource constraints, and a belief that structured surveys are too impersonal and make respondents uneasy. Some developers taking an informal and unstructured approach believe that this method makes respondents more comfortable and helps build a relationship with the community, which is an important, though not necessarily quantifiable, micro-grid development factor. Several developers have started with unstructured approaches and as they have grown, they have transitioned to more structured and sophisticated data collection and analysis. This could indicate that as scale increases, developers see more need and value in standardized approaches that allow them to more easily scale.

The downside to the informal approach is that data collection is not uniform, which makes it difficult to analyze in a systematic framework and apply lessons to future projects. Analysis tends to become more subjective and can be influenced by analyst bias. More structured surveys provide developers with a common set of data on which to judge and rank sites. They can then use a more systematic analysis of data to come to more objective conclusions about which types of sites tend to be successful and the factors that determine that success. Both approaches have their merits, and developers operate with elements from both approaches, though they may favor one over the other. A balanced approach to collect data may permit objective analyses while respecting the human elements of the development process.

2.3 Customer Application Surveys

Developers sometimes perform customer application surveys with individual prospective customers before constructing a micro-grid. These surveys are less universally performed than site surveys; however, two developers do conduct structured, formal surveys of all potential customers. Others survey only a sample of potential customers, and some do not perform customer surveys at all. The primary purpose of these surveys tends to be to screen customers for connections, to estimate demand for electricity, and to collect information used for system design. One developer indicated that it had conducted customer surveys to serve as a baseline for future impact assessment, though follow-up surveys never occurred.

2.3.1 Data Collected

The two developers that conduct formal, structured customer surveys collect similar data, though the timing of the surveys differs. Information is collected about the nature of the connection (whether business or residential) and the coordinates of the building to be connected. For residential connections, data are collected on household demographics, such as the number of residents in different age groups, occupation and sources of income, assets, education level, the size and quality of construction of the home, modes of transportation, and current energy uses/sources. Business connections are asked questions about the nature of their business, current energy uses/sources, income, assets, and the quality of construction of the business premises. One of the developers also asks about electrical appliances that potential customers intend to acquire.

Those developers with less formal customer surveys tend to seek to identify the type of connection, general household demographics, current energy sources, and end-uses. However, this information is not always collected systematically and may target only a sample of potential customers. One developer reported sampling a subset of customers and taking a physical inventory of electrical appliances and energy sources. This developer operates in a region where using diesel generators is common and, therefore, targets customers already accustomed to using electrical energy.

2.3.2 Collection Methods

Developers report using survey teams of 2–3 people for customer surveys. Only one developer reported having a dedicated survey team. Other developers use non-specialized employees to conduct surveys, though one developer acknowledged the advantage of having a team trained specifically to carry out survey work. A couple of developers reported carrying out surveys in cooperation with external organizations that provided enumerators, though these were not customer application surveys.

The majority of developers carrying out customer surveys report using smartphone or tablet apps to collect data. Surveys are designed on a computer and loaded into an app that guides enumerators through the survey and provides a platform to enter open responses or select from predetermined response options. Data are stored locally on the device and uploaded to the cloud later. Data can then be downloaded from any internet-connected device in tabular form.

Some survey tools are also capable of automatically logging coordinates and cellular signal strength, which is used during system design. Three developers reported collecting data with manually written notes or voice recordings. One has abandoned this practice, and another plans to transition to a digital survey tool. The developer that did not report a transition to digital survey tools expressed concern that such formal survey tools make respondents uncomfortable and detract from building relationships with communities. Handwritten notes and recordings are later transcribed, digitized, and stored electronically.

2.3.3 Logistic and Financial Considerations

As with site surveys, the remote location of micro-grid sites presents logistical and cost barriers. Cost of collection, weighed against the value that developers place on the data collected, has deterred some micro-grid companies from collecting customer-level data.

2.3.3.1 Cost of Running Customer Application Surveys

As with site surveys, most developers do not track the costs of their customer application surveys. Costs are driven more by logistics than the cost of labor, which is relatively low. To keep costs low, some developers report using contract workers to conduct surveys, supervised by regular employees.

The East African developer with a dedicated survey team reports the cost of customer surveys at $3 per customer. Customer surveys that target all potential customers can take several days to complete. The survey team of 2–3 surveyors travels by public transportation for customer surveys. This adds significant travel time but, because labor costs are low, this is less costly than paying for private transportation. Typically, several communities in a region would be targeted for survey on the same trip. Through training to improve the efficiency of surveyors, they report reducing the cost of customer surveys from $10–$15 per customer initially to only $3 at present. Another developer with a formal survey program reported customer survey costs of $200 per site, though the actual number of customers surveyed was not clear.

2.3.3.2 Time Required for Surveys

The developers with formal customer survey programs report similar time requirements: about 30 minutes per customer. There is a desire to reduce the length of surveys by assessing which questions produce the most useful information to reduce time and cost requirements. Some developers report that finding potential residential customers at home to complete surveys is challenging. Therefore, as a time-saving measure, a developer reported collecting contact details of potential customers when the survey team arrives in the community to make an appointment to conduct the survey.

2.3.3.3 Whom Do Surveys Target?

Only two of the developers—those with formal surveys—attempt to conduct a census of potential customers. Other developers rely on a representative sample of the population of potential customers to reduce survey time and cost while still obtaining meaningful data. Productive users may be targeted with a different survey to better understand their power needs.

2.3.3.4 Timing in Development Process

In general, developers conduct customer application surveys after carrying out a site survey and short-listing the community for a micro-grid. This avoids wasted costs in surveying communities that are not targeted for development, but it does require an additional trip to the site. Two developers report conducting a sample of customer surveys during the site survey, with one making on-the-ground judgments about whether surveying customers is worthwhile. The two developers with formal surveys differ slightly in approach. One developer conducts full customer application surveys in a single visit. The other conducts a short application survey before construction, asking only for basic information such as the connection location and type, names, and contact information. More comprehensive surveys are conducted during the installation process. In general, there are different points of view on when to conduct customer surveys relative to the timing of decisions to build a micro-grid in a community. Customer application surveys are expensive to conduct; however, they can provide valuable information on the viability of a site. If developers conduct customer surveys after deciding to build at a site, good sites may be overlooked. If they conduct surveys before the decision, money may be wasted surveying sites that are not selected. Surveying a sample of customers during site visits presents a middle ground.

2.3.4 Analysis Techniques

The sophistication of the analysis performed on customer survey data varies depending on the type and depth of data collected. Developers collecting formal survey data have both conducted quantitative analysis relating customer data to subsequent electricity consumption to ascertain which customer characteristics are correlated to electricity demand. They can also use these techniques to make quantitative predictions. Developers with less comprehensive surveys tend to take an inventory-based approach, whereby electricity demand is estimated by making assumptions on which appliances customers will use, their power ratings, and their duration of use. These assumptions may be based on data collected from potential customers on their current and intended use of electricity. For developers with operating data, historical energy use from existing customers may inform these estimates. Developers and recent studies have shown that customers are not good at predicting their own energy use behavior; as a result, the inventory method tends to overestimate electricity demand (Blodgett et al. 2017; Hartvigsson and Ahlgren 2018).

Customer coordinates are used to design the micro-grid reticulation network. Some developers estimate willingness and ability to pay using information reported by customers on current energy expenditure, though the methods applied are not rigorous and involve some amount of experience and intuition.

Analysis performed by those using less formal survey methods tends to be more qualitative. Those that do not perform customer surveys expressed skepticism in the feasibility of predicting electricity demand using survey data. Rather than attempting to predict electrical load, these developers tend to exert more control over how customers can use power and design their systems to be scalable to meet larger-than-expected electrical load growth.

In addition to estimating customer electrical demand, some developers use customer surveys to determine which customers to connect to the micro-grid. Micro-grid companies typically do not charge customers the full cost of connecting them to their system in an up-front connection fee. This means that they must recover this cost over time through tariffs charged for energy use. Connecting customers that use little or no energy therefore represents a financial loss. Approaches to customer screening vary. Generally, there is also a threshold distance beyond which developers will not connect customers. This threshold may be extended for customers if their expected electricity consumption justifies the additional cost of connection. One developer reported connecting all customers within range of the micro-grid. Four developers stated that they connect any customer that can demonstrate ability to pay by paying a connection fee or prepaying for a month of electricity service. Developers with more sophisticated surveys and analysis techniques have more nuanced criteria, particularly for customers that are more expensive to connect. Developers base the decisions on characteristics that they identified through surveys and electricity consumption data for existing customers that they correlated with high demand for electricity. These developers also charge upfront connection fees.

2.3.5 Lessons Learned

Developers tend to fall into two camps when it comes to using customer surveys to estimate electricity demand. Those using sophisticated survey tools apply quantitative methods to estimate demand and design systems to meet this demand. On the opposite end of the spectrum, developers that are skeptical about the ability of surveys to predict demand attempt to exert more control over electricity use and install minimal generation capacity initially with the ability to scale up, if necessary, after directly measuring demand. Each approach has its merits and limitations. Exerting control over consumption restricts the ways customers can use energy and installing capacity in phases will likely be more expensive than a single installation. On the other hand, this approach limits the risk of oversizing the system and reduces spending on unused capacity. Survey-based demand forecasting tools will never produce perfect

predictions, but they help developers design systems capable of meeting customer needs from Day 1. This comes at the cost of conducting detailed surveys.

There are several pitfalls to conducting surveys. Using inexperienced enumerators can lead to surveyor bias. Variances in how surveyors pose questions can lead to different interpretations of questions and different responses. Cultural practices and norms also come into play during the interview. Developers shared several anecdotes about instances of survey bias. For example, one developer noted that some male survey respondents are not comfortable being surveyed by females. Further, language barriers may be present in linguistically diverse African countries. Some respondents were observed demonstrating social desirability bias, exaggerating their education or social status, particularly in the presence of a spouse or peers. Others were observed providing false responses to answers based on their interpretation of the question's purpose. Respondents may also hide assets if they fear they may be used as collateral or exaggerate income and intended electricity use, because they believe it will improve their chances of receiving a connection.

Several developers also reported that respondents had difficulty answering questions with quantitative answers. Income, for example, is often not in the form of cash for subsistence farmers. It is also seasonal, based on agricultural cycles, and varies from year to year. Most farmers do not have a steady income and do not keep records. Expenditures are sometimes used as an alternative data point to income; however, respondents often have difficulty estimating these quantities as well. Multiple developers reported assisting respondents in making these estimations. For example, in trying to estimate expenditure on kerosene, an enumerator may ask how frequently a respondent purchases kerosene and in what quantity. Local prices for kerosene are easy to find, and with this information, the surveyor can estimate monthly expenditure on kerosene.

Developers must carefully phrase questions about intended electricity use to avoid aspirational responses. Respondents tend to list appliances that they would like to have rather than those that they could realistically acquire. They may simply lack information on the cost of appliances and, therefore, cannot accurately judge their ability to acquire them. One developer that does not conduct customer surveys expressed concern that when respondents do not understand questions, the surveyor will infer or suggest a response to complete the survey, leading to acquiescence bias.

2.4 Customer Satisfaction Surveys

All developers collect data after the start of operations on customer satisfaction, but few do so systematically. Regardless, the micro-grid developers interviewed demonstrated a customer-centric approach to their business. In contrast to many national utilities, micro-grid operators engage with their customers more frequently to provide high-quality service and seek out opportunities to enable customers to find more uses for electricity.

2.4.1 Data Collected

Most operators described ad hoc interviews to obtain specific information and informal discussions with customers about their satisfaction with the service received, how electricity access has affected their business and lifestyle, and how electricity services could be expanded to meet customer needs. Several developers have carried out surveys to obtain feedback from customers for a specific purpose. For example, several developers solicited information from customers on appliances they would like to acquire and their interest in participating in programs offering electrical appliances on credit. Developers conducting comprehensive customer surveys also draw on data from customer surveys about desired appliances to target such offers.

Two operators described a systematic and ongoing customer satisfaction survey program. One operator has two separate surveys: one is performed shortly after installation to request feedback on the installation process via SMS with subsequent monthly SMS surveys carried out asking customers to rate, on a scale from 1–5, their satisfaction with service received, whether they would recommend the company to others, the value received for money paid, and the reliability of electricity service. In the second survey, customers are asked to select from a list of barriers that prevent them from using more electricity and how their customer experience could be improved. The other operator using regular surveys collected information at the point of sale with an agent asking questions and registering responses on a smartphone. The operator asked customers what they like about the service received, what new services and appliances they would like to obtain, and how they feel about pricing.

2.4.2 Collection and Storage Methods

The operators collecting regular customer satisfaction data use more automated methods of data collection. One operator uses SMS surveys, and the other collects data via a smartphone app with data entered by a local agent at the point of sale. These data are aggregated via the mobile phone network and stored electronically.

Multiple operators described using regular village meetings as a platform to communicate and obtain feedback from customers. When more specific information is sought, some developers call customers on their mobile phones. Those operators using informal methods of data collection are opportunistic regarding when they collect data and they use site visits for other purposes to engage informally with customers. One operator reported sending questions to local operators to ask informally in the community when specific information is desired.

2.4.3 Logistic and Financial Considerations

Operators did not report specific costs for customer satisfaction surveys. Those operators taking a more opportunistic approach only incur a time cost. Those using mobile phone technology incur costs of data, SMS, and voice calls. Relative to site and customer surveys, the cost of collecting customer satisfaction data is low. Using mobile phone technology to collect data also reduces the logistic complexity of data collection, though the response rate may be lower than for in-person surveys.

2.4.4 Lessons Learned

Many of the operators interviewed only have a small number of pilot sites in operation, and therefore have not yet fully developed customer satisfaction programs. However, operators did express interest in developing tools to track customer satisfaction in a more systematic way. Developers that have already developed such tools have had success administering these surveys using mobile phone technology, be it via SMS, administered by a local agent using a smartphone app or by voice call.

2.5 Project Specific Socioeconomic Monitoring and Evaluation Surveys

Many micro-grid utilities tend to be socially motivated enterprises. Although many seek to earn a return on investment for their services, they also aim to positively impact the communities in which they operate. All developers expressed an interest in tracking the socioeconomic impacts of their services; however, no developers have established a formal self-directed nor independent socioeconomic monitoring and evaluation (M&E) program. A common view expressed is that although they would like to carry out such work, ensuring high-quality service and return on investment is a higher priority and the costs vs. benefit of carrying out socioeconomic M&E can be too high. Further, although common in some instances, in this limited sample size the operators did not report socioeconomic M&E requirements from their funders or other stakeholders. However, multiple developers said that they would be interested in

receiving support to carry out project specific socioeconomic M&E work, and they recognize there may be some value in collecting these data both for their own purposes and as a means of attracting additional investment from impact investors. The operators do, however, monitor business metrics such as the number of consumers, average revenue per user (ARPU) and electricity consumption. These metrics could be correlated to socioeconomic impacts and used as proxies.

2.5.1 Surveys and Productive Use

Most developers described targeting and attempting to create productive users of electricity. One developer is working with a nonprofit organization to provide training and financial support to local entrepreneurs to enable them to use electricity productively. During site and customer application surveys, several developers report administering surveys specifically for productive users. These surveys focus on the technical requirements of productive loads. This information is then used during system design to ensure that the micro-grid is designed to meet these requirements.

3 Surveys for Electrical Load Prediction

Effective surveys can provide very useful data for statistical analysis as well as insightful anecdotal information. Though the survey of developers was composed of a relatively small sample (eight developers), some objectives were to: learn about their survey approaches, discover how they use the survey data, and see if there are approaches on how to improve the surveys themselves or the reliability of energy consumption predictions based on statistical analyses of the data. To frame this, it may be best to look at larger-scale customer surveys that have been done and the statistical analyses approaches that have been employed to extract meaningful data for predictions from them.

3.1 Customer Surveys in Tanzania

Survey data are often used as a basis to predict the electrical load in potential micro-grid recipient communities. However, the methods of analysis vary significantly from developer to developer. A common approach is to take an inventory of current and expected future electric loads and consumer reported use/expected use patterns after connection. Blodgett et al. (2017) found this to result in large overestimates of consumption. It is not surprising that users who have never had a connection to electricity would have a difficult time predicting their own consumption. Further, Hartvigsson and Ahlgren (2018) found that consumers who already have a connection have difficulty estimating their consumption using the same method.

Other developers don't make quantitative predictions of electricity demand with their survey data; rather, they use customer characteristics to screen or classify customers by expected level of demand. A minority of developers have developed statistical models to relate pre-electrification customer characteristics, collected with surveys, to post electrification energy consumption. For these methods to be effective, surveys must capture customer characteristics that are correlated to electricity use. To understand which variables are useful in predicting electricity demand, survey and electricity consumption data were analyzed from 1,044 micro-grid customers in Tanzania.

The survey data were collected before micro-grid deployment using in-person interviews with potential micro-grid customers. Data were entered using a smartphone-based survey app, and questions were asked in Swahili by local enumerators. The data, summarized in Table A-1 in the appendix, includes questions about household composition, business activities, energy use and appliance ownership, household economic activities, assets and income, and transportation mode. Variables indicated by a category followed by "Other Low Frequency" are responses to a question with a categorical response for which the selected response represented less than 5% of total responses. Responses falling below the 5% threshold were grouped for building statistical models, because there is not sufficient data to estimate individual coefficients.

An indication of which variables are related to electricity demand can be obtained by looking at how survey responses correlate to energy consumed. Figure 1 shows the predictors with the top 15 highest correlation with average daily electricity consumption in the first 90 days since connection to the micro-grid. Positive correlation suggests for categorical variables that the presence of this characteristic is associated with higher electricity consumption. For quantitative variables, positive correlation suggests higher values of this variable tend to be associated with higher electricity consumption. Negative correlation suggests the opposite effect. Those reporting to have seasonal income fluctuations are positively correlated with electricity consumption, as are being a longtime resident in the community and occupying a structure made from well-built concrete or wood (which is used as a proxy for wealth). Transportation modes also feature strongly with positive correlation to electricity consumption; however, because all the possible responses are positively correlated, transportation modes do not provide significant information beyond the correlation that people with transportation modes other than walking use more electricity. Sleeping patterns also seem to be correlated with electricity consumption, which is

related to how much time people are active during the night when people tend to use electricity for lighting and entertainment. The strongest negative correlation is with falling into the lowest household income category. However, even higher reported income is negatively correlated to electricity demand. This is likely due to the fact that this income was only recorded for households, which generally use less energy than commercial customers. Commercial customers will therefore be recorded as not belonging to any of the income categories.

The highest average consumption among households are those for which no income category was assigned and those with income between 500,000 Tanzanian shilling (TSH) and 1 million TSH per year (approximately $225 United States dollars [USD] to $450 USD). It should also be emphasized that correlation does not imply causation, and high correlation does not necessarily mean a variable will be valuable for prediction. Variables are correlated not only with electricity consumption but also with one another, making it difficult to untangle which variables directly influence consumption and those that correlate to demand indirectly.

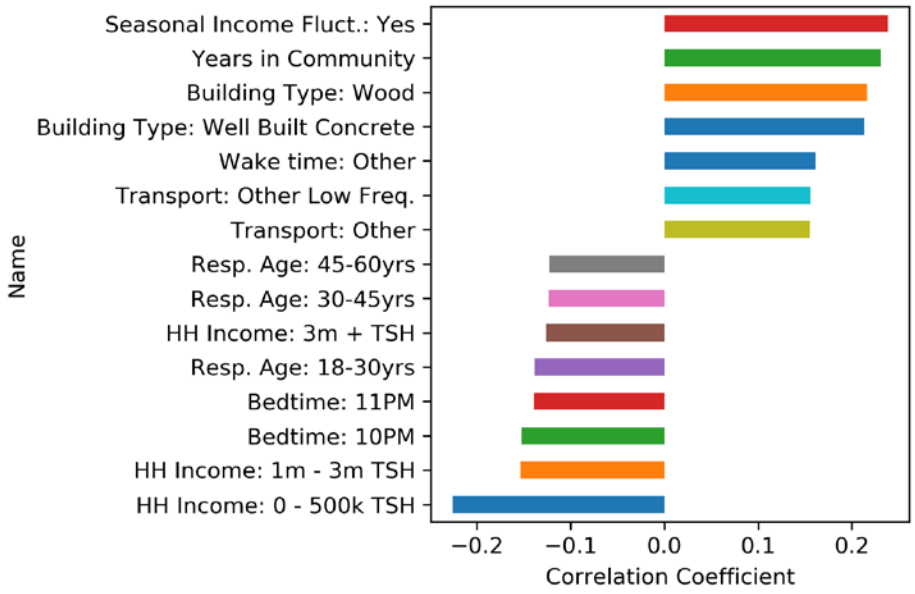

Figure 1. Correlation coefficients between survey variables and daily electricity consumption in first 90 days since connection to the micro-grid.

Note: Household (HH) income is for households only (1 USD = 2,250 TSH).

As noted, correlation by itself doesn't provide a full picture of which customer characteristics are helpful in predicting electricity demand. Many of the data collected are correlated with one another. Statistical models can help address this issue. Table 4 shows the variables selected using a Least Absolute Shrinkage and Selection Operator (LASSO) Poisson regression to model the relationship between electricity consumption in the first 3 months since connection to the 132 variables described in Table A-1 in the appendix, plus controls for tariff structure and price. The LASSO regression has the property that it performs variable selection, selecting the subset of predictors that produce the best predictions and using cross-validation to determine the model-tuning parameter (Tibshirani 1996). Table 4 shows the variables selected using LASSO regression to predict electricity demand for newly connected micro-grid customers as well as the sign of the coefficients. A positive coefficient means that the variable is positively correlated with electricity demand, whereas a negative coefficient shows negative correlation. Energy

sources, transport modes, pre-electrification appliance ownership, building type, connection class, and business type feature strongly.

Table 4. Variables Selected in LASSO Regression Model Including the Sign of Model Coefficients

Variable	Coefficient Sign
Diesel use: heat	+
Transport: other low frequency	+
Transport: boat	+
Gasoline use: electricity generation	+
Business type: bar	+
Building type: wood	+
Pre micro-grid appliances: other low frequency	+
Pre micro-grid appliances: high-watt TV	+
Pre micro-grid appliances: light bulb	+
Pre micro-grid appliances: low-watt TV	+
Business type: other	+
Business connection	+
Pre micro-grid appliances: other	+
Firewood use: cooking	-
Respondent employment: self-employed agriculture	-
Transport: bicycle	-
Energy source: firewood	-
Business type: restaurant	-
Home connection	-

Another method to analyze which variables are useful in reducing prediction error for electricity demand is the random forest model. Random forest models are tree-based, ensemble-learning techniques (Breiman 2001). Ensemble-learning techniques combine multiple learning algorithms to improve predictive performance. Variables in a random forest model can be ranked by "increase in node purity," which is a measure of how much predictions improve by including each variable in the model (Hastie et al. 2008). Figure 2 illustrates the most important variables for demand prediction using the random forest model as measured by increase in node purity. Here, importance is measured by the reduction in prediction error resulting from each variable. Like the LASSO, transport modes, pre-electrification appliances, connection/business type, and building type rank highly. The LASSO model performs better in predicting mean electricity consumption in the first 90 days after connection compared with the random forest model as measured by mean squared error. However, the random forest model is nonlinear and does a better job at identifying customers with high consumption, which is often an objective of customer surveys. By incorporating variables identified from both models, we balance the objective of accurate predictions and identification of high-use customers.

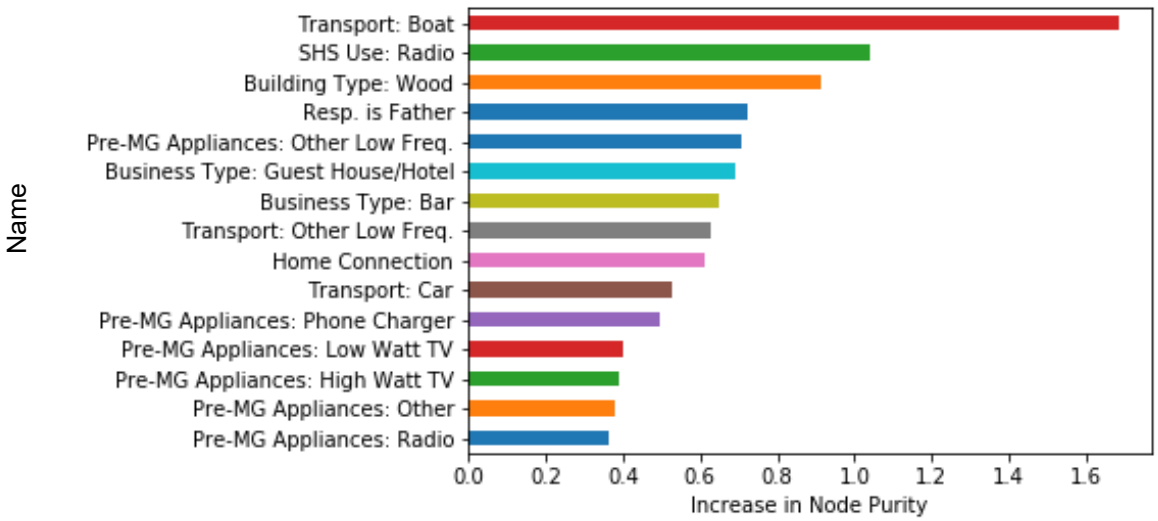

Figure 2. Random forest variable importance for electricity demand prediction.

Note: Higher importance indicates high reduction of prediction error from using the variable in the model.

Other work by Lee (2017), using data from 600 micro-grid customers in Tanzania and data from a survey containing 16 questions, found that building type, mobile phone expenditure, and customer type are significant predictors of electricity consumption.

Overall, our analysis suggests that questions on the following subjects are useful in predicting electrical loads for potential customer demand:

- Customer class (home, business, home/business, public premises): Businesses and home/businesses show higher potential energy usage.
- Nature of business: Not all businesses indicate a potential higher energy use profile, though bars (taverns) tend to show more energy use while restaurants show less.
- Employment status: Only those self-employed in the agriculture space show a negative correlation to energy usage.
- Current source of energy and uses: Generally, use of higher capacity electrical energy sources would provide an initial indication of higher electrical energy use, though only diesel power generation was identified as being a good indicator of higher energy use.
- Current mode of transport: Generally, the more advanced the transportation mode, the higher the energy use, boats, cars, and other transportation modes indicate higher energy use as compared with walking. It is possible that more advanced modes of transportation serve as a proxy for income or wealth.
- Appliances owned before micro-grid connection: The use of larger energy use appliances, as expected, provide a good indication of higher energy use following micro-grid interconnection.
- Building construction materials: Higher quality of construction materials is related to higher energy use.
- Mobile phone airtime spending: Although a direct correlation is not available, airtime spending is an indicator of higher disposable income, which would indicate the willingness to spend on additional services that were perceived as having value.

This set of characteristics could form the basis of surveys, with the objective of selecting high consumption electricity consumers or building models to predict electricity demand before connecting new customers. Table 5 presents a proposed set of survey questions that could be used in this manner to form the basis of customer screening surveys.

Table 5. Proposed Survey Questions for Electrical Load Estimation

Blue indicates correlation with high consumption, while red indicates correlation with low consumption.
What is the nature of this connection? Home, **Business**, **Home/Business**, Public Premises
If this is a business, what business activities are you involved in? **Restaurant**, **Bar**, Guest House/Hotel, Shop, Phone Charging, Other (could specify further options or leave for free entry)
If this is a home, what is the employment of the primary income earner in the home? Self-Employed Non-Agriculture, **Self-Employed Agriculture**, Employee, Unemployed, Other
What are your current sources of energy? **Firewood**, Battery, **Diesel**, Petrol, Kerosene, Propane, SHS
What modes of transportation do you own? **Bicycle**, Motorcycle, **Car**, **Boat**, **Other**
What electrical appliances do you already own? **Lights**, Phone Charger, Radio, **Television**, Sound System, CD/DVD Player, **Other**
What material is the house or structure where you are seeking a connection made from? (could be observed rather than asked) Brick, Crumbling Concrete, **Well-Built Concrete**, **Wood**, Other
In a typical week, how much money do you spend on mobile phone airtime?

4 Best Practices

This section of the report presents best practices for survey methodologies applied to micro-grids, drawing practical insights from the experiences of the developers that participated in this study. This section is divided into three survey phases: design, implementation, and analysis.

4.1 Survey Design

Careful survey design is crucial to ensure that questions are phrased in a way the respondents interpret correctly and provide the developer with the desired information. This starts with clearly defining survey objectives, identifying data required to achieve these objectives, and crafting good questions that avoid, as much as possible, common sources of response bias.

This report and previous research indicate that taking the time to properly develop a survey, including the consultation of professionals in survey development, and using staff specifically trained in proper survey techniques is very likely to improve the results and cost-effectiveness of the entire process.

4.1.1 Writing Questions

Survey data are less useful when respondents do not understand and respond to questions in an accurate and consistent manner. Survey questions should be written in simple, precise, and non-technical language that respondents will interpret accurately and consistently. It is important that questions be specific about what they are asking to avoid ambiguity. For example, in asking about income, it may be unclear to respondents if non-cash income or food farmed for self-consumption is to be included. The question should be specific in defining the information that is being requested.

A good practice includes closed-ended questions that permit respondents to select answers from a closed set of possible responses and require a response. The question can be partially opened by including an "other" response option and free entry of text where none of the predefined responses is a match. This makes it clear that the data are not missing, though a response to the question did not fall under any of the predefined options. Where possible, questions should be written and asked in the language in which the respondent is most comfortable and pretested with trained enumerators and respondents from the target population.

Pretesting is the process of trying out survey questions to ensure that they are understood and interpreted as intended by respondents. Although this requires an additional investment in time and finances, it is a small investment compared with the cost of finding out after a large-scale survey that a question was not well-thought-out and did not provide reliable data. Effective survey questions have a higher likelihood of being reused in subsequent surveys, so the initial expense can yield significant dividends over time.

4.1.2 Sources of Bias

There are various forms of response bias that can result in inaccurate survey responses. Many of these forms of bias were reported by developers during interviews. Pretesting can be used to identify and mitigate response bias.

4.1.2.1 Social Desirability Bias

Several developers reported social desirability bias. This form of bias occurs when respondents seek to paint themselves in a socially desirable light. One developer noted that the extent of this bias is dependent on the presence of peers and family when the interview is being conducted. The developer observed that male heads of household may exaggerate their level of education, for example, if their wife is present during the interview. Conducting interviews in a private setting may help reduce social desirability bias.

Written surveys also afford a level of privacy and anonymity that could reduce bias (Lavrakas 2008). In practice, written surveys may not be a viable option in areas with low literacy levels.

4.1.2.2 Acquiescence Response Bias

Acquiescence response bias occurs when respondents tend to reply positively to questions requesting confirmation. For example, asking if customers are satisfied with the level of service they receive may have a different result than asking customers if they are unsatisfied. One developer interviewed expressed concern about the prevalence of acquiescence response bias. In general, the best way to avoid this form of bias is to avoid using questions with yes/no or agree/disagree responses. In the former example, the question could instead ask customers to rate their experience on a scale of 1–5, with 5 being excellent and 1 being poor (Lavrakas 2008).

4.1.2.3 Primacy and Recency Effects

Closed-ended questions—those with a finite set of responses—are subject to primacy and recency effects. The mode of delivery of the survey affects which of these effects are prevalent. In orally delivered surveys, where response options are provided as a list, respondents tend to select the options they heard most recently, i.e., those at the end of the list. This is called the recency effect. On written surveys, where respondents read the options, the first answers on the list are more likely to be selected. This is called the primacy effect. Where questions do not have a natural order, randomizing the order of options across surveys may mitigate this effect (Lavrakas 2008).

4.1.2.4 Question Order Effects

The order in which survey questions are asked can have an effect on the responses provided by survey participants. Prior questions provide the context and mindset in which subsequent questions will be answered. Question order effects can be difficult to anticipate but can be studied using pretesting (Lavrakas 2008). The Harvard Program on Survey Research suggests that it is good practice to put easy questions at the beginning of the survey and save more difficult or sensitive questions, such as those about income, for the end of the questionnaire (Harrison 2007).

4.1.2.5 Misreporting

Several developers reported issues with respondents providing inaccurate responses as a way of manipulating the survey because of their perception of the purpose of the survey. For example, respondents who fear their assets will be used as collateral may underreport their quantity or value. On the other hand, respondents who believe their likelihood of receiving an electricity connection will be affected by their survey responses may exaggerate their income, assets, or other characteristics that they feel will improve their chances.

Misreporting may also occur because respondents simply do not know the answers to questions. A common concern expressed in interviews with developers was that respondents have a very difficult time giving accurate quantitative responses to questions about income, expenditures, and energy use. Respondents may not keep track of these values, or it may simply be unclear what is being asked. For example, does income refer only to cash income, or does the value of crops harvested by subsistence farmers for their own consumption count? It is important to craft narrow questions that will be interpreted uniformly by respondents. Several developers have reported that they find it useful to break down questions about quantitative values, such as income or energy expenditure, into smaller pieces to help respondents estimate accurate answers. An example of walking through the steps to estimate expenditure on kerosene was provided in the previous section on Customer Application Lessons Learned.

4.1.3 Survey Length

Several developers expressed concerns about respondent fatigue resulting from long survey interviews during which respondents may become bored or tired of answering questions. This can cause respondents to provide incomplete or short responses in an effort to bring the exercise to an end. Respondent fatigue is exacerbated by complex, repetitive, or open-ended questions. Further, longer surveys are more expensive and time-consuming to administer. One of the reasons that some developers have deployed long surveys is that they do not know exactly which information will be useful for their objectives, such as selecting sites, screening customers, and estimating electricity demand. Some developers have now collected enough data to start assessing which data are in fact useful for these purposes. In the Surveys for Electrical Load Prediction section, for example, we performed an analysis of which variables are most effective in predicting future electricity consumption. The results of this analysis can be used to streamline future surveys used for demand prediction.

It is also often good to have an "I don't know" response option so respondents don't feel obligated to provide potentially inaccurate information. If no response to a question is applicable, an "other" or "not applicable" response ensures that data are complete.

4.2 Survey Implementation

It is important that surveys be administered in a consistent manner. Standardized surveys ensure consistency by requiring surveyors to stick to a predefined script. This mechanical approach ensures uniform implementation; however, the rigidity precludes enumerators from using their judgment to clarify questions and provide guidance to respondents that is off script. Further, developers rightly pointed out that surveys are often a company's first contact with customers and communities. Overly rigid surveys may act counter to objectives to build good relationships with communities and future customers. It may also make customers uncomfortable to be asked personal questions by outsiders. Ultimately, survey implementation must balance the dual objectives of gathering accurate data and building trust and goodwill in communities.

Well-trained and experienced survey enumerators are important to ensure that interviews are conducted in a consistent manner. Multiple developers expressed concern about forms of interviewer bias, some of which can be addressed through proper training. One concern expressed by a developer was that interviewers may anticipate answers from respondents and ask questions in a manner that introduces acquiescence bias or lead respondents to an answer. This can be addressed by proper training of surveyors and is particularly important when using non-standardized surveys. Surveyors must be trained to understand the purpose of questions so that they can help respondents understand what is being asked while not suggesting or inferring answers.

Gender- and cultural-based interviewer effects were also raised by study participants. One developer pointed out that in conservative communities, males may be uncomfortable being interviewed by females. Further, developers noted that some respondents were uncomfortable answering questions from enumerators from outside their cultural, ethnic, or racial group, particularly when responding in a language in which they may not be completely comfortable. Using surveyors who are from the area or familiar with the language, culture, and customs of the target community makes respondents more comfortable in their survey experience and avoids miscommunication. This includes respecting local gender norms.

For in-person surveys, many developers interviewed implement their surveys using tablet/smartphone-based survey apps. These tools allow survey designers to create interactive custom surveys that permit both closed- and open-ended questions and can branch into different subsurveys for different customer classes (where, for example, some questions may only apply to a home or to a business). Further, these

applications allow data to be collected offline and uploaded to the cloud when connected to the internet. A major benefit of using these apps is that it standardizes the formatting of data and automatically compiles data into a tabular format. This greatly increases the efficiency of data entry, cleaning, and preparation for analysis. Some of the analysis tools developers report using include droidSURVEY and KoBoToolbox.

In-person interviews can be more expensive to implement than via telephone and are often carried out at early development stages. Contact information of customers and potential customers is often collected during these in-person interviews. Mobile phone numbers allow developers and operators to communicate more readily and affordably with customers. Both voice calls and SMS can be used to collect data from customers over the phone, though they may have lower response rates than in-person interviews.

Ensuring that surveys, or at least a core number of key questions, remain consistent will allow consideration of answers across projects, time, and geographical region. This consistency will allow expanded learning that may lead to improved survey techniques and more accurate load assessments, both of which will improve the reliability of results, lower project risk, and improve the life cycle costs of micro-grid power systems.

4.3 Survey Analysis

Survey analysis methods will vary depending on the type of data being used and the objectives of the analysis. However, decisions made during the survey design and implementation phases can make the analyses easier. These measures generally hinge on ensuring that the data generated are standardized and easy to interpret.

Creating customer identifications or collecting other data, with which data from different sources can be linked to individual customers, will facilitate analysis across data sources. For example, it may be useful to analyze customer meter data in conjunction with survey data containing customer characteristics or to link customer satisfaction data with payment transaction records. This can be difficult to do after data have been collected. This an example of how advanced planning for data collection can help facilitate the integration of different databases to extract meaningful data or causal linkages between data, even when collected in disparate time frames or repositories.

5 Conclusions

The use of surveys in micro-grid development is common in Africa; however, the objectives, implementation, and scope of surveys varies widely within the sector. This document presents a review of current survey practices and lessons learned from a diverse group of eight micro-grid developers currently operating in Africa. The document helps to develop a level of standardization in survey practices and data collection in the sector, which will lend itself to more consistent predictive analyses based on the collected survey data.

Based on the results of this work, it was found that surveys generally fall into five categories:

- Market research
- Site selection
- Customer applications
- Customer satisfaction
- Socioeconomic monitoring and evaluation.

First, not all developers perform surveys to gather this information, and approaches vary widely from informal and unstructured interviews to formal, structured surveys. Both of these approaches have merits that are laid out in this document.

Second, a review of statistical analyses approaches to customer surveys conducted in Tanzania provided a view of the uses and potential benefits of using survey data for predictive electrical load purposes in micro-grid siting and design applications.

Finally, a further aim of this document has been to develop a set of best practices for micro-grid surveys based on insights from developers in Africa with valuable on-the-ground experience as well as established survey practices drawn from the literature. These include:

- Given the breadth of survey work undertaken across the industry, the level of data collection needed to meet specific business or national energy access actions should be clearly understood and defined early.
- Depending on the type of analysis to be performed, a balance must be struck between structured surveys that produce easy-to-analyze and standardized data, and informal interviews that allow respondents to express themselves more freely and build trust and relationships.
- Surveys that are developed with a solid understanding of proper survey techniques and potential sources of survey bias will yield much more accurate results.
- Use of closed-ended questions will ease analysis of data using computational software. Inclusion of response options such as “other,” “not applicable,” or “I don’t know” will help ensure that survey data are complete and accurate.
- Surveys should be developed using current understanding of what information and which questions are more likely to provide accurate representations of expected energy usage, such as those provided in Figure 2.
- Because estimation of income from respondents can be difficult to determine and subject to bias, proxies of wealth such as household building materials, transportation modes, and expenditures on wireless services may be better measures with which to estimate eventual energy usage.

- To the extent possible, surveys should be conducted using mobile device-based assessment tools using clear survey instruments, limiting potential enumerator error, and allowing simplified data entry, storage, and analysis.
- To the extent possible, well-trained and experienced survey enumerators who are fluent in the local language, have experience in energy issues, and understand potential cultural sensitivities should be used.
- Although there is no defined standard and it is expected that survey instruments will change based on specific project needs, incorporating a set of standard questions in all surveys to allow comparison across projects at installation and early years of operation will be more valuable over time.

Finally, based on analysis of more than 1,000 micro-grid customers in Tanzania and in an effort to provide guidance on what kinds of data are useful in predicting demand for electricity among new customers. This work proposes a set of survey questions, that can be found in the appendix, that could form the basis of a model customer survey.

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Appendix

Although it is understood that each survey may be tailored to a specific set of informational needs, the following list of questions provides a good overview of questions that should be included. Questions that should form a basis for electrical load estimation surveys are **bolded**, these include both basic demographic questions that are necessary for further follow up and system design, as well as questions that best support load prediction.

Table A-1. Summary of Customer Application Survey Questions and Response Options

Questions	Response Codes
General Information	
Household contact	**Name of respondent**
Connection unique identifier	**Identifier should include very unique information that will not be repeated by another potential user**
Location of respondent connection	**GPS location of connection**
Consumer contact information	**Respondent phone number or other contact information**
Connection type	**Home connection**
	Home/business connection
	Business connection
	Other connection
Household Respondent Demographics	
Years lived in community	**Years in community**
Household role of respondent	**Respondent is father**
	Respondent is mother
	Respondent is other
Gender of respondent	Respondent is female
	Respondent is male
Marital status of respondent	Respondent is married
	Respondent is single
	Respondent marital status is other
Age of respondent	Respondent age: 18–30 years
	Respondent age: 30–45 years
	Respondent age: 45–60 years
	Respondent age: other
Education level of respondent	Respondent education: some primary
	Respondent education: primary
	Respondent education: some secondary
	Respondent education: secondary

Table A-1. Summary of Customer Application Survey Questions and Response Options	
	Respondent education: university
	Respondent education: other
Employment status of respondent	**Respondent employment: employee**
	Respondent employment: self-employed agriculture
	Respondent employment: self-employed nonagriculture
	Respondent employment: other
Occupation of respondent	Respondent occupation: business person
	Respondent occupation: commercial farmer
	Respondent occupation: subsistence farmer
	Respondent occupation: teacher
	Respondent occupation: other low frequency Includes: nonfarm laborer, doctor, police, nurse, public official, military
	Respondent occupation: other
Household Information	
Number of people in household (HH)	People in HH
Number of people employed in household	Number employed in HH
Number of children under 18 in household	Children in HH
Number of children attending school in household	Children in HH
Average daily hours of study for children	Daily study hours
Number of infants in household	Infants in HH
Number of rooms in home	Rooms in home
Number of sleeping rooms in home	Bedrooms in home
Normal bedtime	**Bedtime: 9 p.m.**
	Bedtime: 10 p.m.
	Bedtime: 11 p.m.
	Bedtime: Other
Normal wake time	**Wake time: 5 a.m.**
	Wake time: 6 a.m.
	Wake time: Other
Annual household income	Income: 0–500,000 TSH
	Income: 500,000–1 million TSH
	Income: 1 million–3 million TSH
	Income: 3 million+ TSH
Does income fluctuate seasonally?	**Seasonal income fluctuation: no**

Table A-1. Summary of Customer Application Survey Questions and Response Options	
	Seasonal income fluctuation: yes
Business Information	
Nature of business	**Business type: bar**
	Business type: guest house/hotel
	Business type: shop
	Business type: phone charging
	Business type: restaurant
	Business type: other low frequency **Includes: agrovet, butcher, chemist/pharmacy, church, mosque, clinic/dispensary, kinyozi/salon, milling, office, school, video hall, other**
	Business type: other
Building Characteristics	
Construction material of building	**Building type: brick**
	Building type: old/crumbling concrete
	Building type: well-built concrete
	Building type: wood
	Building type: other
Ownership status of building	Building ownership: own
	Building ownership: renting
	Building ownership: other
Energy Sources and Uses	
Electrical appliances owned before micro-grid	**Pre micro-grid appliances: none**
	Pre micro-grid appliances: CD/DVD player
	Pre micro-grid appliances: high watt TV
	Pre micro-grid appliances: light bulb
	Pre micro-grid appliances: low watt TV
	Pre micro-grid appliances: phone charger
	Pre micro-grid appliances: radio
	Pre micro-grid appliances: sound system
	Pre micro-grid appliances: other low frequency **Includes: satellite TV receiver, printer/copier, computer, shaver/clippers, microwave, refrigerator, other**
	Pre micro-grid appliances: other
Appliance planned to be acquired	Planned appliances: CD/DVD player

Table A-1. Summary of Customer Application Survey Questions and Response Options	
	Planned appliances: computer
	Planned appliances: electric iron
	Planned appliances: light bulb
	Planned appliances: low watt TV
	Planned appliances: phone charger
	Planned appliances: radio
	Planned appliances: refrigerator
	Planned appliances: sound system
	Planned appliances: other low frequency
	Planned appliances: other Includes: none, high watt TV, printer/copier, shaver, hair clippers, microwave, hair dryer, other
Is firewood used as an energy source?	**Energy source: firewood**
If yes, how is it used?	Firewood use: cooking
	Firewood use: heat
	Firewood use: other
Is a solar home system (SHS) used as an energy source?	Energy source: SHS
If yes, how is it used?	SHS use: electricity
	SHS use: lighting
	SHS use: phone charging
	SHS use: radio
	SHS use: television
	SHS use: other
Are propane, diesel, petrol, kerosene, or batteries used as an energy source?	**Energy source: other low frequency** **Includes: propane, diesel, petrol, kerosene, batteries**
If yes, how are they used?	**Propane use: cooking**
	Gasoline use: cooking
	Gasoline use: electricity gen.
	Battery use: electricity
	Battery use: lighting
	Battery use: television
	Battery use: phone charging
	Battery use: radio
	Battery use: other
	Diesel use: electricity gen.
	Diesel use: heat
	Diesel use: lighting

Table A-1. Summary of Customer Application Survey Questions and Response Options	
	Diesel use: other
	Kerosene use: lighting
	Kerosene use: other
Are other energy sources used?	**Energy source: other**
If yes, how are they used?	Other source: cooking
	Other source: lighting
	Other source: phone charging
	Other source: radio
	Other source: television
	Other source: other low frequency Includes: electricity, heat, fan
	Other source: other
What source of energy is used for cooking?	Cooking source: firewood
	Cooking source: other
What modes of transportation are owned/used?	**Transport: bicycle**
	Transport: car
	Transport: motorcycle
	Transport: boat
	Transport: other low frequency **Includes: animal cart, truck**
	Transport: other

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