SOLAR LIGHTING SUB-SAHARAN AFRICA

ABSTRACT
A review of the state of electrification and recommendations for the future.

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Information and communication technology (ICT) has been widely viewed as an essential tool to achieve development goals. The efficiencies ICT achieves has made it a key factor in increasing economic growth and reducing poverty[1]. ICT is powerful, it addresses development objectives through synergies between increased knowledge share and communications across many fields including healthcare, education, agriculture, and disaster relief.

In order to realize the benefits of ICT, users must be able to power their electronic devices regularly. Without access to electricity sources, ICT cannot reach its full potential and effectively support the advancement of development goals. Electrification rates in developing regions is alarmingly low. There is a large need for electrification whether it is through new infrastructure or off-grid solutions. First this paper will describe the existing energy infrastructure of Sub-Saharan Africa. Next, it will discuss the major energy end-uses, conventional power sources, and their dangers. Then the paper will detail the solar-power products available in the marketplace and the financing options. The paper will conclude discussing the recommended modular and scalable solar-power home system.

Sub-Saharan Africa's Energy

Electrification rates in developing regions are extremely low, especially in Sub-Saharan Africa where on average the electrification rate of households is only thirty percent. The

International Energy Agency reported urban electrification rates are close to sixty percent and in rural areas it is only fourteen percent[2]. The majority of people living in Sub-Saharan Africa, approximately sixty-three percent, are living in rural communities with this limited or no access to electricity[3]. Adding to this dire situation, of those who are considered electrified, one-third is considered "under electrified" due to the inconsistent and unreliable utility services[4]. Therefore, this population cannot light their homes, power ICT devices, or run other household appliances such as refrigerators, putting them at a severe disadvantage.

Indicators show there are no plans to add infrastructure to the poor rural communities. Financial resources are not ear-marked for electrification of rural areas because of the small return on investment. As such, it is likely that electrifying this region and providing these communities with the ability to charge, and therefore use, ICT devices such as mobile phones, radios, computers, may not be realized for decades.

Poor electrification limits a community's access to ICT tools and hinders its ability to magnify development efforts. Furthermore, without power, there is no reliable and safe means to light their homes and businesses after the sun sets. Both access to healthy lighting and power for ICT are key to the reduction of poverty[5]. Next, this paper will explore the current non-renewable energy sources for lighting and ICT device charging.

Current Energy Lighting Options: Kerosene

Kerosene is a major fuel source used to light homes in Africa. It is an expensive commodity for consumers and often results in a tradeoff between other necessities such as access to food. Additionally kerosene is hazardous to both health and safety of its users.

Lighting Africa, a joint program between the World Bank and International Finance Corporation (IFC) seeking to advance commercial off-grid lighting markets, reviewed the prohibitive costs of kerosene. The 2012 study found kerosene prices follow the volatile market price of crude oil, since it is a derivative of crude oil. Additionally, in rural areas, with a higher dependence on off-grid energy solutions, kerosene is approximately thirty-five percent higher than the median price of kerosene available in urban areas. High poverty rates and limited financial resources in rural areas limit consumers to purchasing small quantities of kerosene. This exacerbates their economic situation because consumers end up paying more over the long run than if they could afford to make a larger purchases at a lower rate per liter. Due to the expense and volatility of kerosene many people report they buy less fuel in order to purchase more food[6].

Kerosene is not only expensive it is hazardous to one's health. When burned, kerosene emits carbon monoxide, formaldehyde, polycyclic aromatic hydrocarbons, sulfur dioxide, and nitrogen oxides; many of which are carcinogens. These chemicals cause health issues including dizziness, muscle cramping, loss of consciousness, respiratory and pulmonary symptoms, and in extreme cases result in death. Kerosene lamps produce heavy black smoke and pollute the indoor environment exposing users to the dangerous chemicals in emits[7]. Women and children unequivocally bear the brunt of these effects because they spend the most time in the home using the product.

In addition to these health hazards there are many other dangers associated with using kerosene. First, studies have found kerosene is usually purchased in unmarked old soda bottles and other similar recycled containers that are not clearly marked. The unlabeled

storage has led to accidental child poisonings. Second, kerosene lamps with poor wicks have increased leakage and can cause the entire lamp to ignite and possibly explode. Third, pressure lamps are prone to explosions caused by soot clogging nozzles resulting in unsafe pressure levels[7]. The burns and explosions of kerosene lamps are often fatal.

Kerosene is also an inefficient source of light. The illumination level of kerosene and other fuel-based lanterns is relatively low compared to conventional electric light. The efficacy of these lamps range from only one to ten percent of the necessary light levels recommended by industry experts in developed countries[8]. So, not only are kerosene lamps expensive and dangerous, but it also does not perform effectively.

Current Energy Lighting Options: Candles

Some countries in Sub-Saharan Africa do not have access to kerosene as the predominant fuel to light their homes. As a result these countries tend to rely on candles as a major lighting source. Candles are used for seventy-nine percent of lighting in Zambia and are used three times more often than kerosene in South Africa[8].

Candles are most commonly made from paraffin, a derivative of crude oil like kerosene, and as such it has similar negative health implications. Candles emit toxins on a much smaller scale than kerosene lamps, at a third of the rate, however exposure to candle fumes over a long period of time can result in similar health risks[8].

Candles are very dangerous in the home. They are responsible for forty percent of all settlement fires and are responsible for fourteen percent of all burn injuries. Representative of many regions, Liberia released a statistic that there is at least one shack fire in Monrovia

each week caused by candle fire[8]. One tragic fire responsible for killing twelve girls in a dormitory fire in Tanzania was thought to be caused by a student reading by candle light[9].

Figure 1 Shack Fire[10]

Finally, like kerosene, candles do not produce lumens of the necessary to meet quality standards and the light is poor due to flickering. Candles produce approximately one-third of the lumens of fuel-based lanterns and burn quickly. The lack of quality light causes eye strain, eye fatigue, poor visual performance and these strains can eventually lead to impaired vision[8].

Current Energy Options: Mobile and ICT Devices

In addition to lighting, access to electricity and energy to power mobile and other ICT devices is a requirement to meet development goals and alleviate poverty. In order for ICT to be used and be impactful in development work ICT devices need to be charged so they can be accessed regularly. Charging mobile devices is expensive. On average it costs people in sub-Saharan Africa twenty-five cents each time they charge their mobile device, and the fee does not guarantee full charges on devices. On average in rural areas people are living off only one

dollar per day[11] and approximately seventy percent of sub-Saharan Africans live off of two dollars a day with low and irregular earnings[12]. Charging a phone could be as much as a quarter of one's daily budget.

Using car batteries to charge devices, and other electric needs, is a common method used in some countries such as Uganda[13]. The downside to relying on this technology is it is both expensive and, if wired wrong, can damage chargers and ICT devices.

Kinetic charging options are also available. Hand cranks and bicycles are used to generate electricity to charge devices. Ten minutes of hand crank use yields approximately one to two minutes of talk time while ten minutes of bicycle riding at a rate of 10 kilometers per hour can yield about twenty eight minutes of talk for a low end mobile phone[14]. These options are great alternatives when no other options exist, however they require a great deal of physical exertion to achieve any benefit. Additionally there are ethical concerns around the use of kinetic energy sources because it requires people to perform a great deal of physical activity for small returns. Requiring someone who would not or cannot partake in physical activities, but must in order to charge ICT devices, poses an ethical dilemma. This puts elderly or sick people at a severe disadvantage. In addition, people must buy more food as physical exertion requires additional calorie intake from the participant.

Solar Technologies

Sub-Saharan Africa has access to a variety of renewable energy sources including: solar power, wind power, biomass, geothermal, ocean energy, and hydro-electrical power, that can offset the need for the conventional sources mentioned above. However these options are largely unutilized either due to insufficient technologies or they are cost prohibitive. The

exception is solar. Solar energy is the most accessible renewable energy available to these consumers[5].

Solar energy has the potential to offer consumers, residential and commercial, a clean energy source. The solar products reduce the volatility in their budgets and provide a healthy and safe source of electricity. A market study in Ghana revealed consumers prefer the addition of solar energy options to all other alternatives.

This study identified three types of consumers who would benefit from additional off-grid solar systems: those who have no electricity, those who are under-electrified, and those who are electrified[15]. The consumers were defined as follows:

1. Standalone users: customers without electricity who require a stand-alone system to electrify their homes.

2. Backup users: consumers who are under electrified due to unreliable and insufficient electric service. These consumers often experience brown-outs or black-outs.

3. Hybrid users: consumers who use both solar technology to power low wattage appliances such as mobile phones and radios and use main grid electricity to power high wattage appliances such as refrigerators.

In response to the insufficient energy options, many companies have developed solar technology products. Users obtain energy through photovoltaic (PV) modules which convert solar radiation into energy. Many designs incorporate PV to meet two needs: to provide lighting and to provide various ICT charging options for consumers. Solar products available to Sub-Saharan Africans are detailed below.

Single Light Solutions

Elephant Energy and Angaza are two companies operating in Sub-Saharan Africa. These two companies only offer single light solar powered lighting solutions, as opposed to multi-light systems. The single light products come with one small PV module and one chargeable light.

Elephant Energy offers a variety of solar-powered, single light products with different price points. The most popular model is also the highest quality product, the Sun King Pro Light and Cell Phone Charger by Greenlight Planet. The light has multiple lumen settings and an LED battery meter that indicates the charge level. The battery can store enough energy to run the light for up to 45 hours and has a five year life. The product comes with a wire stand that can either sit securely on a table surface or be pivoted and hang from an overhead rafter or wire. The light also has a 5.5 volt USB port that enables users to charge mobile devices[16], helping consumers avoid additional expenses to charge their mobile devices through other expensive means.

Elephant Energy and Angaza both offer a less expensive solar-powered light also manufactured by Greenlight Planet, called the Sun King ECO. The Sun King ECO is the least powerful light available by Greenlight Planet. This light has a thirty hour charge and battery with a five year life. It also comes with a multi-use wire stand. Unlike the Sun King Pro, this product does not provide a USB port or battery charge metering indicator[16]. The lack of a USB charging station makes this a less desirable option to support ICT tools, but it is a more affordable light that eliminates the need to invest in hazardous lighting options such as kerosene lamps or candles.

Figure 2 Sun King Pro[16]

Figure 3 Sun King ECO[17]

Multiple Light Solutions

M-KOPA, Azuri, and Mobisol are vendors that offer multi-light solar power lighting solutions. They sell lighting kits that power up to three to five lights and have USB charging capabilities.

M-KOPA offers a multi-light solar power lighting system called the M-KOPA III Solar Home System. This product comes in a kit with two overhead lights with multiple brightness/lumen settings. It comes with a third mobile torch light, which is not affixed overhead, and can be used to accommodate a variety of spotlighting needs. In addition the system has a USB port with five attachments to accommodate a variety of charging needs and a solar charged radio[18].

Figure 4 M-KOPA III[18]

Azuri offers an entry level product called the Indigo Duo. This is a box kit and comes equipped with two lights that can be charged to supply eight hours of light, charge mobile devices, and meets the global minimum quality standards[19]. The Indigo Duo kit supplies

customers with a variety of common mobile chargers. Azuri also sells systems with more lights and in addition to charging mobile devices it also has the capability to charge radios. Customers have the option to purchase the larger system upfront or start with the entry level product and later trade up when they can afford to[24].

Figure 5 Azuri PV Module[20]

Figure 6 Azuri Indigo Duo[19]

Mobisol has the most dynamic mini solar home systems. Their base model has two lights and a USB charger. Their most advanced model has five lights, and can power larger consumer appliances including laptops, TVs, or refrigerators. The system can charge up to ten mobile phones simultaneously. The Mobisol system can generate enough energy to power a small business and enables Mobisol customers to sell or pass on excess energy to their community[21].

Figure 7 Mobisol Solar System[21]

Figure 8 Mobisol PV Module[22]

Solar ICT Charging

Solar ICT charging technologies (without lighting) have slowly been gaining popularity as an alternative to other charging options described above. These technologies include solar handsets and external solar chargers.

Solar handsets have been made popular as the solar technology has been improved to supply increased battery life and more effective PV modules. One hour of handset charging enables approximately twenty minutes of talk time, with good solar conditions a phone can be charged within four to five hours. External solar chargers are also a new popular technology. These units are not limited to mobile devices but can also charge light torches, radios, and other low power units. The external solar charger has similar charging times as the solar handsets, mobile devices require approximately one hour of time enabling twenty minutes of talk time.

Financing

Solar energy offerings have evolved in the past few years to make solar realizable for poor consumers. Previously consumers were responsible for figuring out how to purchase mini solar solutions on their own. For many, the only option was to pay in full, whether it was a single light or multi-light solution. Some consumers could obtain micro-loans or other financing options to purchase solar products however this was not typical. Financing was difficult, for-profit companies would not offer loan options because they generated little revenue. The only financing options would possibly come from government subsidies or domestic financial institutions and these institutions rarely extended benefits[23]. Impoverished consumers living off of two dollars a day often cannot save to make large

purchases and need financing; without financial assistance they were left unable to afford the solar-powered products.

Pay-As-You-Go

The market place has changed recently and now many companies offer Pay-As-You-Go (PAYG) financing making it easier for consumers to purchase products. The PAYG scheme requires customers make a down payment to the retailer for the solar-power product. Most PAYG plans require customers to make a deposit that is ten percent of the retail cost of the solar lighting system. Functioning as a lease-to-own arrangement, consumers make installments payments daily, weekly, or monthly for continued access to the product. If payments are missed the technology is turned off but the units are not taken away. The products are turned back on when the customer resumes making the installment payments. Once the product has been paid in full the product is unlocked and the consumer has full ownership and rights to use it.

The most successful PAYG models structure payments so that each payment is less than the cost to buy kerosene for lamps or other alternative energy sources. Customers realize the benefit immediately, they do not sacrifice access to light and energy as a result of investing in solar technology. Contracts last between twelve and thirty-six months. PAYG technology for solar lighting systems is new in the marketplace, but so far the default rates on PAYG have been very small, reported to be under five percent[12].

PAYG has been realizable due to the integration of metering technologies. Metering and pay as you go utility service has been available in the past but it was never applied to smaller

mobile units, this is a new feature in the solar-power marketplace[24]. Many companies offer variations of metering technology. A couple of the leaders in the deployment of meters are:

→ Lumeter Networks: Lumeter Networks built a low-cost meter that is an off the shelf solution to meter solar and other technologies such as water pumps. It was built with tamper proof technology and the ability to manage pre-paid systems, both features are important to avoid theft and other unintended uses.

→ Simpa Technologies: Simpa Technologies has developed a tamper proof meter. The meter uses microcontrollers and user interface to track all pre-payments. The Simpa Technologies meter is only integrated into Simpa lighting products and cannot be used as an off-shelf solution for other companies[24].

Companies offering PAYG purchase plans have developed different methods to collect payments. These payment options are either made through local vendors, scratch cards, or mobile money transfers:

Local Vendors

Elephant Energy is an example of one company that uses local sales representatives to collect payments. Elephant Energy operates primarily in Namibia with poor mobile banking options. The company determined the most efficient business model was to work locally. Agents in the field to directly collect cash payments. The only way customers can make payments is through their sales agent. Payments are not collected electronically and cannot be purchased through other means.

Scratch Card Payments

Azuri Technologies utilize a unique method of payment collection by using scratch cards as a method for customers to "top-off" their solar energy systems. Scratch cards are purchased from a local network of vendors in rural communities. Each scratch card reveals a unique passcode to enter into the Azuri Technologies unit. After the user enters the code the product is unlocked for the number hours the customer purchased. Systems are fully paid off in about eighteen months[24].

Figure 9 Azuri PAYG Scratch Card[25]

Figure 10 Azuri PAYG Code Input[26]

Mobile Banking Payments

Mobile banking is another popular form of collecting payments. M-PESA is a successful mobile banking system in Kenya and M-KOPA, a solar-power system retailer, was established in Kenya by the founder of M-PESA. M-KOPA use M-PESA technology to collect installment payments from customers. M-KOPA is not the only vendor offering mobile payments, two other popular vendors that also accept payments via mobile banking are Fenix International and Mobisol[24].

Future of Solar

Solar energy is the ideal technology to bring energy to off-grid homes in sub-Saharan Africa. Solar energy is safe, clean, provides superior lighting, has the option to charge ICT devices, and it is affordable through PAYG financing.

The options currently available are limited. Single lights only have the capacity to include one USB charger. Multi-light kits have more charging capacity than single lights but cannot be expanded. Mobisol offers the largest solar kit with the ability to power radios, TVs, and refrigerators. This kit is the best in the market in terms of functionality. The Mobisol product would be ideal except it cannot be expanded, consumers cannot add one additional battery or PV module, in order to expand their solar-power system they would have to purchase another kit.

Development efforts and products should be sustainable for the customer and the global environment. Two primary factors supporting this argument are:

1. Single lights and small kits are limited in capacity and life. At the end of the life cycle consumers will either have to make another significant purchase or return to using the expensive and hazardous non-renewable energy sources of kerosene or candles. For example, the single light Sun King products manufactured by Greenlight Planet only have a five year battery life making the product useless at the end of this term.

2. Products that are not long lasting and non-recyclable contribution to e-waste epidemic. E-waste, the disposal of technologies at the end of their life cycle, is a worldwide problem that most gravely effects developing countries[27]. Sub-Saharan African is often the destination for e-waste of other countries. Developing countries

without proper e-waste management systems have unsafe disposal methods including burying and burning the products. Reports show children have higher exposure to lead and other toxins as a result of poor e-waste management[28]. Solar technology solutions are "green" and should not contribute to e-waste pollution at the end of their life cycles. Solar technology should be long lasting and provide the consumer with a future possibility to grow their system, not throw it away.

The future of solar power solutions should be scalable. The systems should have the capacity to be expanded to include additional batteries and PV modules. The modular system recommended by Paul and Uhomoibhi is just that, it starts as a small system with the necessary hardware. The modular system can be expanded as can be afforded. The design is optimal because it enables customers to buy an unlimited amount of additional hardware. The system will be able to support lighting and other end-uses including charging ICT devices. The modular system can eventually be expanded to accommodate running multiple appliances and intensive heating/cooling systems. A light and USB port for charging is a great start, but people in developing countries should have the option to build more capacity.

PAYG is the optimal financing mechanism for the modular solar-power system. PAYG has proven to be an effective financing option enabling consumers to buy solar-power products they would not have been able to purchase otherwise. The small default rate seen of PAYG is a testament to the success. Customers can continue making installment payments while realizing the benefits of solar power in lieu of purchasing alternative fuels and paying for ICT device charging.

Conclusion

Solar technology is the best way to electrify Sub-Saharan Africa. Development goals and poverty alleviation will be accelerated when the population has reliable, safe, and clean electricity. Supplying people in developing countries with solar energy will empower the population. Solar technologies are most effective when implemented in a sustainable way. Consumers should be offered products that will last, not contribute to e-waste, and can be expanded to continually improve the utility available in their home and community.

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