Consumer investment in watt-scale energy products

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Abstract

1.3 Billion people will remain without electricity without significant investment in new energy services. The IEA shows that about half of these services need to be distributed energy to reach those beyond the grid. Current investment focuses on centralized power plants and grid expansion. In the absence of public funding, the unelectrified rural populations must rely on private financing. In this paper, I compare the financial returns from watt-scale consumer products for lighting and mobile phone charging and the available financing for consumers from microfinancing. A comparison of the avoided cost in kerosene or phone charging and the monthly payment for a product shows that microfinance loan payments often exceed the avoided cost. Many customers are not able to tolerate these higher recurring payments even though in the future they will have no payments. In the developed world, innovators create instruments that eliminate upfront costs for energy services and immediately reduce consumer energy expenses. Equivalent innovation in this space could speed adoption of these technologies in the developing world as well.

1 Introduction

Private enterprise offers a credible way to challenge energy poverty by offering energy solutions at a scale that donation or gift-based solutions cannot reach. Renewable energy is the lowest-cost option for many areas that are far from the existing grid. Renewable energy, however, requires an initial purchase in order to gain the benefit of near-zero recurring energy costs. Since many of these customers have little ability to save, they require financing to afford renewable energy products. This financing allows these customers to pay a smaller recurring fee instead of the larger purchase price. If this recurring payment is smaller than the amount the customer currently spends on energy services, the customer can finance the purchase and end up with a lower overall energy cost. Despite several technological and financial innovations, many customers will not be able to lower their overall payments with the options available to them. It will require further development to create affordable solutions for all income levels.

We consider the value of a clean energy product as an investment on the part of the consumer. The consumer is faced with a decision. She may purchase a device at several times her monthly energy expenditure that allows her to avoid that monthly expenditure

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for a time period. To make her decision, one criterion is whether the device will result in a lower overall cost of energy for her household. She must compare the energy costs that will be removed by the device with the payment she must make on the device. The devices we will consider will be solar photovoltaic devices, often with LED lighting and battery storage. This framework is applicable regardless of the technology.

This paper attempts to synthesize various data available on consumer energy expenditures and create a picture of the financial decision. Lighting Africa and Lighting Global and the Millennium Villages Project have published data on kerosene prices, payback period, lantern costs, and the amount of kerosene displaced by solar home systems.[1, 2, 3] Arc Finance has published case studies on businesses selling these systems and the financing options available.[4, 5] This work's contribution is to integrate these data and describe the financial decision facing the potential solar home system buyer and point out ways the humanitarian engineering community can make the systems more affordable.

2 Solar Lantern Results

2.1 Solar Lantern Initial Cost

The purchase cost of the solar lantern device is the most important part of a financial decision for most customers. For the devices available, prices vary depending on the amount of energy available each day, the features of the device, and the quality of the product. Prices can range from as little as 10 USD for a small solar lantern to hundreds of USD for a photovoltaic solar home system with multiple lights and battery storage. To evaluate if a product is affordable, a consumer will compare this purchase price against their current energy expenditures and overall income levels. Like cellphones, small solar lanterns may be affordable to purchase in cash for most consumers while many will require financing to purchase larger systems.

We can estimate the cost of these devices based on the costs of their components. Assuming solar panel costs, storage cost, transportation costs, and the solar resource, we can estimate the purchase price. While we can find prices of these products online and in advertising literature, it is useful to look at the component costs and trends. Lighting Global compiles data on lantern cost in their effort to create uniform standards for solar lantern products. Using prices from Lighting Global [1] in Table 1, we can estimate the costs of solar lantern devices that deliver the desired levels of brightness and run time.

Survey results from Lighting Global show that the least expensive solar lantern that consumers consider acceptable is one that creates 25 lumens of light and runs for at least 5 hours.[1] A lantern of this level can be purchased for about 10 USD. This small lantern may not, however, satisfy all of a household's energy needs while a larger system may provide even more illumination than was previously available from kerosene or candles. An important consideration is then the amount of current household energy expenditure that can be displaced by the solar energy system.

2.2 Energy Expenditures

To determine the amount of available capital in a household for a clean energy purchase, we start by measuring the total amount currently spent on energy. Later we will estimate the fraction of that total energy expenditure that could be avoided by the device. Energy expenditures can take several monetary forms such as kerosene, candles, batteries, and phone charging as well non-monetary forms such as time lost in travel or adverse health effects. For

Component	Value
Overall	10 USD per klm
Solar	5 USD per watt
Battery	0.3 USD per Wh capacity
Balance of system	2 USD per watt
Derate	70%

Table 1: Parameters for solar lanterns from Lighting Global Minimum Quality Standards.

Location	Kerosene	Candles	Total	Monthly
Bonasso	18.5	51.3	69.9	5.8
Ikaram	1.9	48.8	50.7	4.2
Mayange	1.6	11.6	13.3	1.1
Mbola	0.3	33.1	33.4	2.7
Mwandama	7.3	12.0	19.3	1.6
Pampaida	0.4	48.6	49.1	4.0
Ruhiira	2.4	15.1	17.5	1.4
Tiby	1.1	55.8	56.9	4.7

Table 2: Survey data in the Millennium Villages measuring yearly expenditures on fuel-based illumination expenses in USD.

the rest of this analysis, we will only consider the displacement of fuel-based lighting. The Millennium Villages project collected data related to energy expenditures.[3] Table 2 shows these data measuring fuel expenses per household in several Sub-Saharan villages.[3] These values give us some guidance for the likely expenditures in off-grid locations. However, as the variability indicates, it is necessary to evaluate the spending in a location where a pilot is being conducted.

Once we have an estimate of total energy expenditure, we can estimate the fraction of that cost that could be displaced by a solar energy product. Lighting Global has published estimates of the amount of displaced kerosene based on lantern cost that help answer this question.[1] The estimates in Table 3 only include fuel-based contributions to energy spending for lighting. These data are from a small field sample and are not meant to be representative of all households. Data on phone charging expenditures and time spent by household would be a valuable addition to these estimates as larger devices will likely avoid other costs like phone charging. While the total energy spending by a customer is a good basis for estimations, it is important to quantify how much of this spending an energy device can replace and is therefore free for a lantern payment. With the total product price and the monthly energy spending we can calculate what financing options are possible for a consumer.

2.3 Solar Lantern Expected Returns

It is useful to measure the attractiveness of a solar energy purchase using the conventional method of the payback period. This period is defined as the initial price divided by the financial savings per period and is interpreted as the length of time the customer must wait before the initial investment is repaid. In the solar product case, the financial savings per period is the avoided energy cost. From the kerosene displacement rates in Table 3 and the

Lantern Cost	Displaced Kerosene
20 USD	60 ml/day
40 USD	90 ml/day
80 USD	140 ml/day

Table 3: Lantern cost and displaced kerosene. Data from the Lighting Africa report, "The True Cost of Kerosene in Rural Africa".

Location	Kerosene Cost per liter
Rural	1.30 USD/liter
Urban	0.96 USD/liter

Table 4: Kerosene cost in rural and urban markets. Data from Lighting Africa.

average kerosene costs published by Lighting Global [2] in Table 4, we can find the average payback period. This result is shown in Table 5.

These all have a payback time of less than a year, but all require the customer to make an initial expenditure about an order of magnitude greater than their monthly expenditure. That is, the payback can also be thought of as the factor beyond the monthly payment that the customer must provide initially. It may be more relevant to look at payback for the daily purchases, since this is the granularity of budgeting for many households. A harder to measure but plausible return could be increased business at a shop because customers are attracted by the higher quality of light. This benefit would likely disappear as more vendors buy improved lighting. Based on the length of time before the investment is paid back by the avoided kerosene costs, these investments are very attractive. However, not all consumers have the available cash to purchase them. We have to look at available financing options to bridge this gap.

2.4 Solar Lantern Available Finance

At this point the customer knows the purchase price of the lantern as well as the expenditures it will replace. Now the consumer has to determine what financing is available that will result in an acceptable monthly cost. Finance allows the consumer to spread the payments for a power device over time in smaller amounts. The consumer will want to know, can these payments be smaller than her existing energy payments. For many customers, the available finance will result in higher payments. The monthly payment is calculated using a standard formula

$$\text{Payment} = \text{Initial Cost}\frac{i(1+i)^n}{(1+i)^n - 1}$$

where i is the interest rate per period and n is the number of periods.

Most financing options for these products have interest rates above 30% and loan lengths of approximately one year. Payments are made more often than monthly and are as frequent as daily. For solar home systems, microfinance offers interest rates in the range of 35% per year and terms of about 1 year. Another form of finance gaining popularity is financing from the solar lantern provider. This can be either a loan or a pay-as-you-go technology. M-KOPA provides financing of solar lantern products where the daily payment is approximately 0.50 USD per day over one year after a deposit.[4, 5] Assuming the product is sold for 200 USD,

Initial Cost (USD)	Kerosene Displacement (liter/day)	Avoided Cost (USD/month)	Payback Period (Months)
20	0.06	2.3	9
40	0.09	3.5	11
80	0.14	5.5	15

Table 5: Avoided costs from displaced kerosene from lanterns. Displacement rates and per liter costs are from Lighting Africa.

this is an effective annual finance rate of 49%. This financing rate may appear unusually high to many readers, but reflects the transaction costs and difficulty of financing in these areas.

The loan payment on larger systems at these interest rates with these loan lengths exceed the high estimates of monthly expenditures from the survey data. This means that unless households have other disposable income to add to their energy expenditures, larger solar systems will remain out of financial reach. In Figure 1, I plot the monthly payment for a 100 USD solar lantern at a range of yearly interest rates and number of periods using the formula above. Lighting Global's data shows a lamp of this size will displace about 5 USD of kerosene per month. If we assume that this device can displace all of a household's lighting expenditures, the intersection of the curves with the shaded area show when the devices are affordable at the monthly expenditures observed in the Millennium Villages. The financing solutions described above fall outside of this shaded range and thus increase the energy expenses for the consumer. To make these larger systems that deliver more meaningful amounts of energy affordable the costs of systems or financing options must be lowered.

3 Discussion

Solar home systems and solar lanterns have reached millions of new consumers over the past decade but need to reach billions. The innovations provided by pay-as-you-go and microfinance are important but they do not yet promise to scale to all off-grid consumers. This can be addressed by lowering the price of lanterns or by improving the access to longer term loans at lower interest rates to consumers. There are opportunities for the humanitarian engineering community to increase the affordability of these energy products. Technical and economic innovations that lower total recurring expenditures for customers are most likely to scale most quickly.

We will continue to see reductions in the price of solar panels, batteries, and LED lights. However, the large reductions necessary to provide rural customers with a much more affordable solar home solution seem unlikely over the next few years. If we do not believe that these cost reductions alone will make units more affordable, we must look for other solutions. Changing the terms of financing is one attractive area for investigation.

While small solar lanterns are affordable, the monthly expenditures for larger systems are out of reach for many consumers. For these loans lengthening the loan term reduces payments more quickly than reducing the interest rate. For the consumer, it makes sense for the length of the loan to match the time over which the solar lantern provides positive benefits to the consumer. Otherwise the consumer must pay in advance for benefits that will be received later. For the lender, this is more difficult since the lender must wait longer to get the money loaned returned. It also increases the total amount of funding necessary.

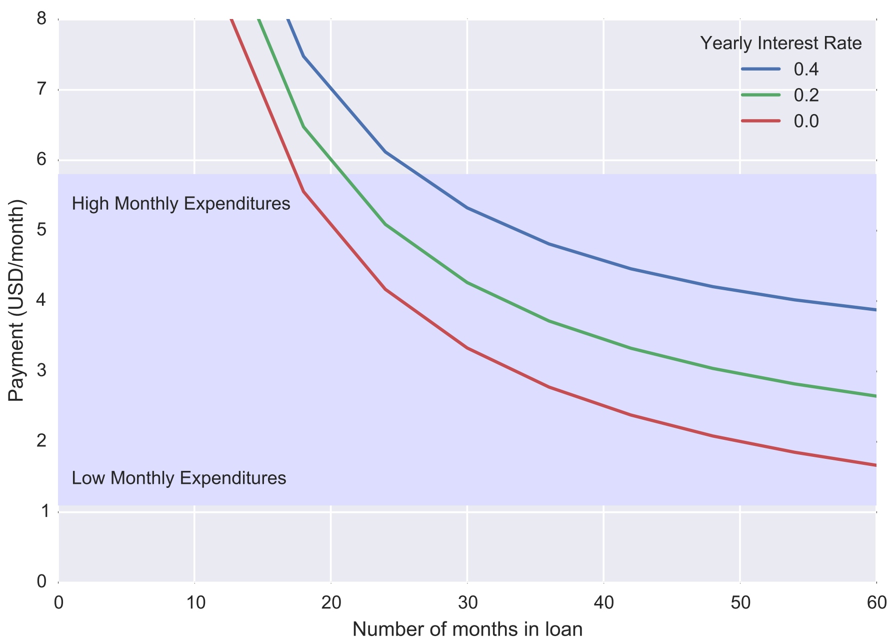

Figure 1: Monthly payment for a 100 USD solar lantern. Low interest rates and long loan terms are necessary to bring the payment into the range of current energy expenditures in rural communities.

The shortest useful life of a solar system is set by the battery lifetime at what is likely 3–5 years. Most loans and finance programs, however, are over about a one year time period. If the loan length could be lengthened at the same interest rate the loan payment would be reduced.

Most engineering focus is on lowering the initial price as much as possible. However, it is also plausible that creating a product that is more expensive but can be used longer, could reduce the monthly price and risk for a consumer. For example lithium batteries are more expensive initially but have longer lifetimes.[6] Another opportunity for the humanitarian community is to consider social and technical systems that allow for longer loan terms. Improvements to the embedded technologies that enable pay-as-you-go (PAYG) systems could be made to create longer loans with lower default rates. There are many good reasons why the shorter terms and higher interest rates are charged. There are many transaction costs and losses in the finances that require these rates. (Engineers may choose to think of the system as lossy.) Monitoring loans in dispersed rural areas requires personnel and travel expenses that must be paid for by the loan. PAYG systems attempt to reduce these costs and should be an attractive area of research and development for humanitarian engineers.

One reason for the high interest rates is that these loans to consumers are considered risky. Consumers, businesses, and investors are discouraged by risk in this space. Humanitarian engineers can address this risk through creating physically robust products as well as electronic transaction technologies that can reduce payment risks. There has already been good progress in pay-as-you-go technologies and the community can make a contribution here as well.

Another factor that causes higher interest rates is the return required by the investor. Many investors require a given rate of return to loan money. Innovations such as crowd funding can lower the required rate of return and in turn lower the finance rate for customers. Organizations are also creating impact investment funds where the opportunity for social impact is a high consideration than the return on the investment. In Bangladesh, IDCOL is able to structure loans to households that are paid back over three years at an interest rate of 12%. Finding large pools of capital that will accept lower rates of return are the key to extending these more favorable loan conditions. There is an opportunity for humanitarian engineers to create systems that allow this financing.

4 Conclusion

Great progress has been made to bring affordable energy solutions to the off-grid population but the current terms are still unaffordable to many customers. The humanitarian engineering community can design products and processes to simultaneously meet these needs of lower cost, longer term loans, and lower risk. Robust engineering can create products with long lifetimes that consumers are willing to accept. Novel technologies for payments can reduce transaction costs and lower the loan cost for consumers. Quality products and open data from pilot projects can add to the body of evidence on consumer payments, product acceptance, and payment risks. Incorporating each of these into the design and prototyping process will accelerate the rate of deployment of technologies in energy and other humanitarian technologies as well.

There is also an opportunity to pursue field work in collaboration with economists in this area. Do lower monthly payments increase adoption rates? Are consumers willing to enter payment contracts that last over more than one year? Do more expensive systems that last longer bring greater benefits to consumers?

Our community can start to map out the path from very small affordable systems that provide small amounts of energy to systems that allow for cooling, food storage, and mechanical work. The key is to consider the financial constraints needed to create these systems. By engineering with these principles in mind the humanitarian community has a better chance of create solutions with meaningful impact.

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