Potential Energy

Monitoring Cookstoves Use Through Environmental Sensors

Goldilocks Toolkit

Innovations for Poverty Action

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Right-fit monitoring and evaluation (M&E) systems embody the principles of Credible, Actionable, Responsible, and Transportable, or CART. In the Goldilocks case study series, we examine the M&E systems of several innovative organizations and explore how the CART Principles can work in practice.

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Potential Energy: Monitoring Cookstoves Use Through Environmental Sensors

Around the world, 3 billion people cook with biomass, causing over four million annual premature deaths, and generating 30% of global black carbon emissions. In addition to the acute health and environmental effects of biomass cooking, there are economic effects, as women across the developing world spend considerable time and money acquiring fuel. For a family in Sub-Saharan Africa, it can cost between 10-30% of total household income to purchase fuel for cooking fires.

Potential Energy (PE) is a not-for-profit organization with a mission of making cooking safe, and affordable, for women and their families. PE's core product is the Berkeley-Darfur Stove (BDS), a high-efficiency wood-burning cookstove As compared to preparing meals over an open fire, the BDS was designed to save users 50% on fuel while reducing cooking time and exposure to smoke.[1]

To date, PE's primary focus has been the distribution of the BDS in Darfur, Sudan, where over 44,000 stoves have been distributed through humanitarian and non-humanitarian channels.

While PE's work is grounded in the belief that cookstoves can minimize environmental, health, and economic costs, the technology can only achieve impact if used consistently by cookstove owners. As part of its M&E strategy, PE wanted to understand how well (or poorly) they were achieving adoption and regular use of their improved cookstoves.

PE worked with researchers at CEGA to deploy temperature sensors, called "Stove Use Monitors," attached to stoves distributed in Sudan. The sensor data, alongside personal interview surveys recorded both by hand, and also via a smartphone software App, were then analyzed to understand stove usage, and identify interventions or "nudges" that might improve regular use. The aim was to go beyond self-reported use through surveys, which can suffer from recall errors, courtesy bias, and other forms of errors or over-reporting.

Technology Solution and Application

The ability to monitor cookstove use with objective and unobtrusive means is critical for improving the product and its delivery, and for measuring impact on households. Some studies have already implemented time-and-temperature logging Stove Use Monitors (SUMs), which can independently measure cooking events. Here, CEGA researchers sought to improve upon previous work by measuring (1) adoption of cookstoves in the context of camps for internally displaced persons (IDPs), and (2) the correlation between user-reported and sensor-measured cookstove adoption both in terms of number of cooking events and hours spent cooking per day.

The Berkeley Darfur Stove (BDS) is the subject of this study. The BDS was developed by scientists and students at the University of California, Berkeley and Lawrence Berkeley National Laboratory. PE managed the technology's implementation in Darfur, Sudan. Between 2009 and 2015, more than 44,000 BDSs were distributed in North Darfur to rural, peri-urban and internally displaced households. About 85% of these cookstoves, including those employed in this study, were disseminated free of charge in the IDP camps.

The Darfur SUMs experiment involved 180 women within the Al-Salam IDP camp just outside of Al-Fashir, North Darfur. The Omda (leader) of each of five administrative units was asked to select 36 women to participate in the

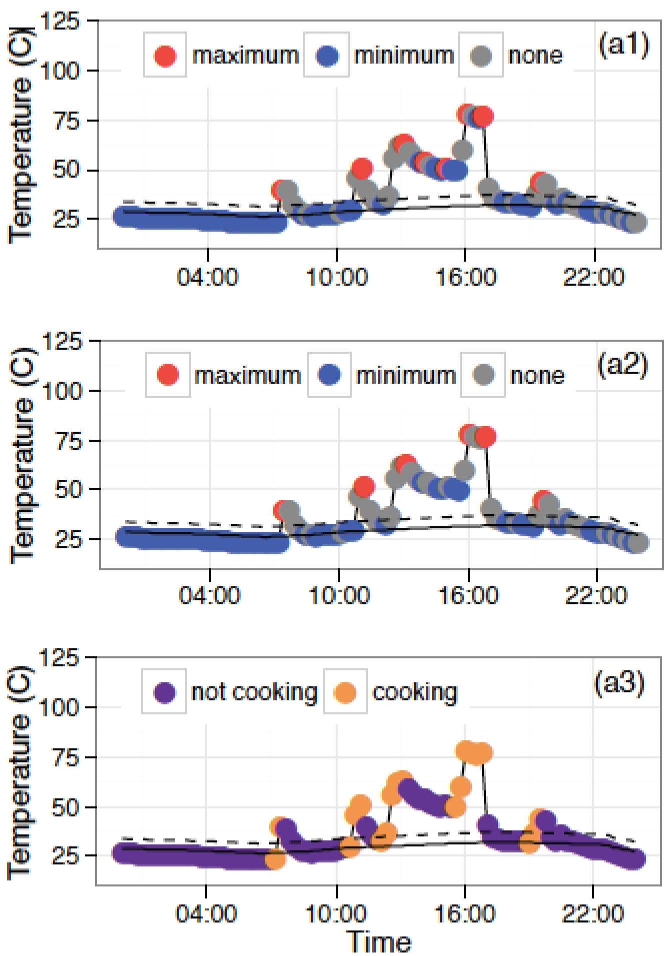
FIGURE 1. WOMEN PARTICIPANTS IN THE DARFUR SUMS STUDY

Women participate in enumeration activities while BDSs wait to be taken home. Human subjects' faces have been hidden; enumerators' faces are shown.

study and be available for surveys. A baseline survey was performed to determine household demographics and cooking practices at the time of BDS dissemination. Subsequently, each administrative unit was followed up with every two weeks. Baseline and follow up surveys were administered by teams of two enumerators who recorded responses on paper and on a cell phone platform running Open Data Kit (ODK). An ODK Aggregate instance was deployed at Berkeley to communicate and collect data from our devices in the field.

Of the 180 participants, 170 women had instrumented cookstoves. SUMs data were labeled as cooking or not cooking using a specific algorithm. This algorithm identified rapid increases in cookstove temperature (due to fire, or active use) as well as intermittent cooling times before a refuel. The algorithm is conservative in estimating cooking duration and may overestimate the number of individual cooking events, but its application enabled rapid labeling of events using a training data set labeled by human observers.

FIGURE 2. EVENT DETECTION ALGORITHM



Boxes (a1)-(a3) illustrate the event detection algorithm over a one-day period for a particular SUM. Ambient temperature is shown in a black line, 5°C above ambient is shown as a dashed black line. Fully processed data are shown in figure (a3). Here non-cooking events are shown as in purple dots, and cooking events in orange dots.

Results and Goldilocks Recommendations

Of the 122 unique cooks who had instrumented stoves and returned functioning SUMs, 117 were administered follow up surveys. By far, the greatest contributor to loss of SUMs was unrecoverable data due to thermal damage. The research team determined that several cooks had inverted the BDS and filled the bottom with charcoal in order to use the BDS as an improved charcoal stove.

The study team defined two distinct groups of cookstove owners: “users” and “non-users.” These were determined by the proportion of days that the stove was in active use. “Users” engaged in cooking for at least 10% of all possible stove-use days during the observed period. Using this classification, 73% are categorized as “users” and 27% as “non-users.”

Participants in this study were found to substantially overestimate their BDS usage in self-reported surveys, both in terms of events per day and total cooking time per day. Relative to algorithmic estimates, 85% of participants overestimated cooking hours and 82% overestimated cooking events. The average participant over-reported daily cooking hours by 1.2 hours and over-reported daily cooking events by 1.3 events (both with 95% CI). Non-users over-reported daily use even more substantially: 1.7 excess hours and 2.2 excess events, both with 95% CI.[2]

Another relevant finding of this study was the strong influence of survey enumeration activities on the “non-user” group. Nonusers were found to exhibit a strong up-tick in adoption starting two days before their scheduled follow-up survey (what the researchers refer to as “courtesy use”). While this spike in usage in anticipation of direct observation is consistent with other studies in the developing world, what was not expected was the nonusers’ sustained adoption in the two weeks after the follow-up survey. 83% of previous nonusers transitioned to “post-follow-up users” and, population wide, 86% of participants became classifiable as users in the post-follow-up period compared with 71% in the pre-follow-up period.[3]

This study’s application of SUMs to monitor the implementation of cookstoves adheres to a number of the CART principles.

Credible: Collect high quality data and accurately analyze the data.

The data collected by SUMs were found to accurately measure cookstoves' use. The measurements are reliable, as SUMs are likely to produce the same results under implemented in similar conditions. Also, compared with self-reported surveys, the data collected are less biased and therefore can be used to estimate actual technology adoption, refine distribution schemes, and test the effectiveness of cookstove training programs.

Actionable: Commit to act on the data you collect.

SUMs that are implemented on cookstoves collect actionable data daily. While the SUMs in this study did not use mobile communications to transmit data to the cloud, there are technologies enabling more real-time data capture. The sensor data can be quickly analyzed, especially with the use of automated classification of cooking events, making the results readily available to actors invested in quantifying household PM exposure or cookstove use.

Responsible: Ensure the benefits of data collection outweigh the costs.

Investing in monitoring cookstoves for actual household use is crucial if we want to address the severe environmental and health issues raised by biomass cooking in developing countries. And monitoring cookstoves performance using SUMs is both more reliable and less costly than the in-person surveys that have traditionally been used.

Transportable: Collect data that will generate knowledge for other programs.

As the growing number of SUMs deployments suggests, monitoring cookstoves with sensors is a very transportable technique. The methodology and the algorithm used by the researchers are highly transportable and should be tested in new contexts where cleaner cookstoves are introduced.

Going Forward

Qualitatively, cookstove adoption in the Al-Salam IDP camp was high considering that women receiving the stove were selected at random and were not screened based on demand for the product. However, the juxtaposition of paper and cell-phone based surveys with SUMs data has highlighted the discrepancies between self-reported and sensor-measured usage patterns. Data from SUMs are more detailed and accurate than self-report use data.

There are areas for improvement. While the SUMs event detection algorithm seems to perform well in terms of face validity, the researchers suggest it should be trained against expert-labeled data for the local cooking context to further refine its performance.

Building on the experience in Darfur, Potential Energy teamed up again with UC Berkeley CEGA affiliated researchers to expand SUMs to cookstoves introduced in Ethiopia. Specifically, a 3-part M&E program to evaluate the potential for economic and social impact in Ethiopia focused on (1) a great program design, (2) affordable data collection, and (3) rapid and affordable data processing.

To assure a great program design, the researchers targeted 1,000 potential users in Debre Zeit, Ethiopia, and designed demographic/customer information surveys. They offered demos to groups, free trials to some group members and then used a purchasing game to understand willingness to pay.

Finally, they observed user behavior via SUMs and follow up surveys with data collected via ODK and IVR phone surveys. The design was meant to help answering questions such as (1) What characteristics in potential customers are correlated with purchasing and consistently using the Berkeley Ethiopia Stove (BES)? (2) What customer characteristics are correlated with high willingness to pay (WTP)? (3) How does WTP change when someone gets a free trial? And (4) What perceptions do people have of the stove and how do those perceptions change as they learn more?

To make data collection as cost-effective as possible, the research team decided to use ODK software (version 2.0) on mobile phones and planned to use interactive voice response (IVR) surveys as an additional means of data collection (in collaboration with VOTO Mobile). As there is currently not a cheaper option on the market, SUMs were deployed again to monitor stove usage. At the same time, with resources from CEGA and the Goldilocks project, ongoing support was given to a team of engineers at UC Berkeley working on cheaper Advanced Stove Use Monitors (ASUMs).

ODK 2.0 has systems in place that enable the easy export of data that can then be analyzed in a statistical program such as R. However, SUMs generate massive data sets that take a long time to process. To make data processing more rapid, UC Berkeley engineers devised a tool (the "SUMSarizer") that allows someone with no coding experience to upload data and hand-label cooking events in a small subset of the data. It then auto-labels cooking events on the rest of the data set and outputs tables and graphs that summarize the data and allow the user to do much simpler analysis in tools like Excel.

With a more thoughtful program design and cheaper and more practical tools to collect and process data, the Ethiopian study builds upon the previous deployment of SUMs in Northern Darfur. While the results are expected to be published this year, the deployment of sensors in Ethiopia will make actual contributions to future cookstove distribution and marketing in developing countries.

Endnotes

1. See www.potentialenergy.org for an image of the BDS.

2. Wilson, Daniel Lawrence, Mohammed Idris Adam, Omnia Abbas, Jeremy Coyle, Angeli Kirk, Javier Rosa, and Ashok J. Gadgil. "Comparing Cookstove Usage Measured with Sensors Versus Cell Phone-Based Surveys in Darfur, Sudan." *Technologies for Development* (2015): 211-221.

3. Wilson, Daniel Lawrence, Jeremy Coyle, Angeli Kirk, Javier Rosa, Omia Abbas, Mohammed Idris Adam, and Ashok J. Gadgil. "Measuring and Increasing Adoption Rates of Cookstoves in a Humanitarian Crisis." *Environmental Science and Technology* (2016): 8393-8999.