Cost-Benefit Analysis of Off-Grid Solar Investments in East Africa

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Economists from USAID's Office of Economic Policy conducted a cost-benefit analysis (CBA) of four off-grid solar energy investments, representing $8.4 million in development assistance through USAID's Development Innovation Ventures (DIV). The objective of the analysis was to determine the value for money of USAID's investment by measuring the financial and economic cost of producing and distributing these products, as well as the impact on households.

An initial review of the results suggests USAID's $8.4 million investment is creating over $17 million in net present value to the East African countries of Rwanda, Tanzania, and Uganda. A majority of this value addition comes in the form of consumer surplus estimates, as households are spending less of their income on energy sources while enjoying additional hours of higher-quality lighting. At the same time, solar households continue to use large amounts of non-solar energy sources to meet their overall lighting needs.

Assuming an average product life of five years, results from the solar PV system analysis suggest that the ownership of each of the solar products causes a positive financial net present value (NPV) at the household level, meaning customers are experiencing a net increase in their incomes due to lower expenditures tied to annual lighting costs. The range of household benefits depends on the customer's payment plan. Households participating in a pay-as-you-go plan (where customers pay for the solar systems in monthly installments over a 12 to 36-month period) experience a net financial gain ranging from $50 to $137, while households paying the full upfront cost at a 15 to 25 percent discount experience a net financial gain ranging from $53 to $117. Households purchasing smaller solar lanterns also experience net positive financial returns of around $45.

Each of the private companies funded by these investments supported different aspects of the supply chain, allowing for the evaluation of separate approaches to delivering solar products ranging from solar lanterns to PV home systems. Although there are positive economic gains associated with each of these solar investments, more work needs to be done to find financially viable distribution systems, in particular for less expensive solar products targeting low-income households. The primary constraints are the excessive cost of product distribution, high default rates among pay-as-you-go customers, and a breakdown in partnerships among different actors along the supply chain. The profitability of these companies is also under threat from a proposed policy change to remove an East Africa Community (EAC) tariff exemption, as this move would raise consumer costs, trigger a greater number of product defaults for pay-as-you-go customers, and drive a large number of competitors out of the market.

The makeup of East Africa's solar industry is also constantly evolving and being driven by market innovations, expanding distribution systems, and sophisticated product targeting. Understanding the income distribution of households is critical to understanding the off-grid solar market. The segment of the population that can afford solar but is not yet connected to the grid is smaller than most people assume. In Rwanda, for example, an estimated 70 percent of households cannot afford to spend $1.50 per week for both lighting and phone charging.

Realizing these customer dynamics, actors in the East African solar energy market have begun to differentiate themselves by targeting higher income groups with more aspirational products like solar televisions. This move is rational for private businesses operating on thin profit margins as their goal is to earn a respectable return for their shareholders. Development partners, however, should decide if investments in this arena are targeting income groups that are aligned with their social and economic mission before determining where best to place public funds.

In summary, the preliminary results from this cost-benefit analysis demonstrate how Development Innovation Ventures' investments into the East African solar market have created value for money in terms of an economic gain of $17 million – one of the most important metrics for evaluating a development investment as it signals the entire economy, or in this case a number of economies, is benefiting from USAID's investments. Moreover, many of the secondary impacts of supporting these companies to test new innovations and distribution approaches have not been captured in this analysis due to the difficulty of identifying attribution. This suggests the real value of these investments could be even greater than reported here.

CBA Methodology[1]

Overview

In simple terms, cost-benefit analysis (CBA) is a systematic assessment of the costs and benefits of a development intervention intended to weigh whether expected benefits justify costs and to identify the key drivers of each. CBA compares the projected costs and benefits of a USAID investment with the costs and benefits of a status-quo situation where USAID does not invest. In other words, analysts compare the costs and benefits "with project" to the costs and benefits "without project". The calculation of incremental costs and benefits allows analysts to determine if the project makes key stakeholders better off compared to their expected situation without USAID involvement. Every CBA is constructed on a series of cash flows to properly catalog the cash outflows (or costs) and cash inflows (or benefits) of a project, usually on an annual basis.

Financial Analysis

Cost-benefit analysis involves assessing the projected costs and benefits of an intervention from several perspectives. Each perspective provides a look at the incentives for one group of stakeholders in a project—the primary recipients, the primary implementer of an investment, the government, financial institutions, and/or the whole economy. In the financial analysis, we look at the intervention from the perspective of key stakeholders in the economy, using actual market prices to reflect the value of costs and benefits as they are actually experienced by the stakeholder. In addition to measuring the incremental net cash flow for each stakeholder, the financial analysis considers the financial sustainability of the investment without USAID assistance.

Economic Analysis

The economic analysis of a project is a very important part of the CBA because it measures whether society as a whole benefits from the project. It does so by adjusting the financial analysis of a project's activities by correcting the economic distortions that exist in the economy. The economic analysis establishes economic prices (the prices that would exist if there were no distortions) for each of the inputs used in the course of the project's activities, as well as the outputs produced by the project. Using these economic prices shows the total benefit (or resource inflows) of what the project produces and the total costs (resource outflows) of what the project used up. It shows the net benefit (or cost) of the project to society as a whole.

Box 1.1: Key CBA Terms for Measuring Impact

Net Present Value (NPV): The primary measure of a project's financial and economic impact, after accounting for all costs and benefits. The NPV is the increased benefits generated by the project in present value terms.

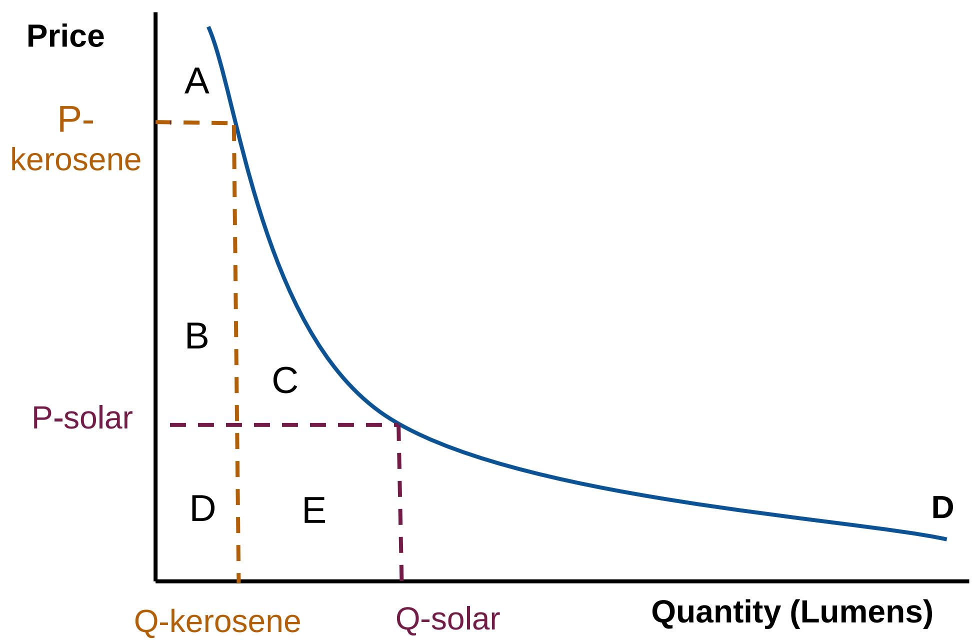
Discount Rate: A measure of how much more someone would need to receive (or be willing to pay) in the future in order to forego consumption (or payment) in the present.

Internal Rate of Return (IRR): A measure of project value that looks at the project from an investment perspective, in terms of the return to the investor. The IRR is the discount rate which causes the net present value of a stream of cash flows to equal zero.

[1] The methodology summarized here is based directly upon *USAID Guidelines: Cost-Benefit Analysis*.

In order to evaluate off-grid energy projects, the World Bank and other institutions use consumer surplus estimates to capture the economic benefits of fossil fuel and renewable energy by estimating the social welfare impact of increasing energy consumption and lowering price.[2] Consumer surplus is calculated by using the difference between the maximum willingness to pay and what the consumer actually pays. Through the analysis of surveys, it is possible to estimate the willingness to pay for light by estimating how much it costs to purchase a certain number of lighting products (e.g. kerosene, candles, battery-powered flashlights, etc.) and how many lumens[3] the average person consumes from these lighting products. This gives us a starting point on the demand curve, assuming a log-linear demand curve. In the following figure, the original consumer surplus is (A) and the new consumer surplus is (A+B+C).

Figure 1: Consumer Surplus Estimates for Off-Grid Investments



Sensitivity Analysis

Sensitivity analysis is the identification, estimation, and interpretation of the sources of uncertainty around a project. In the context of a CBA model, sensitivity analysis attempts to predict how changes in the underlying assumptions about model inputs could impact the project's outcomes. The purpose of sensitivity analysis is to understand how a project's risk variables – variables that are difficult to predict and important to the project's outcome – can affect the results of the CBA model. This analysis focuses on the project outcomes, most notably the net present value (NPV).

[2] A description of the consumer surplus methodology is provided in the World Bank's 2008 *The Welfare Impact of Rural Electrification: A Reassessment of Costs and Benefits.*

[3] A lumen is a measure of the quantity of visible light emitted by a lighting source. Although we chose to use lumen output in this CBA study, it is not the only measure of light output. Another common option is to measure the area in square meters that receives a minimum threshold of brightness. Lighting Global tests for total area with illumination > 50 lux. A lux is equal to one lumen per square meter.

Investment and Implementation Overview

Overview

The market value chain for solar PV systems and other solar products typically starts in Asia, as solar goods are manufactured in the region and then shipped to destination markets in Africa and other parts of the world. Upon clearing customs, the products are stored in a local warehouse facility and then await delivery to local sales agents and technicians who are responsible for selling, installing, and/or repairing the solar home systems. Of the four companies included in this analysis, one sold exlusively solar lanterns, and three sold solar home systems ranging from a two-light system that provides a total of 120 lumens, to a three-light system that provides a total of 400 lumens. Each of the four companies analyzed for this study use or used different distribution models with unique customer payback timelines, ranging from one upfront cost to a 36-month payback timeline.

Challenges to Project Implementation

Each of the solar companies faced several financial and logistical challenges when entering new markets, including the high cost of producing and distributing solar products in rural areas, low revenue flows, high default rates among pay-as-you-go customers, and a breakdown in partnerships among different actors along the supply chain. Other challenges were related to technical aspects of the solar technologies and payment systems.

Although the global cost of producing solar products has decreased substantially over the past several years, there are still significant cost hurdles to providing affordable solar products to off-grid households. According to the International Renewable Energy Agency (IRENA), from 2012 to 2015 the total installed cost of solar home models in Africa can be separated into the following cost categories: battery costs (14-69% of total installed cost); soft costs[4] (40-50%); other hardware (4-53%), PV modules and lights (10-47%); and charge controllers (3-23%).[5] It is evident from these wide variations that costs are heavily dependent on the quality/power of the solar product and the customer distribution market.

Initial cost estimates for producing and delivering solar home systems range from $159 to $280 per unit delivered. Cost of delivery of a solar lantern averaged $21 per unit. Company revenue flows are only able to cover a portion of these expenses, as many off-grid solar customers are unable to pay beyond a certain price point. In Rwanda, for instance, around 70 percent of off-grid households are unable to afford the least expensive PV home systems.[6] While the unit price for each company varied, the PV solar providers had comparable prices in terms of the unit cost of lumen output, ranging from $0.79 to $0.90 per lumen of output.

A comparison of the projected and actual difference between the cost of installing a solar unit and customer price provides some insight as to the separation between expenses and revenues. There are,

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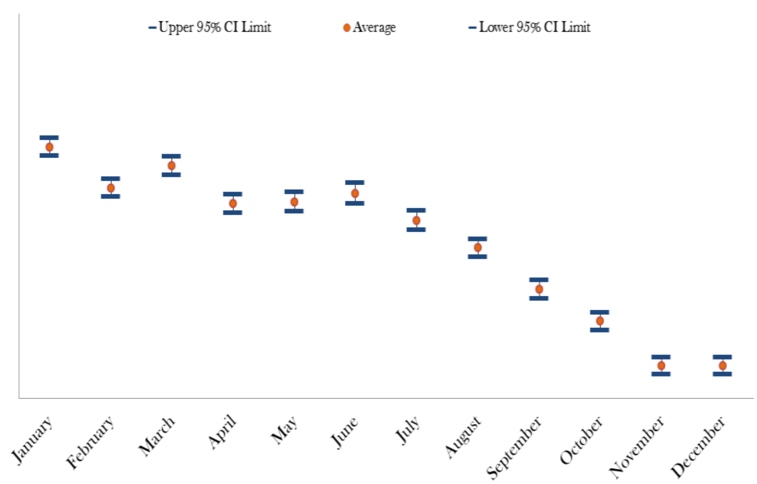
[4] Soft costs include installation, customer acquisition, marketing, etc.
[5] IRENA (2016), Solar PV in Africa: Costs and Markets. www.irena.org.
[6] Based on a presentation by Rocky Mountain Institute in January 2016.

however, several factors to keep in mind when assessing this information. First, some grantees targeted wealthier customer groups with the total estimated product costs accounting for around one-third of GDP per capita. Second, customer costs for each of the PV solar products were paid for over a certain period of time under the PAYG system. The customer group with the highest overall product cost had the longest pay-back period at three years, as compared to 18 and 12 months for the other PV providers. Although this means customer expenses are spread out over several years, there are also lower realized cash inflows due to movements in the exchange rate.[7] Third, the estimates provided in Figure 1 do not account for customer defaults and lower monthly household payments so the per unit profit margin experienced by each firm is actually lower than reported here. Finally, the financial margins do not account for the social welfare impacts experienced by customers experiencing greater access to light over an extended period of time at a lower cost.

A customers' ability to pay for the upfront investment and/or monthly payments is contingent on a number of factors, including incremental financial savings due to lower lighting and phone charging expenses and seasonal income flows. According to customer surveys, and secondary data sources, households experience net financial gains as a result of switching from traditional energy sources (e.g. kerosene, battery-powered lights, etc.) to the observed solar products. A summary of these savings is provided in the customer financial impact section.

However, many of the surveys used for estimating these savings do not account for movements in purchasing patterns of rural households due to changes in the agriculture production cycle, meaning a customer's ability to meet monthly payment obligations under the PAYG model fluctuate by season. Figure 1, for example, shows the average monthly payment of one firm's customers in 2015 when the average payment varied from approximately $3.20 USD in January to $1.50 USD in December. This compares to an average expected payment of $4.25 USD. Similarly, approximately 20% of another PV company's customers had lower monthly payments than originally expected.

Figure 1: Average Monthly PAYG Payments for Company's Customers



[7] For example, a Tanzanian customer agreeing to pay $76.46 or 122,674 TSZ in annual payments in 2013 would only pay $61.60 in 2015.

As previously mentioned, the higher-than-expected default rate has been driving down the profit margin for some of these companies. Companies that had originally expected default rates of 5% per year, or .42% per month found their actual average default rate was almost five times higher; in low harvest months, PAYG PV companies have seen default rates as high as 3.97%, represents an annual default rate of 47.7%. There have been a greater number of defaults than originally expected across most companies but it is not clear if this is due to an inability of customers to pay, lower prices for alternative goods like kerosene, or a realization by customers that an extended payback period (e.g. three to ten years) may not be in their best interest.

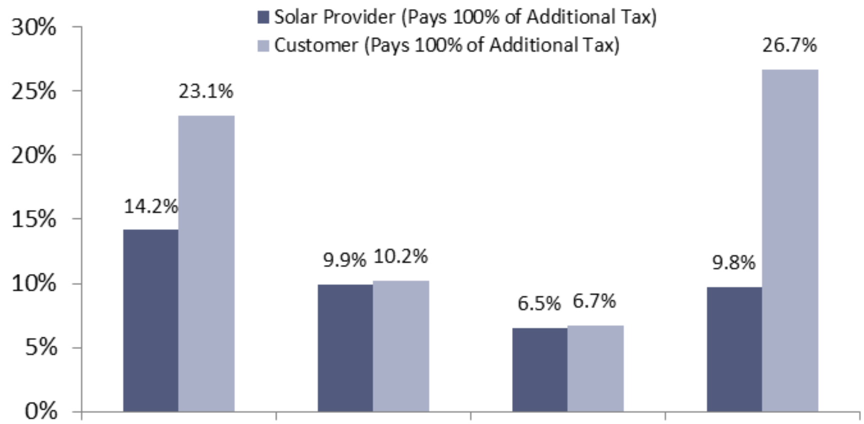
The complex market chain for solar products also poses a number of challenges to African solar providers. Firms' partnerships with local distribution partners have been hampered by slower-than-expected deployment of products and cash flow issues due to exchange rate fluctuations, customer defaults and/or lower-than-expected monthly payments, and technical issues related to the product and payment issues. These problems led some companies to partner with multiple distribution companies, and transition from PAYG to cash-up-front payment structures, while others moved to control each aspect of the market chain by creating their own R&D units and controlling the production process through partnerships with manufacturing firms.

Impact of EAC Tariff on Solar Providers

As firms continue to develop the off-grid solar market in East Africa, it is important to consider the effects that the proposed EAC tariff would have on company performance. The tax can be paid by the firm (by keeping the price of the unit the same and absorbing the cost internally), by the customer (by passing the full cost of the tax on to the end user), or by a combination of the two. For the purposes of this study, the analysis only considers the scenario whereby either the company or the customer takes on the full cost of the EAC tariff. Moreover, the analysis does not assume that the number of units sold changes in this model, although in reality a higher price would most likely reduce demand for solar products among the target customers.

Figure 2 shows the effects of a hypothetical 25% tariff on solar products sold by each of the grant recipients. If firms bear 100% of the tax, the cost of installation per unit would increase by 6.5% to 14.2%. The values are less than 25% because the cost of goods sold is only one of many costs borne by the company. For example, installation, maintenance, and administrative costs are unaffected by the tariff. Alternatively, the tax could be passed on to the customer via higher prices. In this case, the largest burden will be on customers of companies for which the capital cost of the solar unit makes up a very large percentage of the retail price charged to the customer.

Figure 2: Impact of Tax Exemptions



Source: CBA Models

Financial Analysis – Firm Perspective

CBA uses two financial analyses to determine the impact of its investments. The first is associated with the incremental impact of the investment. In three out of the four projects, it is assumed that the project would not have occurred in the absence of USAID funding. As such, the incremental impact of USAID's investment is assumed to be the money contributed through the grant less the total financial cost. In the case of one of the four projects, USAID funding accounts for only 1% to 5% of cash inflows in any given year so the incremental impact of this investment is the additional grant cash flow for those years, meaning it is assumed that this company's operational expenses and customer revenue would have remained the same without USAID assistance. This provides this company with an incremental NPV of $4.1 million over the grant lifetime.

The second type of analysis is related to the financial sustainability of each of the investments. For the off-grid solar market to scale up and operate independently from donor assistance, private sector firms must be financially sustainable. By this we mean that revenues exceed costs on the company's cash flow statement at a rate of return that is acceptable to investors. Our analysis shows that only one of the four projects is potentially financially sustainable, two have a negative net present value (NPV), and the fourth did not provide the financial records necessary to make an assessment although the separation between costs and prices suggests that it is not able to cover all expenses (e.g. cost of goods sold and soft costs). The remainder of this section focusses on this analysis.

One of the companies initially planned on using USAID's assistance to cover the cost of goods sold, while in-kind contributions and customer revenues were expected to cover the remaining costs. After accounting for sales revenue, and USAID and in-kind contributions, this company is estimated to have a financial NPV of approximately -$90,000 and a negative internal rate of return (IRR). These negative financial returns were the result of low revenue inflows and high capital expenses associated with its cost of goods sold. It is clear from these estimates that a drastic increase in customer prices and/or a substantial reduction in total installation costs would be need to be realized in order for this company's local operations to be financially sustainable. It is, however, important to note that the DIV award supported a pilot of a new PAYG model for low income households in remote areas, so the low financial returns were expected.

Similarly, another company has a negative financial NPV of nearly -$-113,000, which is the result of a sales revenue stream that barely covers the cost of goods sold. Total revenues before grant contributions were just barely above zero, and razor thin margins on sales were not nearly enough to compensate for the cost of salaries and other expenses. However, it is important to recognize that non-profit companies with mandates to serve customers on the low end of the income distribution and often live in remote areas, will necessarily be challenged in attaining financial sustainability.

Only one company achieved a positive financial NPV and modified IRR. Although the company financials have the potential for positive gains, there are some important caveats to consider about this kind of business model and USAID's contribution. Where a company's financial success is the result of significant equity financing, grant contributions are likely to comprise a very small percentage of total cash inflows, meaning these companies would most likely achieve profitability without USAID's contribution. Additionally, projected profitability of this model is dependent on reducing the soft costs associated with in-country operations; if the company is unable to reduce total costs sufficiently, its financial NPV may actually be negative.

It is not surprising that many of the grantees did not achieve financial sustainability during the grant period, especially when considering that most of these investments were in a pilot phase. In fact, it provides a good justification for providing grant funding if the social welfare impacts are positive and/or if there is good potential for achieving financial sustainability. Some of the companies are adjusting their operations to improve their bottom line. Solar companies are expanding through the development of high-end, aspirational products that are unaffordable to many people living in rural areas, even when financing is available. Additional efforts are being made to reduce the soft costs of marketing, distributing, installing, and maintaining the solar products, but it is not clear if any of the companies have been able to achieve substantial reductions on a per customer basis. Finally, the financial sustainability of any solar company operating in East Africa would be negatively impacted by any changes to the existing trade regime that provides tariff and tax exemptions for renewable energy products.

There is one final and very important variable to consider when evaluating the financial impact of each USAID solar investment is the average beneficiary cost to FNVP ratio – a metric that attempts to capture the financial value created per beneficiary as a result of USAID's investment.[8] Among companies profiled in this analysis, the FNVP per beneficiary ranged from .50 to 4.66 (meaning for each US dollar invested by USAID, anywhere from $0.50 to $4.66 was created for each customer). From this perspective, it appears that USAID's solar investments create the most financial value when placed in smaller solar providers.

[8] There are a couple of shortcomings associated with this measurement. First, it is driven by assumptions regarding the number of customers reached as a result of USAID's assistance. Second, it does not consider of sources of financing, including in-kind contributions, stock options, etc.

Financial Analysis – Household Perspective

In order for the off-grid solar companies examined in this study to continue scaling, it must make financial sense for consumers to purchase their products. Moreover, it is imperative for USAID to estimate the financial impact on end-users to evaluate whether the project is meeting its intended objective. Because solar lighting products do not have ongoing operating costs once paid for, they should offset some consumption of traditional lighting sources like kerosene lamps and lead to household savings. An examination of net incremental cash flows, which show the difference between inflows and outflows for a household with the product and a household without the product, allow us to see the financial impact that these products have on customers.

The financial NPV shows how much wealthier in present value terms solar customers are because of their solar investment. The average incremental financial NPV (FNPV) ranges from $45 to $125, showing that customers of higher-end solar home systems achieve substantially greater FNPV over the product life (estimated at seven years).

While an assessment of the net incremental cash flow shows us the difference between a household's cash flow with and without the product, the cumulative customer cash flow provides a better understanding of the aggregate cash savings accruing to households over an extended period of time. Additionally, it shows the point at which a customer is expected to recoup the cost of their investment, including their initial investment cost plus monthly payments. For two of the companies, on polar ends of the product spectrum, customers have a positive cumulative cash flow in the first and second years; the other two companies' customers' cash flows become positive in the third year. However, this timing does not clearly correspond to the highest cumulative cash flow by the end of the seven-year time horizon.

The cumulative cash flows are important when considering the financial incentives for households to invest in these products. They also highlight the importance of the products having long useful lives. For PV customers, systems would need to last at least two to three years before the customer would recoup the cost of their investment. Based on secondary research and interviews with company representatives, a product lifecycle of five years was deemed appropriate for this analysis although newer models reportedly have lifespans up to seven to ten years.

Although each of the solar products produces a net financial gain for its customers, it is important to keep in mind the affordability of each product as this indicates the income groups gaining from USAID's investment. To make this determination, USAID estimated the affordability of each solar product using two separate poverty statistics from the World Bank's PovCalNet database. First, the monthly cost of each product was compared to the average per capita income for those living under the poverty line. The most affordable product was priced at 3% of monthly per capita consumption, with other products accounting for 38%, 40% and 95% of monthly per capita consumption. The second measurement, monthly solar cost as a percentage of average household consumption for those living in poverty, shows that as a percentage of monthly income, the product cost ranges from 1% to 19%. From a per capita perspective, the PV system cost is clearly unaffordable to low-income households, but it becomes more affordable as we account for every member of the household.

Identifying customer groups that are able and willing to pay through the various PAYG models is key to achieving greater financial returns. Some companies are planning on expanding through the development of high-end, aspirational products that are unaffordable to most East Africans, even when financing is available. These firms have begun to differentiate themselves in part through their decisions to target customers with different income classifications. This is an issue that USAID may want to consider when funding similar investments moving forward.

Finally, for the household perspective, it is important to estimate the impact of the proposed EAC solar tariff on households (modeled here at 25%). The proposed EAC tariff would, not surprisingly, lead to higher costs as a percentage of per capita consumption. For low-income households below the poverty line, the cost per unit makes up a substantial percentage of per capita consumption, and the tariff would exacerbate that issue.

Economic Analysis

The World Bank and other institutions use consumer surplus estimates to capture the economic benefits of fossil fuel and renewable energy projects by estimating the social welfare impact increasing energy consumption and lowering price. Consumer surplus is calculated by using the difference between the maximum willingness to pay and what the consumer actually pays. Through the analysis of surveys, it is possible to estimate the willingness to pay for light by estimating how much it costs to purchase a certain number of lighting products (e.g. kerosene, candles, battery-powered flashlights, etc.) and how many lumens the average person consumes from these lighting products. Below is the formula used for making the consumer surplus calculations in this analysis:

$$C = \int_{Q_k}^{Q_e} K * Q^{\eta} \, dQ \; - P_s * (Q_s - Q_k)$$

or

$$C = \frac{K}{\eta + 1} * \left(Q_s^{\eta+1} - Q_k^{\eta+1}\right) -\cdot P_s * (Q_s - Q_k)$$

Where K is a constant, η is the elasticity, P_s is the price of solar, Q_s is the quantity of solar lumens, and Q_k is the quantity of other energy sources in the absence of the solar products.

Depending on the product under question and the customer payment plan, the highest quality PV systems produced the greatest consumer surplus at an individual household level. These companies' customers would be expected to earn the greatest consumer surplus given the large increase in lumen output as a result of their solar investment.

To get at the overall economic estimates, the USAID investment was deducted from the aggregate consumer surplus estimates, and the incremental financial gain/loss was also accounted for. At the project level, the company producing the highest-quality solar home product created the largest economic gain at $14.8 million primarily due to the large number of customers reached through their distribution system and the large household consumer surplus. In total, USAID's investments created net wealth of $17.1 million including $15.7 million for Tanzania, $1.2 million for Uganda, and $178.521 for Rwanda.

Critical Assumptions and Limitations

To perform cost-benefit and beneficiary analyses it is oftentimes necessary to make certain assumptions, in particular in cases where there are significant data limitations. The uncertainty inherent in those assumptions impacts the level of validity attributed to the final result. Additionally, by identifying critical assumptions it is possible to conduct a sensitivity analysis to determine the impact each of these variables has on the final result. Finally, it provides decision makers with a list of variables that may be considered when making future investments and/or may be captured in monitoring and evaluation plans. The main assumptions and limitations relevant for all CBA models are as follows:

(i) **Total Energy Use – Without Solar:** Some firms used *ex-ante* and *ex-post* household surveys to capture total energy consumption for similar households that had not purchased the solar products. For household energy use estimates in one country, a baseline household survey for those living off-the-grid was used to estimate energy use in the "without" scenario. This assumes the energy consumption profile for different companies' non-solar customers is similar, when higher-end PV customers most likely have greater energy use and are in a higher-income bracket.

(ii) **Total Energy Use – With Solar:** Some firms' surveys captured total energy consumption for households using their products, while others did not have this information. As a result, the analysis used conservative assumptions regarding the percentage reduction in traditional energy use (e.g. kerosene; battery powered torches; etc.) when households convert to the latter companies' solar products. These assumptions were based upon survey findings, as well as secondary research pertaining to evaluations of similar projects.

(iii) **CBA Time Horizon:** The cost-benefit model reflects the core logic of project alternatives by comparing the incremental results of households who purchase the solar products with those who do not. CBA models typically account for these savings over a certain period of time based on the useful life of the primary capital investment. The CBA models use a 5-year time horizon as it was determined the solar products would have an average useful life of this time period. However, results for a 3-year and 7-year time horizon have also been provided in the models to show how this assumption impacts the final results.

(iv) **Attribution:** USAID's practice is not to make use of multiplier effects in performing CBA on investments; in other words, it does not attempt to capture the benefits and costs of successive rounds of spending. This is because multiplier effects are often speculative and context-specific. Moreover, there needs to a solid base of evidence linking USAID's direct investment to subsequent activities, including a detailed list of the cost and benefit flows of all related activities. A justification for the assumptions regarding the total product counts for each solar provider can be found below.

(v) **Discount Rate:** The model assumes a financial and economic discount rate of 12 percent in order to compare the investments across each of the respective countries. However, the financial discount rate for customers and the weighted average cost of capital for each of the firms may be quite different from 12 percent.

(vi) **Economic Analysis:** The economic analysis does not factor in all variables that may affect the net present value of these projects. First, environmental externalities are not included. Households that adopt solar home systems reduce their consumption of traditional dirty lighting sources such as kerosene, which produces a large amount of CO2 equivalent emissions for the level of light output. These reductions in CO2 could be estimated, then valued using a social cost of carbon.[9] If positive environmental externalities were included, then it would also be appropriate to include negative externalities, such as environmental damage from the mining of silica to create the PV panel, or the manufacture and disposal of batteries. The negative externalities would be much more difficult to estimate. The study also excludes possible health and education benefits of using solar lights. Indoor use of kerosene lamps can lead to respiratory issues, so the reduction in use of kerosene should lead to improved health. Meanwhile, a child having access to more hours of high quality light may lead to more hours spent studying. While these links seem clear, actual empirical evidence on these outcomes is both mixed. Because these factors have not been included, we can assume that this study represents lower-bound estimates of the NPV and IRR.

[9] Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Interagency Working Group on Social Cost of Carbon. United States Government

Sensitivity Analysis

It is essential to analyze the sensitivity of the model to the critical assumptions (i.e., changes in key variables and parameters) mentioned in the previous chapter. This is done through the use of one-way and two-way tables that show how the final result changes with modifications to the values of certain parameters, everything else being held constant. In this section, there is a brief summary of the key variables that were tested and how sensitive the model results are to changes in those assumptions, including results from tornado analysis conducted using Crystal Ball. Details from these sensitivity analyses are available upon request.

Monitoring and Evaluation

The CBA evaluative process can inform monitoring and evaluation (M&E) plans that help track progress of USAID-funded activities and encourage the use of evidence-based approaches to improve off-grid solar investments. Through CBA modeling and in-country interviews, the team identified three categories of data sources and indicators that may be used in future M&E plans. First, when feasible, an impact evaluation should be conducted to capture valid estimates of the activity's impact on households. The impact evaluation should include baseline and endline data on both a treatment and control group. This microdata is an important input into a CBA and it can be used to develop cash flows for household with and without the solar home system. An illustrative list of key variables that may be captured in an impact evaluation include:

- **Energy Expenditures:** household expenditures on each lighting source, disaggregated by fixed costs (e.g. the purchase of a lamp), fuel costs, and other related expenses (e.g. general operation and maintenance).
- **Energy Consumption:** daily hours of light disaggregated by each lighting source.
- **Other Time and Cost Savings:** time spent on trips exclusively to purchase kerosene or to charge mobile phones, and the weekly cost of charging mobile phones.
- **Other Measures:** household education and income levels, time children spend studying, health outcomes, and environmental benefits of using solar product in lieu of other lighting sources like kerosene lanterns.

A second category of M&E data is related to the administration of solar activities, including the two general distribution models evaluated by the CBAs – PAYG and cash-up-front. Table 3 provides a general list of six administrative indicator categories. Investment indicators may be used to measure the ability of solar activities to reach target customers and to determine the actual cost incurred by households. Payment, energy use, and income indicators may be used to track investments and monthly costs while factoring in extraneous variables such as household income flows and weather patterns. Repayment indicators may be used to track the effectiveness of solar activities in transferring solar product ownership to customer households. Warranty indicators may be used to track the number and costs associated with maintaining and repairing solar products. Similarly, default indicators will enable program managers to measure the net impact of the solar activity, as well as to adjust the activity to correct for any issues. Finally, external financial indicators may provide additional information as to the cost and affordability of the solar products for the targeted customers.

Table 3: Administrative Indicators

Indicator	PAYG	Cash-up-Front
Investment Indicators		
Number of potential customers by key grouping (e.g. income, geography, etc.)	●	●
Proportion of customers in the target group who have installed the solar unit	●	
Number of sales by month	●	●
Investment cost by customers (up-front cost)	●	●
Payment, Energy Use and Income Indicators		
Average monthly payment per customer (local currency)	●	
Average monthly/seasonal HH income in targeted area (agriculture cycles)	●	●
Number of hours of sunlight per month	●	●
Repayment Indicators:		
Number of customers who have repaid/are on track to repay on time	●	
Number of customers who are behind on payments but not in default	●	
Warranty Indicators:		
Number of claims	●	●
Average cost to repair solar units under warranty	●	●
Defaults / Returns		
Number of customers defaulting / returning product	●	●
Reason for default / return (e.g. technical issues, tampering, non-payment, etc.)	●	●
External Financial		
Number of customers accessing external financing	●	●
Source of external financing	●	●
Cost of financing by month	●	●

The third category of M&E data is related to the financial reports of solar providers (Table 4). Ideally this would include all costs along the solar market chain to reach the end-user. For example, this would include the costs associated with tradable and non-tradable inputs used in solar products, including expenses associated with solar tariffs and any negative resource flows tied to exchange rate movements. Additionally, this would include key line items needed to estimate cash flow statements for grant recipients and any other stakeholders impacted by USAID's investments. An illustrative list of key financial indicators is provided in Table 4.

Table 4: Financial Indicators

Indicator	PAYG	Cash-up-Front
Macroeconomic Indicators		
Import duties and other tariffs on solar imports	●	●
Exchange rate fluctuations	●	●
Financial Statements (grant recipient)		
Gross revenue flows	●	●
Non-operating income (e.g. USAID and non-USAID grants)	●	●
Cost of goods sold	●	●
Operating costs disaggregated by category (e.g. personnel, marketing, etc.)		
Financing costs (e.g. interest payments)	●	●
Other Financial Statements (sub-grantees or other implementing partners as needed)		
Gross revenue flows	●	●
Cost of goods sold	●	●
Operating costs	●	●
Financing costs	●	●

Recommendations and Conclusions

The results of our analysis and research have led us to several recommendations and conclusions to inform future work in the off-grid solar energy market.

1) **Donors should consider supporting solar investments that produce social welfare benefits, at least until companies can create financially sustainable investments in partner countries.**

   Each of the analyses demonstrated how the economic returns to the projects were positive, meaning there were net social gains for each investment despite the financial losses. These positive gains are attributed to the consumer surplus gained by households able to purchase lighting devices for a price that is less than the highest price that they would be willing to pay. It is thus clear the economic returns to the investments are being driven by households. A determination should be made as to the most effective way to deliver cleaner energy to households with the objective of supporting the most cost-effective delivery models. This may require an analysis looking at a variety of energy options, such as mini-grids, hydroelectric power, etc., in a country-specific context.

2) **Identify the target beneficiary group, and make sure projects support the selected beneficiaries.**

   It has become clear through our research that companies and NGOs in the East African solar energy market have begun to differentiate themselves in part by targeting different income groups. The segment of the population that can afford unsubsidized solar products but is not yet connected to the grid is smaller than most people assume, so it is critical to understand the income distribution in each recipient country, the affordability of solar products, and the benefits provided to customers.

3) **Focus innovation efforts on three main constraints to financial viability: the distribution model, the payment system, and the supply chain.**

   The four grantees studied in this report have developed unique distribution models, payments systems, and supply chains. Some have been more successful than others, and often there are pros and cons in these choices. For the off-grid solar market to fully scale, it must become financially viable without donor assistance, but in most cases this is not happening. The profit margins on most solar products are not sufficient to cover the distribution costs in rural areas of East Africa. Pay-as-you-go models provide a financing option to bring new technologies to poor customers, but the default rates are high. Upfront payment models can be successful, but they prevent most customers from purchasing products beyond basic lamps and lanterns. International supply chains are threatened by tenuous partnerships, tariffs, and exchange rate fluctuations that add risk to investment opportunities and discourage further growth.

Ultimately, more work needs to be done to find a financially viable business model to reach low and middle income households in East Africa.

4) **Emphasize data and evidence collection**

One of the biggest impediments to this CBA study was a lack of good data, particularly household survey data specific to energy consumption. Solar is just one of many energy sources available to households in East Africa, and customers must make economic decisions every day about what sources to use and how much. Although many impact evaluations have been done on solar, few provide the details necessary to conduct an incremental cost-benefit analysis of how household energy use and expenditures—for both lighting and phone charging—changed after the adoption of solar. Data must be disaggregated by income, access to grid electricity, household size, and region, just to name a few. Other important variables could include default rates and costing trends related to soft costs. This can be established in the initial grant agreement and reported through regularly enforced increments as part of a monitoring and evaluation plan.

Concluding Remarks

The CBA study presented here provides new and in-depth information about the DIV solar portfolio and the East African off-grid solar energy market in general. The DIV grants, through their innovation and risk taking, have expanded our knowledge of the off-grid solar energy market, tested the financial and economic viability of a variety of business models, and provided detailed information to improve the energy portfolio at USAID. The four grant recipients evaluated in this CBA study have created over $17 million in net present value on a USAID investment of $8.4 million. This is a positive result that USAID can build on moving forward.

Finally, the authors would like to thank the Global Development Lab for funding this research and offering their time, resources, and full cooperation. It is a prime example of the value of intra-agency cooperation here at USAID. And of course, none of this would have happened without the openness, transparency, and cooperation of the grant recipients. They made their staffs available for meetings, organized customer interviews, managed TDY logistics, provided detailed financial data, and answered numerous questions from the research team. We couldn’t have done it without you. Thank you!