



How solar home systems temporally stimulate increasing power demands in rural households of Sub-Saharan Africa

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Received: 25 November 2019 / Accepted: 18 June 2020
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Abstract

Small solar home systems (SHS) have emerged as potential alternatives to grid electrifications, enabling households to make modest investments into their power systems, and to modify those systems according to their changing economic circumstances and power demands. Study shows that introduction to basic electricity access temporally stimulates increasing power demands in rural households, leading to eventual installations of larger systems that can power more electric appliances. Specifically, study shows that once households get access to basic electricity, they get to realise the socio-economic benefits of it and start to desire more appliances, with TV being the most desired appliance, followed by stereo systems, small fridges, and small cooling fans. These desires are realised temporally with increasing household incomes, leading to increasing loads, and thus to the modifications of the originally installed small SHS, to meet those increasing load demands; the desire for luxurious appliances leads to activities that contribute to increased household incomes, and thus to the modifications of the initial SHS. Acquisitions of luxury appliances lead to improvements in quality of life and to improved esteem visibility and social status within the local communities. Potentially, increasing load demands within a given community could lead to extensions of the national utility grid to those areas, as total loads justify such investments. SHS therefore potentially act as grid electrification stimulators, leading to eventual grid electrification of a given community.

Keywords Temporal power demands · SHS modifications · Rural electrification · Grid electrification · Desire for appliances · Household income

Introduction and background

Electrification rates in rural sub-Saharan Africa are very low compared to the rest of the world, with over 580 million people still lacking access to basic electricity, as shown in Table 1 [1]. These low electrification rates are attributable to many factors including insufficient power generation by the host nations, low load demands in rural areas leading to delayed electricity infrastructure developments in those regions, and prioritized dispatch of electricity to urban areas with high productive-use demands, leaving electrified rural areas to suffer frequent blackouts and brownouts [2–5]. Many studies have laid out the socio-economic benefits of access to electricity [2–8]; these studies have also concluded that basic access to electricity brings with it a wide range

of health benefits to rural households, including removal of fire and smoke risks associated with kerosene lanterns and firewood, access to a wide range of medication that require refrigeration, and access to useful health information through access to TVs and other electric information devices such as radios [2–8].

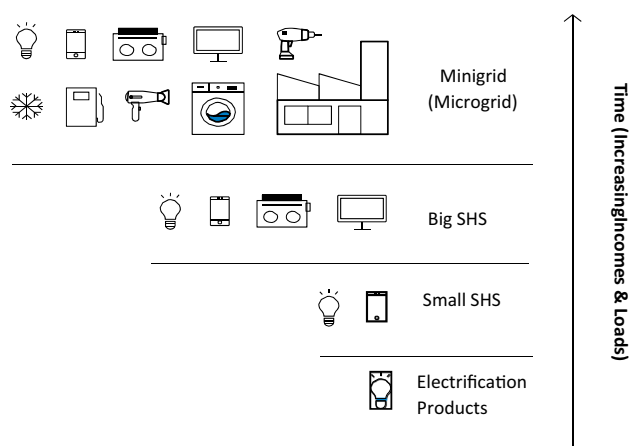
As reported by Opiyo et al., decentralized power generation systems based on locally available renewable energy resources initially provide cost-effective rural electrification options to extensions of existing utility grid systems in sub-Saharan Africa [2–5]. Most rural households only initially require basic electricity for lighting and to power small electric devices such as mobile phone chargers, and in some cases, small TVs and radios [2–5]. For these households, basic solar home systems (SHS) have emerged as the most cost-effective stepping stones to future grid-level electrification [2–5]. These small systems, rated between 8 and 60 Wp are tailored to match basic power needs and are modifiable with changing loads or changing household incomes, allowing individuals to temporally climb the energy ladder

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Table 1 Electricity access 2016—regional summary [1]

Region	Rate of access			Population without access (million) 2016
	National	Urban	Rural	
	2016 (%)	2016 (%)	2016 (%)	
WORLD	86	96%	73	1060
Developing countries	82	94	70	1060
Africa	52	77	32	588
North Africa	100	100	99	< 1
Sub-Saharan Africa	43	71	23	588
Developing Asia	89	97	81	439
China	100	100	100	-
India	82	97	74	239
Indonesia	91	99	82	23
Other Southeast Asia	89	97	82	42
Other Developing Asia	73	87	65	135
Central and South America	97	98	86	17
Middle East	93	98	79	17

**Fig. 1** Energy ladder [9]

as shown in Fig. 1 [9]. Furthermore, nearby households with SHS can network their systems into small communal microgrids or regional grids, with centralized or decentralized storage, leading to access to grid-level power and thus to improved reliability and availability of power, to improved system security, and to improved overall system efficiency [9, 10].

Many factors influence choices of rural electrification, with the main ones being availability of electrification sources, costs, and demand [2–5, 11]. To this end, SHS have emerged as the most sufficient electrification choices for rural households with basic electricity demands; in Kenya for example, a basic 8 Wp SHS costs about \$150 cash and about \$240 when purchased through hire-purchase [12, 13], making it more cost-accessible to rural households when compared to the utility grid that costs about \$350 in

connection related expenses, not taking into account the monthly bills [14, 15]. Many companies such as M-KOPA and Azuri Technologies offer hire-purchase options called pay-as-you-go (PAYG) where a consumer pays a deposit of about \$30 and a daily amount of approximately \$0.50 for about 1.5 years, for a basic system [12, 13]. This arrangement has enabled over 600,000 households in rural East Africa to gain access to basic electricity, and thus to enjoy the socio-economic benefits that come with it, over the past few years [12, 13, 16–18]. However, a daily cost of \$0.50 is still too high for most rural households, considering that a litre of kerosene, that could last a small household for up to two weeks, costs about \$0.99 [15]. In other words, households get to choose between spending \$7 a fortnight for access to basic electricity or \$0.99 for kerosene lanterns. For rural households, most of which live below the poverty line, kerosene becomes the more affordable choice. Moreover, many households are not able to afford the \$30 SHS deposit charged by the PAYG companies, as evidenced by the hundreds of millions of residents that are still unelectrified in those regions [1]. However, with favourable policies and grants, the PAYG platforms could be exploited by stakeholders to offer rural households more access to basic electricity through microfinancing, and thus to stimulate rural socio-economic growth through temporally increasing power demands and thus through eventual grid-level electrifications in those regions.

In this work we investigate how access to basic electricity stimulates demand for more power; we look at how households temporally modify their basic SHS with changing incomes and demands, to determine how introduction to basic electricity stimulates growth in a household's power demands. We then investigate how cumulatively increasing

power demands of a given community justify investments in extensions of utility grid transmission and distribution networks to that area, i.e., how initial installations of basic SHS by households within a given rural developing community eventually lead to grid electrification of the said community.

Methodology

Survey construction

An initial household survey was developed and carried out in Kendu Bay area of Kenya in 2014/15 to identify different means and sources of electrification in the area, as reported by Opiyo et al. in [5]. Kendu Bay was chosen because it represents a typical rural developing sub-Saharan Africa community, with plenty of sunlight due to proximity to the equator, with poor infrastructure, and with sparse population [4, 5]. From the survey data, a total of 513 positive respondents, representing 1.74% of the areas' total population, were identified from the three villages of Gendia, Kanam, and Pala and categorised into three groups based on electrification status as: (1) Grid-connected, (2) Not grid-connected but SHS installed, and (3) Not electrified, as summarized in Table 2 below [5].

From the initial survey, it was determined that about 4.7% of all households in Kendu Bay area had installed SHS of various sizes, representing about 345 households. A total of 27 households that had just installed basic SHS were selected for a further study on how introduction to basic electricity temporally stimulates demands for more; a comprehensive questionnaire was prepared and used to collect the required follow-up data, as shown in Table 3. The same questionnaire was then subsequently used every 6 months to update the previously obtained data, to monitor any modifications to the initially installed SHS, and to identify reasons for such modifications. This has been going on for the past 5 years, with the latest data collected in June/July 2019. Table 3 below highlights the main questions asked in the questionnaire. A particular focus is given to current SHS size, current household income, current total household load and related new appliances, and costs of modifications.

As reported by Opiyo in [2–5], Kendu Bay area of Kenya was chosen for the study because of ongoing research in the area since 2014. Even though the government considers the

area electrified, over 96.1% of the households in the area still lack access to grid electricity due to inability to afford associated costs [2–5]. About 18.5% of the households are dependent on small solar home systems for electrification while the remaining 77.6% rely on kerosene and firewood for lighting and cooking [2–5]. The survey questionnaire was constructed with cultural inhibitions in mind and collected data is anonymised to protect the respondents.

Data collection and analysis

Data was collected through face-to-face and door-to-door interviews, with the responses filled into paper questionnaires before compilation into a laptop computer, as had been the case since the initial and subsequent surveys in [2–5]. This was deemed the most viable option after a risk and cost analysis [2–5]. The head of the household, the person responsible for making energy decisions, always answered the questions on behalf of the whole household. To ensure uniformity of the data acquisition processes and analysis, the survey was always carried out by one person, the corresponding author, who is originally from the area, can speak the local language, and understands local cultural norms, and thus understands sensitive cultural issues and inhibitions. As noted by Opiyo et al., a single surveyor also enhances security and integrity of the collected data, ensuring safety of the participants, and accuracy of the results [2, 3]. As previously stated, the main objective of the research is to determine whether introduction to basic electricity stimulates demands for more power, and to identify factors that lead to such changes in demands, if any. In particular, the aim is to look at how electricity stimulates: (a) desires for luxurious appliances, (b) changes in households' income-generating activities, (c) acquisitions of luxurious appliances, and (d) modifications (upgrades) to original SHS.

Each household has its own data set on current SHS size, changes to SHS over the past 6 months, total household appliances with details on their power ratings etc., changes in household appliances over the past 6 months, daily hours of operations of appliances, current household income, and changes in household income over the past 6 months. These data are entered and updated every 6 months, based on the survey results. The data are used to analyse how households temporally modify their initial systems, and what factors lead to those modifications. Specifically, we first look at

Table 2 Household electrification status in Kendu Bay area

Village	Sample	Grid-connected (%)	SHS installed (%)	Not electrified (%)
Gendia	173	11 (6.36%)	8 (4.62%)	154 (89.02%)
Kanam	171	0 (0.00%)	9 (5.26%)	162 (94.74%)
Pala	169	5 (2.96%)	7 (4.14%)	157 (92.90%)
Kendu Bay (Total)	513	16 (3.12%)	24 (4.68%)	473 (92.20%)

Table 3 Sample Survey Questionnaire

1. What is the rated size of your current SHS?

2. Since last survey, list modifications made to SHS?

3. Total cost of modifications to SHS:

4. How did you finance your SHS modifications?

5. Appliances Powered by the SHS:

Appliances	Number	Wattage	Daily Load	Monthly Load	Annual Load
Bulbs					
Phone Charger					
TV					
Stereo					
Fridge					
Fan					
Laptop					
Others					
Total Load					

6. Since last survey, list changes to monthly household income:

7. What influenced changes to household income?

8. List of desired (coveted) appliances:

9. Since last survey, list newly acquired appliances:

10. How strongly did changes to household income influence acquisitions of new appliances?
 Very Strongly Strongly Somewhat Not Much Not at All

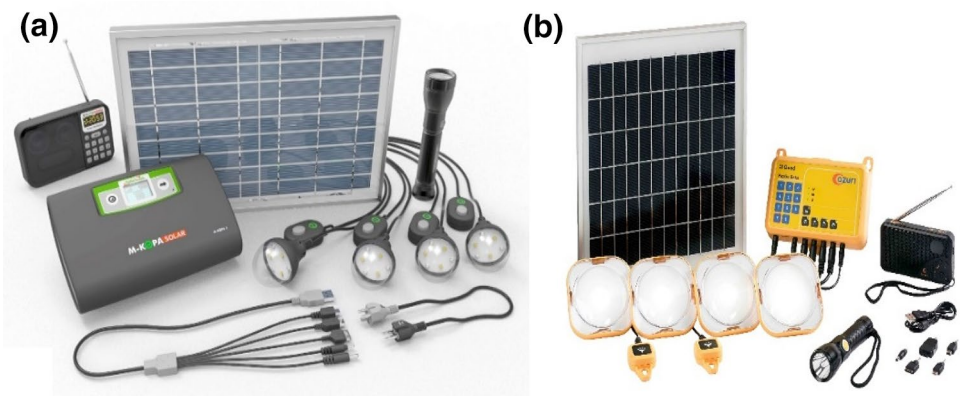
11. How strongly did your desire for more appliances influence your household income activities?
 Very Strongly Strongly Somewhat Not Much Not at All

12. How strongly did acquisitions of new appliances influence your SHS modification decisions?
 Very Strongly Strongly Somewhat Not Much Not at All

13. How strongly did changes to household income influence your SHS modification decisions?
 Very Strongly Strongly Somewhat Not Much Not at All

14. Other than need for lighting/phone charging, what was the main influencing factor for your SHS modification decision?
 Change in Income New Appliances Damaged Panel Damaged Battery None of the above

Fig. 2 **a** 8Wp M-KOPA solar home system and **b** 10Wp Azuri technologies solar home system [12, 13]



whether desires for more luxurious household appliances lead to activities that impact on households' incomes. If there is any such correlation, we then look at how changing households' incomes lead to acquisitions of the desired appliances. Following that, we analyse how acquisitions of new appliances, and thus increasing loads, lead to modifications of existing SHS systems into order to meet the increasing power demands. We then look at cumulative load increases of a given community, to determine if such increases warrant extensions of grid to the area. We then analyse policy implications of our findings, and draw a conclusion.

Results and discussion

Initial systems and desired appliances

Initial survey data showed that each of the 27 systems identified for further study were mainly used to power 2–4 light bulbs rated 1.2 W each, mobile phone chargers, rechargeable torches, and rechargeable FM radios. Figure 2a shows an image of an 8Wp system as marketed by M-Kopa, while Fig. 2b shows a 10Wp system as marketed by Azuri technologies [12, 13]. These systems come with 4 light bulbs each, multiple port mobile phone chargers, rechargeable torches, and rechargeable FM radios. They thus meet the most basic power needs of rural households.

Figure 3 shows how households ranked the main reasons for their initial SHS installations. From the figure, improved lighting quality was the main motivating factor, with all the households listing it as the most important reason for SHS installation. This was followed by mobile phone charging, as most rural households own some form of mobile phone or another, and they are used for many activities beyond calling, such as micro-banking, business transactions etc. Improved security, which is a factor of improved quality of lighting, was also identified as an important motivation for SHS installations. Improved health benefits ranked the

Reason for SHS Installation

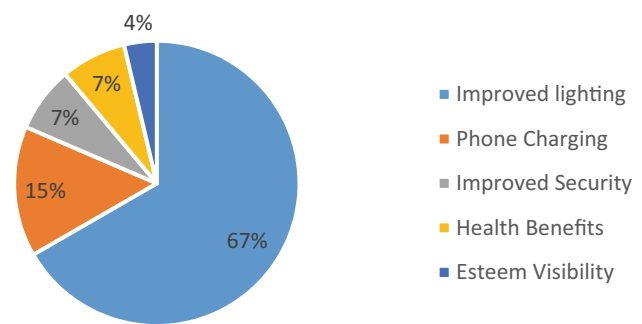


Fig. 3 Reasons for SHS installations

Rate of Power Consumption by Appliances

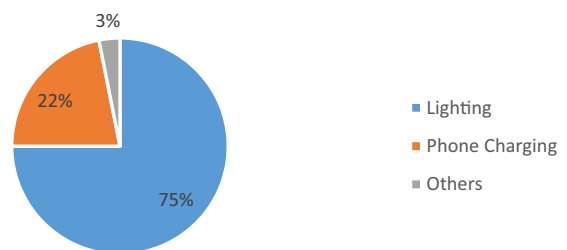


Fig. 4 Ratio of loads powered by basic SHS

same as improved security as removal of kerosene lanterns resulted in fewer fires and smokes. Esteem visibility was the least influencing factor in SHS installations decisions.

On average, it was determined that each household consumed about 23Wh per day, which computed to about 700 Wh per month or about 8.3kWh per annum. As shown in Fig. 4, the main load was lighting at about 75% of total energy used, followed by mobile phone charging at about 22%. The other loads consumed about 3% of the total energy used. Figures 3 and 4 correlate, showing that over 90% of

SHS-generated power was mainly used for lighting and to charge mobile phones.

From the initial and subsequent surveys, a list of desired appliances beyond lighting and phone charging emerged, with TVs being the most desired electric appliances. This was followed by stereo systems and then by small fridges. TVs and stereos were desired for entertainment, information and sports, while fridges were desired for chilled drinks, food preservation, and medicine preservation. Figure 5 shows a chart of desired items by level of desirability.

Changes in households' incomes

From the initial survey data, 13 of the 27 households depended on civil service salaries of between \$200 and \$250 per month. 8 households were small business owners with shops (kiosks) at local markets and with reported monthly net incomes of between \$150 and \$250. One household was a transporter with two motorbike taxis, giving him a net income of about \$200 per month. The remaining 5 households held various employments at non-governmental organizations, averagely earning about \$200 per month. With this income bracket (\$150-\$250/month), 19 of the 27 households managed to purchase their initial SHS systems on cash basis after saving for many months [2]. The remaining 8 purchased their systems though pay-as-you-go (PAYG) arrangements. To entice consumers to acquire luxurious appliances, PAYG companies started offering product packages that include small DC appliances such as TVs, stereos, and even fridges, the three most desired appliances by the consumers; companies such as M-Kopa now sell self-branded TVs and other appliances, with an estimated 70,000 units sold by July 2017 [12]. As another example, Azuri Technologies has joined with a local home entertainment satellite provider in Kenya, Zuku, to provide a combined package of SHS, a 24" DC TV, a satellite dish and Zuku Smart+ entertainment with 54 TV and 21 radio channels [13]. Through these PAYG channels,

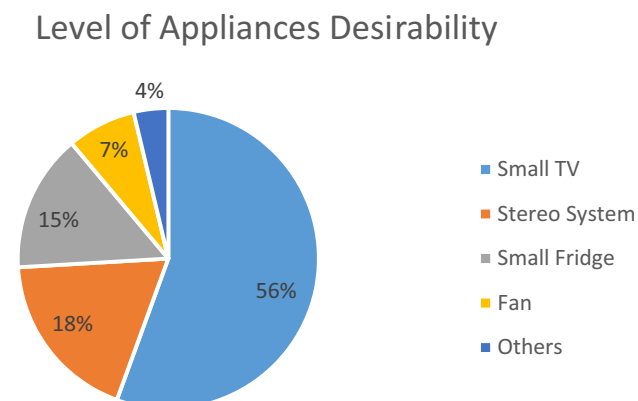


Fig. 5 Levels of desirability of appliances

consumers are offered opportunities to purchase desired appliances on hire-purchase or on cash basis, depending on their financial situations.

To afford these luxury appliances, 23 of the 27 monitored households reported starting side businesses in order to get more income, while the remaining 4 households depended only on salary increases and savings in order to acquire luxury appliances. By the end of the first year post-acquisition of initial SHS, 4 households started offering home-based mobile phone charging services to neighbours, earning about \$25 monthly in the process. By the end of the fifth year, this number had increased to 23, with only 4 households not offering the same services. To even further increase incomes, 3 households acquired motorbike taxis through hire-purchase arrangements, additionally earning \$75-\$100 in net monthly income. Eight households that were originally identified as small business owners diversified their businesses by offering additional services. For examples, all of these households now offered mobile phone charging services in addition to sales of goods and food-stuff. Four of these households opened barber shops and hair salons in addition to their original shops, generating between \$25 and \$50 in additional net monthly incomes. Three civil servants employed as primary school teachers formed a tutorial group, offering tutorial services to pupils during weekends, at small fees. This earned them between \$50 and \$75 monthly, pro-rata. Another main moonlighting activity by civil servants was health workers running their own small chemist shops (pharmacies) in local towns and earning about \$200 in monthly net incomes. Privately employed individuals also engaged in second employments in order to acquire more incomes, so as to afford more appliances. Table 4 shows income-generating activities by households, from year zero (2014/15) to year 5 (2018/19).

From survey data, the main additional income-generating activity was phone charging, with 23 out of 27 households participating in it by year 5. Acquisition of second jobs was second, with a total of 7 households engaging in second employments by year 5. Four households had opened barber/salon kiosks by year 5, while 3 had purchased motorbike taxis. Another 3 had opened chemists (pharmacies). Table 5 and Fig. 7 summarise the above information.

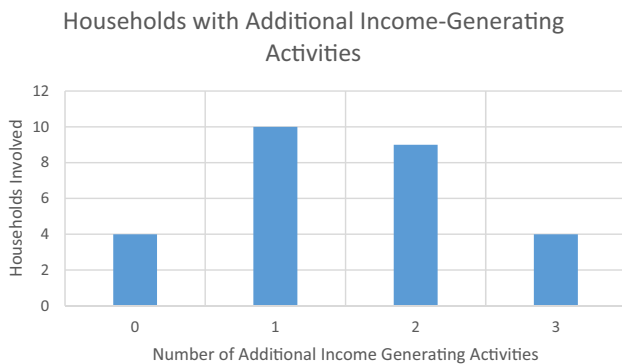
By the fifth year, many households were engaged in more than one additional income-generating activities in order to afford luxury appliances, as shown in Fig. 6. A total of 10 households engaged in mobile phone charging only, in addition to basic income sources. 9 households engaged in one more additional income-generating activity, in addition to mobile phone charging. Specifically, 3 households started barber/salon kiosks, 4 households acquired second jobs, and the remaining 2 households acquired motorbike taxis. Four households engaged in three additional income generation activities, with all of them engaging in mobile phone

Table 4 Households income sources

Income-generating activities	Number of households					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Civil service only	13	11	9	6	3	2
Civil services & aside business	0	2	4	8	10	11
Civil service & 2nd job	0	1	4	5	5	6
Private employment only	5	4	3	3	2	2
Private employment & aside business	0	1	2	2	3	3
Private employment & 2nd job	0	0	0	1	1	1
Small business only	9	7	4	1	0	0
Small business & aside business	0	2	5	8	9	9

Table 5 Additional household income-generating activities

Income-generating activities	Number of households participating					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Phone charging	0	4	8	13	19	23
Barber/Salon Kiosk	0	1	2	2	2	4
Motorbike Taxi	0	0	1	1	2	3
2nd Job	0	1	4	6	6	7
Chemist	0	0	0	1	3	3

**Fig. 6** Number of additional income-generating activities after 5 years

charging, 3 s jobs and chemist shops, and one in barber/salon kiosk and a motorbike taxi.

Additional income-generating activities lead to increasing average monthly incomes. In year 1, the average basic income was \$210.00/month, and \$216.85/month with additional income-generating activities. By year 5, the average household income had temporally increased to \$285.38/month for basic income and to \$357.05/month with additional income-generating activities, as shown in Fig. 7. The increasing monthly incomes enabled households to acquire additional appliances as discussed in the next section. In year 1, the lowest total household income was \$150/month while the highest total household income was \$275/month.

By year five, the lowest household income had risen to \$242.44/month while the highest household income had risen to \$605.77/month. These represent increases of 15.45% and 112.26% for lowest and highest earning households, respectively.

Acquisitions of desired appliances

Table 6 shows temporal acquisitions of desired appliances by households over a period of 5 years. By the end of the first year, one household had acquired a stereo with USB player. The first TV and fridge were acquired during the 2nd year by a single household. The household also purchased a stereo system. By the fifth year, 21 households had purchased stereo systems, representing 77.8% of all households under study. 13 households had acquired TVs, representing 48% of all households. This was followed by 4 fridges, 2 fans, and 1 laptop computer. All the 13 households with TVs also had stereo systems. All the 4 households with fridges also had TVs and stereos. More households were able to acquire stereos than TVs and fridges because a typical stereo cost about \$50, and is thus more affordable compared to a 24"TV that costs about \$175 and to a 100-L fridge that costs about \$150. Eleven households acquired their appliances through PAYG arrangements with local vendors, and in the process automatically upgraded their SHS systems.

Figure 8 shows a correlation between additional income-generating activities, additional incomes, and acquisitions

Fig. 7 Temporal rise in household incomes

Basic and Total Average Household Monthly Incomes

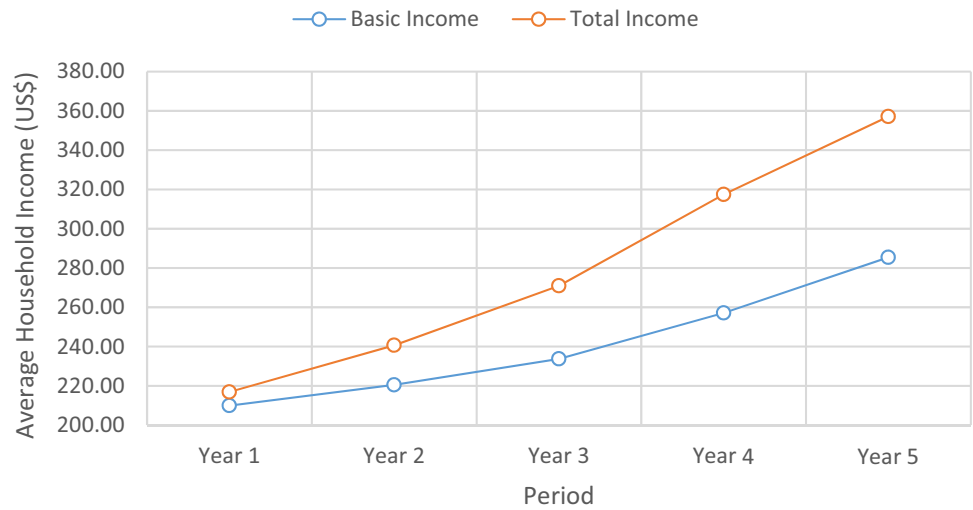
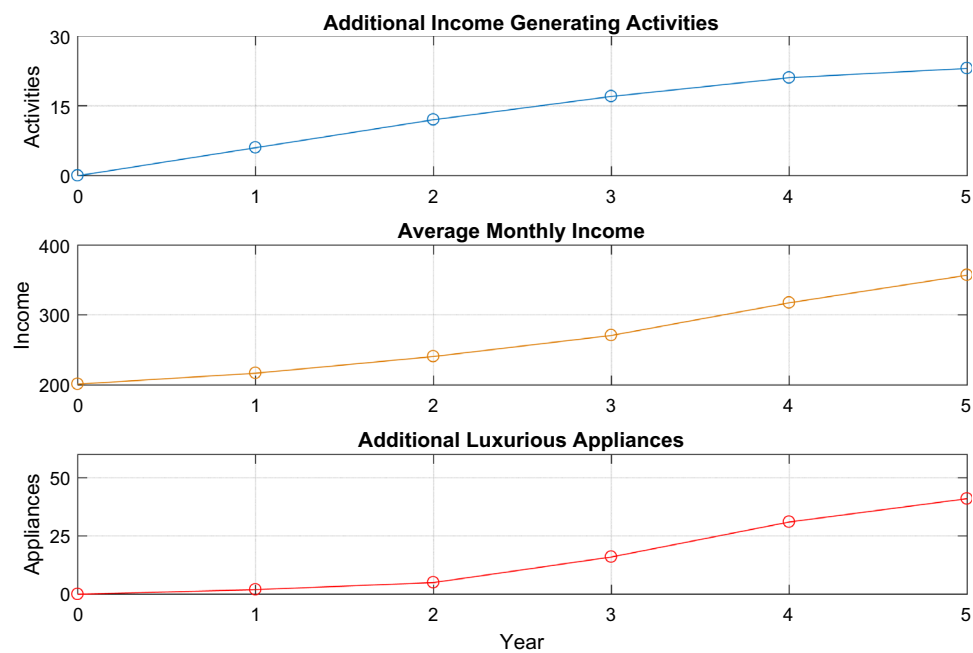


Table 6 Households with additional appliances

Desired appliances	Number of households with appliances					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Stereo systems	0	1	2	8	16	21
TVs	0	0	1	4	9	13
Small fridges	0	0	1	2	3	4
Fans	0	0	0	1	2	2
Others	0	1	1	1	1	1

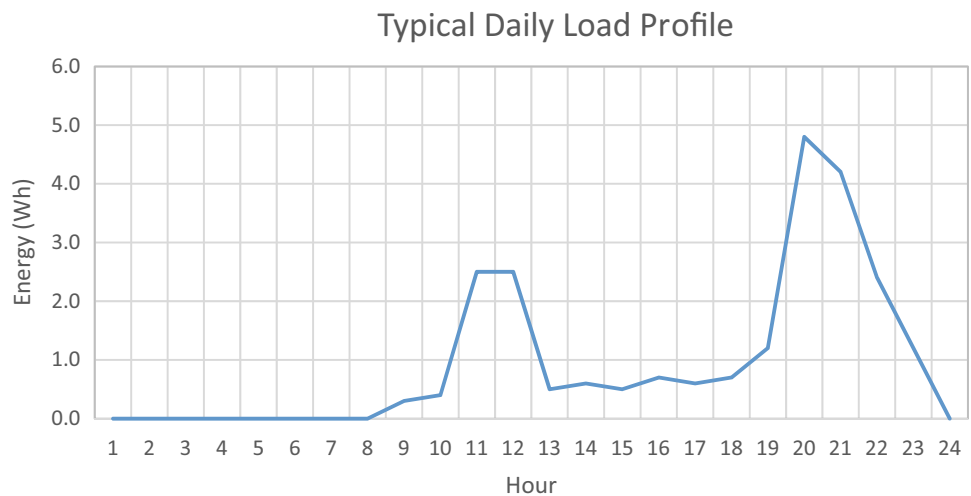
Fig. 8 Correlation between additional income-generating activities and acquisition of additional appliances



of desired appliances; as households temporally earn more money, they start to temporally acquire desired appliances. Desires for more appliances therefore lead to activities that

lead to increased households' incomes, and to eventual acquisitions of those desired appliances.

Fig. 9 Typical daily load profile of a household in with 8 Wp system



Modification to original SHS systems

Figure 9 shows a typical daily load profile of a household with basic 8WP PV system while Fig. 10 shows a typical annual load profile during the first year. Main power consumption occurs between 6 and 10 pm when lighting is needed. No power is consumed between midnight and 8 am as the appliances powered are just lighting and mobile phone charging. Phone charging occurs mainly during the day, between 9am and 4 pm. Most of the power generated by the PV system during the day is used to charge the battery for use in the evening. On this occasion, a total of 23.1 Whs was consumed by the household. The difference between the maximum daily power usage and lowest daily power usage in a given month is only about 1.9 Wh, due to basic household power demands, and due to available basic power sources.

Figure 11 shows average daily power usage by a household in a month over a 5 years’ period while Fig. 12 shows

average daily power usage by a household in a year, over the same period. Daily usage exponentially grows from about 23 Wh in year 1 to over 125 Wh in year 5 as more and more households begin to temporally acquire additional appliances such as stereos, TVs, fridges and fans. The average total energy consumed by a household in year 1 is 8.3 kWh. This exponentially grows to over 45.8 kWh by years 5, indicating increase in power demands with acquisitions of new appliances.

To meet the increasing power demands, households temporally modified their SHS systems to power their newly acquired appliances. SHS modifications and appliances acquisitions occurred simultaneously, as local vendors sold tailor-made systems for, and with, specific appliances such as TVs, stereos, or even small DC fridges. The most common first SHS upgrades were the acquisitions of M-KOPA 600 systems that came with 24” flat screen TVs, 30 WP solar panels with associated systems, TV aerials, LED light bulbs, rechargeable torches, rechargeable radios/stereos,

Fig. 10 Average monthly loads for year 1

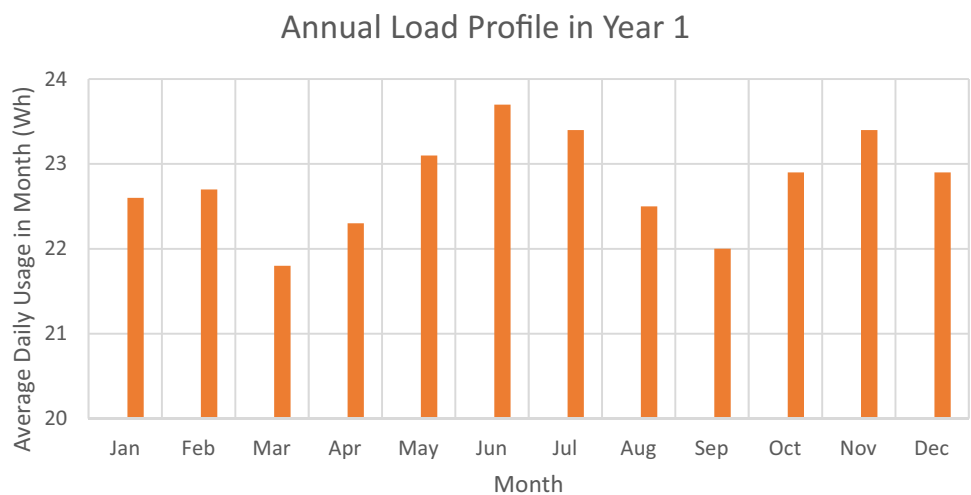


Fig. 11 Average daily power usage in a month over 5 years

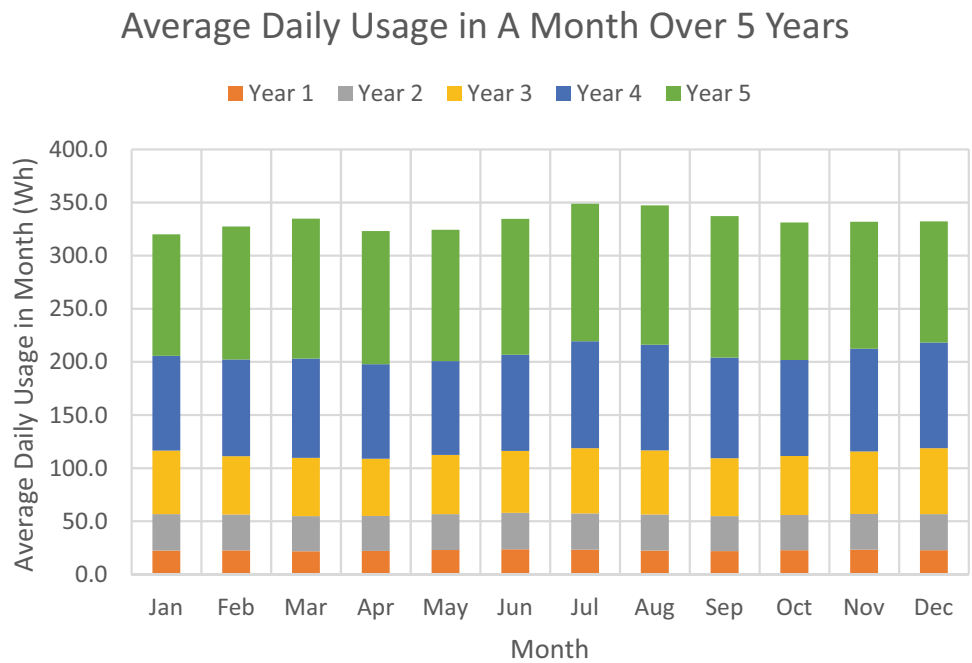
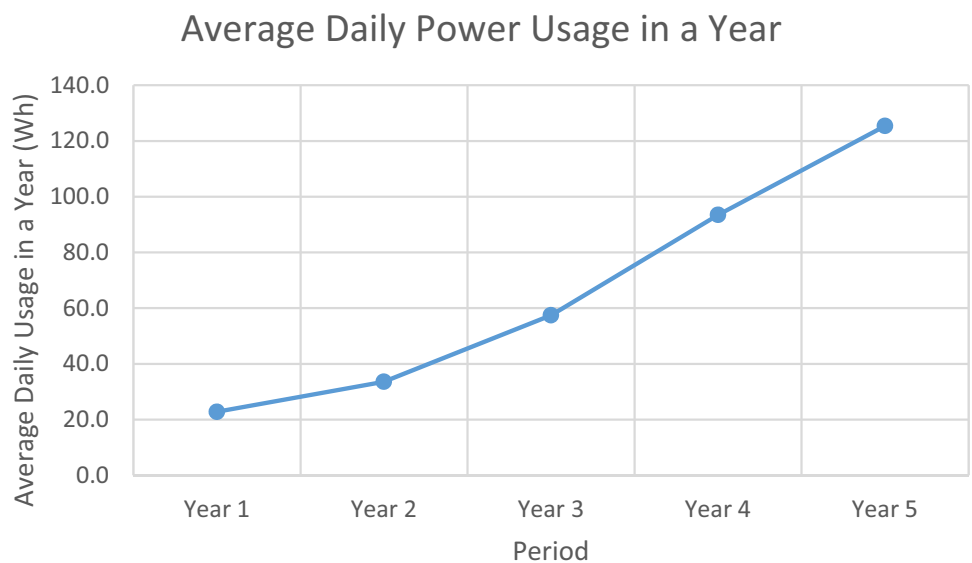


Fig. 12 Average daily power usage in a year over 5 years



and multiple port phone chargers and cables [12]. These systems cost about \$550 when purchased cash, and about \$650 when purchased using hire-purchase PAYG systems, with a deposit of \$60 and 590 equal daily payments of \$1 [12]. In addition to TVs, and satellite dishes, some M-KOPA packages also include cooling fans and 100-L fridges. Figure 13 below shows assortment of M-KOPA SHS systems and products. With excellent after-sales support, warranties, and quality assurance, M-KOPA systems have become the most commonly acquired in Kendu Bay area.

Other than M-KOPA, Azuri Technologies offers AzuriTV systems that come with 50Wp solar panels, 24" or 32" LED

TV, satellite dish with 60+TV and 30+radio channels, 4 1.2 W LED solar bulbs, mobile phone charger, rechargeable/radio/stereo, rechargeable torch, and additional USB cables and ports for mobile phone charging, as shown in Fig. 14 below [13].

Table 7 shows how households temporally upgraded their SHS systems with acquisitions of more appliances. By the end of year 5, only 2 households out of 27 had not modified their systems, and both households had connected to the grid, through their landlords. This basically means that all households had transitioned to higher level of power access than basic SHS. From the table, M-KOPA's 30Wp



Fig. 13 Commonly available M-KOPA SHS systems [12]



Fig. 14 Azuri technologies’ AzuriTV system [13]

that they had all installed basic SHS in 2014/15, their initial energy demands would have been 23.5 MWh, increasing to 126.5 MWh by year 5. Assuming the same trend in load profiles, in 10 years, the energy need of the village would increase to over 554 MWh, making it economically viable to extend the grid to the area. The domestic power demands, coupled with microeconomic activities that come with increasing power access, potentially lead to eventual grid electrification of the area. In addition, temporal increases in productive power usage lead to socio-economic development of the community, and to overall improvement in standards of living.

and 60WP systems are the most popular, with 7 households having upgraded to each of the systems by year 5. Six households had upgraded to the Azuri TV system. The remaining household had upgraded to larger systems in order to power more appliances.

Cumulatively the total energy consumed by the 27 households increased from 224.1 kWh in year 1 to 1.24 MWh in year 5. If we take one village for example, say Pala, with a total of 2763 unelectrified households [19] and presume

Conclusion and policy implications

Energy poverty in sub-Saharan Africa is attributable to many factors including insufficient power generation by host nations due to lack of necessary investment capital, delayed infrastructure development in rural areas due to low power demands, and lack of proper electrification plans and policies to suit the needs of rural household with basic power demands. The emergence of PAYG companies that sell tailor-made pico SHS systems for rural sub-Saharan households has seen an exponential rise in PV installations,

Table 7 Temporal modifications to SHS Systems

System	Total households with system					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
8 Wp	17	16	13	8	3	1
10 Wp	10	10	10	9	4	1
16 Wp	0	1	1	2	2	1
30 Wp	0	0	2	4	6	7
50 Wp	0	0	0	1	4	6
60 Wp	0	0	1	3	6	7
80 Wp	0	0	0	0	1	1
120 Wp	0	0	0	0	1	2
160 Wp	0	0	0	0	0	1

with over 600,000 systems sold in East Africa in the last 5 years [16–18]. These companies offer microcredit facilities in form of hire-purchase arrangements to enable rural households without credit history to acquire basic PV systems, through mobile money platforms. By marketing themselves as microcredit avenues to rural poor households for sustainable energy access, the PAYG companies have managed to raise over \$950 million from donors in the last 5 years and are projected to raise billions in the next 5e years [16, 17]. However, even with such investments, the rate of PV uptake through PAYG companies has not been able to curb the low electrification rates as most rural households still cannot afford the cash deposits required by those companies, and as mentioned earlier, the daily instalments are still out of reach of many rural households that live below the poverty line. Moreover, as reported by Opiyo et al., levelled the cost of delivered electricity (LCOE) from PAYG companies is about US\$:2.82–US\$:3.45/kWh while the national grid LCOE is about US\$:0.20/kWh [3], which is a huge discrepancy.

In this work, we investigated how introduction of households to basic electricity temporally stimulates demands for more power, as they realise its socio-economic benefits. We looked at how these demands are brought about by coveting and acquisitions of new appliances, enabled by increasing household incomes. We then looked at how households modify their systems to meet the increasing power demands. Results show that introduction of households to basic electricity stimulates demands for more power. The increasing demands, brought about by desires for more and luxurious appliances, stimulate and lead to additional income-generating activities by the households, with some households engaging in up to 3 additional income-generating activities, ranging from home-based mobile phone charging to motor-bike taxis. These additional income-generating activities lead to substantial increases in household incomes, enabling households to acquire the desired appliances. Usually, such appliances are sold together with the correctly-sized SHS to power them, in tailored and packaged systems by local vendors for M-KOPA, Azuri Technologies, among other PAYG companies. Results show that, by the end of year 5, 93% of households had upgraded their systems after engaging in additional income-generating activities. Moreover, by the end of year 5, the average daily energy consumption by a household was 125.4Wh, and about 45.8kWh per year. This is in line with the average power consumption by households in grid-electrified urban areas in Kenya, and thus justifies investments in grid extensions to the area. In summary, introduction of households in a given rural village to basic electricity leads to sequences of activities by the electrified households that could eventually leads to grid electrification of the village.

Results from this study show that there is a yearning for electrification in rural sub-Saharan Africa and that basic SHS system could act as the stimuli to future grid electrification. Therefore, to achieve the goals of affordable and sustainable rural electrification for all, developing communities should try to find affordable alternative paths to grid extensions, while taking advantage of the innovative PAYG financial models that already exist today. The goals should be to provide electricity that suits demand at prices that are competitive to those of the grid and of kerosene. To meet those targets, the following rural electrification policies are suggested:

1. Based on the results from this study and other studies [2, 3], developing communities should consider seeding unelectrified rural villages with basic PV systems to stimulate temporal growths in power demands, for potential future grid electrification; as a rural electrification policy, seeding of unelectrified rural households with basic SHS should be the first step, then letting them grow and modify their systems, for potential future grid extensions to the areas.
2. While using the PAYG financial models as their foundations, developing communities should consider appealing directly to donors and to investors so as to remove the middle men and reduce the LCOE of the PV systems. This would make them much more affordable, with low deposit requirements, and with daily instalments at par with fossil fuel (kerosene) costs. This would also lead to a wider access to microcredit facilities.
3. In addition to removing the middle PAYG companies, and thus unnecessary costs, developing communities should consider introduction of subsidies; previous studies of PV diffusion in Kendu Bay area have shown that introduction of subsidies would lead to exponential growths in PV installations [2, 3]. Combining subsidies with affordable and accessible microcredit facilities would lead to even more PV installations.
4. Lighting Africa and Lighting Global developed a testing framework for quality assurance that has now been accepted by the international electrical committee as a technical specification IEC/TS 62257-9-5 and has been adopted as a pre-condition for receiving carbon credit finance under the UN Framework Convention on Climate Change (UNFCCC) [16, 17]; as a policy, all developing communities should adopt and enforce this framework to limit influx of generic products into the market that has seen a downfall of some PAYG companies [20, 21].

Acknowledgements This research was partly funded by the Government of Kenya.

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