GridAlert: Using a Sensor-Based Technology to Monitor Power Blackouts in Kenyan Homes

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ABSTRACT
Power blackouts (outages) are a common occurrence in Kenyan households. They affect people's livelihoods, and damage their property (household electrical items). We explore the role of GridAlert—a sensor-based technology we designed—in monitoring power blackouts. We worked with local technicians to design GridAlert's housing and integrate GridAlert with Kenya's electricity infrastructure. Then, we used interview, observation, diary, and data logging methods to understand 18 households' experiences using the system. Our findings provide insights for using sensor-based technology to monitor power usage and blackouts in Kenyan households. We also present participants' thoughts about GridAlert's housing, and about how it influenced their actions when using the system. We use these findings to discuss design insights for power monitoring systems, and to offer new perspectives on the role of technology in monitoring blackouts in Kenyan households.

Author Keywords
Domestic technology; electricity; blackouts; monitoring; sensors; hardware; Kenya;

CSS Concepts
• **Human-centered computing → User Studies**

INTRODUCTION
The World Bank estimates that an average household in sub-Saharan Africa experiences 700 hours (the equivalent of one month) of blackouts (failure of electrical power supply) per year [34]. These events are less common in industrialized countries (e.g., 1.8 hours per year in the US) [35]. In Kenya, the country's power supply company (Kenya Power) received an electricity reliability score of 0 out of 8 (where 0 implies a completely unreliable system and 8 an extremely reliable one) from the World Bank [34]. Power blackouts constrain economic well-being, damage electrical appliances, increase crime rates, and reduce the benefits of using 'welfare-improving' machines e.g., fans and refrigerators [21,25].

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In this paper, we explore how sensor-based technologies can support Kenyan households' efforts to monitor power blackouts. We build on prior work by implementing a power blackout detection deployment strategy in a natural setting and allow end users to interact with it [9,10]. Prior research suggests that sensors can be used to collect power blackout information and send it to electricity supply companies [10,21,22]. However, their impact on providing feedback—to end users—about power blackouts has not been considered in HCI. Further, little is known about how sensors can be used to monitor power usage in Kenyan households. Investigating these issues in HCI can motivate researchers and designers to explore novel ways of using technology in non-Western households.

These questions guided our research: How can sensor-based technologies support monitoring blackouts in Kenyan households? What are the implications of using sensor-based technologies to monitor power usage in Kenyan households? To answer them, we collaborated with local technicians in Kenya to design and develop GridAlert: a sensor-based system that detects domestic power blackouts, and sends a notification to users via a mobile app. GridAlert also allow users to control their appliances (e.g., turn on/off appliance, schedule appliance runtime, and visualize appliance runtime). Our study had two phases. We initially conducted 18 interviews with participants in their homes, to understand how they monitor power blackouts. Next, we deployed the GridAlert system in their homes for one month. During the deployment, we asked participants to record their experiences using a diary. We also logged power blackouts and restorations data, as well as participants' interactions with the system (e.g., switching on/off appliances). After a month, we conducted follow-up interviews with our participants and asked them about the impact of GridAlert in their homes.

Our findings suggest that GridAlert can help participants monitor blackouts in their households. It allowed them to protect their home appliances, and also to manage their time between power blackouts and restorations. GridAlert seemed to minimize participants' time lost due to blackouts: they were able to resume their activities as soon they received a notification about power restoration. Our findings also suggest awareness benefits that helped participants to minimize electricity costs in their households. Participants also repurposed GridAlert for other activities in their homes (e.g., monitoring how long their children spend watching television). Furthermore, GridAlert's form factor prompted mixed reactions among participants. Unlike other studies in HCI/ICTD that have focused on interface design, our study examines how the design of GridAlert's hardware (using locally available resources) influenced participants' experiences with the entire system.

This paper makes these contributions to HCI: (1) evidence that sensor-based technologies can help Kenyan households navigate blackouts and manage power consumption; (2) implications for designing power blackout monitoring system's hardware and software; and (3) draws attention to future opportunities in HCI for investigating sensor-based technologies in Kenyan homes.

LITERATURE REVIEW

Numerous researchers have conducted ICT studies in Africa and similar contexts (generally described as "developing" countries) [11,24,27,31,32,40]. These researchers have broadly investigated how mobile phone applications can be used to address socioeconomic problems on the continent by providing people with "useful information" on education, health, governance, agriculture, and livelihoods (see [27,37,42] for overviews). However, less is known about how ICTs can address other significant problems in these regions, such as monitoring power usage and blackouts in homes. We review prior studies that investigate how ICTs can support monitoring blackouts and power usage in the home.

Power Blackout Monitoring

Power blackout monitoring is a significant topic of interest in various computing disciplines (e.g., computer science and engineering [6,21,22,30,33]). Yet, the HCI community has devoted less attention to this topic. Researchers in computer science and engineering have used sensors and smartphones to collect data about power blackouts and report this information to electricity companies. Klugman et al. designed GridWatch: a mobile application that crowd-sources power blackout data and send it to electricity companies in developing countries. This helps electricity companies to distribute power across different regions proportionately [22]. In a related study, Correa et al. evaluated strategies for deploying GridWatch. Their findings suggest that power outage detection improves dramatically with increasing density of sensors per transformer [9]. the higher the penetration of electricity blackout detection tools within a transformer, the higher the confidence of blackout detection. We adopt this prior work's strategy, and use it to deploy GridAlert in Kenyan households.

In the US, data mining and machine learning techniques were used to analyze social media data to detect power outages [2]. Bauman et al. relied on social media users as social sensors for detecting blackouts. This approach was based on identifying keywords related to power blackouts in Twitter discussions. Their findings suggest that integrating this approach with other methods (e.g., phone calls) can complement power blackout detection systems. However, their findings also suggest that many people—especially those living in rural areas—do not regularly tweet about power blackouts [2]. Social sensors integrated with other methods for detecting blackouts are effective in high population density areas where social media data are available at large volume [15].

To understand the challenges of deploying sensor-based power monitoring system, Klugman *et al.* designed and deployed *DumsorWatch* and *PowerWatch*—a mobile app and sensing technology that detects absence of electricity — in Ghana [21]. Their findings suggest that ignoring collaboration with local stakeholders leads to problems due to complexities of sensor deployment. They suggest that technologists should collaborate with local technicians when deploying power monitoring systems. We build upon their work by collaborating with fundis (Swahili for technicians) in the design and deployment of GridAlert.

Prior studies conducted in Africa primarily used technology to provide information about blackouts to electricity companies [9,10,21,22]. However, they rarely considered end users of electricity; furthermore, they did not provide metrics on how electrical appliances were consuming power. We extend prior studies by focusing on the end users. Providing this information to end users is important for helping them to navigate power blackouts. Other studies that explored Internet usage with end users suggest that providing users with feedback motivates them to use power in a cost-effective manner [7,31]. Chetty et. al conducted a study in South Africa, India, and the United States to understand how users manage Internet data. Their findings suggested that developing usable tools that provide consumers visibility and control over Internet usage is an important area of HCI research problems [7]. Our research builds on this work by exploring how to design power monitoring devices that provide consumers visibility and control over usage of electricity in their households.

Energy Monitoring in Homes

HCI researchers have investigated how technology can support monitoring energy usage in homes to reduce consumption, save the environment, and minimize unnecessary expenses [12,13,20,29]. Pierce et al. investigated domestic interactions and energy consumption in 12 households in the US. They collected data via interviews, home tours, and daily log-forms. They also administered an online survey to 646 respondents. Their findings suggest interactions with home technologies are mostly performed without conscious consideration of energy consumption, stating that interactions tend to be "unconscious, habitual, and irrational" [29].

Dillahunt et al. explored the relationship between energy-saving behavior, external factors, and users' intrinsic values and beliefs in the US. They used photo diaries and interviews to collect data from 26 participants. They found that lack of feedback on how households use energy is a common problem [13]. Their findings suggest that mobile phones can provide feedback to households about how they use their utility systems. Various scholars have explored how to do this [13,20,28]. Patel et al. explored the design and evaluation of an end-user power consumption sensor to enable researchers in HCI to deploy energy monitoring system faster and more easily. They designed a whole house contact power consumption sensor (CPCS), deployed it in three US households, and conducted an online survey [28]. Their findings suggest participants had a positive opinion about installation procedure and 86% of the respondents indicated they would be comfortable installing their CPCS. Kjeldskov et al. developed a mobile app—Power Advisor—that allowed ten Danish households to monitor their electrical appliances' power consumption [20]. Their participants owned standard household appliances (e.g., washing machines, freezers, ovens, microwaves, laptops, TVs, and gaming consoles). Findings from this study suggest using the app raised awareness of how neighboring households consume electricity [20]. Participants' ability to comparatively visualize electricity consumption helped them to gain a deeper understanding of their own electricity consumption. Power Advisor only allowed participants to receive feedback on how their appliances consume energy without any features for controlling appliances in the home. Our work builds on this prior work by including action features (e.g., scheduling appliance runtime) on power monitoring systems, and explores their impact in a different context.

These prior studies have mostly been conducted in the homes of industrialized countries (e.g., US and Denmark). However, "homes are not the same everywhere", and neither are the varied ways that ICTs have—and will—become integrated into people's domestic lives [3]. Living conditions, culture, household appliances, and other factors might all play a role on how people use energy in their homes [13]. Our study provides insights for designing power monitoring systems in the context of Kenyan households.

SYSTEM OVERVIEW

In this section, we describe GridAlert's design (Figure 1). GridAlert is a sensor-based system that supports monitoring power outages and electrical appliances in Kenyan homes. When initially developing the system, we considered using commercially available smart power strips. However, these required access to the Internet via Wi-Fi or cable network, and this is limited in Kenyan households [23]. Instead, we designed our system so that it could access the Internet

Figure 1: GridAlert System

using the Global System for Mobile Communications (GSM) network, that is widely available in Kenya.

Our system has two components: the power strip, and an accompanying mobile phone application. The power strip supports a Particle Electron micro-controller (with its battery and antennae), which controls two G-type sockets and also senses power blackouts and restorations. GridAlert mobile app is an Android application that works as an interface for participants. It allows them to check power availability logged through the power-strip, switch on/off electrical appliances, and see reports on how long their electrical appliances are used each day. GridAlert automatically protects appliances connected to its sockets; however, it had only two sockets, and therefore appliances not plugged on GridAlert required physical unplugging.

We developed the app using Apache Cordova, that was linked to the physical device via a web-server. GridAlert syncs to the app using the GSM network that is widely available in Kenya (most products available on the market sync to apps using cable or Wi-Fi network, which are rarely available in Kenyan homes). The system relays real-time data about power status to the server; the app reads information from the server, and displays it on its interface. Similarly, users' actions (e.g., switching on/off appliances) with the app are logged on the server to control appliances.

Electricity Blackout Detection Mechanism

GridAlert's micro-controller is powered by these sources: grid electricity and an embedded battery. The battery is charged by grid electricity. It provides backup power to run the micro-controller when there is no grid electricity. GridAlert detects power blackout when the micro-controller charging system switches from grid electricity source to the battery source, and detects power restorations when the charging system switches from battery back to grid electricity.

One challenge with this system is that it detects 'false blackout' (i.e., reports of a blackout when grid electricity is still available) when participants manually switch off electricity from their main switch. Prior research suggests that increasing the number of sensors deployed in a particular area can improve the robustness of power blackout detection [9,10]. To prevent false blackouts, we

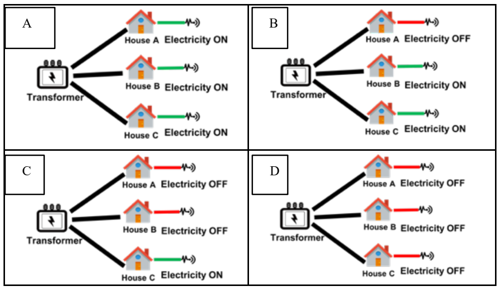

Figure 2: (a) No blackout detected (b) False blackout detected (c) True blackout detected (d) True blackout Detected

designed the system to work with other GridAlert devices within the same transformer (Figure 2). A true blackout was reported if at least two different systems from the same transformer logged a blackout at the same time.

Designing GridAlert

The lead author designed a preliminary version of GridAlert, and then worked with fundis in Kisumu, to refine its design. Over the course of the project we worked with two electricians, three carpenters, and one painter. They: soldered electronic components together; designed GridAlert housing; and assembled and tested research products. Working with local technicians helped to ensure that GridAlert would work in Kisumu. The technicians adapted the US-based 110V system to operate under the Kenyan 240V electricity supply. They procured step-down transformers (devices for converting high voltage to low voltage) for each unit. Step-down transformers ensured that GridAlert operated based on its input voltage, thereby preventing the system from overheating. Together, we iterated upon our design, testing different transformers until we got a portable transformer.

Local fundis also helped us design GridAlert's housing. We worked with the technicians to make different sketches before coming up with the final model. We used plywood, because it is widely available in the area. Once the carpenters finished working on the boxes, they painted them brown. Carpenters chose the color brown because they observed that most wooden items (e.g., furniture) in Kenyan homes are brown, and therefore the system match would match with other household property. Finally, the electricians recommended making holes in the GridAlert housing, so that system electronics would not overheat as a result of poor ventilation. We paid each technician 5500 KES (about $53).

STUDY DESIGN

Our study had two phases (prototype deployment and follow-up study). We used in-depth interviews, observations, diary study, and data logging methods. These methods allowed us to understand power use in participants' homes and how they interacted with GridAlert during the month-long period. We told participants their participation was voluntary, and that all information would be anonymized, and asked for verbal consent (all agreed).

Ethical Considerations and Researcher Reflexivity

The research team was led by a Malawian graduate student, who has a background in computer science and physics. He is pursuing a graduate degree at Michigan State University. He has 20 years of experience living in his country; these experiences influenced the project, in particular the focus on power blackouts. Our study received approval from our university's IRB, and from Kenya's National Commission for Science, Technology and Innovation (NACOSTI) (the organization that grants research permits to foreigners conducting research in Kenya).

Study Context

The study took place between May and July 2019 in Kisumu, Kenya, a port city on Lake Victoria. Most people living in Kisumu rent their homes (about 80% [19]), and just 18% percent of these homes are connected to grid electricity [18]. Similar to other areas in Kenya, blackouts are typical in Kisumu [34]. Other sources of electricity that are used as alternatives to grid electricity are solar and kerosene; however, these sources of power are of low capacity, and are only used for lighting, charging phones, and listening to the radio). Residents typically have multiple livelihood strategies, such as fishing, owning small-scale businesses (e.g., selling soft drinks, printing and photocopying business), working for government agencies, and working for the private sector [17].

Participants

Working with a local research assistant, we recruited 18 households using purposive sampling [4]. Specifically, we recruited participants who owned smartphones (GridAlert worked on Android phone) and had grid electricity in their households. We primarily interviewed heads of households (ten men and eight women, ages 21-59). We grouped our sample into six clusters to prevent detection of false blackouts (see System's Overview Section). In this paper, a cluster is a set of three participants whose households' grid electricity comes from the same transformer. Table 1 summarizes demographic information of our participants.

Phase I: Prototype Deployment

During the study's first phase, we reviewed our project with participants, and then asked for and received informed consent. We then conducted interviews to learn about their power usage, their experiences with power blackouts, and the ways they monitor power in their households. Questions asked during the interviews included: What appliances do you have? How do you monitor electricity use in your house? How often do you experience blackouts? At the end of the interviews, we toured participants' homes [5], and observed what they had.

We then introduced GridAlert to participants, and demonstrated how it works. We installed the app on participants' mobile phones. Next, we gave participants instructions to follow when using GridAlert. These instructions included how to switch the system on and off. We also included our contact information, and encouraged participants to contact us if they experienced problems with the system. We asked participants to use a diary to write about their experiences with the system. This allowed us to continue collecting data about participants' experiences with the system throughout the deployment period. These diaries had prompts (e.g., has anyone commented about the system today?) that participants were to respond to every week. To encourage participants to use the dairies, we sent 100 KES (about $1) of airtime each week, since prior work suggests participants can otherwise lose interest (over time) in writing [38]. We also used SMS to send them weekly questions (e.g., describe your experience using GridAlert this week. Please write your response in the diary). At the end of this phase, we gave participants 200 KES ($2) as compensation for their time.

Participant #	Age	Gender	Household Size	Smartphones # in home	Occupation
1	53	Female	4	2	Farming
2	44	Female	3	1	Farming
3	42	Male	3	2	Small-scale Business
4	31	Male	3	1	Fishing
5	36	Female	5	1	Small-scale Business
6	28	Female	1	1	Works for solar company
7	37	Female	3	1	Farming
8	25	Male	2	1	Business
9	44	Male	6	2	Works for solar company
10	35	Male	2	2	Farming
11	39	Male	5	2	Small-scale Business
12	32	Male	3	2	Small-scale Business
13	21	Female	1	1	College Student
14	59	Female	7	1	Farming
15	26	Male	2	1	Small-scale Business
16	28	Female	3	1	Small-scale Business
17	32	Male	2	2	Own Innovation Hub
18	42	Male	7	2	Small-scale Business

Table 1: Participants' demographic information

Phase II: Follow-Up Study

After a month, we returned to participants' homes and asked them to participate in another interview. Questions included: Tell me three things you appreciated about the system? Tell me three things you did not appreciate about the system? Walk me through an example of how you used the system? Are there any moments you expected the system to work but it did not work? At the end of the interviews, we observed where participants had placed the system and if it was connected to anything. We then collected the system and the diary. Finally, we gave participants a transformer adapter (valued at 1500 KES) and 200 KES as a compensation for their time, in addition to the 200 KES they received for participating in phase I and 400 KES they received as prompts for the diary entries. In total participants received 2300 KES (about $22) for their participation in the study.

Data Logging

During our study, we used data logging to collect GridAlert's usage information (e.g., system runtime and blackout count). We used MySQL to log time stamps of when the system detected power blackouts in participants' household. We also logged participants' activities on the GridAlert App. Some of these activities included switching on/off electrical appliances, scheduling electrical appliance runtime, and checking reports on electricity usage in their household.

Data Analysis

Data analysis began in the field. Every day, we wrote fieldnotes to document our experiences with participants. Interviews were audio recorded and transcribed. We used open coding to analyze our data, and then generated categories. We then used affinity diagramming to refine these categories. These categories were used to generate themes that informed our findings. Data credibility was enhanced by triangulation, which involved the analysis of our field notes, interview transcripts, digital photographs, diary entries, and logged data. We used this approach for both phases of the study. Logged data in MySQL database tables was converted into CSV files. We then used R's ggplot2 to plot graphs.

FINDINGS

We first present findings from the first phase of the study (before deploying GridAlert). These are frequency of power blackouts in people's homes, and how they monitor them. We then present findings about the month-long deployment of GridAlert. We describe how it seemed to help participants to manage time, and how they used GridAlert to monitor their electrical appliances. We also present participants' thoughts about the system's material qualities (e.g., form factor). Throughout this section, we provide an analysis of how participants monitored power in their homes and how GridAlert's design influenced their actions.

Before GridAlert: Electricity Blackout Frequency and Monitoring

Participants told us they experienced two to three blackouts each week. These typically lasted about an hour, although some participants said they could last an entire week. All participants told us that short blackouts were primarily caused by rain, and/or by "load-shedding"—that is, Kenya Power's efforts to relieve stress on their power generators when the demands for electricity is the greatest. Seven participants said that they experienced blackouts that lasted more than three days. These were typically caused by transformer problems, which took a long time to repair.

Here in Kisumu, there is always a problem with electricity, mostly on Sundays. I think Kenya Power switches it off deliberately to improve the service. And then when it rains, blackouts are more frequent.

Participants experienced problems that were related to blackouts. Though blackouts have negative effects everywhere in the world, people face these challenges in different ways based on context, and how they use electricity. Blackouts in Kenya result in frustration, and in lack of trust between Kenya Power and its clients. Our participants' specific problems were damaged electronic appliances, loss of time, and business closures. Participants said that they have lost different electrical appliances due to the high voltage that comes with power restoration. In this representative quote, Jane[1] explains:

There is a day I forgot to switch off my TV when there was a blackout. Electricity came back with a lot of force and damaged my TV. (...) I bought a power guard to prevent damage in case I will forget again.

Participants who used candles—during electricity blackout—said it cost them more money to buy candles frequently, and that they can be dangerous. Additionally, participants who had businesses that required electricity (e.g., barbershop) said they close when there is a blackout. Ephraim—who has a video show (cinema)—said that when it's taking long for power to be restored, he returns home to wait. He has no way of knowing when power has been restored other than calling someone near the market area and asking; as a result, he does not know when he can reopen his business, and consequently loses money.

Electricity Blackouts Detection Before GridAlert

Participants had various strategies for learning about power blackouts and restorations. Thirteen participants said they use electrical appliances (e.g., television, light-bulb and fridge) that are currently running to learn about the power cuts. Mary told us that when she is watching TV, she just realizes that the power has gone off unexpectedly. She added that when this happens, she turns off all electrical appliances in the house to prevent damage.

I know there is a blackout if I was watching TV and then there's no power or sometimes when the fridge is on and then all of a sudden that sound is not produced, then I know there's no power.

Participants told us that it's difficult to know when power is restored; many relied on auditory cues from machines (e.g., sound from fridge) to learn when their electricity is restored. Just six participants owned a power surge protector (an electrical device used to protect electrical appliances from voltage spikes), and they told us that they leave one appliance (e.g., radio) running to notify them when power is restored. Participants who live near a "posho mill" (a machine used for processing maize), said they wait for it to make a sound, in order to know that electricity has been restored. Others told us that they switch their lightbulbs on and off to check if power is restored—a process many described as "tiresome" because they need to repeatedly abandon other activities so that they can to check power status. Additionally, participants said this process works when they are home; however, there is no way to know the power status in their households when they are away.

Mostly I do not know that electricity blackout is over since I switch off all appliances. I keep on switching on the light to see if there is power. It's a tiresome process.

These findings draw attention to the challenges households face when they are unable to predict blackouts. Findings from our first phase suggests that the methods participants use to detect power blackouts are inconvenient. We also found that participants want to receive alerts about the status of power in their households. They also want to protect their appliances from the damage that is a typical consequence of a blackout.

GridAlert's Deployment Findings

Participants said that during the deployment, several blackouts occurred. GridAlert's logged data suggests there were 46 blackouts from all clusters during the deployment period. This number is slightly lower than what participants reported. Eleven participants said that—on average—there were about three blackouts each week in their households, two participants told us there were less than five blackouts the whole period, and three participants said they could not exactly remember. Participants might not have given the exact number of blackouts encountered during deployment period. These blackouts ranged from 30 minutes to four hours, with 2.5 hours being an average length.

Protecting Electrical Appliances in the Home

Participants also used GridAlert as a blackout awareness tool. They consistently told us that GridAlert's detection feature was useful because it protected their electrical appliances from damage. Eight participants said that whenever they see a notification of a blackout, they immediately switch off all electrical appliances. We observed that participants mostly placed the GridAlert power strip near their music system stand (Figure 4c). These participants said that they do not switch off appliances that are connected to the GridAlert power strip, because the system would control the appliances when electricity is restored. In a typical quote, Jim explains:

I used GridAlert to protect my gadgets. Once I see a notification that there is no electricity, I switch off appliances that are not connected to GridAlert. I wish all appliances in my home were connected to GridAlert so that I shouldn't bother to switch them off: GridAlert has protect things when electricity comes with more force.

Although six participants had a power surge protector, their diary entries suggested that they understood GridAlert as a different device. They wrote that that GridAlert's app gave them more control for their appliances. Unlike surge protectors (which only protected their appliances), they were also able to interact with their appliances even when they are outside or away from home. The following is a representative

[1] All participants' names have been replaced with pseudonyms to preserve their anonymity.

diary entry showing participants' comparison of GridAlert and a power surge protector:

The gadget controls damage of my appliances just like a 'fridge guard' (a common term used for power surge protector). But GridAlert has an app which I use to monitor my appliances are running. I am also able to schedule them. It also doesn't matter where I am, I can receive a notification on the app at any time electricity goes on/off.

Participants told us that it would also be useful if all their appliances were automatically protected, instead of needing to manually switch them off. Many seemed frustrated when they received notifications—while they are away from home—that there was a blackout in their household, because they were unable to return home and switch off their appliances. Participants wanted GridAlert's power strip to be connected to all of their household electrical appliances.

Time Management

Our analysis of participants' diary entries suggest that they appreciated that GridAlert notified them when power was restored. Ten participants wrote that this awareness helped them to get back to work, and to other activities that required power. Elestina, a student said that when she sees a notification that electricity is restored, she returns home from wherever she was (mostly at her neighbor's place) to continue writing assignments on her computer. Felix—a barber—said he goes back to open his shop.

When there is a blackout I go home to rest. I wait for GridAlert to send me a notification that electricity is restored. Then I go back to open my barber shop.

These findings suggest participants used GridAlert to manage time during episodes of electricity blackout. Prior works suggest electricity blackouts negatively affect economic activities [14]. Our findings suggest participants found GridAlert useful because it helped them to save time, get back to business and make money.

Monitoring Electrical Appliance's Consumption

Participants appreciated GridAlert's feature that displayed (Figure 3a and 3b) how much time (in hours) their appliances used. These appliances included sub-woofers, televisions, phones, fans, and iron boxes. Nine participants said that after a day, GridAlert's household report graph showed the number of hours they spent using electricity each day. Our analysis suggests that participants were surprised to see that the runtime for their electrical appliances could be hours longer than they had thought. This gave them an understanding that sometimes they leave their appliances running even when they are not being used. For example, Joseph said that his security light is only useful at night, and that mostly he forgets to switch it off in the morning. Through GridAlert's weekly reports, he realized that forgetting to switch off security light resulted in more hours of electricity use. He explains:

Since I started using the system, I check the report to see how long my gadgets are running. At first, the report was showing that my gadgets are running for many hours. I have realized that this might be because of my security light. I mostly forget to switch it off in the morning when I am going to work. So, when I switch it on in the evening, I use GridAlert to schedule that it should go off at 6am.

Having the GridAlert app on Joseph's phone prompted him to switch off his security light every morning. Whenever he was switching on his security light using GridAlert, he also scheduled it to go off at 6am. Similar to Joseph, other participants mentioned that after two to three weeks, they noticed that their electricity units were lasting longer than before: they were not buying electricity units as frequently, and their digital meters (a device for buying electricity credit and checking balance but no metrics about electrical appliance energy consumption) also showed that they had not used as much credit. However, participants recommended that GridAlert should also report the amount of money consumed by each appliance (i.e., electricity costs). Frank, (who sold firewood in town) said that he mostly pays 250 KES ($2.50) for electricity units every two weeks. He was surprised when, after two weeks with GridAlert, his landlord informed him that he only had to pay 160 KES (about $1.60). Frank explains one memorable thing he will always remember about using GridAlert:

The fact that GridAlert has been able to reduce my bills from 250 KES to 160 KES will be the most memorable thing (…). I have always been paying more than 200 KES every two weeks; however, now things are different. Even my neighbors were asking me why my bill was less this time. I told them about GridAlert and they asked it to have it.

Data from our logs suggest that the amount of time participants used electrical appliances each day decreased over the deployment period. For example, Florence's weekly reports (Figure 3a and 3b) supported this observation. Our data showed that the average amount of time she used her electrical appliances during the first, second, third, and fourth week decreased with time. This suggests that using GridAlert prompted some participants to switch off their appliances when they were not in use. This reduced participants' electricity consumption.

Participants also said that the GridAlert app provided them with more control over their appliances. More specifically, GridAlert's scheduling function gave them more flexibility to switch on and off their appliances at the exact time they want. This reduced the amount of time they kept on physically switching on/off their appliances. Participants said this made their appliances "ishi kulinanga na kila siku" (commonly used term for 'fit in with everyday activities'). For instance, Doris, who loves listening to music, explains:

When I go to bed I bring my music system to the bedroom. I play music throughout the night. In the morning, I feel bad that I left the music system to run all night. With GridAlert,

Figure 3: a - b) Electrical appliance runtime weekly graphs on participant's phone c) GridAlert in one of participants' homes

I started timing that the music system should switch off after two hours for I know after that I will be asleep. Now, I always find my music system off every morning

It seemed that participants also used GridAlert to ensure that their domestic activities were not affected even if they had gone to work. For example, Jim said that he had to charge a new shaving machine for eight hours. However, he was supposed to go to work and he wouldn't be home to switch if off after the eight hours had elapsed. He used GridAlert's scheduling function to specify when the shaving machine should stop charging. He explains:

I bought a shaving machine. It had an instruction to be charged for eight hours before use. Unfortunately, I was going to work: I couldn't be home to switch it off when the eight hours is over. I used GridAlert to set the timer to charge the machine from 7am to 3pm. When I came back, I found that the shaving machine was fully charged and GridAlert switched off power exactly at 3pm.

These findings suggest participants' interaction with GridAlert allowed them to control their appliances without disrupting their daily activities. Participants' interaction with GridAlert also allowed them to learn more about how their appliances consume electricity, thereby minimizing costs and saving energy.

Repurposing GridAlert

Our analysis revealed ways that participants repurposed GridAlert. Five participants used it to control the amount of time their children spent watching television. They said their children spent more time watching television instead of doing homework or chores (e.g., washing dishes, fetching water), especially when their parents were away from home. Participants said GridAlert app allowed them to control their television from anywhere. This allowed them to monitor whether their children are watching television or not. For instance, Charlie said:

I am happy that I have this system to control my appliances. My children mostly spend their time on television especially when I am not around. With GridAlert, I am able to see whether they busy on the television. I can switch it off from anywhere to make sure that they are doing other things.

Participants also used GridAlert for experimentation. For example, Joel said he wanted to verify whether GridAlert could be used to monitor a television. Though he didn't own a television, the presence of GridAlert in his house prompted him to borrow a 24-inch television from his neighbor. Another participant was curious to see if GridAlert was compatible with other smartphones. She asked her neighbor (who was not participating in the study) to install the app in her phone. It seemed that these forms of experimentation helped participants to think more about how sensor-based systems can be used in their communities. Such experiments allowed participants to understand how GridAlert works thereby inspiring more ideas of how else it can be used. For example, participants suggested that it would be interesting if there were sensors for checking whether there is network at banks before they go to withdraw or deposit money.

These findings suggest that participants can play a significant role during the system design process. Similarly, a sensor-based security technology probe deployed in Kenya influenced men who had patriarchal attitudes to use it to monitor their family members [8]. We did not anticipate participants would use GridAlert in this way, however, as it disrupted participants' routine.

GridAlert's Material Qualities

Here, we discuss participants' thoughts about GridAlert's design, in particular its material qualities (i.e., the housing). Participants had mixed feelings about this. Some associated GridAlert with other things in their homes that were also made of wood. More than half said they initially thought GridAlert was a sub-woofer (a device for reproducing sound). During our home tours, we observed that participants' sound equipment (e.g., speakers and amplifiers) were made of wood. These findings suggest that it was not a new thing to introduce an electrical appliance made of wood in participants' households.

While those participants appreciated using an electrical appliance made of wood, seven thought the wooden box was not a "cool" way of casing GridAlert. These participants described the wooden box as "old" and "traditional." They recommended using plastic casings when redesigning the system, so that it would be more similar to other appliances manufactured in the US and China. It seemed that participants felt socially superior in their communities when they had gadgets that were more obviously from abroad. We observed that such gadgets were typically placed in their sitting room so that visitors could easily see them. This participant's reactions to the system's design was typical:

It's not supposed to be a wooden box, it's not presentable that way to put it on the sitting room. I like all things on my sitting room to look modern. Though I use it to monitor my gadgets, I put it behind my TV then a teddy bear in front of it so that nobody sees it. I like what the system does but I don't want people to see I am using a wooden box because they will think of me as an old-fashioned lady.

Prior research emphasizes designing technological systems by utilizing locally available resources (e.g., materials and labor) [21]. However, our participants believed that imported products are appealing, modern, and long-lasting; they did not associate GridAlert with these words. Although participants had this perspective about GridAlert's housing, they found the system's functions important:

I thought the system would be made of plastic. I think the wooden box makes it look like an old technology. However, its ability to control things through my phone is the opposite of old technology. I enjoy controlling things from my phone and that's why I still use it.

These findings suggest participants' ability to use GridAlert's despite their thoughts about its material qualities. Odom *et al*. underscored that the "presence of new technologies results in obsolescence of an object's function; however, a single-purpose functional object is more likely to continue to endure if it has some sense of engagement" [26]. GridAlert's function—monitor electrical appliances and blackouts—provided a sense of relevance in participants' households. Though participants had mixed feelings about GridAlert's housing, it offered them some level of familiarity, as it was similar with other electronic appliances they have used; furthermore, its ability to control electrical appliances projects its sustainability.

DISCUSSION

It is clear that power blackouts are part of Kenyans' everyday lives. Returning to our research questions, we offer evidence that suggest that a sensor-based technology can be used to monitor power usage and blackouts in Kenyan households. It is well established that sensors can help power companies improve electricity reliability [10,21,22]; however, there is little research on how end users can use sensors to learn about and navigate blackouts. Our study builds upon prior studies by demonstrating the potential for sensors to do this in Kenya.

Our findings suggest that GridAlert supported participants' efforts to manage their time between power blackouts and restorations, protect their appliances, and monitor power usage. Participants' interactions with GridAlert prompted detailed stories about living with intermittent power supply. These stories are useful for motivating new design concepts in HCI. GridAlert also inspired users to consider novel ways sensors could be integrated into their homes. A contribution of this study is how these stories draw attention to future opportunities in HCI for designing sensor-based technologies in Kenyan households. Our discussion focuses on how to design human-centered technologies for Kenyan households, and draws attention to broader challenges that HCI researchers must understand when designing systems.

Design Implications

Designing Systems Using Local Resources

Our collaboration with local technicians proved useful for configuring GridAlert to work in Kenyan households. Our study demonstrates the importance of collaborating with local technicians, but also questions whether participants prefer using products made within Kenya. Local technicians have a better understanding of the electricity infrastructure in their community, and they provide local support. Indeed, it is important to involve local technicians for a successful deployment of an electricity-monitoring systems.

Participants had mixed reactions to GridAlert's wooden housing. These reactions raise questions about whether systems designed for the developing world should utilize locally available resources. Various researchers in HCI/ICTD encourage the practice of empowering local technicians to design systems using local materials (e.g., reused and broken-down materials) [1,16]. Our findings suggest that participants prefer using hardware materials made abroad (e.g., US and China). They find these to be attractive and well-fitting with the modern world. A study that was conducted in Kenya to explore *M-Kopa* (a solar home system) suggest that participants described it as durable, able to withstand dust, contact with water, and being dropped [39]. Unlike GridAlert, M-Kopa is designed, developed, and assembled in the US. This supports our finding that participants seem to prefer imported products. HCI/ICTD researchers should investigate this topic further in order to understand whether we should encourage technicians to make products using local materials.

Designing for Whole Household Access and Automatic Appliance Protection

The ways household members interacted with GridAlert suggest requirements for designing power-monitoring systems in Kenya. Our previous study [8] proposed that designers should consider how their systems will be integrated into existing infrastructure so that they will be functional. For example, it is well established in literature that not everyone in Kenya has a smartphone or even owns a basic phone [41]. Power-monitoring systems should be accessible to household members through multiple channels. For example, the hardware should have an in-built interface for controlling the system (e.g., when the phone is off due to low battery). SMS platforms can also be utilized to ensure that other household members—who own a basic phone—have access to control the system.

Our findings suggest manually monitoring blackouts is a tiresome process, especially in areas where blackouts are frequent. Instead of connecting two appliances to GridAlert, we propose designing power-monitoring systems to automatically protect all appliances when there is a blackout. For example, the GridAlert sensor can be integrated with a household's main switch, to protect all appliances. This would reduce, or even eliminate, the need to switch off appliances when there is a blackout, and therefore reduce interruptions to participants' activities. In industrialized countries (e.g., US), entire household power monitoring sensors have been used [28]; however, they require households to own cable, Wi-Fi network, or computers. These resources are not available in most Kenyan households. Designers, engineers, and other experts should work with Kenyan technicians to explore ways of integrating these systems to work in Kenya.

Probing with GridAlert

Our goal was to explore the role of sensor-based technologies in monitoring power blackouts. However, participants also repurposed GridAlert for other activities (e.g., monitoring family members' television use). Power blackouts do not occur predictably, or a set number of times per week. Hence, rather than waiting for the next blackout notification, participants found the system useful for other activities. This allowed us to learn about participants' everyday lives, including the economic challenges that are a consequence of blackouts. These experiences were not only about blackouts, but also about monitoring power usage in Kenyan homes (e.g., scheduling GridAlert to switch off security lights in the morning). GridAlert worked as a technology probe—unveiling other ways sensors could be used in Kenyan homes (e.g., it was beyond our expectations that participants would use it to monitor and control the amount of time their kids spend watching TV). Wallace *et al.* described probes as tools for design and exploration centered on personal significance [36]. Our findings suggest that GridAlert captured rich inspirational stories for designers. These stories included unanticipated real-life use scenarios (e.g., controlling the amount of time kids spend watching TV), that motivate the design of sensor-based systems to meet users' practical needs.

These activities also prompted some participants to think about how sensor-based systems can be used in their community. Participants' ideas provide opportunities for HCI researchers to explore other areas of participants' interest. For example, participants suggested exploring how sensors can be used in banks, to make customers aware whether the bank has network access before they go there to request services. These are areas that have not been explored, and that require attention in HCI. We propose using multiple functions in HCI to explore more opportunities for research.

Integrating Electricity Monitoring with Existing Tools

Our findings suggest that some participants had digital meters and power surge protectors for topping up electricity credit and protecting appliances from damage. Despite participants' interest in learning how their appliances consume electricity, these tools did not provide any metrics for electricity usage in participants' homes.

Power surge protectors could be integrated with mobile phones to alert participants when there is a power blackout/restoration. We also propose integrating digital meters with mobile apps. Instead of only reminding users to buy electricity credit, these meters should show the amount of power (in Kenyan Shillings) consumed by each appliance in the home. Prior work suggests a "need for domestic devices that do not only stimulate consumption but instead offer alternatives and raise awareness" [3]. We propose that future research should consider working with Kenya Power so as to including feedback about an appliance's energy expenditure information on digital meters.

LIMITATIONS AND FUTURE WORK

Our study begins to address the question of how sensors can be used to monitor power blackouts in Kenyan households. However, this study has its limitations. We acknowledge that a four-week period is insufficient to fully learn the long-term implications of GridAlert; clearly, more research is required. Participants' feedback provided implications for redesigning GridAlert (e.g., automatically controlling all electrical appliances when there is a blackout). In future, we will return to Kenya with a new version of GridAlert, whose design will incorporate participants' feedback. We will also conduct a study that will help us understand GridAlert's long-term implications in Kenyan households.

CONCLUSION

In this paper, we explored power blackouts and consumption monitoring in Kenyan households. Our findings suggest sensor-based technologies can be used to minimize challenges Kenyan households face because of blackouts. These challenges include damage of electrical appliances, and time losses due to lack of awareness of power restorations. Findings also suggest that GridAlert provided power consumption information in participants' households. This prompted them to find ways of minimizing power consumption. This study's findings also question whether it is important for HCI researchers to encourage local technicians in Kenya to use locally-made materials when designing and building technologies. Our discussion provides design implications for designing blackout-monitoring sensor-based technologies in Kenya. These implications provide new opportunities for conducting design research in Kenyan households.

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