Minazi Energy Kiosk

Experiences from Solar Battery Charging Kiosks in Rwanda

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EQUINOX

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ABSTRACT

Un-electrified communities in the developing world suffer a number of harmful consequences from the lack of access to even the most basic provision of a modern energy source [1]. Solutions to electrify such communities have often targeted solar photovoltaics as a cost effective technology, through products such as solar home systems and solar lanterns. Such delivery models often come with a high upfront cost to the consumer and exposes households to the risks of product failure. The Battery Charging Kiosk, or Energy Kiosk, is a distribution model for supplying small electrical loads within un-electrified communities, which aims to overcome these issues. Such kiosks can be powered from a number of technologies such as solar, micro-hydro or even the grid if there is access locally, and have been implemented across developing nations in Asia and Africa [2-5]. The student organisation e.quinox has been trialling this distribution model in rural and peri-urban areas of Rwanda for the past four years. This paper aims to bring together the experiences gained to date, and subsequently to assess the degree to which such a distribution model can provide a sustainable, scalable and financially viable solution to rural electrification. The social implications of implementing the kiosk model will be discussed in addition to economic and technical factors. It is shown that removing high upfront costs and the risk of product failure for the consumer, through a pay-for-service business model, results in a need for extensive local management and experience, particularly in kiosks situated close to an alternative electricity supply. Financial sustainability remains a challenge due to high upfront costs and low return rates of customers, resulting from very low electricity demands.

CONTENTS

1 INTRODUCTION

Electricity is a scarce resource in much of the developing world, where 1.3 billion people lack access [6]. In Rwanda, as much as 93% of the population lacks access to electricity to provide safe, clean, affordable lighting and communication [7]. e.quinox is a student-led organisation based at Imperial College London that aims to develop innovative, clean, sustainable and scalable means of rural electrification. One of the solutions being trialled is the Energy Kiosk. Since 2009, e.quinox has implemented 6 of these projects in rural Rwanda as well as Tanzania.

The Energy Kiosk model offers a potential solution to the rural electrification challenge. The concept revolves around a centralised charging station where electricity is provided from an energy source, such as solar photovoltaics. Battery boxes are distributed to customers within the local community to provide LED lighting and other small electrical loads such as phone charging, and are recharged at the kiosk for a fee. These boxes are rented as opposed to being purchased up-front in order to make them affordable to the community. The income generated from the kiosk is subsequently used to finance the salary of a shopkeeper who manages the kiosk, and maintenance of the kiosk. Similar concepts have been implemented in a variety of world regions, such as India, [2], South East Asia [3,4], and Africa [5,8]. Many previous projects implementing the kiosk model have failed due to both technical and nontechnical reasons [8,9,10,11]. This provided the initial drive for e.quinox to try and develop a financially sustainable business model around the kiosk concept to ensure the longevity of an Energy Kiosk.

The solution provides a number of advantages over the purchase of small solar home systems, a common alternative for individuals. The Energy Kiosk provides lower up-front costs for the customer, and ensures maintenance and all of the equipments are handled by the operator. This considerably reduces risk of product failure for the end user, and provides the operator with a high level of control. The majority of equipment remains in the possession of the operator, allowing for simpler maintenance and ensuring a constant relationship between the operator and the customer.

This paper outlines the experience of e.quinox in operating a number of such Kiosks over the past 4 years. The challenges of this solution are highlighted along with solutions proposed for successful implementation of a Kiosk. The paper will start by discussing the social barrier to implementation of an Energy Kiosk, followed by an evaluation of the financial sustainability of the model and the technical developments of the project.

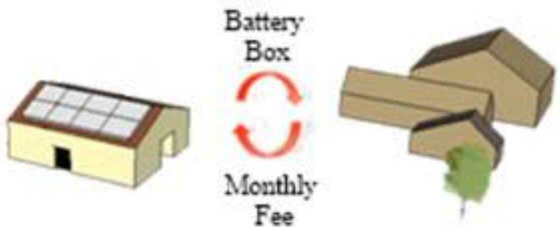


Figure 1 - The Energy Kiosk concept

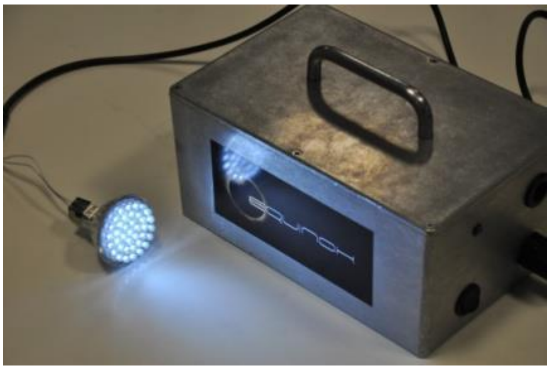


Figure 2 - A battery box and light used by kiosk customers

2 ECONOMIC ISSUES

2.1 Customer Payment Model

Two different payment models have been trialled at our kiosks; pay-per-recharge and a monthly fee. Both models have been trialled in a number of kiosks, with one kiosk located in Minazi, Northern Rwanda running both models simultaneously with two different sets of customers. Analysis of the accounts of the Minazi kiosk allows for a direct comparison of these models, see table 1. This experience has shown that a monthly fee yields a greater income than a pay-per-recharge model.

Table 1 - Financial Accounts for Kiosk located in Minazi Sector, Northern Rwanda, showing comparison of income from customers on pay-per-recharge and monthly fee models; Pay-per recharge fees were set at 1,000RWF[1] for a 12Ah battery box and monthly fees were set at 1,500RWF for a 5Ah battery box

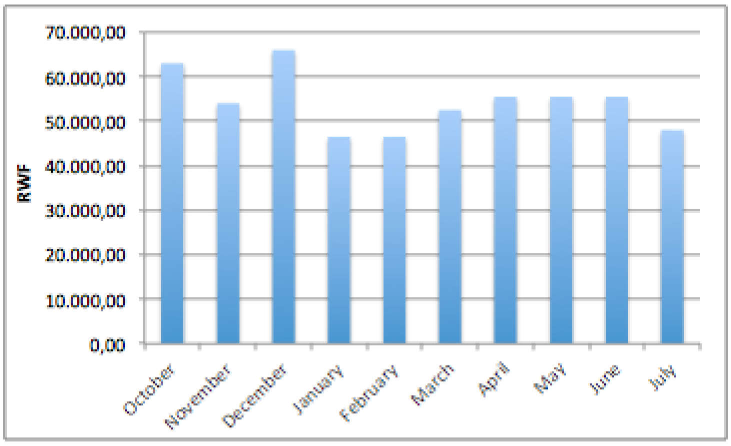
Year	Overall income per year (both models)	Pay-per-recharge income per customer per year	Pay-per-recharge # of customers average	Monthly fee Income Per Customer per Year	Monthly fee # of customers average
2009-2010	343,000 RWF	6,860 RWF	50	-	-
2010-2011	1,061,500 RWF	6,383 RWF	47	12,708 RWF (only 11 months)	~ 60
2011-2012 (only 10 months)	735,000 RWF	4,173 RWF	46	12,340 RWF	44

With a pay-per-recharge model, customers do not necessarily recharge their battery immediately after it has been depleted, either for lack of financial resources or simply the effort required. On a monthly scheme, however, customers are incentivised to use the batteries as much as possible. This brings certain advantages to both customer and kiosk operator, whereby customers maximise the benefits they receive from the kiosk service and kiosk owners have a more reliable income stream.

A strong seasonal peak has been observed during times when agriculture has yielded more profits, meaning that some customers have struggled with paying the monthly fees during times of financial hardship. This has been accommodated by allowing customers to either pay fees in advance or at a later date when income is more readily available.

[1] 1000 RWF = 1.57 USD

Figure 3 - Variation of monthly income through monthly fees at the Minazi Energy Kiosk in 2011-2012; A seasonal peak can be observed between April and June; This peak re-occurs yearly.



2.2 Shopkeeper Payment

Two different salary structures for the shopkeeper were tested; a set monthly wage and a system whereby a base rate is paid with a percentage of the kiosk income added.The incentivised wage was introduced in a number of kiosks to motivate the shopkeeper to encourage customers to come back more often, open the kiosk at times when it suited the customers and to reduce the number of free recharges given away by the shopkeeper to friends, family and government officials.

Results from implementing an incentivised wage at one kiosk showed that three customers greatly reduced the time between recharges (suggesting they were no longer receiving free recharges). Despite this, the new wage structure had little impact on the total income from the kiosk.

2.3 Financial Sustainability of the Energy Kiosk Model

With the experience of running six different kiosks, e.quinox has concluded that it is not possible to recover the initial investment costs of an Energy Kiosk, but that operational costs and a proportion of equipment replacement costs can be paid through the revenue generated by the kiosk.

The initial investment in an Energy Kiosk ranges from $15,000 to $30,000, for a kiosk with 100-200 customers and depending on the sizing of the kiosk, equipment transport costs, quality of equipment and method of energy generation (micro-hydro, solar).

Assuming an Energy Kiosk to have 100 customers with a monthly recharge fee of 1,500RWF or about $2.30 (a typical fee value for e.quinox's projects, which has been seen to be at the upper limit of affordability in the communities in which e.quinox has worked), the kiosk could theoretically generate monthly revenue streams of 150,000RWF. This does not, however, take into account customer defaults either due to failure of equipment or due to lack of purchasing power, which reduce this income by a significant amount. Taking the figures from the Minazi Energy Kiosk, we note that in 2010-2011, the average income from monthly fees from around 60 customers was 70,000RWF, which is 20,000RWF or 22% less than the expected value. In 2011-2012, the average income from monthly fees with 44 customers was 54,300RWF, which is 11,700RWF

or about 18% less than the expected value. When estimating monthly revenue streams and determining shopkeeper salaries, it is therefore essential that a default rate of at least 20% is assumed and very rigid operational structures are put into place to reduce this default rate as much as possible.

e.quinox has been paying its shopkeepers a salary of about 45,000RWF a month, which is just below Rwanda's average GDP per capita [6]. Deducting this shopkeeper salary from the monthly income and having used various battery box pricing mechanisms and a varying number of total customers, the Minazi kiosk has made a profit of roughly 800,000RWF from October 09 to September 12, yielding an average profit of just over 260,000RWF or around $420 per year. Considering the cost of a battery box to be around $40, the kiosk has generated enough income to allow the purchase of an additional 10 battery boxes each year. With about 100 battery boxes in circulation in Minazi, this would mean batteries would have to last for 10 years for the kiosk to be able to pay for their replacements. Experience has however shown that batteries need replacing after a maximum of three years, which means that only 30% of battery replacement costs can be covered by the kiosk. It is also worth noting that additional costs may be incurred through the repurchase of other equipment such as storage batteries or inverters, or costs for monitoring and managing the kiosk.

It can be concluded that from a financial point of view, the implementation of an Energy Kiosk with a battery rental model is only viable if the total upfront cost can be funded through a grant and continual funding is available to maintain the kiosk. Similar conclusions have been drawn by analysis of a large kiosk programme in India [12].

2.4 "Black-charging"

One key aspect of the Energy Kiosk is its interaction with the local environment. e.quinox's experience has seen issues arise when customers decided to charge their batteries either directly from the grid or from self-owned solar panels. This leads both to significant loss of income for the kiosk as well as potential damage to the battery boxes.

This has been the greatest problem for Energy Kiosks placed in proximity to a grid line. e.quinox has experimented with installing an Energy Kiosk that directly takes electricity from the grid to charge the batteries, which was intended to serve those who are not able to afford connections to the grid. Due to large financial losses resulting from customers "black-charging" directly from the grid, the kiosk had to be shut down. Consequently, both current and future developments in grid extension in the desired area of implementation should be evaluated.

Additionally, batteries could be designed so that they can only be charged with an unusual charging cable, minimizing the possibility that customers will be able to charge their batteries using the grid. Finally, pressure can be established via a customer contract, stating clearly that any black-charging will be considered an offense to the contract and results in a fine or the loss of kiosk membership.

3 TECHNICAL ISSUES

3.1 Electrical Design of the Energy Kiosk and Battery Boxes

The electronics in the e.quinox solar kiosks consist of off-the-shelf components, most of which are available in the countries where the projects operate. The first kiosk designed by e.quinox was a fully DC system as shown in figure 4. This is a cheaper and more obvious solution since batteries boxes are charged from a DC current, thus an AC inverter is not required. However, this design showed a number of problems. Firstly the DC Battery Box chargers used did not feature DC step-up voltage convertors as they were designed for solar panels which typically step-down the voltage. This meant that the Battery Boxes could only be charged to the voltage of the storage battery. This is not a problem during time of high solar irradiance but during times of low irradiation, the kiosk storage battery will be significantly depleted, hence the voltage will drop, meaning that the Battery Boxes cannot be fully charged. DC chargers featuring step-up voltage converters are not readily available at an affordable price.

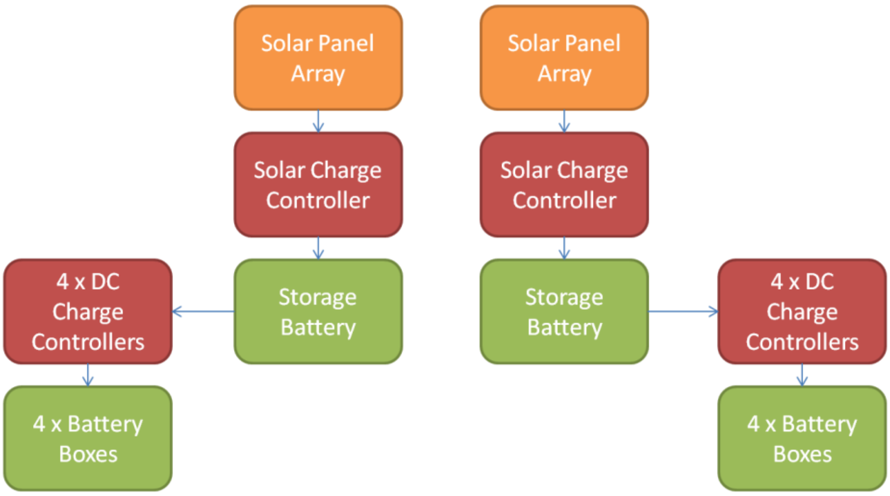


Figure 4 - Old DC Kiosk System

Secondly the fully DC system does not allow the kiosk operator flexibility in what devices they can charge. Mobile phone charging is a secondary source of income for the kiosks and in a DC system a USB output would be required and along with the correct charging cables for all phone types. With an AC system, the owner of the phone can provide the AC charger, which is normally purchased along with the mobile phone. As such, newer kiosks have been designed with an AC output as shown in figure 5.

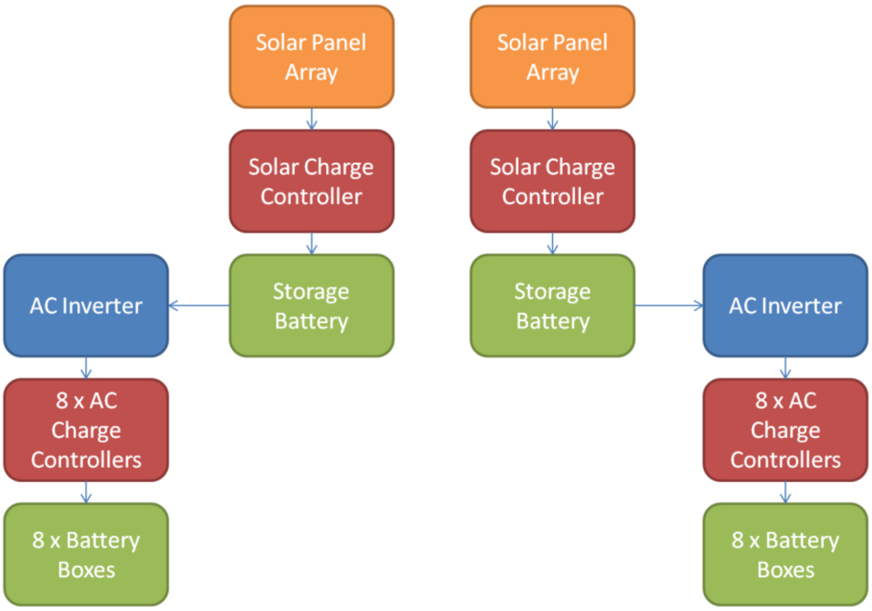


Figure 5 - Schematic of electrical layout of a solar energy kiosk.

A number of AC/DC configurations have been tried with the customer's battery boxes. After first implementing a Battery Box with only a DC output, it was found that customers desired an AC output. This allowed the customers more flexibility in the use of the energy however building a reliable, power efficient DC to AC inverter in each box is expensive. Early boxes included inverters however these were unreliable and very inefficient. It was discovered that most customers were using these AC outputs to power the AC lamps provided by e.quinox or to charge mobiles phones (which convert the AC power to DC when charging). In the latest battery boxes it was decided to replace the AC output with a 5V USB output which can be used to recharge mobile phones and other appliances such as radios, and replaced the lights with LED DC lighting which has become considerably cheaper recently. A DC output provided in this was believed to be the most appropriate solution to meet the majority of the consumer's needs.

3.2 Parallel Systems for Redundancy

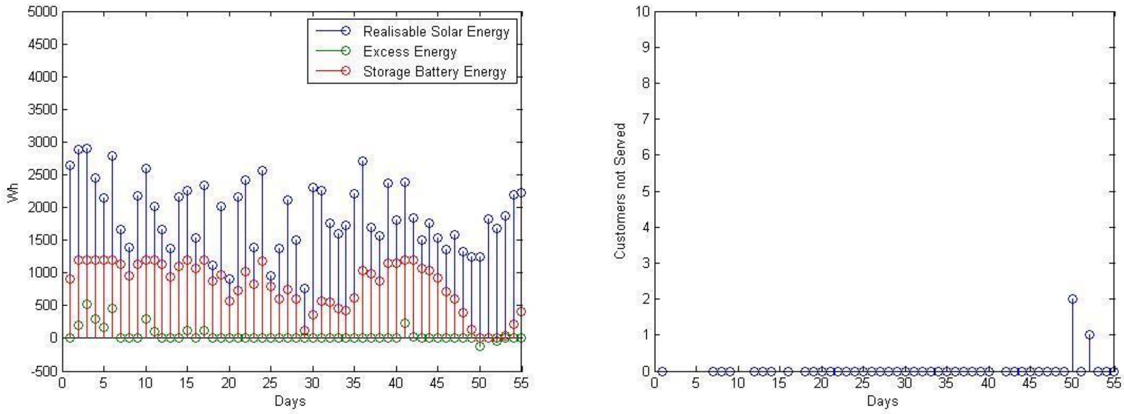
The electronics in e.quinox's kiosks have been designed to ensure that there is redundancy built into the system in order to provide a high level of system reliability. This was realised by the use of two parallel systems within each kiosk (see figure 5), with each sub-system consisting of a group of solar panels, a large storage battery, and an inverter to provide an AC output to charge customer battery boxes. Some components are expected to fail during the lifetime of the kiosk and providing replacement can be a lengthy process due to the often isolated nature of systems located in rural communities. The inbuilt redundancy of the kiosk system therefore allows customers to recharge their battery boxes whilst part of the system is awaiting a replacement component. This has proved extremely valuable in the case of an inverter failure at the Batima Kiosk in the summer of 2012. A replacement was installed 2 months later, however, the kiosk still functioned during this time, and the failure had limited impact on the service provided.

3.3 Kiosk Sizing and Solar Intermittency

Sizing of a kiosk is dependant of many factors including system efficiency, insolation, number of customers and typical customer usage. Whilst some of these parameters can be easily calculated others are more uncertain and prone to fluctuation which is one of the main difficulties faced when sizing a system.

Figure 6 shows such a simulation based on irradiance data collected over a two month period at the kiosk in Minazi sector, a mountainous region of Northern Rwanda. This demonstrates how daily variations in irradiance can be smoothed with a storage battery thus ensuring all customers are served even on days with low sunshine. A kiosk could be made considerably cheaper if storage batteries were not included. However, the intermittency of solar power has a considerably greater impact on operation of a kiosk compared with an individual solar home system, since days of low irradiance leads to customers being denied any service at all, rather than just reduced service as is seen with a solar home system. Figure 7 shows the effect of removing the storage battery from the system. In this case the number of customers not served rises from 3 in the case with kiosk storage batteries to 67 over the two month period.

A kiosk should be sized to ensure customers can be served on a continual basis. However, fluctuations in customer demand as well as solar insolation results in a substantial amount of electricity generated by the system is not used [13]. This results in electricity supply from the being considerably more expensive than if all electricity from the PV system was used. This has been seen to a much greater extent in other example of the kiosk concept [8].



[Model Parameters: 100 customers, 10 Day Average Recharge Rate, 2x50Ahr Storage Battery]

Figure 6 - Model of Minazi Kiosk based of two months of collected data. The left chart shows the storage battery energy over the period in red and well as the realisable solar energy in blue. The green plot shows the amount of daily energy neither used nor stored and the shortfall in energy required to serve all customers. The second graph shows how this data translates to the number of customers who could not get their battery box recharged each day.

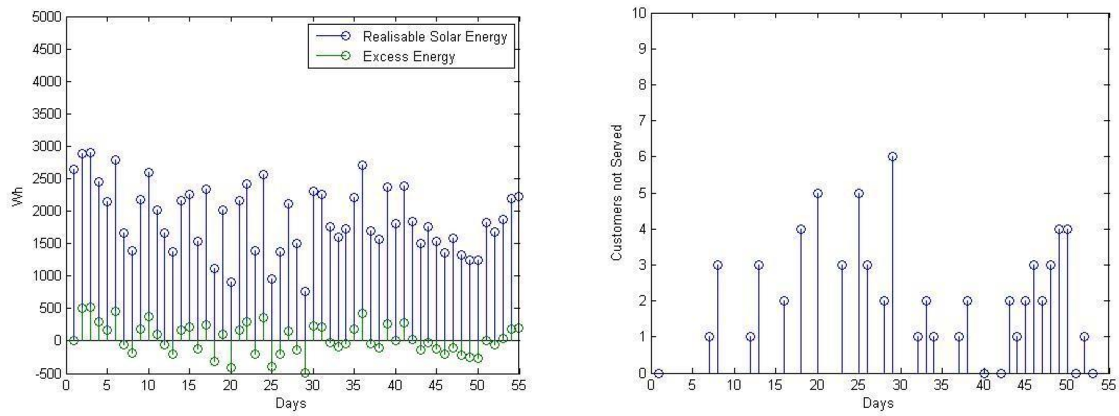


Figure 7 - Model of Minazi without Storage Battery. This model is based on the same data as Figure 6 but removing the storage battery from the model. Here we observe that 67 customers could not be served in this period. With the storage batteries this is reduce to only 3.

The model used to create the results seen in Figures 6 and 7 was developed in Matlab and can be used to simulate different scenarios and kiosk setups. Specifications of the kiosk, such as the number and size of solar panels, are taken as inputs, along with the capacity of the batteries, the number of customers and their average daily usage. Kiosk operation is then simulated at 10 minute intervals with the chance of a customer requesting a recharge being given by a Poisson distribution, and power generation being calculated using recorded solar irradiation data. Once the specified simulation duration has finished, the model displays the number of customers who had to be turned away due to there not being enough energy in the kiosk to charge their box. While this is a useful simulation when sizing a kiosk there are many limitations, mostly stemming from the assumptions made. The major assumption which cannot be reliably modelled is the likelihood of a customer requesting a recharge. Experience has shown that the capacity of the battery divided by their expected daily usage is a poor real-life indicator of recharge intervals. Fluctuating usage, inconsistent income and misjudged performance of the customer battery box all contribute to the situation being different in practice. However some insight into the timing of customer coming to the kiosk can be determined from the location of the kiosk, such as early morning recharges being most likely for a kiosk located near a school.

4 SOCIAL ISSUES

4.1 Education of shopkeeper and customers

In the set-up and operation of an Energy Kiosk, e.quinox has found that the education of customers and staff alike play a vital role in the sustainability of the system and ensuring customers accrue all possible benefits from the kiosk.

4.1.1 Understanding of Energy Use

A technical understanding of basic energy use is crucial to emphasise in the training of shopkeepers, and later, in the education of customers. This includes the understanding that a mobile phone uses more electricity than two lights, which respectively use more electricity than one light, thus depleting the battery faster. It is good practice to educate customers on how long they will be able to use their battery for with different appliances.

Prior testing of the batteries on behalf of the implementing organisation is essential, as a discrepancy later between promised and actual usage times can lead to conflict. Both battery degradation and differences in quality across different batteries are equally worth testing and emphasising to customers.

4.1.2 Care of Batteries

Customers who understand that different boxes may have different life spans often prefer not to exchange their boxes at the kiosk, but to collect their own boxes once recharged. Battery boxes often receive physical damage to the box due to them being hit or dropped due to the high mobility of battery boxes associated with a kiosk model. Care must be taken when designing the boxes and selecting the material to ensure they are reasonably robust. In addition, the level of usage of battery boxes greatly impacts the rate of degradation, such that boxes which are recharged more regularly will deteriorate faster (and so last a shorter amount of time before needing to be recharged).

4.1.3 Increased Income from Electricity Access

Customers of the Energy Kiosk often fail to realise that they can increase their income from using the batteries in a productive way, for example by charging other people’s mobile phones or by using a shaver in a barber shop. Information leaflets can be used to explain this. Better practice is to set up a workshop prior to the opening of the kiosk, explaining all potential uses of the battery boxes and quantifying potential gains in terms of weekly incomes and payback periods for a mobile phone charging or other business. It is also important to make sure that these additional gains are sensible given the battery size. If different battery sizes exist, the varying possibilities should be emphasised.

4.2 Battery Sizing

Data from customer surveys taken at all kiosk sites suggest that many customers prefer large capacity battery boxes, hence allowing for less frequent trips to the kiosk. However, customers often fail to realise the implications this would have on the end cost of both the initial deposit, regular fee for the battery box and the weight of the battery box.

At the kiosk in Minazi sector, Northern Rwanda, three battery sizes have been trialed. Initially, a 12Ah battery was distributed. The initial deposit, which was set at one third of the battery cost, was found to be far too high for community members to afford. Subsequently, future battery boxes were designed to be smaller so that the deposit would become more affordable.

In addition, since larger batteries need to be recharged less often, each recharge cost needs to be much greater than for a smaller battery to ensure financial sustainability of the kiosk. Lack of financial planning and savings ability of many members of the community meant that these infrequent but high payments were unaffordable. By designing a smaller battery, more frequent but lower payments are made, making the system more affordable.

The second battery box introduced had a capacity of 5Ah at 12V which on average lasts a customer for 2-3 days. Customer surveys have shown that many in the Kiosk communities deem this to be too often to be convenient, and thus the latest generation of battery box developed has been sized at 7Ah, enough to supply around 22 hours of light on a full recharge.

5 CONCLUSION

The Energy Kiosk solution has the potential to bring significant advantages to people's lives in developing countries. However, it is not a viable solution to run as a sustainable business in the form presented here. While the e.quinox kiosks have been able to pay for shopkeeper salaries and partially for battery replacements, they have been unable to recover the initial investment while still being affordable for the local communities they served. In comparison to Solar Home Systems, the greater battery capacity required for the Energy Kiosk model (since all customers have their own battery in addition to the kiosk battery) as well as lower utilisation of the electricity generated by the PV system (due to greater variability in demand), means that such a model results in considerably more expensive unit cost of electricity delivered to the consumer.

Yet it is worth noting the benefits of this solution for providing access to electricity in poor rural communities. For an NGO operating in a particular community, this solution provides some advantages over subsidised distribution of solar home systems. It ensures control is maintained of much of the equipment, making fault detection and maintenance simpler and considerably reducing the risk of product failure for the end user, whilst also providing local employment.

6 ACKNOWLEDGEMENTS

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