

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

41 This paper attempts to synthesize various data available on consumer energy expendi-
42 tures and create a picture of the financial decision. Lighting Africa and Lighting Global
43 and the Millennium Villages Project have published data on kerosene prices, payback pe-
44 riod, lantern costs, and the amount of kerosene displaced by solar home systems.[1, 2, 3]
45 Arc Finance has published case studies on businesses selling these systems and the financ-
46 ing options available.[4, 5] This work’s contribution is to integrate these data and describe
47 the financial decision facing the potential solar home system buyer and point out ways the
48 humanitarian engineering community can make the systems more affordable.

49 **2 Solar Lantern Results**

50 **2.1 Solar Lantern Initial Cost**

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

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

66 Survey results from Lighting Global show that the least expensive solar lantern that
67 consumers consider acceptable is one that creates 25 lumens of light and runs for at least
68 5 hours.[1] A lantern of this level can be purchased for about 10 USD. This small lantern
69 may not, however, satisfy all of a household’s energy needs while a larger system may
70 provide even more illumination than was previously available from kerosene or candles. An
71 important consideration is then the amount of current household energy expenditure that
72 can be displaced by the solar energy system.

73 **2.2 Energy Expenditures**

74 To determine the amount of available capital in a household for a clean energy purchase,
75 we start by measuring the total amount currently spent on energy. Later we will estimate
76 the fraction of that total energy expenditure that could be avoided by the device. Energy
77 expenditures can take several monetary forms such as kerosene, candles, batteries, and phone
78 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.

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

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

97 **2.3 Solar Lantern Expected Returns**

98 It is useful to measure the attractiveness of a solar energy purchase using the conventional
99 method of the payback period. This period is defined as the initial price divided by the
100 financial savings per period and is interpreted as the length of time the customer must wait
101 before the initial investment is repaid. In the solar product case, the financial savings per
102 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.

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

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

116 2.4 Solar Lantern Available Finance

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

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

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

125 Most financing options for these products have interest rates above 30% and loan lengths
 126 of approximately one year. Payments are made more often than monthly and are as frequent
 127 as daily. For solar home systems, microfinance offers interest rates in the range of 35% per
 128 year and terms of about 1 year. Another form of finance gaining popularity is financing from
 129 the solar lantern provider. This can be either a loan or a pay-as-you-go technology. M-KOPA
 130 provides financing of solar lantern products where the daily payment is approximately 0.50
 131 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.

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

135 The loan payment on larger systems at these interest rates with these loan lengths exceed
136 the high estimates of monthly expenditures from the survey data. This means that unless
137 households have other disposable income to add to their energy expenditures, larger solar
138 systems will remain out of financial reach. In Figure 1, I plot the monthly payment for a
139 100 USD solar lantern at a range of yearly interest rates and number of periods using the
140 formula above. Lighting Global’s data shows a lamp of this size will displace about 5 USD of
141 kerosene per month. If we assume that this device can displace all of a household’s lighting
142 expenditures, the intersection of the curves with the shaded area show when the devices are
143 affordable at the monthly expenditures observed in the Millennium Villages. The financing
144 solutions described above fall outside of this shaded range and thus increase the energy
145 expenses for the consumer. To make these larger systems that deliver more meaningful
146 amounts of energy affordable the costs of systems or financing options must be lowered.

147 3 Discussion

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

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

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

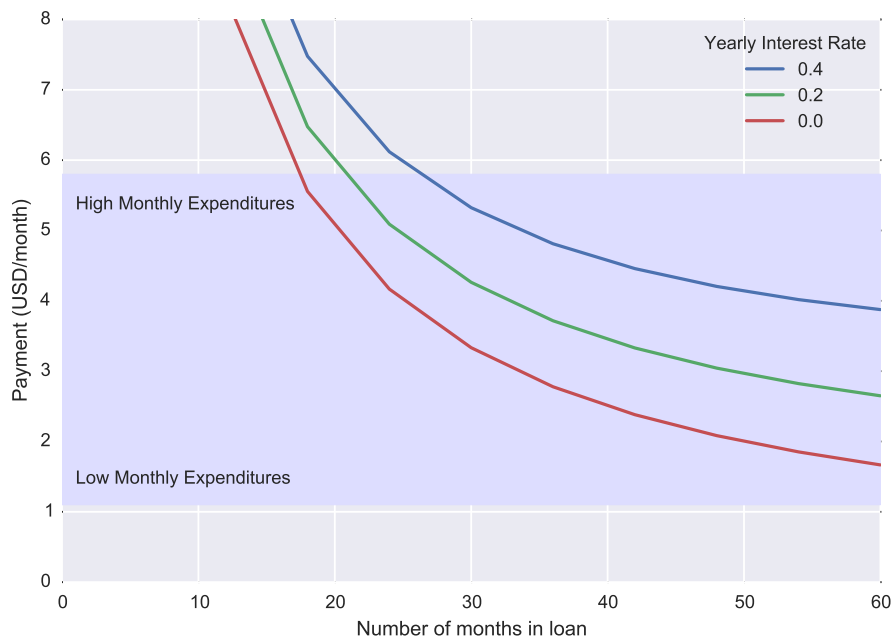


Figure 1: Monthly payment for a 100 USD solar lantern. Low interest rates and long loan terms are necessary to bring the payment into the range of current energy expenditures in rural communities.

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

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

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

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

199 4 Conclusion

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

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

213 that last longer bring greater benefits to consumers?

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

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