Experimentation in Product Evaluation:

The Case of Solar Lanterns in Uganda, Africa

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Comprehensive Initiative on Technology Evaluation (CITE)

Massachusetts Institute of Technology (MIT)

Contents

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Executive Summary

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Introduction

Given the recent proliferation of small-scale technologies for individual and household use in the developing world, the Comprehensive Initiative on Technology Evaluation (CITE) at MIT was established to develop a comparative evaluation methodology to differentiate between these products. Drawing on a broad cross-section of faculty, researchers, and students from the Department of Mechanical Engineering, the Department of Urban Studies and Planning, the Engineering Systems Division, the Sloan School of Management, and D-Lab, the CITE team investigates three principle dimensions of a product:

- Suitability (the ability of the product to perform its intended purpose)
- Scalability (the capability of the supply chain to scale up at an effective cost as demand increases), and
- Sustainability (the likelihood that product use will be sustained given the social, economic, and environmental context)

During its first year of inception, CITE experimented with measurements to assess these three dimensions of evaluation (the 3S's) using the case of the solar lantern product family in Uganda. What follows are: key tenets of the originally proposed methodology; its application to the pilot product family and context; learning outcomes; and proposed changes for the next round of product evaluation.

Sunrise in Fort Portal in western Uganda, one of Solar Sister's regional hubs.
Photo taken by Jonars Spielberg.

Evaluation 1: Solar Lanterns

Product Family Selection and the Ugandan Context

CITE selected personal-use solar lanterns as the first product family for evaluation because of their widespread use in the developing world and potential impact on key development outcomes. Solar lanterns are relevant in many parts of the developing world that have low or unreliable electrical coverage; they also provide a more affordable alternative to electricity for low-income households.

CITE's choice of Uganda as the setting for the first product evaluation was determined jointly with the U.S. Agency for International Development (USAID) to learn from its existing partnership with Solar Sister, a social enterprise operating in Uganda. Also, MIT and Makerere University (based in Uganda) are both members of the Higher Education Solutions Network (HESN) created by USAID.

According to World Bank indicators, approximately 84 percent of the Ugandan population lives in rural areas [1], where access to power infrastructure is limited and unreliable, and the country's electrification rate is low (15 percent) as compared to the average across sub-Saharan African nations (31.8 percent).[2] Solar lanterns were introduced in the past five years to reach a large portion of the population and thereby have a significant effect on the well-being of Ugandan households. However, solar lanterns are not yet widely available in local markets. Solar Sister, an NGO, addresses this problem by creating a network of women to serve as for-profit sales agents of solar lanterns in their communities.

Evaluation Methodology and Its First Application: Solar Lanterns

CITE's goal was to create a comparative framework for evaluation of products, similar to the model used by the U.S. nonprofit organization Consumer Reports. Prior to conducting fieldwork in Uganda, each of the three "S" teams (i.e. Suitability, Scalability, and Sustainability) had developed preliminary evaluation methodologies to analyze the solar lantern product family. While the Consumer Reports approach mapped easily onto the "suitability" dimension of a product, it proved difficult to adapt to the "scalability" and "sustainability" dimensions; hence, these two dimensions were explored through other evaluation techniques. Students and faculty collected data on 11 solar lantern models from both field and laboratory tests, as well as through interviews, surveys, and participant observation of product users and Solar Sister distribution agents.

The following table summarizes the methodology, application and evaluation outcome of each product dimension.

[1] World Bank, World DataBank World Development Indicators, 2013. (http://databank.worldbank.org/data/views/reports/tableview.aspx)

[2] International Energy Agency, World Energy Outlook, 2013. (http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/)

Table 1-1. Summary of the methodology, pilot application, and evaluation of a product's dimensions.

	Methodology	Pilot Application: Solar Lanterns	Evaluation Outcome
Global	Define product family comparative evaluation methodology	Examination of personal/household use of solar lanterns of differing varieties and brands in Uganda	Identification of methodological strengths, weakness, and challenges
Suitability	Define key product attributes that affect technical suitability; scientifically measure key attributes of multiple products within a family	Definition of solar lantern attributes, laboratory and in situ tests of 11 models and 60 surveys of existing users	Comparative solar lantern suitability rating chart
Scalability	Evaluate the supply chain established by the product's original equipment manufacturer (OEM) in five areas: procurement, production, distribution, sales channels, and aftermarket support	Investigation of features and attributes of the supply chains of solar lantern OEMs for the Ugandan market using primary and secondary sources	Comparative attribute and feature assessment of three of the five solar lantern OEMs that operate in Uganda
Sustainability	Define criteria for assessing product sustainability (social, economic, and environmental); conduct "deep dive" studies; and model four subsystems: user, technical, supply, and change agent	Participant observation over a six-week period and 102 structured interviews regarding the product diffusion organization Solar Sister	Identification and assessment of the Solar Sister product diffusion strategy

The findings from the solar lantern evaluation represent the characteristics of specific solar lantern models examined at one point in time in Uganda. However, these specific findings can lead to general concepts that can be translated to a wide variety of products and locations. For instance, the effect of transportation costs on product scalability (high transportation costs present a barrier to scaling up innovations) and the need for a financially sustainable business model (which Solar Sister currently lacks) are both findings that are relevant to the success of any technology designed for use in developing countries. These generalizable findings also inform the ongoing development of CITE's product evaluation methodology.

Key Learning Outcomes

The experience of applying the 3S methodologies to the solar lantern product family suggests modifications for future product evaluations. Key learning outcomes are:

1. **CITE's global methodology:** Practical boundary conditions, such as the time and budget necessary to create and implement evaluation metrics, need to be taken into account to create a widely replicable evaluation methodology.

2. **CITE's global target audience:** Even though each of the 3S dimensions may be of interest to different stakeholders, CITE may need to narrow the target audience for future product evaluations to maximize impact. For example, the "Scalability" and "Sustainability" teams evaluated product attributes important for donors, implementing agencies, and the private sector, whereas the "Suitability" team created an evaluation applicable to these audiences as well as to end users. Rather than addressing all product stakeholders' needs, CITE may need to focus on the needs of key groups.

3. **Suitability dimension:** The way that product attributes important to end users are analyzed in developed-world laboratories may not capture well the preferences of users in the developing world. For example, CITE learned through user surveys that the ability of a lantern to charge a cell phone may be more important to some users than how well the lantern produces light.

4. **Scalability dimension:** Maintaining an arms-length relationship with the organizations in a product's supply chain while simultaneously studying those same organizations does not yield the kind of information necessary to evaluate scalability. CITE could not obtain the information necessary to conduct rigorous evaluations of solar lantern scalability without deeply engaging with the organizations comprising the supply chain.

5. **Sustainability dimension:** Even though program-implementing agencies and their specific diffusion strategies affect the product's social sustainability, in future evaluations CITE will focus on the product as the central unit of analysis to assess social, environmental and economic sustainability. Understanding how Solar Sister operates was necessary for assessing the organizational sustainability of how products reach the end user; however, that effort shifted the evaluation focus from the product to the program-implementing organization.

Considerations for Subsequent Product Evaluations

Evaluating solar lanterns was a fruitful learning experience, but the task revealed the conceptual challenges CITE faces in creating an integrated methodology for a large, interdisciplinary research project. In particular, CITE will need to consider the following five challenges in planning the next product evaluation.

The Role of Context

The solar lantern evaluation demonstrated good use of technical metrics for product evaluation, but its generalizability is constrained by the specificities of the Ugandan context. Unlike the Consumer Reports model, which had inspired CITE, the first evaluation revealed that CITE faces the critical challenge of how to incorporate contextual variables, such as geographical and locational specificities, climatic peculiarities, political conditions, and particular program implementation patterns, in any rigorous evaluation.

As CITE proceeds with future evaluations, each of the 3S teams will identify key contextual variables that are most likely to affect evaluations in the future. CITE plans to partner with multiple organizations to generate rich data to better understand local context and ultimately distinguish between local particularities and generalizable criteria for evaluation.

Product Demand Estimation

The evaluation of solar lanterns did not directly address the issue of product demand. Even though demand estimation is not central to CITE's program goal, it did emerge as a critical variable for understanding why some products were more or less scalable and/or sustainable than others. Therefore, the question is: What is the optimum way to take into account product demand in CITE's overall evaluation?

As the 3S dimension teams revise their methodologies for the second product evaluation, they will address which variables affect product demand. Economic affordability, which considers both product price and a consumer's ability or willingness to pay, is one example of the kind of assessment criteria CITE will investigate by drawing on socio-demographic data, product user surveys, trips by anonymous shoppers, and other methods. Such an analysis will ultimately identify barriers to adoption and scale.

A better understanding of which characteristics and attributes of any product have the greatest influence on user demand requires a modified strategy for consideration of authentic user concerns. As proposed in a recently completed master's thesis by a CITE student in mechanical engineering who participated in the solar lantern evaluation[3], there could be alternative evaluation strategies: a problem-based approach, a crowd-sourced approach, or a combination thereof. These alternative approaches are being reviewed in future product evaluations.

Finally, CITE seeks to collaborate with HESN partners with prior experience of product demand studies, such as the Development Impact Lab at the University of California, Berkeley or AidData at the College of William and Mary. CITE research assistants attended the recent Revealing the Demand for Pro-poor Innovations Conference hosted by the Development Impact Lab, and the issue was reviewed by CITE researchers at the Lab Directors Conference in April 2014.

[3] Pombrol, Christopher. *CITE Suitability: An Exploration of Product Evaluation Methodologies for Developing World Technologies.* MIT Department of Mechanical Engineering, 2014.

Neutrality

The CITE solar lantern evaluation illustrated how difficult it can be to obtain reliable information about how products are designed for and used by people at the bottom of the economic pyramid. Without two-way working relationships based on mutual trust between CITE and product manufacturers, as well as distributors, it is not possible to fully appreciate organizational constraints. Yet, such a collaborative approach may convey the impression that CITE evaluations favor certain manufacturers over others.

As CITE moves forward in upgrading product evaluation strategies, it intends to retain conceptual autonomy from all the actors in the innovation pipeline. This is a challenge, because a certain level of embeddedness with key stakeholders is necessary to obtain the information required to develop useful product evaluations for them—necessitating a somewhat different procedure than followed by Consumer Reports. However, it is not CITE's goal to provide information to improve existing or proposed products. CITE will continue to maintain the position of an impartial evaluator. This is essential for CITE's reputation in comparative product evaluation.

In addition, CITE does not purport to certify products. Given the wide spectrum of specific product attributes that need to be considered to assess each product in a particular setting, certifying products would likely divert CITE from fulfilling its core mission, which is to prepare comparative evaluations within specific product families on three dimensions (i.e. suitability, scalability, and sustainability).

Audience and Unit of Analysis

Based on CITE's ongoing dialogue with USAID and partner organizations, the first round of evaluations was oriented to better inform donors and implementing agencies (e.g. social enterprises, nongovernmental organizations, and nonprofits), as well as the private sector. Although each of the three evaluation dimensions focused on a distinct unit of analysis in the solar lantern evaluation (i.e. suitability focused on the product, scalability focused on the original equipment manufacturers, and sustainability centered on the Solar Sister organization), the overarching goal was to provide a product evaluation relevant to the primary audience of donors and implementing agencies.

CITE is aware that the primary audience of the first evalutation is not the ultimate end user of the product; however, we assume that learning from this audience can leverage CITE's technical expertise to inform decision-makers who are responsible for making bulk product purchases such as donor organizations, national, and local governments. By making the product evaluations freely and publically available via the website, CITE could eventually reach a wide variety of stakeholders.

In CITE's next evaluation, all three dimensions will concentrate on the same unit of analysis—the product itself. This does not diminish, however, the need to understand the ways in which the product manufacturers and implementing organizations influence product delivery. Hence, issues of scalability and sustainability will be analyzed by focusing on the product but will secondarily consider how other entities affect a product's overall evaluation.

The "S"-Connection

CITE originally conceived the 3S framework as encompassing three overlapping dimensions of any product – i.e. suitability, scalability, and sustainability. The goal was to construct one comprehensive evaluation for each product. Learning from the solar lantern experience, however, CITE is now considering how the three dimensions overlap, what kind of data would identify the overlaps, and how to draw on the three-way analysis to best address the wide range of stakeholder needs.

In future evaluations CITE will adopt the following strategies:

1. Appoint a project coordinator with technical expertise in the specific product family under consideration. This technical person will coordinate the three aspects of product evaluation and will facilitate the conceptual integration of the 3S dimensions.
2. Revise the methodology of the three dimensions of evaluation by focusing on the same unit of analysis: the product. CITE's teams responsible for the scalability and sustainability dimensions will also adjust their methodologies, as well as the presentation format of their results, to complement the product rating chart used to compare the suitability dimension.
3. Align specific data needs and their complementarities for each of the three evaluation dimensions prior to fieldwork. The Solar Lantern pilot evaluation demonstrated the specific types of data that each of the 3S dimensions requires for the product evaluation. However, other data, particularly regarding information from current product users, may be necessary for all three "S" dimensions.

A study participant hangs his Barefoot Power Firefly Mobile lantern and charging cell phone from a bush in his yard to prevent them from exposure to the sun while charging. Photo taken by Victor Lesniewski.

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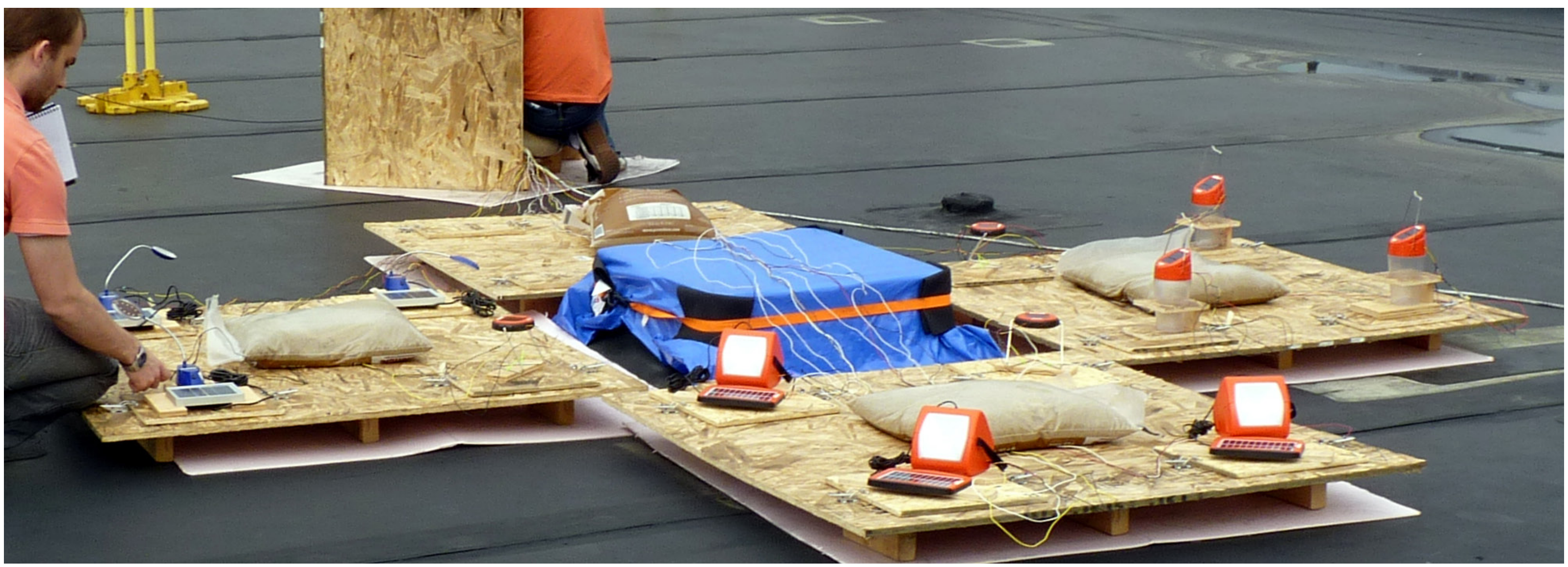
CITE
Solar Lantern Evaluation: Suitability

In the developed world, lighting is taken for granted. For many people in the developing world, however, access to reliable, safe lighting continues to be a serious issue. Many homes in Africa, Latin America, and Asia are lit with kerosene lanterns, candles, and other forms of expensive and dangerous fuels. Lighting Africa, an organization working to improve the quality of lighting in Africa, reports that the average cost of fuel for lighting applications has risen to as much as five percent of household income across the continent [1]. In addition, approximately one quarter of the population that uses kerosene lanterns has suffered some injury as a result[2].

Solar lanterns offer an alternative source of illumination with the promise of safe and long-lasting performance. In recent years, a large number of such devices have been designed specifically for use in the developing world.

The Comprehensive Initiative on Technology Evaluation (CITE) at MIT undertook its first comparative evaluation of solar lanterns in 2013. This report and associated rating table highlight the results of that testing to demonstrate the usefulness of such devices and to assist international agencies in making more informed purchasing decisions.[2]

The primary purpose of this report is to succinctly present the portable solar lantern evaluation results as an example of a comparative product rating. The results of this evaluation are not indicative of the complete range of solar lighting options available and do not imply an endorsement of any particular device. This report is meant primarily to test the feasibility of comparative product testing for the developing world and secondarily to provide information on solar lighting options and their applicability in Uganda.



(Top) MIT Lantern roof exposure, photo taken by Jeff Asher.

[1] Lighting Africa. (2013). *Lighting Africa Market Trends Report 2012: Overview of the Off-grid Lighting Market in Africa.*

[2] Mills, E. (2012). “Health Impacts of Fuel-based Lighting.” Berkeley: Lawrence Berkeley National Laboratory.

Background on Solar Lanterns

The growth of the renewable energy sector in the last 10 years has been remarkable. In 2004, the renewable energy sector in Africa was worth $750 million. By 2011, it had grown to $3.6 billion and is forecasted to continue to expand (Proctor, 2013)[3]. During this same period, portable solar lanterns proliferated in the developing world. The technology required to manufacture solar-powered lighting options, in the form of LEDs and solar panels, has been available for decades. However, only recently have component prices decreased enough to make marketing these products to developing world users practical. Solar lanterns are now available at prices ranging from $10 to $100 for personal or small-scale systems and offer many advantages over traditional technologies, such as kerosene lamps. Solar lanterns are much safer and much cleaner than traditional kerosene lamps. Furthermore, they have no recurring fuel costs.

However, despite rapid growth and obvious technical advantages, there remain challenges to the widespread adoption of portable solar lanterns. First among these is cost. Although prices have dropped significantly in recent years, unit prices in the $10 to $100 may still be too expensive for a person living on $1.25/day to afford in the absence of financing. High upfront costs are a critical barrier to scale in the absence of savings or finance even if overall lifetime costs are decreased by reduced fuel consumption. Further, there have been incidents of counterfeit solar lanterns, fake batteries, and low-quality solar panels being sold (Proctor 2013). Such imitation products can severely damage the consumer perception of a technology, causing a negative impression of all solar products, even those that might provide great benefit.

These issues can at least partially be addressed by providing authoritative, scientific information on the price and technical performance of existing portable solar lanterns. CITE's contention is that a comparative evaluation of portable solar lanterns will help institutional buyers select the highest performing and most cost-effective products available, reducing waste and increasing benefits to end users. Should such a tool prove to be useful to development practitioners, we hypothesize that it could be extended to a number of product families often employed in developing country settings.

[3] Proctor, K. (2013). "Solar Energy: African Economies' Secret Weapon." Fortune.

Contrast with Previous Testing and Standards

A significant amount of work has already been done in the field of solar lantern evaluation. Lighting Africa (LA), a joint initiative of the International Finance Corporation and the World Bank created to foster the development of markets for clean, off-grid lighting solutions, has conducted the most work in this area. LA created an extensive testing and certification process for personal solar lanterns which is implemented by a number of standard laboratories around the world. These laboratories use LA's extensive battery of tests, now published as International Electrotechnical Commission (IEC) TS 62257-9-5, to certify solar lanterns. These standards include testing to verify specific aspects of solar lantern performance. For example, to pass the IEC standard, a solar lantern must maintain a brightness of 70 percent of the original value after 2,000 hours of operation using a particular test setup and procedure (International Electrotechnical Commission, 2013)[4]. Examples of other parameters that are taken into account include light output, impact resistance, and battery capacity. Should a product pass LA's stringent testing, it is given a certification document valid for a period of two years.

Lighting Africa is industry-sponsored in the sense that manufacturers must pay LA for testing and certification. As a consequence, the detailed testing results remain proprietary and only the certification document, which contains summary results, is made public. The certification sheet itself is not designed for easy cross-comparison and contains many binary (pass/fail) tests. Thus, the only conclusion that can be made from LA certification is that a specific product has passed or failed to meet the IEC standard. In contrast, CITE seeks to provide information on how individual products perform in comparison to other products.

The IEC standard provided an excellent reference as CITE developed its comparative testing protocols. The team also referenced the Illuminating Engineering Society's The Lighting Handbook, 10th Ed., which provides suggested benchmarks and guidelines for task and ambient lighting [5]. Finally, information on the performance of existing lighting methods was gleaned from work done at Lawrence Berkeley National Laboratory (Mills, 2012)[6].

[4] International Electrotechnical Commission. (2013, April 3). Recommendations for small renewable energy and hybrid systems for rural electrification—Part 9-5: Integrated system—Selection of stand-alone lighting kits for rural electrification. Geneva, Switzerland.

[5] DiLaura, D., Hauser, K., Mistrick, R., & Steffy, G. (2011). *The Lighting Handbook* (10th Edition). New York, NY, USA: Illuminating Engineering Society.

[6] Mills, E. Technical and Economic Performance Analysis of Kerosene Lamps and Alternative Approaches to Illumination in Developing Countries. Berkeley: Lawrence Berkeley National Laboratory.

Audience

In development interventions, oftentimes the decision to purchase a product does not lie with a product's end user. Products are commonly chosen by organizations implementing aid programs (nongovernmental organizations, nonprofits, social enterprises, etc.). In such cases, the implementing organization makes the purchasing decision on behalf of the end user and could benefit from a user-centered comparative evaluation of various products.

The information obtained in this product evaluation is potentially relevant to multiple audiences but is specifically designed for the situation described above. Test results are reported with the goal of informing groups that may be purchasing solar lanterns for mass distribution or for resale. The comparative rating chart (Figure 2-1) assumes that these organizational users are familiar with the presentation of graphical data and can assess the data effectively and independently to make informed decisions. Competency of this sort is common at organizations making bulk purchases of products, such as portable solar lanterns.

In Matugga, Central Uganda, a Solar Sister customer demonstrates how he arranges his Firefly Mobile's solar panel in his yard for charging during the day. Photo taken by Victor Lesniewski.

The Product Ratings

The comparative ratings chart show in Figure 2-1 is presented as an example of a decision tool for institutional purchasers. In a style similar to Consumer Reports, it differentiates among various portable solar lanterns found on the market in Uganda based on their key attributes and features.

This section introduces several key concepts and explains how they are used in the attached comparative ratings chart. Scores, weightings, and ratings are also elucidated.

Product attributes comprise the set of testable characteristics that are common within the **product family**—a group of products designed to address a similar user problem. For solar lanterns, these attributes might include brightness, runtime, and time to charge.

Product features are those that are not central to product identity, but which might nevertheless be commonly found within the product family. For example, in order to be included within the solar lantern product family, it is not necessary for a product be able to charge a mobile phone. However, some products might have that feature.

Each attribute and feature was tested in accordance with a customized laboratory protocol designed by CITE at MIT. The development of each protocol was informed by existing standards, field interviews, and data collected from 37 instrumented solar lanterns deployed with individuals and families in Kampala and Gulu, Uganda, during the summer of 2013[7].

Score refers to the numerical "grade" given to each model in each individual attribute or feature category. The performance of each model on each testing protocol determined the raw score (generally given as a unit of measure). This score was then placed on a scale ranging from 0.49 to 5.49 tied to the standard deviation of the set scores. The scores were then translated into the graphical icons found in the rating matrix.

Weightings are the levels of significance given to individual attribute scores in order to compute a composite or overall rating. Consumer Reports, for example, develops its weighting scheme based on extensive consumer surveys about what is important to those who use a particular product. This enables weightings to be formed from objective data with a minimal amount of subjectivity brought in by the product testing staff.

The CITE team determined the weightings applied to product attributes by applying the Max Diff method to a small survey data set (n=37) collected in Uganda by student researchers in July and August 2013. The Max Diff method allows investigators to obtain survey data regarding the relative importance of different product attributes by grouping product attributes and asking respondents to select the most important and least important attribute from the group. In future evaluations, the weightings may be linked to statistically significant surveys or user-generated data/input.

If this were a product that was tested periodically, the weightings would be refreshed with new and greater consumer survey data about use patterns. Further, in other locations, certain product attributes and features may be more important to users. As a result, it should be expected that the weightings would change substantially if the focus of the study were to shift from Uganda to another location.

Ratings are the overall weighted sum of the attribute and feature scores for each individual model, scaled to between 0 and 100.

[7] Kampala and Gulu represent two areas where Solar Sister had active operations as of July 2013.

How to Use The Solar Lantern Comparative Rating Chart

The Portable Solar Lighting Devices Comparative Rating Chart and the associated test protocols were developed to reflect the needs of the solar lighting user, with the assumption that an institutional purchaser would derive the most success from meeting end-user needs. Accordingly, it builds upon existing solar lighting testing and minimum certification schemes. Unlike certification documents, however, this chart enables purchasing institutions to quickly and easily understand the variations in performance of a solar lantern relative to similar, competing products across a number of user-derived attribute categories.

The results of the testing clearly show the top technical performers in the product family. In addition, they show the relative performance increase as a function of price, i.e. the "value for money." This allows decision-makers to balance the trade-off between overall performance and price, as well as between various attributes when making a purchasing decision. The user of the chart may choose to select a product based on overall score, score as a function of price, or by factors critical to a specific set of needs.[8]

What is not included in Figure 2-1 is an assessment of strictly nontechnical factors or issues that could not be tested in a cost-effective or timely manner. These include the social and cultural acceptability of solar lighting, customer willingness to pay, ease of repair and maintenance, product durability (mean time to failure), and accessibility/customer support offered by the manufacturers of the devices listed herein. The prices and models in Figure 2-1 are current as of August 2013.

[8] While not the focus of this study, serious safety issues can also be uncovered during testing. These issues would be noted within the rating chart.

Figure 2-1: Solar Lantern Comparative Rating Chart

product information				product attributes									features
make/model	overall score	cost (usd)	type (handheld/ desktop)	runtime on high setting		charge time		brightness	task lighting	ambient lighting	luminous range	water resistance	
				hours	score	hours	score	score					
SunKing Pro	88	$39.95	H/D	13.1	Average	8.7	Outstanding	Outstanding	Outstanding	Outstanding	Poor	Average	Battery charge indicator, End of charge indicator, Mobile phone charger
WakaWaka Power	85	$79.99	H/D	21.2	Outstanding	17.7	Poor	Outstanding	Outstanding	Outstanding	Poor	Poor	Battery charge indicator, End of charge indicator, Device charges from AC, Mobile phone charger
d.light S300	77	$49.95	H	6.1	Poor	13.3	Average	Outstanding	Outstanding	Outstanding	Outstanding	Poor	Battery charge indicator, End of charge indicator, Device charges from AC, Mobile phone charger
SunKing Solo	67	$29.95	H/D	22.1	Outstanding	13.4	Average	Average	Marginal	Marginal	Poor	Outstanding	Battery charge indicator, End of charge indicator
WakaWaka Light	59	$39.99	H/D	18.1	Very good	19.6	Poor	Marginal	Marginal	Very good	Poor	Outstanding	Battery charge indicator, End of charge indicator
Firefly Mobile Lamp	58	$36.99	D	7.5	Poor	6.7	Outstanding	Very good	Average	Poor	Marginal	Outstanding	Battery charge indicator, Mobile phone charger
SunKing Eco	50	$19.95	H/D	19.1	Outstanding	8.2	Outstanding	Poor	Poor	Poor	Poor	Outstanding	Battery charge indicator, End of charge indicator
ASE Solar	50	$60.00	H	12.5	Average	19.0	Poor	Marginal	Average	Outstanding	Marginal	Poor	Battery charge indicator, Device charges from AC, Mobile phone charger
d.light S2	43	$14.17	D	12.0	Marginal	13.7	Average	Marginal	Poor	Average	Marginal	Very good	Battery charge indicator, Device charges from AC
d.light S20	42	$17.55	H/D	11.8	Marginal	9.8	Very good	Poor	Poor	Marginal	Poor	Outstanding	Battery charge indicator, Device charges from AC
UniteToLight	29	$20.00	D	10.4	Marginal	17.9	Poor	Poor	Poor	Poor	Marginal	Outstanding	

features

battery charge indicator	Device notifies user that the battery is receiving a charge.
end of charge indicator	Device notifies user that the battery has completed charging.
device charges from ac	Device not only charges from the sun but also from AC power.
mobile phone charger	Device includes the ability to charge mobile phones.

legend

- OUTSTANDING
- VERY GOOD
- AVERAGE
- MARGINAL
- POOR

- BATTERY CHARGE INDICATOR
- END OF CHARGE INDICATOR
- DEVICE CHARGES FROM AC
- MOBILE PHONE CHARGER

attribute definitions

run time on high setting	Length of time which a fully charged device can emit usable light when switched on to its highest setting.
charge time	Time to fully charge a completely discharged device using ambient sunlight.
brightness	Light intensity from a standard distance, in lux.
task lighting	Ability of the device to illuminate a tabletop workspace at or above a reference lighting standard.
ambient lighting	A light's capacity to illuminate a room.
luminous range	The ratio of a device's brightness on its lowest setting to its brightness on its highest setting.
water resistance	The ability of a device to resist damage from water.

notes

1. The "Overall Score" shown in this ratings is applicable for Uganda, Africa. For use in other countries, it is suggested that individual attribute scores be a guide to decision making.

2. This evaluation may not include all the portable solar lighting devices available in Uganda. Rather, the ratings show a representative sample of products available on the market during the summer of 2013, along with several other models designed for use in the developing world that may be applicable in Uganda.

Applicability of Results

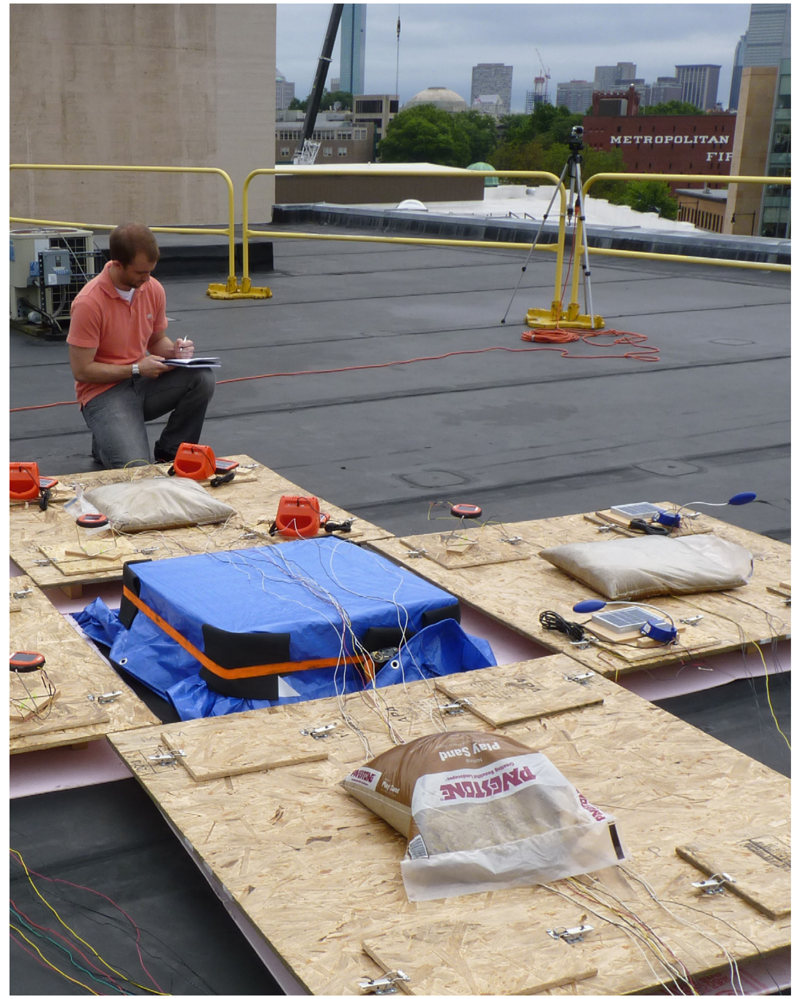
The scores in each attribute category are based on standard tests and so are internally valid. However, the overall product ratings are influenced by the Ugandan user preferences. Thus, although the evaluation report contains information relevant to other markets, such information must be used with caution.

When consulting the chart in Figure 2-1 for implementations outside Uganda, the user is advised to disregard the overall score and instead compare products using individual attribute category scores, matching the attribute-specific performance of each device to the requirements of a particular use. It would then be possible to select models that perform well in selected categories.

Price

Product price is an important factor in any purchasing decision; accordingly, the market price of each product as of July 2013 appears in the comparative ratings chart. However, for the purposes of this evaluation, price was not included in the overall rating of each product. CITE assumes that institutional buyers have a budget within which they must work and therefore developed a chart that enables them to consider their own budgetary circumstances when making buying decisions. The report shows the relative value of each solar lantern model evaluated by prominently displaying its price next to its cumulative score. In this way, a purchasing institution can explicitly make tradeoffs between price and performance.

However, CITE will consider additional audiences in future evaluations. For instance, if the target audience were a bottom-of-pyramid user, price could be critical to calculating the overall rating. Therefore, CITE will carefully consider including price as a weighted component of overall score in future evaluations.



(Top) MIT Lantern roof exposure: During the summer of 2013, CITE was able to charge up to 16 lanterns by exposure to the Boston sun using one of MIT's rooftops. From sunrise to sunset, the solar radiation was monitored for its intensity by a radiometer. This measure of incident radiation was used to determine the efficiency of the lantern's solar panels in bright sun or when there was a cloudy overcast. The time to charged and discharge were analyzed to give a measure of lantern usefulness where a long time to charge and/or a short time to stay lit makes it less useful to a consumer. Photo taken by Jeff Asher.

Methodology, Testing, and Results

Determination of Test Categories

Attributes were selected for testing based on a number of factors, including user interviews, user observations, previous work completed by MIT graduate students, and the judgment of the CITE team.

Researchers from the CITE team conducted 64 semi-structured interviews with solar lantern users in Uganda. These users were asked to provide details about how they used their lanterns and which activities the products were used to illuminate. Additionally, solar lantern users were asked which lantern characteristics were most important to them. During semi-structured interviews, CITE researchers also took note of how end users employed their solar lanterns.

The data gathered in the field study allowed the CITE team to create a list of potential attributes to test. For example, users indicated that durability (mean time to failure) was one of the most important product attributes. From field observations, it was determined that the most likely causes of device failure were exposure to water, exposure to dust, and physical impact. In another example, the team was able to select ambient lighting as an important attribute by observing users mounting solar lanterns on the ceilings of their dwellings and using them to illuminate entire rooms. The CITE team then used its collective judgment to select which of these attributes to test, focusing only those that were mostly likely to result in significant results useful for product comparisons.

Once selected, the team consulted the literature to review existing protocols and modify them for comparative testing purposes. The sections below outline the list of attributes and features tested and explain the testing procedure.

Runtime on High Setting

Metric: Hours of discharge at usable light level

Scoring: Longer time to discharge is favorable

This test examines each lantern's primary attribute: the ability to produce usable light. Usable light was defined several ways for this test, all of which made reference to existing lighting standards. The Illuminating Engineering Society's The Lighting Handbook, 10th Ed., and IEC/TS 62257-9-5 were used to define the upper luminance boundary based on each standard's lighting level for reading[9]. The lower luminance boundary was derived from work completed by Lawrence Berkeley National Laboratory based on the light output of a standard kerosene lamp[10].

The importance of total runtime was corroborated in user interviews in which discharge time was recorded as the second most important product attribute behind brightness. In addition, this is an area in which manufacturers make many of their headline claims, which are often prominently featured on product packaging and in marketing materials. Therefore, independently verifying the actual, use-based discharge performance can provide institutional purchasers with a level of confidence in the product they procure.

[9] DiLaura, Hauser, Mistrick, & Steffy, 2011; International Electrotechnical Commission, 2013; Lighting Africa, 2013; Mills E. , 2012; Mills E. , 2003; Mills E. , 2003.

[10] Mills, E. Technical and Economic Performance Analysis of Kerosene Lamps and Alternative Approaches to Illumination in Developing Countries. Berkeley: Lawrence Berkeley National Laboratory.

Total device runtime was determined by tracking lantern voltage and current over a full discharge cycle and identifying the point at which lantern current draw dropped below a certain threshold [11].The cutoff threshold was determined by identifying that lantern with the smallest ratio of current draw between its highest and lowest discharge settings, which was about 5 percent [12]. Interestingly, many lanterns that received low scores for charge time received very high discharge time scores. This likely reflects differences in the internal components of each model (battery size, solar panel, charge controller, etc.). As a result, it must be noted that although time to charge is an important user variable, it alone is not indicative of a superior or inferior device and must be taken together with performance in other categories.

Time to Charge

Metric: Hours to charge

Scoring: Shorter time to charge is favorable

Time to charge is an important variable in a portable solar lantern. In order to charge a lantern, users must leave it exposed to the sun for an extended period of time. The shorter this period of time is, the less likely the unit is to be exposed to damage or theft. Further, a lantern that can charge quickly spends less time charging and can be used more readily.

Although all lanterns were able to fully charge within a two-day test period, there were significant variations in charging times. This is likely due to lanterns using batteries of varying capacity and solar panels of different sizes.

Among all models, the average time to charge over a period of two runs on two similar solar days was approximately 13 hours. Results can be scaled to represent solar flux profiles in other regions.

Task Lighting Capability

Metric: Area illuminated at 12.5 lux
(lumens per square meter)

Scoring: Higher area is favorable

Task lighting is an important use category for solar lanterns. Common tasks for which solar lanterns can be used include studying, reading, and cooking. In fact, lighting with traditional kerosene lamps can be dangerous for these activities, which often require close proximity to the light source. For this test, fully charged lanterns were turned on to their highest settings and positioned such that the point directly below the bulb was illuminated at 25 lux, a reading standard set by Lighting Africa. From this position the area that illuminated at a level of 12.5 lux, representing roughly twice the output of a kerosene lantern, was recorded and the devices were ranked. The CITE team repeated this test at varying luminance levels, each of which was based on an existing standard, and found the response to be linear.

Ambient Lighting

Metric: Weighted illumination at 12 spatially
distributed points in a room

Scoring: Higher weighted sum of lux values is favorable

Ambient lighting, or the ability to light a room for general purposes, proved to be a common and important lantern feature for many interviewees in Uganda. Oftentimes each room in a home will be occupied and used by several family members at once, all of whom are completing different tasks. Furthermore, our field team observed lanterns of all types mounted to the ceilings of rooms to provide ambient lighting. Therefore, for this test, lanterns were hung 6 feet high and evaluated on their ability to illuminate a cylindrical area at several different heights. The lux readings were then weighted by location and summed to produce a raw score.

[11] Lanterns were fully charged at the beginning of the test and were set to discharge on their highest setting.

[12] Lighting Africa. (2013). Lighting Africa Market Rrends Report 2012: Overview of the Off-grid Lighting Market in Africa.

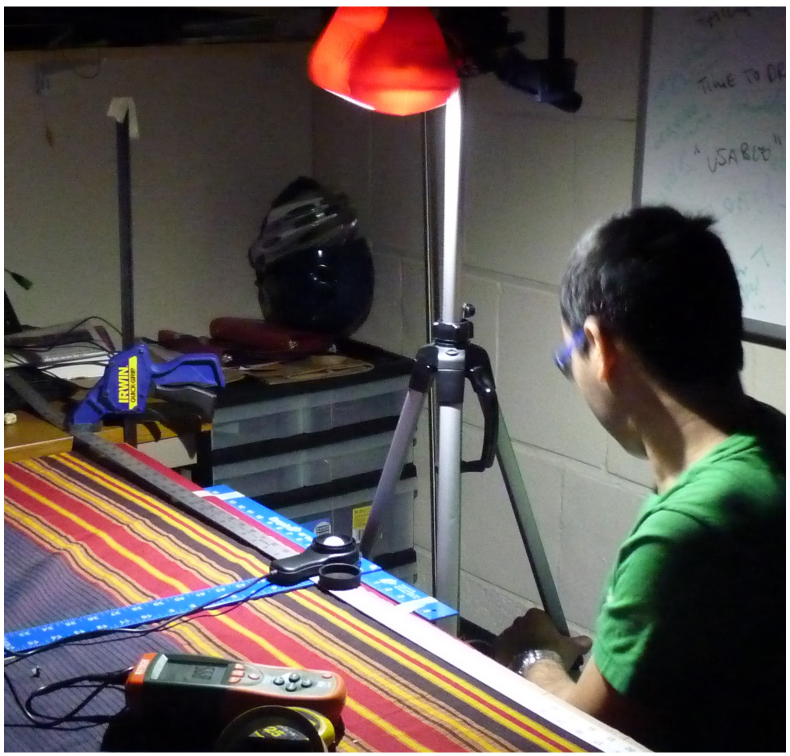
Brightness

Metric: Lux

Scoring: Higher value is favorable

Interview respondents ranked brightness as the most important product attribute, among attributes that could be tested in the laboratory. Lanterns were scored by the luminous flux per square meter produced on their highest setting at a standard distance of 18 inches.

(Bottom, Right) Lantern light quality testing 1 and 2: Lanterns sometimes have uneven light with a relatively low intensity. In these experiments, two methodologies were applied to determine: 1) how uniform the light was and 2) for various distances away from the lantern the level of light intensity. Significant differences were found that would make some lanterns a good or poor source of light for work tasks such as reading or walking in the dark. Photo taken by Jeff Asher.

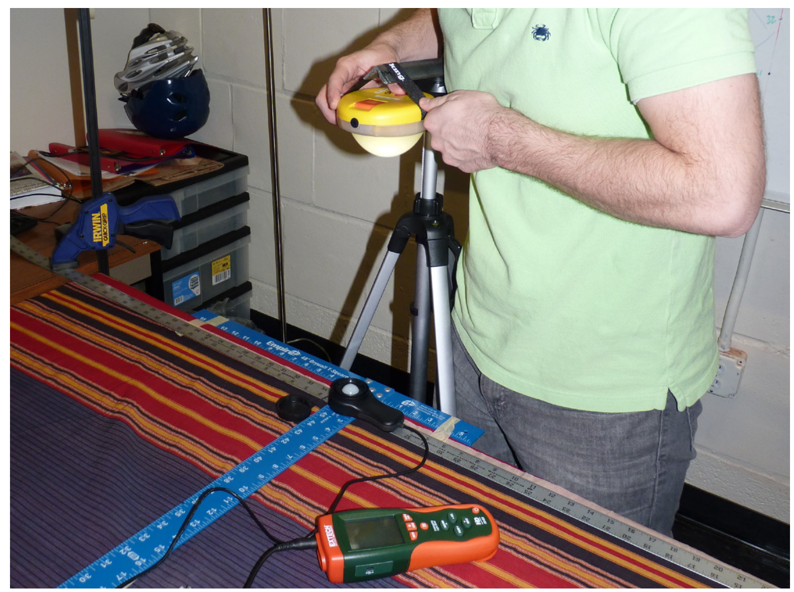


Luminous Range

Metric: Ratio of lux at highest setting to lux at lowest setting

Scoring: Higher ratio is favorable

This simple test is designed to give a user a sense of each device's luminous range. Each light is suspended 18 inches from a surface and the ratio of the maximum and minimum setting brightness is measured. Many people in Uganda use their portable solar lanterns for several purposes, including reading, ambient lighting, and security. Each of these tasks requires a different intensity of light. For instance, a search task might require a very bright light while a nightlight or security light may only require a dim glow. Lanterns that are able to produce a wide range of brightness prove to be more versatile than those that only offer a single brightness setting or a very limited brightness range. In particular, the S300 offered superior flexibility in this category, with a highest setting 37 times brighter than its lowest setting.



Water Resistance Testing

Metric: Pass/fail

Scoring: Various pass/fail cases through three tiers of testing

Exposure to moisture can present serious problems for electronic devices. For those living in extreme poverty, investing in what for them may be an expensive product that is easily ruined by moisture and not easily repaired can cause undue financial hardship. Further, existing testing organizations have not developed standardized moisture exposure tests that consider the real operating conditions under which many of these devices are used. Therefore, CITE developed a three-tiered testing regimen to rate lighting units based on their resistance to water. These tests involved complete submersion, exposure to heavy rain in a vulnerable orientation, and exposure to heavy rain in an “as charging” position. Representative rainfall rates were determined by examining rainfall rates from storms in various locations in the United States and extrapolating these figures to Uganda. This test revealed two interesting facts. First, many lanterns survived full submersion in water without any measurable damage whatsoever. Second, two lanterns, the WakaWaka Power and the S300 both failed at least one trial in an orientation matching the charging position.

Features

Metric: Various

Scoring: Various

Features are those optional characteristics that exceed the set of attributes that define the product family. Sometimes these features are incorporated to increase the price of the product but they do not provide greater convenience or function. Nonetheless, during this study, the testing team identified several key features, highlighted below, that were commonly available and identified (through consumer interviews in Uganda or by the evaluation team) as potentially beneficial to a user. Each device is given an additional score for presence or absence of the following key features:

Battery charge indicator: During solar charging it is convenient for the lantern to in some way indicate that it is charging. This may cue the user to take corrective action when the unit is not receiving a charge while exposed to the sun.

End of charge indicator: This feedback is quite helpful for the user to be sure that the lantern has attained a full battery charge and there is no further benefit to leaving the unit in the charging location. As noted in the “Time to Charge” section, some lanterns took two days or more to completely charge, making this feature particularly useful.

Charging from AC: Some lanterns had the option to charge through alternative means, such as an AC outlet. This feature can prove useful in cloudy weather or when access to reliable electricity is possible.

Mobile phone charging: Field interviews indicated that solar lantern users desired mobile phone charging capability in their devices. Each device with mobile phone charging capability was tested by charging a standard mobile phone with a depleted battery.

Lessons Learned and Future Evaluations

In performing this evaluation, the CITE team encountered interesting challenges that highlight possible ways to adapt the comparative product testing process for future use in developing world applications.

First, there is a need for timely, accurate information regarding available models and use patterns. CITE has found that information about available models is difficult to obtain through deskwork or even through partner organizations. In the future, this information may be obtained through strategic partnering with market research firms in country.

Second, comparative testing produces information relevant not only to institutional purchasers but also to any decision-maker involved in the supply chain. Therefore, alternative audiences, such as those previously identified, must be considered. Most importantly, new, more flexible methods of conveying comparative product data can and should be developed so that end users who may not be familiar with chart representations can easily access the results of the evaluation.

Third, the CITE team found it most challenging to assign weightings to product attributes and determine realistic test protocols. CITE now plans to develop or implement additional data collection and research design methods pertinent to uncovering consumer behavior and preferences.

Fourth, CITE had trouble initially setting the boundary between those products that comprised the portable solar lighting device category and those that did not. This difficulty calls attention to the fact that comparing products can be difficult if those products are meant to serve similar, but subtly different purposes (for instance a desk light vs. a flashlight or torch). In the future it may make more sense to evaluate products designed to address a certain problem (i.e. solutions) regardless of their form, rather than products within a product family. One can imagine, for instance, evaluating kerosene lamps vs. portable solar lanterns vs. battery-operated lanterns.

Fifth, at least one solar lantern model was updated during the course of the evaluation, causing testing results to become outdated very quickly. Development of alternative, dynamic testing methods would allow evaluations to be updated periodically and to remain fresh in the eyes of the user. In the future, CITE may begin using online or text-based data collection to allow end users to provide real-time feedback on products that CITE is evaluating. In this way the evaluation would become a living experiment rather than quickly becoming an historical document. Deeper connections and communications with manufacturers could also help to reduce surprises during the testing process.

Finally, Figure 2-1 provides a comprehensive summary of the technical performance of solar lanterns. There are, however, areas where additional data may be useful that is not directly covered by this pilot report. For instance, while durability was a key user concern, only one aspect of durability was assessed (water resistance) because other aspects require a longer time period and more expensive information gathering methods. In future evaluations, CITE aims to gather this and other information from laboratory testing and user reviews.

3

CITE
Solar Lantern Evaluation: Scalability

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Scalability Evaluation Methodology

This section offers a pilot evaluation of the potential for three original equipment manufacturers (OEMs) to scale up their supply of solar lanterns to Uganda. The purpose of this pilot evaluation was twofold:

1. To inform institutional buyers of solar lanterns about OEM capabilities, and

2. to pilot and refine our methodology for future work.

The following subsections identify key aspects of the evaluation of "Scalability," as applied to solar lanterns in Uganda.

Scalability Definition

The term "scalability" is broadly understood in the international development community. This report evaluates a supply chain's ability to scale up the manufacture and distribution of a product at an effective cost as demand increases. Other key aspects of scaling up depend on additional facets of a product that are covered in the CITE evaluation: the design and performance of the product (suitability) and the dissemination of the product in the market (sustainability).

We evaluate the scalability of an OEM in terms of its capability to supply and support product sales, considering its supply chain design, costs, constraints, and risks. The scope of our evaluation includes the OEM's end-to-end supply chain, from raw materials to the delivered finished good, and the product support from acquisition through disposal. We divide the evaluation of the OEM supply chain into five categories:

- **Procurement** entails how the OEM acquires the raw materials and components for its products.
- **Production** encompasses the processes used to manufacture and assemble the final product, plus the implied cost structure and capacity.
- **Distribution** examines the network structure, including inventory and transportation strategies.
- **Sales channels** consider the variety of partnerships and strategies through which the OEM can sell a product to a consumer.
- **Aftermarket** assesses the support systems that maintain and dispose of the product after purchase by the consumer, including service and repairs.

A Solar Sister customer near Jinja, Eastern Uganda, attaches his lantern to near the ceiling for evening lighting. The following morning, he takes down the Firefly Mobile for charging during the day. Photo taken by Victor Lesniewski.

Audience

The target audience for this evaluation is institutional buyers. Since the Comprehensive Initiative on Technology Evaluation (CITE) focuses on international development, this audience includes procurement groups from government agencies and nongovernmental organizations (NGOs) that might use these products in their programs. Donors to such organizations are an indirect audience as their in-kind donations or guidelines for funding use may influence procurement decisions. Note that our evaluation does not address whether solar lanterns are the right product for the targeted purpose of a specific development program. Rather, the evaluation is intended to reduce the risk that poor product selection will impede program implementation.

The audience of institutional buyers primarily includes private sector actors such as distributors and retailers who are seeking to expand product lines or enter new markets. Other potential actors are entrepreneurs in manufacturing and sales who are seeking market entry.

This evaluation is specific to the Uganda market. However, some of the information provided could be useful to institutional buyers in other parts of the world. For more information, see the "How to Use this Report" section that follows.

Scope

We contacted all five OEMs that manufactured the products referred to in the Solar Lantern Suitability Evaluation and were able to have substantive discussions about scalability with three: Greenlight Planet (GP), Barefoot Power (BP), and Unite to Light (UL). Each OEM is based in a different country, and the three range widely in terms of sales volume and staffing. GP, the largest, has 450 full-time employees and had sales of approximately 600,000 units last year. UL is the smallest with one full-time employee and 22,400 units sold. BP falls

between these two with approximately 80 full-time employees and annual sales of roughly 100,000. Additionally, GP and BP are for-profit, private companies, while UL is a nonprofit. This evaluation specifically focused on the companies' delivery of solar lanterns to Uganda markets, which is the context for the Suitability and Sustainability Solar Lantern Evaluations.

Data Collection and Limitations

Data collection comprised publicly available sources and semi-structured interviews with individuals in the companies. Publicly available data were limited since all companies in this analysis are privately held. Hence, our analysis depends solely on the information the companies were willing to share and does not incorporate information from any independent third parties.

Given limited information, and especially little quantitative data, our analysis and assessment were qualitative. First, we described features of the OEM supply chain and analyzed them based on common supply chain principles. The analysis briefly highlights where and how scalability is constrained in the supply chain. Then, relying on academic knowledge and industrial experience, we developed attribute assessments. These assessments considered the supply chain designs of the OEMs in light of prevailing supply chain theory. With the qualification that we were limited by the availability of data, we provide categorical rankings of the attributes for each OEM. Note, however, that we did not attempt to combine these rankings into a simple, overall score, as we did not have sufficient confidence in our data or analysis to do so.

How to Use this Report

Institutional buyers of solar lanterns can use this report in their procurement process. Procurement decisions typically rely on price and perhaps an assessment of a limited number of supplier attributes, most of which are financial. This report provides information to help ensure that the supply chain of the selected OEM will deliver the product and aftermarket support. This is especially critical when the product is needed in large quantities and/or the delivery is time-sensitive. We provide an overview of the supply chain for each OEM in the five key areas of supply chain scalability: procurement, production, distribution, sales channels, and after market. A brief analysis of the features and constraints to supply chain scalability are also included and summarized in Figure 3-1.

The report can also help organizations with implementation planning. Here are two examples:

1. Organizations must plan how much inventory to carry so they do not run out of stock when opportunities and needs arise. Inventory levels further determine storage and personnel requirements. Information on expected lead times for the product to arrive after it is ordered, and the reliability of that expectation, are critical in setting these inventory levels.

2. Budgeting for future purchases requires an anticipation of prices. Information on supplier cost structures helps to assess the current and future potential for reducing costs. For example, a manufacturer with a high fixed cost but low variable cost would be able to reduce prices as sales increase, whereas a manufacturer with a high variable cost structure must maintain higher prices.

This evaluation is specific to solar lanterns in the Uganda market. However, some of the information would be useful to institutional buyers in other parts of the world. Much of the analysis is relevant for regional buyers in East Africa, since the Uganda supply chain is part of an East Africa sales region serviced in the same way by the OEM. A buyer in another East African country would need to further consider the particular sales channels in that country. The manufacturing aspects of the evaluation—such as cost structures, sourcing, and assembly lead times—apply to all global markets.

Figure 3-1: Supply Chain Feature Chart

MFCTR INFO		NAME	**Barefoot Power**	**Greenlight Planet**	**Unite To Light**
MFCTR INFO		PRODUCTS TESTED	Firefly Mobile Lamp	SK Solo, SK Pro, SK Eco	UTL
SUPPLY CHAIN FEATURES	PROCUREMENT	SOURCING	Single sourcing	N/A	N/A
SUPPLY CHAIN FEATURES	PROCUREMENT	PROCUREMENT MANAGEMENT	Mixed	Internal	Internal
SUPPLY CHAIN FEATURES	PRODUCTION	FACILITIES	China: Contract manufacturer & owned final assembly	China: Contract manufacturer	China: Contract manufacturer
SUPPLY CHAIN FEATURES	PRODUCTION	PRODUCTION PLANNING	Make to stock	Make to stock	Make to order
SUPPLY CHAIN FEATURES	DISTRIBUTION	INVENTORY ECHELONS	Nairobi: Regional Kampala: Country	Nairobi:Regional	None
SUPPLY CHAIN FEATURES	DISTRIBUTION	WAREHOUSE MANAGEMENT	Internal	Outsourced	N/A
SUPPLY CHAIN FEATURES	DISTRIBUTION	TRANSPORTATION MANAGEMENT	N/A	N/A	3PL
SUPPLY CHAIN FEATURES	SALES CHANNELS	MANUFACTURER REPRESENTATIVE	●	⊘	⊘
SUPPLY CHAIN FEATURES	SALES CHANNELS	COMMERCIAL	●	●	⊘
SUPPLY CHAIN FEATURES	SALES CHANNELS	MISSION	●	○	●
SUPPLY CHAIN FEATURES	SALES CHANNELS	DISTRIBUTOR	◐	●	⊘
SUPPLY CHAIN FEATURES	SALES CHANNELS	BROKER	○	◐	⊘
SUPPLY CHAIN FEATURES	AFTER MARKET	WARRANTY DURATION	Two years	Two years	One year
SUPPLY CHAIN FEATURES	AFTER MARKET	WARRANTY TYPE	Repair	Replace through sales channel partners	Replace on a case-by-case basis

LEGEND	
PRIMARY	●
SECONDARY	◐
OPPORTUNISTIC	○
NONE	⊘

Supply Chain Features and Analysis

This section provides an overview of the supply chain for each OEM in the five key areas of supply chain scalability: procurement, production, distribution, sales channels, and aftermarket. A brief analysis of the features and identification of constraints to supply chain scalability are also included.

Procurement

Each of the three OEMs takes a somewhat different approach to its sourcing of components. GP sources all components itself; that is, for each component in a lantern, GP chooses the supplier, which nominally entails certifying that the supplier has the capability of providing the component reliably and at sufficient quality and quantity for the OEM. GP also negotiates contracts with each supplier, including pricing and delivery specifications.

BP uses a hybrid procurement method by which it sources only "key" components itself. BP assumes responsibility for sourcing the LEDs, solar panels, and circuit boards, with a single supplier for each component. The sourcing of other, less-critical components is delegated to BP's contract manufacturer in China. UL does not source any of its components, delegating all component sourcing to its manufacturer in China.

To the best of our knowledge, all three OEMs use fairly standard components in their products; that is, the components are not custom-designed for the OEM but are generic items that can be sourced from multiple suppliers. The use of fairly standard components allows for some flexibility in finding suppliers and means that procurement is not likely to be a binding constraint to scalability.

However, the differences among OEM procurement strategies could potentially affect scalability. For example, BP uses single sourcing for many components. (We could not determine how many suppliers GP or UL utilize.) Single sourcing typically offers lower component costs due to volume discounts. However, the OEM's ability to scale up is limited by the capacity of the single supplier. Further, any disruption to the supplier—such as a quality issue or mechanical breakdown—will constrain (or shut down) the OEM's production until it can qualify a new supplier.

Second, the OEMs vary in strategies for procurement management, with a blend of full outsourcing, partial outsourcing, and internal sourcing. Completely insourcing procurement offers the greatest control, as internal staffers make all decisions and actively manage relationships. However, there is a fixed cost associated with establishing such expertise within the company. Furthermore, the internal staff may have less experience identifying good suppliers than an outsourced contractor, at least initially. As a company scales up production, and its employees gain experience, it can share the cost of managing its own component sourcing over the larger sales volumes. We do not have enough information about the capabilities of internal staff as compared with outsourced vendors to identify if the incremental investment is worthwhile.

Production

Suppliers complete the primary manufacturing of solar lantern subassembly components: solar panels, LEDs, consolidated molding, battery, circuit board, and remaining components. The OEM production effort is focused on final product assembly, which is labor-intensive and requires only a modest investment in capital equipment. All three OEMs perform final assembly in China, although there are key differences in the way they perform the task.

GP subcontracts final assembly to an outside manufacturer but maintains an internal team of GP employees at the facility to perform quality assurance. UL completely outsources assembly to a contract manufacturer in China, although UL is in the process of bringing another manufacturer under contract to double the current capacity of roughly 3,000 units per month. UL volunteers and partner organizations perform quality checks on its products in California using periodic batch shipments from the manufacturer. In contrast, BP has manufacturing space in China where it assembles the finished goods with an internal team of 15-20 BP employees.

As in the case of procurement, the OEMs vary in strategy for outsourcing versus insourcing final assembly. The tradeoffs among production strategies are similar, but the impact is more pronounced than in procurement. Internal production ensures the greatest control of the final product, with guaranteed capacity that is not contingent on subcontractor reliability. However, the fixed cost of facilities, equipment, and staff can be significant, and the ability to maintain quality and capacity may be limited by the internal team's expertise. GP's strategy, whereby it contracts out the process but maintains its own team on the ground for spot quality control, is a compromise.

In this case, given that assembly of solar lanterns is a relatively labor-intensive process, the fixed cost of facilities and equipment may not be that significant. The most significant difference in cost may lie in the OEM's and/or contract manufacturers' level of workforce productivity. In terms of capacity and lead times, an internal operation may prove to be more responsive to increased orders or product differentiation requirements. In terms of quality, the internal operation offers the most control, but may not be much different from an actively managed contract manufacturer.

Distribution

There are three distinct distribution strategies utilized by the OEMs to bring solar lanterns to the Ugandan market. East Africa is UL's primary market, but its relatively low demand necessitates its direct shipping strategy with no dedicated warehouse space. Additionally, UL has outsourced all of its logistics to Trade Without Borders (TWB), a third-party logistics (3PL) firm based in Hong Kong. Given a potential order, TWB provides shipping and time estimates, and, once the order comes in, arranges transportation from manufacturer to customer—including handling customs. Given the small order sizes, air transportation is used, which means that delivery is quick but expensive.

GP and BP both have warehouses in Kenya to serve East African countries. Given the sales volume in the region, ocean containers are used to ship the products from China to Kenya. Mombasa is the port of entry, and units are moved from there to the warehouse hub in Nairobi by truck. The average lead time for the trip from China is about six weeks, and this can depend on the order quantity. Large orders using dedicated containers can ship immediately, while less-than-container-load (LCL) orders may have to wait for other shippers' freight to consolidate into a full container.

GP and BP distribution strategies differ downstream from the regional warehouse. BP has an additional echelon of inventory at its warehouse in Uganda, and BP employees staff its warehouses in Nairobi and Uganda. BP stocks three months of average demand at the regional warehouse and 1.5 months of average demand in Uganda. A Quickbooks Enterprise Accounting System is used to manage and replenish inventory from China based on forecasted demand.

On the other hand, GP outsources warehouse operations to a third party in Nairobi. This is not a traditional 3PL warehouse provider; the partner actually takes ownership of the goods, acting more like a regional distributor and charging a fee based on a percentage of the selling price on each unit. Although the physical handling and ownership of products are outsourced, GP employs staff to forecast demand, review stock levels, and place replenishment orders with the manufacturer in China.

These distinct distribution strategies affect cost, capacity, and customer response time. With direct shipments to customers by air, the most expensive mode, UL has no warehousing cost and low inventory carrying requirements, but has high transportation costs. When

[1] Landed cost is the cumulative cost through all stages of the supply chain until it lands at the point of consumer acquisition.

combined, the landed cost[1] is likely higher than competitors, which may affect its ability to further penetrate the market. On the other extreme, BP's two-echelon warehousing strategy has the highest fixed cost from operating an additional warehouse but the lowest transportation costs since it can consolidate larger replenishment shipments into Kenya and Uganda. GP is in between, incurring additional variable cost with the fee for its outsourced warehouse in Kenya, but lower warehouse and inventory carrying costs than BP. It does have higher inventory carrying costs than UL, but benefits from much lower transportation costs.

Although the distribution capacity depends on specific warehouse sizes and inventory levels, the extra echelon for BP does provide capacity potential. Although it does not have a warehouse, UL's distribution capacity may be sufficient if it has reliable air service. With stock in-country, BP's customer response time should be the best; however, it takes the risk of carrying extra inventory if demand in Uganda slows or extra cost if it become necessary to ship goods to other countries where demand is higher. GP has longer response times due to the transit time from Nairobi. Even with inventory far away in China, UL may be fairly responsive to customers since it ships by air, assuming there is sufficient inventory at the contract manufacturer. The difference in response time between GP and UL may depend on transport availability and customs clearance.

Sales Channels

We identify five main sales channels for solar lantern OEMs in Uganda. "Commercial" describes OEM sales to traditional retail outlets or direct to consumers. "Mission" represents sales to NGOs, nonprofits, and/or government agencies that use the lanterns in various programs, including NGOs who train, sponsor, and work with micro-entrepreneurs. The "Distributor" channel identifies partners who buy from the OEM and then resell the product into other sales channels. "Manufacturer Representatives," described by the company as micro-entrepreneurs, are trained by the OEM and charge a recommended markup. "Brokers" are independent actors such as micro-financing institutions (MFIs) and savings and credit cooperatives (SACCOs) that facilitate and finance sales to consumers and/or businesses and communities. Table 3-1 provides a summary of the sales channel strategy utilized by each OEM.

One factor influencing the sales strategy is the type of company. GP and BP are for-profit, so their channel partners sell products to consumers, and the OEMs strive to ensure that their chosen partners maintain competitive pricing strategies. UL is a nonprofit that sells about 80 percent of its solar lanterns to other nonprofits, which then donate or subsidize sales to consumers; the remaining 20 percent of production is donated directly by UL to beneficiaries (such as disaster victims).

BP has 25 employees in Uganda, including two members of the sales team in each of the four sales regions. One sales representative manages corporate accounts, building partnerships with established distribution chains such as retail stores and telecom companies, and the other trains and manages the micro-entrepreneurs. This staff investment enables BP to cultivate more channels to market and tailor strategies to the region. Sales are divided fairly evenly among the three primary channels: Commercial, Mission (with partnerships such as Solar Sister, Living Goods, and BRAC Uganda), and—via BP-trained micro-entrepreneurs—Manufacturer Representative.

BP sales managers have trained roughly 500 micro-entrepreneurs in the last five years and currently have around 50 active agents. They lose about two-thirds of trainees within a year, perhaps when representatives have fulfilled the easiest sales in their personal networks, but will re-train them on a case-by-case basis. While microfinance institutions (MFIs) have become a popular source for extending credit, the BP micro-entrepreneurs are averse to MFIs due to high interest charges. They prefer financing directly from the OEM, although both BP and GP are hesitant to provide credit due to low repayment rates. In interviews, OEMs indicated a preference for micro-entrepreneurs with the resources to self-finance and reported having experienced greater success and commitment from those who were able to do so.

A new Broker model BP has used with some initial success is “Projects”—a system of targeting villages with the goal of installing hundreds of units in homes and businesses. Projects rely on local SACCOs to promote the effort and finance sales to consumers. SACCOs benefit not only from interest on the loans, but also from the margin captured from successful projects when they can buy from the OEM with a bulk discount.

GP has a less robust presence than BP, with seven employees in all of Africa. Its primary sales channels in Uganda are large distributors, commercial outlets – specialized retailers that can support a consultative sale, and MFI brokers who market the products to their client base. GP did not emphasize sales through the Mission channel, although such partnerships do exist. The GP Uganda sales strategy, which is limited to partners, is substantially different from its strategy in India, where it has 4,000 to 5,000 Manufacturer Representatives trained and managed by GP sales managers.

UL focuses exclusively on the Mission channel through partnerships with Rotary International and other nonprofit organizations. Additionally, the business has a partnership in Uganda with Village Energy, which rebrands the company’s UTL-1 product as the “Freedom Light” and provides the lanterns to schools. UL would like to transition to a more sales-based, micro-entrepreneur model but has not been able to thus far. There had been some discussion of partnering with Solar Sister, but that option is not being pursued at this time.

The capacity of any OEM sales strategy depends on the mix of sales channels selected, the potential each channel has to reach consumers, the saturation of each channel in the market, and the share the OEM has in each channel. Data to determine these attributes requires market research capabilities that may be expensive or unavailable. An example of such research is included in the Sustainability Solar Lantern Evaluation Summary, which focuses on one organization in the Mission channel.

At a high level, we can assess the mix of channels selected by the OEM. GP may have greater growth potential if it is able to replicate the Manufacturer Representative channel the company has used successfully in India. However, given its current operational setup in Uganda, that capacity is not available. BP’s Manufacturer Representative channel is working well but is expensive to support. Significant effort is required to continually train micro-entrepreneurs, given that only 10 percent of those trained to date are still active.

Both GP and BP utilize indirect sales channels but with a distinct mix. GP targets large distributors and specialized retailers, while BP works with a larger variety of retailers. UL’s sales potential is volatile since its focus is exclusively on the Mission channel, which is subject to the variability of donor funding.

The largest opportunity for BP sales growth is in the Broker channel, where its project approach with SACCOs is showing promise. GP seems to have a somewhat larger presence in this channel, using MFIs as brokers, but it also has room for growth. Partnering with financial institutions as brokers is an effective way to ensure payment while cultivating sales outside other channels. However, in all cases it is critical to monitor the cash flow and repayment reliability of each channel partner.

Table 3-1. Sales channel strategies used by OEMs.

	BP	GP	UL
Manufacturer Representative	Primary	None	None
Commercial	Primary	Primary	None
Mission	Primary	Opportunistic	Primary
Distributor	Secondary	Primary	None
Broker	Opportunistic	Secondary	None

Note: Primary indicates an OEM's key selling channel; secondary is a selling channel that an OEM employs to a lesser degree; opportunistic indicates a channel with low volume but that the OEM is open to utilizing; and none indicates that the OEM has no plans to utilize the channel.

A sign at a Total station in Rukungiri, Uganda, advertising the availability of d.light solar lanterns at stations nationwide. The campaign was taken as part of Total's CSR program. Photo taken by Jonars Spielberg.

Aftermarket

Lighting Africa requires that all certified solar lanterns have at minimum a one-year warranty; all lanterns offered by the OEMs in our sample satisfy this requirement. The more important issue is how that warranty is serviced. Service performance is especially crucial in developing markets, such as Uganda, where consumers are relatively inexperienced with warranties, both in terms of the responsibility of the OEM as well as their own requirements. It is also critical since replacement parts are expensive and difficult to find, especially when they come from abroad. However, the low profit margin per unit makes it challenging for OEMs to support repair operations.

GP offers a two-year warranty and uses a replacement model, where a defective solar lantern is replaced with a new product. To request a replacement, the consumer needs to contact the organization or micro-entrepreneur that made the original sale. UL also offers product replacement on a case-by-case basis. UL is considering a model to collect and sell individual batteries, since the lantern's life expectancy of 5-10 years exceeds the typical battery lifespan by roughly two years.

BP invests in warranty service that offers a mobile registration process and provides services at five dual-role retail/service centers in Uganda. The mobile phone-based short message service (SMS) system makes it easy for the consumer to activate the warranty and for the technician to verify its legitimacy. BP decided to offer the repair model in part because replacement is not economical for some of its product lines, such as multi-unit solar home systems. BP offers a 1-2-year warranty, depending on the product. Batteries are the most frequently replaced parts, with switches and cables following. Many parts are sourced from China, although batteries can often be found on the local market.

Effective aftermarket support can drive further sales, and scalability, by building consumer trust in the product. The replacement model offered by GP and UL is the most expedient model for the consumer, but only if the consumer has access to the sales organization, which in turn is able—and willing—to provide a replacement promptly. The OEM has strong influence over this consumer experience based on the level of support provided to the sales channel.

The repair model can offer advantages over replacement if deployed well. OEMs that deploy service centers close to the consumer have the opportunity to build a direct relationship with future buyers. They may also establish a referral network if the customer's experience is positive. The repair model removes effort and paperwork from sales channels, which should improve that relationship. Finally, it can be more economical since individual components, rather than entire units, can be replaced. However, it requires an effective supply chain to ensure spare parts are available at service centers and repairs are made promptly.

Attribute Assessment

The CITE team developed the following list of attributes through interviews with NGOs and nonprofits in international development. As mentioned above, the research team considered the supply chain designs of the OEMs in light of prevailing supply chain theory to determine likely attribute outcomes. We briefly outline the rationale for each attribute assessment below and summarize the results in Figure 3-2.

Landed Cost

Lacking data to estimate landed costs for the OEMs, we characterized cost structures, as follows:

Fixed cost structure. Of the three OEMs, BP has the highest fixed costs; the company is vertically integrated, assembling the solar lantern in-house, operating two echelons of warehouses, and managing the sales channels and service centers on the ground. GP has lower fixed costs; the company contracts out assembly to China and warehousing and distribution in Africa. UL has the lowest fixed costs, contracting out all sourcing, manufacturing/quality, and distribution.

Variable cost structure. Variable costs comprise almost all of UL's costs. With just one paid employee, all of the company's sourcing, assembly, distribution, and 3PL costs depend on the number of lanterns sold. UL ships by air and therefore has the highest shipping costs per unit. GP and BP have similar costs as they both ship by sea. GP also has variable costs based on the number of units stored at its contracted warehouse in Nairobi.

Lead Time

Supply chain lead time. We do not have enough information to evaluate the lead times for production and procurement. GP and BP have similar transportation lead times with sea shipments from China to Africa and then distribution by truck to Uganda. Sea transport takes weeks in transit, and lead times can be very long if the shipper waits for full container loads before replenishment. UL's transportation lead time is faster because the company ships products by air directly to the customer.

Supply chain lead-time reliability. We lack information on lead times and buffer stock levels and thus assume that reliability increases with the OEM's control over processes. BP has control over some of the sourcing, all assembly, and warehousing in two echelons. GP controls sourcing, contracts out assembly (with onsite monitoring), and relinquishes control of the product at the warehouse. UL fully outsources procurement, assembly, and transportation, but maintains high reliability of distribution by shipping directly to customers.

Delivery lead time. BP takes the least amount of time to deliver a customer order in Uganda by using multiple sales channels supported by an in-country warehouse. GP has a longer delivery time with fewer sales channels and inventory across the border in Kenya. UL's make-to-order strategy means that delivery lead time includes production and transportation from China.

Delivery lead-time reliability. Similar to supply chain lead-time reliability, delivery lead-time reliability is commensurate with the OEM's control over the distribution process. In addition, delivery lead-time reliability is higher when the OEM holds higher inventory near the customer base.

Waste/Shrinkage

We assume that two factors affect waste and shrinkage: the amount of inventory and the number of echelons. Higher inventory increases the potential for damage, loss, and theft. Each additional echelon offers more locations for product to be lost or damaged. We do not have information on inventory turnover and thus cannot make conclusive statements on the waste in the system. However, UL holds no stock outside the production site, and thus has low risk.

Capacity

We do not have data regarding the capacity of manufacturing facilities, warehouse facilities, or terms of outsourcing contracts for any of the companies studied. While BP has the most sales channels, without more information we cannot assess capacity.

Inventory

We lack information on the amount of inventory in the supply chains of BP and GP. Except for stock held at the production site, UL holds no inventory.

Flexibility

We have limited information to use to evaluate the flexibility of the individual supply chains. However, we can assess the flexibility gained by holding inventory centrally, where it can more easily be diverted to meet demand in several locations. BP has the least flexibility by committing some inventory to a country warehouse in Uganda. GP has more flexibility with a central warehouse in Kenya serving East Africa. UL has a high level of flexibility by holding all inventory centrally, but it has limited control over manufacturing capacity.

Information Flow

We have limited information on the information systems utilized. Thus, we used the number of employees as a proxy for information flow capacity. BP has 25 employees in Uganda at the warehouse and repair shops and also has manufacturer representatives on the ground. GP has seven employees based in Kenya and has an active role in planning with all supply chain partners. UL has no internal representatives on the ground in Africa or China.

Consumer Reach

BP is able to reach consumers through a wide range of channels, including Manufacturer's Representative, Commercial, Mission, and Distributor. GP relies on Commercial and Distributor channels, with some use of the Broker channel. UL's reach is limited to Mission-related sales.

Warranty Support

BP has the most extensive warranty system, with repair services at five locations in Uganda. GP will replace a product only through the sales channel. UL offers product replacement on a case-by-case basis.

Robustness[2]

BP has the most control and facilities in place to be robust, including two echelons of inventory and five repair centers in Uganda. GP controls less of its supply chain and only has one warehouse in East Africa. UL has no inventory and limited manufacturing control, but air transportation offers quick response capacity.

[2] We define robustness as the ability of the supply chain to deal with contingencies or disruptions.

Figure 3-2: Supply Chain Attribute Assesment Chart

	NAME	Barefoot Power	Greenlight Planet	Unite To Light
MANUFACTURER INFORMATION	PRODUCTS TESTED	Firefly Mobile Lamp	SK Solo, SK Pro, SK Eco	UTL
	TYPE OF COMPANY	For profit	For profit	Non-profit
	YEAR FOUNDED	2005	2008	2011
	GLOBAL SALES	100K in 2011	600K in 2012	22K since 2011
	GLOBAL EMPLOYEES	80	450	1
SUPPLY CHAIN ATTRIBUTES	FIXED COST STRUCTURE	◕	◑	○
	VARIABLE COST STRUCTURE	◑	◕	●
	TRANSPORTATION LEAD-TIME	Weeks	Weeks	Days
	SOURCING LEAD-TIME RELIABILITY	◑	●	◑
	ASSEMBLY LEAD-TIME RELIABILITY	●	◑	○
	DISTRIBUTION LT RELIABILITY	●	◑	●
	DELIVERY LEAD-TIME	Days	Days-Weeks	Weeks
	DELIVERY LEAD-TIME RELIABILITY	●	◑	●
	FLEXIBILITY	◑	◕	◕
	INFORMATION FLOW	◕	◑	○
	CONSUMER REACH	◕	◑	○
	WARRANTY SUPPORT	●	◔	○
	ROBUSTNESS	●	◑	◑
	WASTE/SHRINKAGE	N/A	N/A	○
	CAPACITY	N/A	N/A	N/A
	INVENTORY	N/A	N/A	○

LEGEND	
HIGH	●
MEDIUM-HIGH	◕
MEDIUM	◑
LOW-MEDIUM	◔
LOW	○
INSUFFICIENT DATA	N/A

NOTE:
Attribute evaluations represent an informed judgment based on data gathered through structured interviews and OEM review. High variable cost structure means that the variable cost is a high percent of the overall cost of the product.

Lessons Learned and Future Evaluations

The solar lantern pilot evaluation revealed opportunities to improve and clarify the supply chain scalability assessment in future evaluations. The following overview discusses our insights related to data collection, analysis, and presentation.

Data Collection

Our requests for interviews with OEMs during the solar lantern evaluation were met with limited response. In addition, OEMs lacked the data we requested or hesitated to disclose proprietary data. Because of this experience, in future evaluations we plan to supplement OEM interviews with data collected from their customers: product distributors and retailers. We will develop surveys for each echelon within the supply chain, and, using appropriate sampling techniques, we will conduct surveys with multiple actors in the echelon.

This multi-layered approach to data collection permits cross-validation of information across independent sources for each product brand or model, and it will increase the accuracy of product cost estimation and availability throughout the supply chain. Data from retailers help to validate costs, financing options, inventory levels, and supplier (OEM and/or distributor) performance. In addition, retailer surveys offer the opportunity to gather information about the sales channel beyond the OEM's experience.

Analysis and Presentation

The solar lantern evaluation spanned a large number of attributes that were tailored to a supply chain audience. In future evaluations, we will reduce the number of attributes to improve the usability of the evaluation's results, while maintaining the foundational attributes identified through the solar lantern pilot evaluation.

The three broad attributes we will consider include affordability, availability, and aftermarket:

Affordability, comprised of:

- **Total landed cost:** The total cost accumulated until the product lands at the point of sale. This cost, combined with the retailer markup, sets the market price. The attributes from the solar lantern study – fixed and variable cost structures – are key components in determining the landed cost for different potential sales volumes.
- **Ability to pay:** The solar lantern pilot demonstrated the critical importance of financing in the sales channels. Future analysis of affordability will incorporate financial channels that support material channels, as well as publically available data on household income levels.
- **Total cost of ownership:** While the initial acquisition cost may be a notable barrier for end users, the total cost of ownership is another important factor in determining whether to adopt a product. Surveys, along with data from retailer surveys will inform the usage patterns and cost components for this calculation.

Availability, comprised of:

- **Lead time:** The expected lead time and the reliability attributes are critical in determining the availability of products at the retail point.
- **Inventory:** In addition to lead time, the inventory of the upstream distributor or manufacturer is critical in determining availability.
- **Sales channel reach:** OEM sales channels that reach into less attractive markets provide critical availability to end users.

Aftermarket, comprised of:

- **Warranty service:** This includes not only whether the warranty is offered but, more importantly, how it is serviced. Engagement of the sales channels will again be key, and retailer surveys will provide a new, rich font of data.
- **Replacement parts affordability and availability:** The solar lantern evaluation illustrated the potential difficulties of battery replacement and how something so seemingly simple can affect the scalability of a product. In future product evaluations, we will collect data on the cost and availability of replacement parts.

Audience

Finally, the pilot evaluation led us to reflect on how to expand our evaluation results to have broader applicability beyond institutional buyers. Reflecting upon this pilot evaluation, we see the potential in leveraging the supply chain attributes to provide end users with useful information. We offer two examples: (1) end users who see a manufacturer with more extensive sales channels may be more interested in inquiring about the product at their local shop, and (2) end users who know something about the total landed cost are in a better position to negotiate with the seller for a reasonable sales price. One possible outcomes of future evaluations is the production of a simple guide for end users.

Another audience that the pilot evaluation has brought to our attention is that of investors. This group includes donors, such as government agencies and foundations, or for-profit or philanthropic financial investors. The supply chain is a key part of any organization's business plan, and our evaluations will help investors determine the best opportunities for scalable impact.

A lantern charging display at Barefoot power headquarters in Kampala, Photo taken by Jonars Spielberg.

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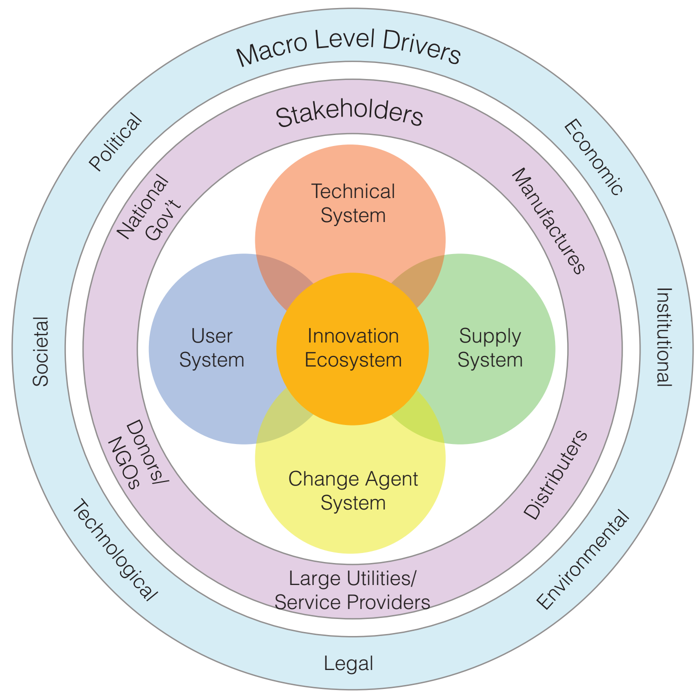
4

CITE
Solar Lantern Evaluation: Sustainability

Technology evaluation is inherently product-centric, and yet all products are embedded in larger innovation ecosystems that influence how they are used and the extent to which they gain currency in the market. These are complex sociotechnical systems with four separate but interdependent elements—the technical, user, change agent, and supply systems—that are influenced by macro-level drivers and outside stakeholders, as shown in Figure 4-1 (below). Modeling the interaction between and among these elements can shed light on whether or not a product will be adopted and whether a system's support structures and actors will be able to meet and sustain growing demand for the product over time.

Figure 4-1: Sustainable Innovation Ecosystem



Understanding the complex processes by which innovation spreads, as well as attendant barriers to this spread, is at the heart of the Sustainability team's research effort. Our goal is to help donor organizations and their implementing partners ensure that their chosen technology has the greatest chance of providing a positive impact on the lives of low-income families for the greatest period of time. Specifically, our research program includes three separate but interconnected efforts: 1) to evaluate, through comparative ratings, how well specific products work within a given innovation ecosystem relative to similar products being used in the same context; 2) to author "deep dive" studies on specific elements of a product's adoption and diffusion that require further investigation; and 3) to create simulation models and decision support tools that focus on how social, economic, environmental, and technical factors lead to varying diffusion and adoption outcomes over time.

In this first evaluation on solar lanterns in Uganda, the Sustainability team was asked to evaluate a solar lantern distribution program by a partner of the U.S. Agency for International Development (USAID). However, since this was a pilot evaluation, a full comparative rating was not performed.

A Solar Sister customer near Jinja, Eastern Uganda, has devised a way to attach his Firefly Mobile lantern to a crossbeam using an elastic band so that he can light the entire room at night. Photo taken by Victor Lesniewski

Background for Solar Lantern Evaluation

In consultation with USAID's Higher Education Solutions Network (HESN) and Development Innovation Ventures (DIV), CITE chose for its first evaluation a solar lantern project in Uganda. Solar Sister, a DIV grantee, is a small social business established in 2009 that distributes solar lanterns through a network of women entrepreneurs. Solar Sister recently won a DIV Phase 2 grant and is currently expanding into Tanzania and Nigeria—a move that will test the company's ability to scale its micro-franchise business model to different contexts and accommodate increasing demand. The CITE Sustainability team had two objectives: to evaluate Solar Sister's organizational health and potential for growth and to understand the key barriers the business may face to scaling up in the future.

A d.light S10 (Kiran) solar lantern charges in the sun behind the Kabalega diner near Nakitoma on the Kamapala-Gulu Highway. The lantern belongs to Scovia Aboth, a 24-year old Solar Sister Entrepreneur (SSE) who works at the diner. Photo taken by Jonars Spielberg.

Solar Lanterns and the Ugandan Context

Uganda is a land-locked country of 35 million people on the northern shore of Lake Victoria in Eastern Africa. Most people, 85 percent, live in rural areas (World Bank, 2013) where access to power infrastructure is limited and unreliable. Uganda's official electrification rate hovers around 10 percent (5 percent in rural areas), which is low even relative to other sub-Saharan African nations (IEA, 2011). Despite the Rural Electrification Agency's Rural Electrification and Strategy Plan (RESP) 2013-2022, which aims to achieve universal electrification by 2040 and to eliminate all kerosene lighting by 2030, low electrical coverage will likely persist. High capital costs, rapid population growth, and a geographically diffuse populace have resulted in inadequate investment, evidenced in aging infrastructure with low generation, transmission, and distribution capacity. Even with a tiered tariff scheme, the cost of electrical services remains well above many households' ability to pay.

Because the solar lantern sector is only 5 to 6 years old and has yet to penetrate fully into local markets, knowledge about nongrid solar lighting for households remains low. This ignorance persists despite the low prevalence of electrification and the clear need for alternatives to kerosene lamps, which, according to the 2002 Ugandan census, are used by 75 percent of households (UBOS, 2006). Kerosene lamps are not only poor sources of light, but are also hazardous to health, harmful to the environment, and often constitute a significant portion of household spending. The relationship between low electrification rates and poverty has been studied by the World Bank and others[1], and the results of these studies show that access to electricity is critical to human development because it frees up time for education and health, allows for refrigeration and other household electrical goods, and replaces costly and polluting alternatives, such as kerosene. Though the potential market for off-grid energy solutions may be considerable—as high as 90 percent of the population—demand is tempered by cost, lack of product awareness, and limited product availability.

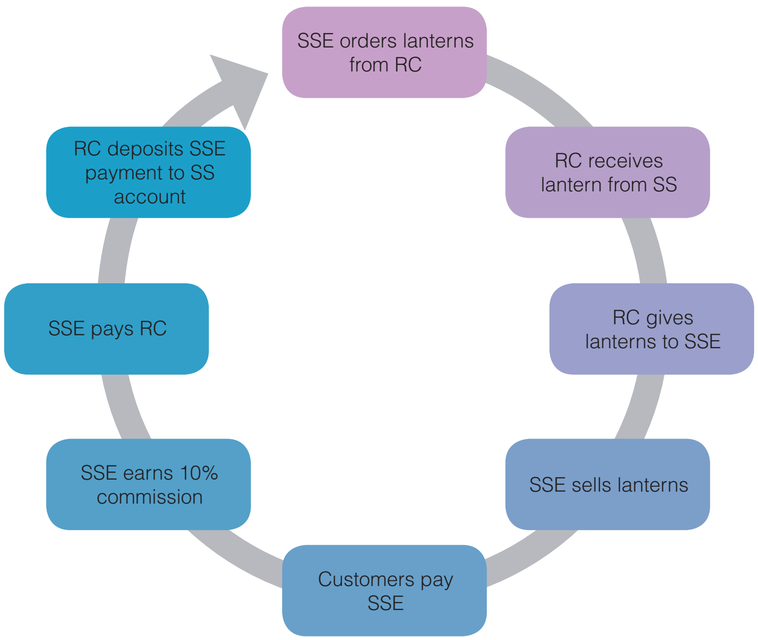
[1] World Bank. (2008). The welfare impact of rural electrification: A reassessment of the costs and benefits. An IEG Impact Evaluation. Washington DC: World Bank; E.Crousillat, R. Hamilton, P. Antmann, "Addressing the Electricity Access Gap," A Background Paper for the World Bank Group Energy Sector Strategy, June 2010. Accessed at: http://siteresources.worldbank.org/EXTESC/Resources/Addressing_the_Electricity_Access_Gap.pdf on June 23, 2014.

Barriers to Adoption

- User does not know about product
- User cannot afford product
- User cannot access microfinance
- User cannot always find product in stores due to variable inventory
- User cannot buy product in village due to transportation issues
- User lacks confidence in performance due to past experience with poor quality product

Solar Sister

Figure 4-2: Solar Sister Sales Cycle



Key: Solar Sister entrepreneurs (SSE), Regional Coordinators (RC)

Solar Sister was founded in 2009 by Katherine Lucey, an American businesswoman with extensive experience working as an investment banker in the energy sector. Through her participation with a philanthropic organization working in rural Uganda to provide access to solar renewable energy, she saw first-hand that many Ugandans lack access to affordable, reliable, clean energy. As a mission-driven organization, Solar Sister has a triple bottom line: to empower a network of women (Solar Sister entrepreneurs, or SSEs) through solar lantern sales in their communities; to provide access to clean energy, especially in rural areas; and to turn a profit from the sale of solar lanterns.

Solar Sister gives women the opportunity to own micro-businesses by providing training and startup capital—a "business in a bag" containing solar lanterns (numerous different models have been distributed) and marketing and training materials. SSEs sell the lanterns to people in their social networks, earning per-sale commissions that contribute to household income while simultaneously bringing energy and light to areas that need it. Since its inception, Solar Sister has grown rapidly, recruiting more than 400 entrepreneurs in Uganda, about 275 of whom remain active. Beginning in 2013, the organization began to scale its operations into Tanzania and Nigeria; Solar Sister's goal is to recruit 3,000 additional entrepreneurs by 2015.

Methodology

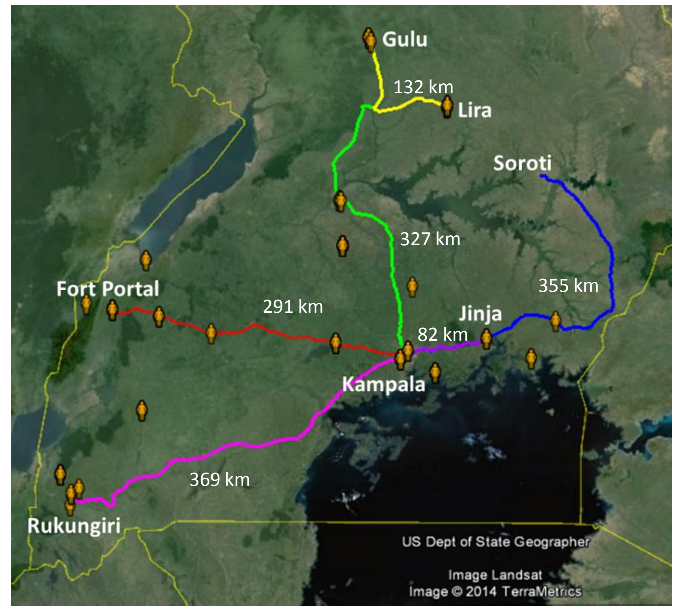
The CITE Sustainability team used a variety of research methods and analytical techniques to assess the social and economic dimensions of Solar Sister's operations and its approach to the dissemination of solar lanterns in Uganda.

Interviews and Surveys

The CITE Sustainability team conducted 102 interviews in Uganda: 80 with SSEs, 12 with Solar Sister staff (primarily covering financial data and modes of operations), and eight with lantern suppliers (to understand some of the supply chain aspects of Solar Sister's distribution approach). Questions and prompts for the SSEs were developed based on literature reviews and consultations with scholars and Solar Sister staff; they were then finalized based on feedback provided during a pilot in Uganda. Interviews were divided into six sections, covering: demographic information; entrepreneurship background; the decision-making process behind becoming an SSE; on-the-job experience and skills; capacity for learning; and community engagement. The SSE interviews were only semi-structured, as the largely qualitative nature of our research goal demanded flexibility during the information-gathering process.

As shown in Figure 4-3, GPS coordinates were recorded for each interview to tie responses and financial data to the distance and time between the SSEs, regional coordinators (in cities indicated in the figure), and Solar Sister headquarters (in Kampala). The color-coded routes indicate the major transportation routes used by Solar Sister to distribute the lanterns. SSEs often travel from locations off these routes to regional coordinator sites.

Figure 4-3: Interview Locations and Transportation Route Distances



Kampala-Fort Portal	181 miles (291 km)
Kampala-Gulu	203 miles (327 km)
Kampala-Soroti	220 miles (355 km)
Kampala-Jinja	51 miles (82 km)
Kampala-Rukungiri	229 miles (369 km)
Gulu-Lira	82 miles (132 km)

Solar Sister Entrepreneur Interview Location

Financial and Statistical Analysis of Solar Sister Data

Solar Sister has a philosophy of total transparency and provided the CITE team with a wealth of data on lantern movements through the supply chain (differentiated by region, year, model, and SSE), as well as its full database of financial data going back to 2010. This information, especially when combined with the survey data, was used to assess the financial health of the organization and to compare how many of each lantern model were ordered by SSEs. It should be noted that Solar Sister does not record sales between the SSE and end user: Thus, "sales" in this report refers to sales from Solar Sister to the SSEs.[2]

Probability Analysis and Logistic Regression

SSE success is integral to Solar Sister's sustainability; SSE sales generate income for the entrepreneurs as well as revenues for Solar Sister. Therefore, we sought to identify the characteristics that are common among most successful SSEs. To do so, we coded relevant survey data and performed two complementary statistical analyses: a probability analysis based on set theory and a multivariate logistic regression specified by a linear prediction function. For both analyses, a successful SSE was defined as someone who achieved a paid-to-sales ratio above the within-sample median value (0.68). Thus, an SSE's paid-to-sales ratio—the percentage of lanterns SSEs acquired from Solar Sister on credit ("sales") and then paid back to Solar Sister—served as the basis for the dependent variable ("success") for both analyses. SSEs that exhibited paid-to-sales ratios > 0.68 were categorized as successful (1); those who did not were categorized as naught (0). After testing paid-to-sales ratio against a variety of independent variables, three emerged as statistically significant: intrinsic motivation (μ) good communication skills (γ) and willingness to travel (τ).

[2] The sale is one part of the supply chain, which in this case includes physical movement from supplier to Solar Sister headquarters, to Solar Sister regional coordinators, to SSEs, and to end users.

Findings

The main findings from the CITE Sustainability team's evaluation are summarized in Tables 4-1 and 4-2 below and sorted into two parts: sustainability issues with the Solar Sister program (including technical issues that were reported during interviews with SSEs and regional coordinators; other issues reported by the SSEs; issues specific to Solar Sister as an change agent organization; and supply issues); and general barriers to scale for solar lanterns supplied by any organization using a hybrid business model (i.e., social goals coupled with a desire for profit).

Table 4-1: Sustainability Issues with Solar Sister Program (Based on Interviews and Observation)

Technical System	After storage, some lanterns need a "reboot" (direct charging by electricity until a minimum charge is reached) before they can complete a solar recharge cycle. This requires return of the lantern to the supplier in Kampala. Some lantern models charge poorly in cloudy weather.
User System	Lanterns are unaffordable for many; this was the No. 1 barrier to adoption cited by SSEs interviewed. Financing is not available formally thorough Solar Sister. Some SSEs allow customers to pay in installments, but payback periods can be lengthy and 100 percent payback is not guaranteed Knowledge about off-grid, household solar lighting remains low, especially in rural areas. Kerosene lamps are ubiquitous and cheap, so it is difficult to convince people to change to an alternative. Income exhibits temporality: Potential customers can afford lanterns only at certain times of the year. Though improving, Solar Sister's "brand" recognition is relatively low.
Supply System	Solar Sister does not use a commercial trucking company. Rather, it is dependent on the national bus service for shipping lanterns from Kampala to other regions. There is no systematic distributed warehousing. All lanterns are stored at headquarters in Kampala. Solar Sister is largely dependent on funding from grants and donations. Financing from carbon credits was explored, but the costs of applying and performing audits far outweighed potential financial benefits. Aftermarket support is weak: Repair and replacement time is lengthy, and the end user must go without a lantern during this period.

Table 4-1: Sustainability Issues with Solar Sister Program (Based on Interviews and Observation) Continued

Change Agent System	The retention rate for recruited SSEs is 66 percent.
	SSEs and lantern sales are regionally concentrated in urban areas, namely Kampala Central.
	Solar Sister does not use mobile telephony in a systematic way to recruit, train, and communicate with SSEs or end users, or to automate sales payments.
	Regional coordinators are the main conduit between headquarters and SSEs, and if they prove ineffective or overburdened, inefficiencies and bottlenecks within the organization propagate.
	Most SSEs have multiple income streams, and being an SSE is often not a priority.
	Many SSEs not in the Kampala Central region expressed a lack of connection to Solar Sister.
	Nearly all SSEs noted that the first few weeks of becoming an SSE were difficult.
	An SSE's commission on lantern sales is relatively small, especially considering the effort required to make the average sale.
	The time and transportation costs associated with trying to sell lanterns are high for SSEs.
	Finding new customers becomes harder over time as SSEs' social networks become "saturated."
	Key communication flows are weak, leading to delays in information dissemination and missed opportunities to share knowledge and expand social networks.
	Trainings are useful, but occur intermittently.
	New no-credit policy means that SSEs must pay for lanterns before selling them. Many SSEs expressed concern about finding the money to pay for lanterns in advance.
	Regional coordinators must act as debt collectors to receive money from SSEs, which creates ill will and distracts them from more important responsibilities.

Table 4-2: Barriers to Scale for Solar Lanterns Using a Hybrid Business Model

Technical System	Though warranties were a notable selling point, aftermarket support remains poor. In-house technical support, though under development, is currently minimal.
User System	Lanterns are expensive, and no credit is available.
Supply System	The planned rapid increase in entrepreneurs needs to be accompanied by a scale-up in the supply chain. Accounting and purchasing processes are not systematized. Roads in Uganda make travel cumbersome and uncertain. This leads to increased supply costs. Highly populated urban areas are conducive to lantern sales, but it is difficult to travel long distances to distribute the lanterns and reach end users in rural areas. All lanterns are shipped from manufacturers in China, though some models are warehoused in eastern Africa. This creates large lead times for many models.
Change Agent System	Selling primarily to friends and family creates a limited market. No financing system is in place for Solar Sister entrepreneurs. It is a challenge to recruit and retaining qualified country-level staff. There is growing competition from other sources, including hawkers and private companies (though Solar Sister is exploring partnerships). It is questionable whether Solar Sister's business model—which unites economic thinking with the desire to create social value—is structurally sound. Time spent by staff collecting outstanding balances. (Entrepreneurs are overestimating their ability to sell lanterns.) There is a quality/quantity tradeoff in recruiting entrepreneurs for Solar Sister, and it is unclear which strategy is better for the Solar Sister model. Shift in credit model represents a potential tradeoff between organization's financial health and women's empowerment.

Based on the issues identified in Tables 4-1 and 4-2, the CITE Sustainability team prioritized two areas for its analysis: the high dropout rate of SSEs and the low repayment rate by SSEs for lanterns given to them with 90 percent credit.

Strengths and Challenges of Solar Sister Model

There are several benefits to joining Solar Sister as an entrepreneur, including increased social status and pride (family members and friends typically reacted positively to the decision to become an SSE). Trainings were another key positive feature of being a SSE, yielding the opportunity to learn new business skills (accounting, marketing) and interact with other entrepreneurs. Many SSEs were able to integrate lantern sales into their daily lives—selling lanterns at work, when traveling, or at night when lanterns are easy to demonstrate. SSEs also realized that sales tend to be seasonal, especially in rural areas: Customers are more likely to buy lanterns when they have more cash on hand, such as post-harvest. Since monthly spending exceeded household income on average, the additional income generated by lantern sales was much needed, going toward children's education expenses, food, and small household items.

Despite the many positive aspects of entrepreneurship, nearly all SSEs interviewed faced a steep learning curve and faced numerous difficulties, especially during their first few weeks on the job. Convincing potential customers of the product's merits—particularly given high lantern prices—and transportation (including associated costs, which cut into commission earnings) were consistently cited as top challenges.

Strengths

- Trust, strong customer-service orientation
- Community embeddedness and "insider" knowledge of SSEs
- Large potential market
- Focus on last-mile (poor, rural) users

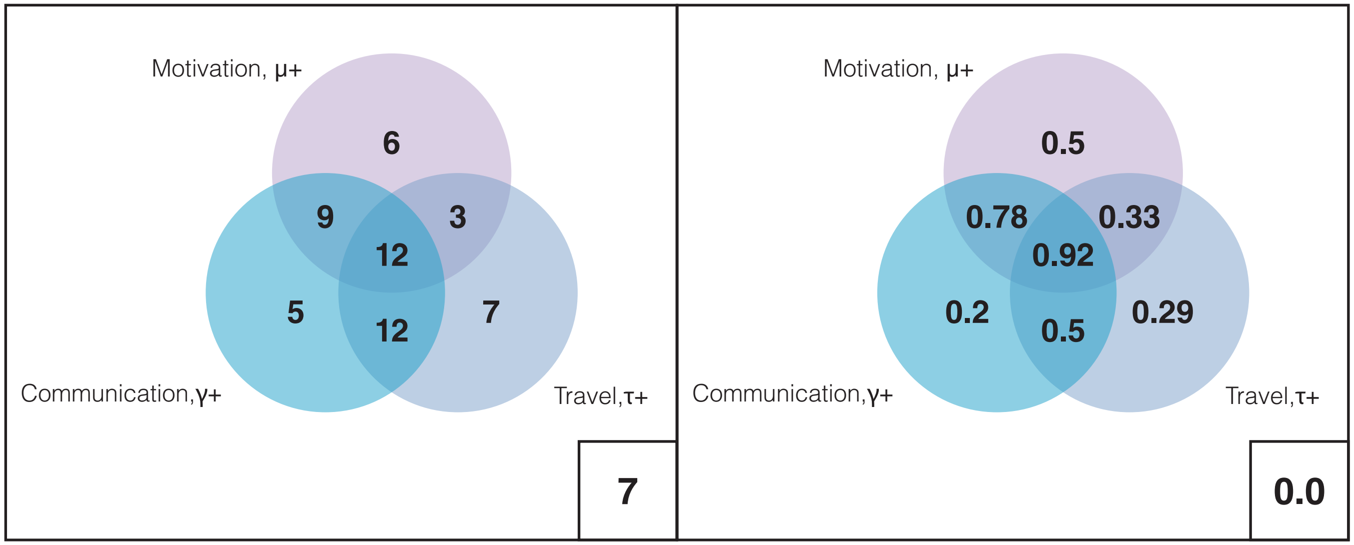
Challenges

- Transport and distribution
- Consumer knowledge about lanterns
- Financing, credit, and payback
- Balancing social and financial objectives
- Entrepreneur retention: quality vs. quantity

What Characteristics Lead to Entrepreneurial Success?

- Intrinsic motivation
- Good communications skills
- Ability and willingness to travel

Figure 4-4: Results of Probablistic Analysis Showing Characteristics of Successful SSEs



An additional challenge was growing competition from two quarters: hawkers whose products are of poor quality and lead to market spoilage, and private companies, such as Total, who have begun to sell the same solar lanterns, often at lower prices. Another common frustration for SSEs was that many consumers wanted to purchase the lanterns (especially ones with phone-charging capability) but could not afford them. Even when SSEs completed a sale, getting some customers to pay the full price of the lantern proved problematic. While these difficulties challenge the model's sustainability, the ongoing success of recruitment efforts and the existence of profit-making SSEs signify the viability and attractiveness of selling solar lanterns through a network of women entrepreneurs.

As described above, probabilistic set theory analysis (Figure 4-4) paired with a multivariate logistic regression (Equation 4-1), revealed evidence that the vast majority of successful SSEs possess at least one of the following three characteristics: intrinsic (non-monetary) motivation (μ), good communication skills (γ), or willingness to travel long distances to find potential customers (τ).

In Figure 4-4 (above), eight profiles emerge from the probabilistic set theory analysis. For instance, Profile 7 [μ - τ + γ -], describes entrepreneurs who indicated no intrinsic motivation to sell lanterns, did not learn communication skills while selling lanterns, and did not travel far to sell them. Based on our sample data, this entrepreneur profile is represented seven times (out of all, n = 61). Of these seven, two (out of n = 31) were above the median paid-to-sales ratio and deemed "successful entrepreneurs." Figure 4-4 (above) demonstrates the ratio of successful-to-total entrepreneurs for each profile category. The figure reveals that entrepreneurs with Profile 1, [μ + τ + γ +], have the highest likelihood of becoming successful entrepreneurs out of all eight entrepreneur profiles assessed, while those with Profile 8, [μ - τ - γ -], are least likely to succeed.

The findings above were validated by the following logistic regression, which was run on the same data used for the probability analysis:

Equation 4-1: Multivariate logistic regression

$$\ln(\text{odds of success}) = -2.629 + 2.204\,(\text{motivation}) + 1.585\,(\text{communication}) + 1.53\,(\text{travel})$$

A test of the three-variable model against a constant-only model was statistically reliable (chi-squared = 22.8, $p < .001$), indicating that the predictors reliably distinguished between entrepreneurs that were successful and those that were not. The explanatory power of the three variables – motivation (μ) [$p = .001$], communication (γ) [$p = .018$], and travel (τ) [$p = .124$] – appears to be quite robust, yielding 72.1 percent overall predictive accuracy. More complete logistic regressions that included other demographic factors—such as income, education, occupation, sales integration into one's daily life, direct exposure to entrepreneurship as a child, improved record-keeping skills, and level of communication with one's regional coordinator—yielded negligible increases in predictive capacity relative to the parsimonious model presented here. As such, trainings geared toward cultivating intrinsic motivation, communication skills, and willingness to travel may help improve SSE retention and sales.

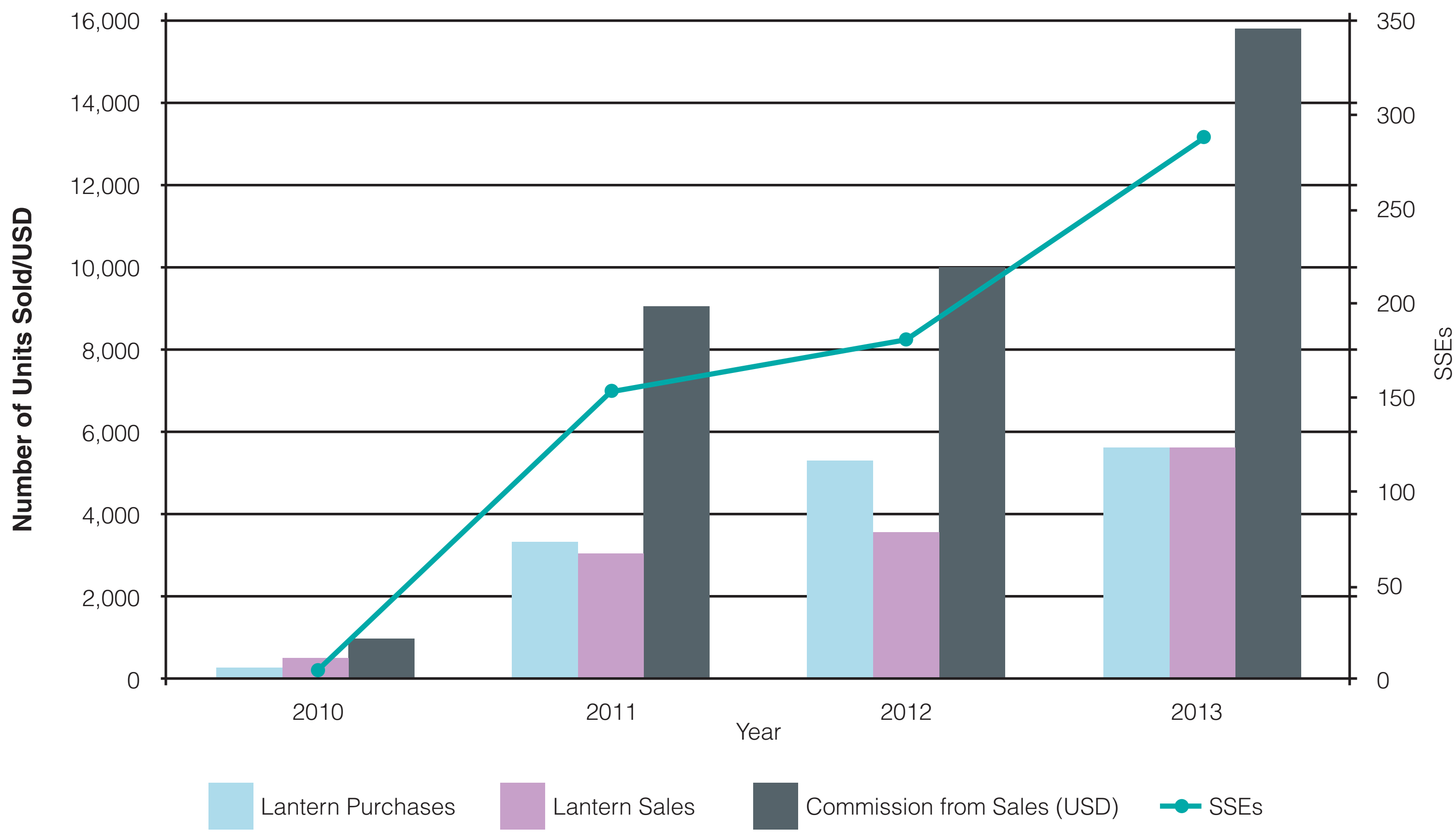
Financial Health of Solar Sister

While Solar Sister has grown significantly, as shown in Figure 4-5, sales ratio metrics seem to have remained relatively constant since 2011. On an aggregate level, approximately 70 percent of lanterns purchased by Solar Sister from manufacturers were sold.[3] Lantern sales per entrepreneur have remained even over the last two years at around 19 per year. Likewise, the average annual commission for the 290 active SSEs was $55 in 2013 and has changed only marginally since 2011.

Solar Sister's performance can also be measured by lantern model sales, in total and regionally. Lantern sales have changed over time as Solar Sister strives to find the best products for its end users. Based on the sales data, d.Light's S20/Kiran and S300/Nova models were popular in 2010 and 2011. The Kiran was relatively cheap at $15 for the end user, had a built-in solar panel, and diffused light well (according to SSE interviews), while the Nova ($44) could charge phones and was durable (based on SSE and regional coordinator interviews). In 2012, Solar Sister began purchasing GreenLight Planet's SunKing Pro model ($50)—which could charge phones, had a bright light with multiple settings, and had a unique design that allowed users to point the light in any direction—and the product became its best seller in the early part of 2013, followed by the d.Light S1/S2 model and the Firefly Mobile. This finding is in line with the Suitability team's ranking of the SunKing Pro as the top lantern available in Uganda, but only for those users who can afford it. For users who can only afford to spend about $15, the d.light S2, though low in the comparative rankings, is preferred.

[3] Sold is defined as lanterns Solar Sister has distributed to SSEs, for which they are financially accountable.

Figure 4-5: Solar Sister Growth



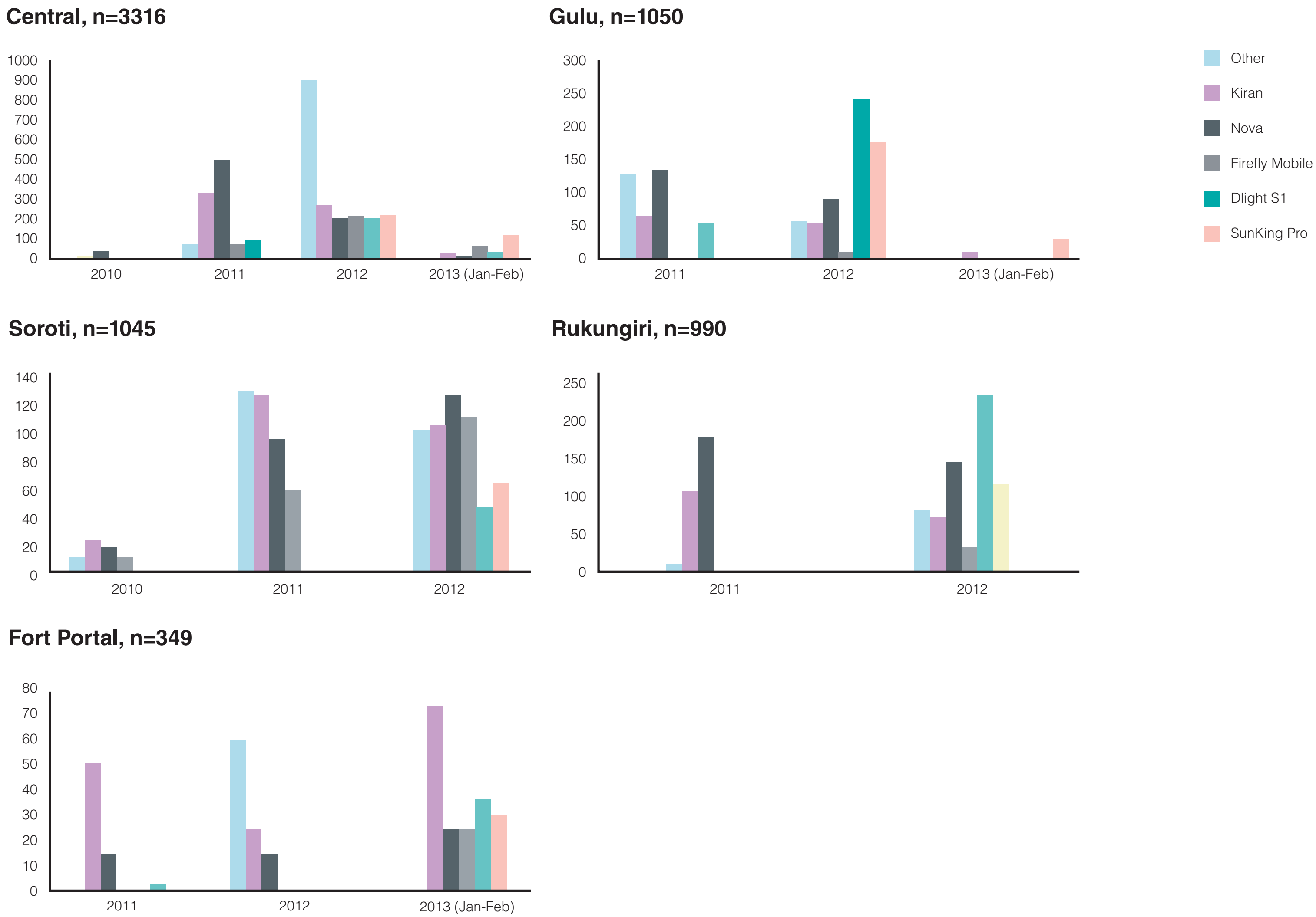
Though the number of models has expanded considerably, the number of lanterns distributed to SSEs seems to have declined. In 2010, 100 percent of all lanterns purchased by Solar Sister were distributed to SSEs for sale. In 2013, this percentage had dropped to a range between 58 percent and 12 percent, depending on the model. This may suggest a supply issue where the amount of time a lantern is stored at the central warehouse before being sold to a SSE is longer than desired, or it may be a function of the decision to limit credit to SSEs, which may make it difficult for them to buy certain lanterns.

When looking at the number of lanterns distributed by region and model (Figure 4-6), it's important to recognize that in 2010, only the Soroti and Central regions were active; Gulu, Fort Portal, and Rukungiri were initiated in 2011; and Jinja (not shown) joined in 2012. Between 2010 and 2013, the Central region managed to distribute a larger proportion of purchased lanterns to their SSEs than the any other area. Soroti followed Central, successfully distributing 87 percent of its purchased lanterns to its entrepreneurs from 2010–2013, with Gulu and Rukungiri not far behind at a cumulative sales ratio of 77 percent and 79 percent, respectively. Fort Portal lagged at 44 percent. From this, there appears to be a correlation between the length of time that a region has been involved with Solar Sister and its sales ratio, suggesting that, in time, this metric may improve for recently initiated regions such as Jinja and Fort Portal.

Based on the interviews with Solar Sister staff, it's clear that over time the organization's credit model has evolved in response to on-the-ground experiences. Initially, a 100 percent credit model was adopted, the logic being that Solar Sister wanted to keep the barrier to entry as low as possible. However, it quickly became apparent that this model was untenable: without any monetary stake in their success or failure selling lanterns, SSEs were not particularly motivated. To remedy this, Solar Sister moved to a 10 percent commitment fee, requiring SSEs to pay for 10 percent of the lanterns they order up front. This was an improvement, but Solar Sister still faced challenges with timely payback. Now Solar Sister has transitioned to a no-credit model, reflecting its success in Nigeria and Tanzania; this requires SSEs to pay for 100 percent of their product up front. It is too soon to say whether or not this shift is working in Uganda, but this evolution speaks to the central importance of finding an appropriate financing mechanism to ensure organizational success and get as many solar lanterns into the hands of end users as possible.

Based on analysis of the data provided by Solar Sister, the income-to-expense ratio suggests that the financial strength of Solar Sister Uganda is not as strong in 2013 as it was in 2012. This is due to many factors, including personnel problems (hiring of a new country manager, financial manager, and coordinator for Soroti) and a changing credit model in Uganda.

Figure 4-6: Number of Lanterns Distributed by Region and Model



Summary

Solar Sister's distributed, direct-sales, hybrid social/business model has grown significantly since 2010, and with it has come some significant challenges, especially in trying to balance the dual goals of high desired social impact and financial viability. These challenges, however, have been acknowledged, and Solar Sister has demonstrated flexibility and a willingness to learn and improve—important attributes for sustainability, especially during the startup phase of an organization.

The use of social networks and the active promotion of new technology are core strengths of Solar Sister's hybrid model.

Providing SSEs with the support and tools they need to be successful achieves all three of Solar Sister's goals: It empowers women through economic opportunity, it puts clean energy into the hands of end users, and it increases the proportion of operating costs covered by sales. Doing so cost-effectively and resource-efficiently will be a primary indicator of Solar Sister's sustainability as it scales.

Key Finding

While having good credit policies and choosing high-quality, low-cost lantern models is important, the sustainability of Solar Sister's approach hinges on its ability to recruit, train, and maintain SSEs.

Solar Sister Entrepreneurs (SSEs) we interviewed from the Nakaseke in Central Region, Uganda. 13 July 2013. Photo credit: Jennifer Green.

Lessons Learned and Future Evaluations

The CITE team as a whole learned a great deal by doing this pilot evaluation. First, it is clear that in order to align its work with the Suitability and Scalability teams, the Sustainability effort should focus on the product—not the project—as the unit of analysis. For future evaluations, the Sustainability team has developed an evaluation matrix for calculating comparative sustainability scores for each product. This matrix considers four product-independent criteria (social, economic, environmental, and user needs) as well as one additional criterion that is important for the product being evaluated. For example, the fifth criterion for the upcoming evaluation of water filters is "health." Each of the criteria has two to four indicators, as shown in green in Figure 4-1. For the product-related criterion, the indicators will be specific to that product.

The Sustainability team is developing cell-by-cell algorithms that will convert end-user survey data into a score for each indicator and criterion. To gauge the overall sustainability of each product, the individual indicator and criterion scores will be weighted to best reflect the priorities and decision-making behaviors of the target population. An extensive literature review—paired with survey data regarding frequency of proper use, benefits acquired through use, and reasons for use—will inform our weighting schematic. CITE Sustainability will also create methods to enable development actors in other countries to replicate the surveys, adjust the weightings, and use the Sustainability matrix to customize this tool for their own decision-making.

By simplifying and focusing its evaluation methodology, the Sustainability team will have more time to devote to areas where we have a comparative advantage—namely, the creation of complex systems models and decision support tools. The Sustainability team has developed similar models and tools to address challenges in other sectors, work that has revealed that these types of research techniques can shed new light on the interdependent barriers to product adoption and scale in a development context.