Survey-based behavior and impact assessment:
A case study of Ecocina cookstove adoption in rural Honduras

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Executive Summary

The practice of burning firewood for cooking in rural developing communities is typically inefficient and produces harmful products of incomplete combustion. Use of traditional methods contributes to global anthropogenic climate change, has been attributed to at least 4 million premature deaths every year, and can create significant opportunity costs, especially for women and children. To address such challenges, many international organizations have worked to provide improved cookstoves for these communities. However to be most successful, these projects must be able to evaluate the impacts of these technologies as well as to understand what motivates consumers to change their traditional practice. To address this need, this project applied surveys incorporating research methods from the social sciences to focus on the role of users in successful implementation of improved cookstoves.

Through a partnership with StoveTeam International and the support of Dining for Women International , this project disseminated approximately four hundred Ecocina improved cookstoves in the Copan Ruinas region of Honduras. In conjunction with the technology dissemination, a set of before-and-after surveys was administered in the households during the winter of 2016-2017 to evaluate decision-making behavior of the users regarding the choice of cooking device. The Theory of Planned Behavior (TPB) integrated with social network analysis was used to quantify the influential attributes that form individual's decision whether to adopt a new technology or not. Such attributes consist of personal beliefs, social norms, the role of important community members, and the perception of one's ability to execute a behavior. Baseline data collection captured the status quo conditions of the study variables prior to the introduction of the Ecocina cookstoves. After two months, a follow-up survey was used to evaluate the households' experiences and impacts of using the improved cookstove.

The distribution of the 400 Ecocina cookstoves impacted at least 1,765 beneficiaries, 40% of whom are children under the age of 17. Results indicate that approximately 90% of the households kept the Ecocina in their kitchens and in working condition, and 85% of them stated that the Ecocina has become their primary stove. The main perceived benefits of using the

Ecocina was less fuelwood consumption and less time to cook food relative to the traditional practices, while the size of the stove, choice of material, and addition of a chimney were identified as potential improvements. Compared to traditional Plancha as the primary stove used by 97% of the households before distribution of the Ecocina, 80% of the households mentioned that level of the effort to cook with the Ecocina was significantly less than traditional Plancha, required less time to cook, and consumed less firewood. Every participating household except one mentioned that using Ecocina is equally (13%) or more safe (87%) than traditional practices. Households reported saving an average of 11.3% of time resulting from less or shorter firewood collection trips and a weighted average of 37% less fuel based on surveyors' estimates. Self-reported health and safety measures showed approximately 85-93% less occurrence of negative health impacts such as burns, eye irritations, coughing and sneezing, and shortness of breath. It should be noted that while the use of qualitative surveys can lead to insights on the user experiences and perceptions of new technologies, self-reporting can be error-prone and subject to bias. Therefore these findings should be further verified with additional quantitative measurements over a longer time frame.

Applying the Theory of Planned Behavior to analyze behavioral impacts of adopting cookstoves also revealed that adopting the Ecocina significantly improved the user's attitude toward the behavior of cooking with an improved stove, moving from -2.87 in the baseline to 4.76 in the follow-up. This indicates that in general respondents' attitude was initially not in favor of cooking with improved cookstoves but after two months of using the stove their individual experiences were satisfactory enough to persuade them to change their behavior in favor of using the Ecocina. In addition, TPB analysis revealed that households felt a social obligation to use the Ecocina because a significant subset of other community members were using the stove as well. The intention to cook more meals with the Ecocina was solidified through positive attitude toward cooking, generation of a social norm to do so and the ability to easily cook with the stove. Social networks in the communities were also analyzed to help project leaders to improve implementation strategies and achieve higher adoption rates. However, the results were inconclusive and a more robust surveying technique exclusive to social mapping is recommended for future studies.

Introduction

Traditional open fire cooking has a multitude of negative consequences on livelihoods for households in rural developing communities such as public health issues, increasing scarcity of fuel, and contributions to climate change. For 2.7 billion of the world's population, firewood is the primary source of energy and can meet more than 90% of a households' energy needs for cooking and heating (Gwénaëlle et al., 2009; Johnson and Bryden, 2012). According to the 2010 Global Burden of Disease, household air pollution (HAP) from this practice contributes to 3.5-4 million premature deaths every year (Lim et al., 2013; Smith et al., 2014). Solid fuel combustion can contribute to deforestation and forest degradation as well, with 27-34% of the annual global firewood harvest being reported as unsustainable (Rudel, 2013;. Bailis et al.,2015). Global contributions to climate change due to such practices are also significant, as recent estimates show 34 – 45% of the warming due to black carbon is generated by traditional biomass combustion (Bailis et al., 2015; Bailis, Ezzati, and Kammen, 2005; Bond et al., 2013; Ramanathan and Carmichael, 2008).

To address such challenges, improved cookstoves such as the Ecocina (Figure 1) developed by StoveTeam International have been disseminated for nearly three decades. These small energy technologies seek to increase both heat transfer and combustion efficiency of biomass combustion, reducing the emission of toxic chemicals and consuming less firewood to complete the same cooking tasks. In addition, improved cookstoves can provide households with higher safety and less time required for collecting firewood and tending the fire.

Figure 1 – A woman pictured with her traditional (left) and Ecocina (right) cookstoves

The goal of this study was to evaluate the adoption and impacts of these types of cookstoves in rural communities, and to better understand the motivation for consumers to adopt them. In collaboration with StoveTeam International and funded by the non-profit Dining for Women, four hundred locally manufactured Ecocina cookstoves were distributed in eight rural villages in Copan Ruinas, Honduras. In conjunction with the provision of the cookstoves, a series of two surveys were used before and after to evaluate the drivers of stove adoption and its impact on the livelihood of the participating households. The behavior and baseline values of study variables were measured in each household shortly before provision of the cookstoves, followed two months later by the follow-up survey that included several questions similar to the baseline, as well as questions related to the respondents' experience with Ecocina. The changes in the variables from baseline to follow-up are used to assess the impact of the technology on the households.

Background

Despite the potential positive impacts of using improved biomass cookstoves, successful user adoption of improved cookstoves can be a challenge because the technology must be in harmony with the users' perspectives and needs. Multiple studies have discussed the importance of user behavior on improved cookstoves' adoption (Barnes et al., 2017; Lewis and Pattanayak, 2012; Shankar et al., 2014; Whittington et al., 2012). Households in low resource settings by nature are faced with a number of competing challenges and it is therefore necessary to formulate the cookstove design and dissemination strategy based on households' priorities.

Recognition of the various household priorities and reflecting them into design and implementation of improved stoves was addressed in an study in rural Bangladesh (Mobarak et al., 2012). Results indicated that households do not consider indoor air pollution as an important issue, and the authors suggested that design of cookstoves with features that users value, such as less fuelwood consumption or any cost saving attribute, could help to alleviate low adoption rates. Another study in rural regions of Northern India obtained preferences of more than 2,000 households and concluded that widespread adoption of improved cookstoves was not likely in the area due to supply-side challenges in providing applicable alternatives to traditional stoves, and that users perceived their benefits by both the technology and promotion messages (Jeuland et al., 2015). The authors suggested that user preferences must be applied to develop more effective policies.

User's preferences and values are reflected through behavior. Therefore, a better understanding of user behavior could inform the designers and project implementers about best approaches for technology design and dissemination. The impact of user behavior on successful technology adoption is recognized in a four-year study in a rural region in India by Hanna, Duflo, and Greenstone (2016). Their long-term results indicated that even though the performance of the introduced technology was effective in laboratory tests, low stove valuation by users precluded

improvements in health or firewood consumption. Their study concludes that if users decide not to use the stove regularly and properly, avoid regular maintenance, or do not update their beliefs about how to use it, the health and fuel saving impacts may not be achieved. Therefore, the present study is focused on systematic assessment of users' behavior, changes in their attitudes related to use of improved cookstoves, and stove usage patterns in order to evaluate the adoption's impact.

Understanding user behavior requires systematic incorporation of users in an intervention project. The Theory of Planned Behavior (TPB) is one method to facilitate comprehensive integration of user behavior in technology design and adoption. TPB is laid upon the assumption that human behavior is a direct function of individual's intention. According to this theory, the intention is composed of three categories of attributes that form the decision: attitude toward behavior, social and subjective norms regarding a specific behavior, and perception of the control an individual has regarding the behavior (Ajzen, 1985; Ajzen, 1991). TPB is an action determination model that throughout the literature has been successful in explaining environmental actions (e.g. Bamberg and Schmidt, 1998; Boldero, 1995; Nordlund and Garvill, 2002). A review of the literature suggests that TPB is among the most frequently applied methodologies in the field of psychological decision-making studies (Albarracín, Johnson, Fishbein, & Muellerleile, 2001; Armitage & Conner, 2001; Conner & Armitage, 1998). Klöckner (2015) reviews the popularity of the TPB in environmental psychological behavior and concludes that the theory's structural simplicity and universal applicability across behavioral domains is its advantage compared to other methods. Godin and Kok (1996) review whether TPB was successful to explain health-related behaviors after 10 years of its implementation in the domain of health, concluding that the model satisfactorily predicted behavior.

The main hypothesis of the present study is that household's stove choice is based on health related motivation or environmental concerns. The literature suggests that TPB is robust to predict user behavior in both scenarios. Applying TPB, this study assumes that the main cook's intention to use the Ecocina explains her behavior. The diagram of Figure 2 illustrates the theory's building blocks that form intention. Aside from behavior, the other two categories of attributes in TPB (subjective norms and perceived behavioral control) are quantified through the standard TPB method presented in the literature (Francis et al, 1988; Ajzen, 2013).
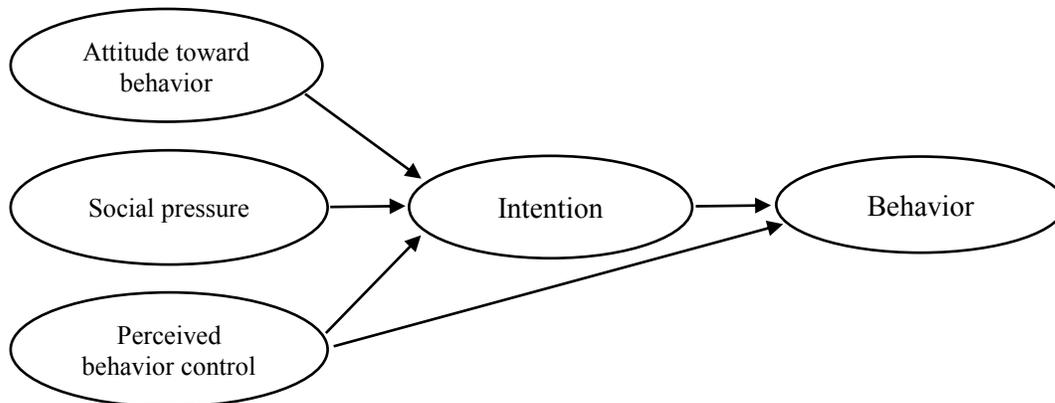
Figure 2- Structure of the theory of planned behavior (adopted from Ajzen, 1991)

Conventional wisdom states that society plays a role in an individual's decision-making behavior, and the influence of a society on the individual is reflected through the person's ties to the community (Robins, 2015). These community scale relationships and social interactions influence the personal evaluations regarding a newly introduced technology. Therefore, understanding the influential actors of a community could lead to higher adoption through more effective implementation plans. Kempe, Kleinberg, and Tardos (2005) developed an algorithm to maximize the spread of influence in a social network by identifying a subset of individuals to focus on convincing others to adopt a technology in order to create a cascade of further adoption through their influence in a community. Some of the early social network analyses studied diffusion of medical and agricultural technologies in the developing and developed world (Coleman, Katz, and Menzel, 1966; Rogers, 2002; Valente, 1995).

Social network analysis has been applied to improved cookstove diffusion to some extent. A study in Northern Peru suggested that individual decisions regarding adoption are correlated with village scale usage patterns, meaning that households' stove adoption decisions in a village with strong social ties are highly dependent on the village scale stove experiences (Adrianzén, 2014). The study found that negative comments and the spread of information regarding malfunctioning stoves was more influential on households' decisions than positive reports. Their findings correlate with a more general finding stated by Chen et al. (2011) that explains negative feedback is relatively more influential within a network than positive feedback. In addition, the use of social networks to raise public awareness and consensus regarding importance of improved cookstoves has been successfully applied by Proyecto Mirador in Honduras. There Ramirez et al. (2014) analyzed how information moves through society without any formal marketing by developing a map of social actors in the context to identify the actors who play an important role technology diffusion. Such network maps enabled project managers to allocate resources to different actors in the way that maximizes the spread of information.

Methodology

This study developed and implemented before-and-after surveys that incorporate methodology from TPB and social network evaluation to provide a more comprehensive approach to understanding user behavior with regard to adoption of improved cookstoves.

The Theory of Planned Behavior

To quantify user intentions, each of the three categories of TPB presented in Figure 2 is associated with multiple questions in the survey that capture a respondent's beliefs on a Likert scale with 1 and 5 representing opposite extremes. Examples of these are shown in Table 1. Recorded responses are used to develop a regression function with intention as the dependent variable and attitudes toward behavior, social pressure, and perceived behavior control as the explanatory variables. Values of each category are recorded using relevant questions in the TPB section of the baseline survey follow-up surveys of Appendix I. The TPB questionnaire includes three to five questions for each category that ask respondent about her beliefs, and evaluations in different formats. After cleaning data from responses of entire sample size, the most statistically significant questions for each category were selected to explain the variation in intention, which is recorded by three separate questions as dependent variable. The regression analysis indicates the level of each category's influence on the intention. As a result, TPB can explain in part the decision-making behavior of the users for adopting the Ecocina in a community because the decision is formed based on personal beliefs and attitudes, social pressures, and the perception of individual regarding controlling the behavior. Quantifying each category's influence on the intention sheds light into best community scale implementation policies to approach higher adoption rates.

Table 1 - Example of TPB questions

Category	Question
Intention	How many meals do you cook each day with the ecocina?
	None 1 2 3 4
Attitude toward behavior	How much do you think less fire smoke is important?
	Very important Important Doesn't matter Not important Not important at all
Social pressure	How much do you value other people's experience using Ecocina over your experience?
	Very much A little bit I don't know Not particularly I don't care what they think
Perceived behavior control	How much do you think Ecocina is designed to meet your needs?
	Very well designed Its fine I don't know It's not the best design for my need It's not designed based on what I need

In order for the TPB to model the actual decision-making behavior, questions must be designed to be comprehensive in capturing factors that shape the decision. Therefore, this is important to follow the theory's instructions in designing the survey questions. Ajzen (2013) explains how separating the three categories of explanatory variables provides a reasonable estimate of the actual behavior. According to the author, attitude toward behavior consists of personal beliefs and evaluations. This means a person's overall attitude is the outcome of her personal beliefs and her evaluation regarding validity of such beliefs. Similarly, an individual's related value for subjective norms is the outcome of her normative beliefs and her evaluation of the social pressure for conforming to such normative beliefs. Finally yet importantly, the person's perception for the control she has over the behavior is a function of her control beliefs and the power she feels in such control beliefs. Therefore, understanding the common beliefs in the community plays an important role in designing survey questions that are understandable by respondents. For this purpose, this project conducted a pilot study to elicit the general beliefs regarding stoves in the community. Using the results of the pilot study, survey questions were developed in the way that ask respondents about widespread beliefs to link with their personal evaluations. The questions are presented in Appendix I, in section TPB of the baseline survey, and section I in the follow-up survey. Example of the questions are presented in the Table 1.

Social Networks

This study asked each respondent questions to help draw the social network of the community through the use of name generator questions. Such questions enable researchers to map a network

out of a sample size based on only a few attributes (Marsden, 2011). Table 2 presents the social network questions in both baseline and follow-up surveys.

Table 2 - Social network questions

Study phase	Question
Baseline	Among your relatives, friends, or acquaintances are there people who have cell phones? (list up to four)
Baseline	Among your relatives, friends, or acquaintances are there people who have improved cookstoves? (list up to four)
Baseline	Do you know anyone who can give you advice as to whether to use an improved cookstove or not?
Baseline	Do you know anyone who has government or NGOs links?
Baseline	Do you know anyone in the community that is handy repairing household equipment?
Follow-up	Who have you talked to about your stove and what did you discuss with them about the stove?

To analyze the results, two centrality measures were used to determine influential community members (Hanneman & Riddle, n.d.). Higher centrality values reflect higher prominence or importance of an individual. Degree-centrality focuses on the number of connections each node (individual in the community) has. Higher degree centrality means more people are in touch with the person related to the stove experiences. Betweenness-centrality determines how important is a person in a community regarding flow of information from different members of the community. In general, such attributes indicate that how influential a specific person is in the community regarding cookstoves. Recognizing such influential people enables project managers to enhance their marketing and spreading of the word strategies.

Study Design

This study was conducted in collaboration between Oregon State University's humanitarian engineering program and StoveTeam International with in-field support of the E'Copan Stove Factory. StoveTeam facilitated the communication between researchers and the field partners and supervised the data collection projects. Overall, 379 households participated in the surveys. These households were identified by the local partner through information campaigns and advertisements.

This project was carried out in three phases: pilot, baseline, and follow-up. First, in January 2017 a pilot study was conducted with a randomly selected sample of 10 households in the community. This pilot survey incorporated seven open-ended questions to develop the TPB questions in the way that complied with widespread beliefs in the target community. Responses were recorded in Spanish and translation of the responses was provided by the project manager to the research group. The results of the pilot suggested that firewood consumption, cleanness of the kitchen and cooking time were among the most important attributes valued by households in the community. Thus, belief related questions in the TPB section were designed to ask household opinions based on time, emissions, and firewood consumption, enabling ranking of the attributes with respect to community's priorities rather than the researchers' interests. This is necessary for the behavior research to evaluate the proper beliefs in each context (Ajzen, 2013). For example, a researcher may be inclined ask questions regarding indoor air pollution. However, if this is not a priority for this set of users, the researcher will be unable to capture the real user evaluations. Asking the user evaluations based on a user's priorities however will reflect the user's dominant beliefs and be more likely to explain the actual behaviors.

In the second phase, a baseline survey was implemented to measure the status quo. The questions intended to draw out households' experiences with traditional stoves and their impacts on livelihood, as well as expectations regarding an improved cookstove. The baseline survey was implemented in February 2017 and the field partner began to distribute Ecocinas to the participants at the same time. In the third phase, the follow-up data collection was conducted in April 2017. The purpose of follow-up study was to re-measure many attributes for improving the validity of responses, and to evaluate user experiences, uptake, and impacts of Ecocina.

Both baseline and follow up were carried out from an identical sample size of 379 households. A variety of variables were incorporated in the surveys to capture many aspects of cookstove adoption such as direct stove experience, health, TPB, and social networks (Table 3). Some topics that are included in both surveys to determine if a respondent's answers change after her experience of cooking with the Ecocina. In some cases, asking particular questions before and after intervention can quantify the Ecocina's impact. In addition, for the TPB section, one way to validate the results of data collection is through a practice called test-re-test reliability analysis (Ajzen, 2013). This means asking questions two times or more over a period to avoid short-term biases affecting respondents indirectly. The full questionnaires are presented in Appendix I.

Table 3 - Survey questions' topics and types of questions

	Section	Number of questions (B)-baseline (F)-follow-up	Type of questions
1	Participant identification	9 (B) + 9 (F)	Open ended
2	Stove use patterns	24 (B) + 21 (F)	Multiple choice/ open-ended
3	Fuel procurement	17 (B)	Multiple choice/ open-ended
4	Household demographic information	22 (B)	Multiple choice/ open-ended
5	Theory of Planned Behavior	34 (B) + 28 (F)	Multiple choice/ open-ended
6	Social network	6 (B) + 3 (F)	Open-ended
7	Health and safety	28 (B) + 29 (F)	Multiple choice
8	Stove and kitchen area observation	6 (F)	Multiple choice/ open-ended
9	Cooking dynamics	7 (F)	Multiple choice
10	Fuel procurement	16 (F)	Multiple choice/ open-ended
11	Income generating impacts	4 (F)	Multiple choice
12	Perception of the Ecocina	10 (F)	Multiple choice/ open-ended

Results

In addition to detailed demographic details, the study's major findings in TPB, health and safety, stove experience, and social impacts are presented in this section. Additional details and statistics of responses to each question of the survey are provided in Appendix II.

Demographics

Results of the surveys showed that the cookstoves distribution has directly impacted at least 1,765 individuals, 684 of which (39%) are children under the age of 17. Additional demographic information is presented in Table 4. The main demographic attributes such as age and income distribution and sources are presented in Figure 3 through 10.

Table 4 - Demographic information of the sample.

Sample size	**379**
Number of villages	8
Affected population	1765
Population by gender	Female: 892 (51%) Male: 873 (49%) Total: 1765
Number of children (under 17)	Female: 353 (52%) Male: 331 (48%) Total: 684
Main cook's age distribution	Minimum: 15 Maximum: 94 Average: 37.4 Std. dev.: 14.5
Income average	770 HNL Std. dev.: 895 HNL
Education (primary income earner)	No education: 70% Incomplete primary education: 30%

In the sample, 19% of the participants had a functioning refrigerator and 67% of them had cell phones. Results showed that 66% of female heads of the family are able to read and write. Figure 3 illustrates the school attendance of children in the sample size who are in the school age range, showing that more than 80% of the children attend school every day it is in session. Of children who do not attend, 7.5% are reportedly needed to help at home and the remaining 5% cannot afford school. In addition, 86% of the respondents mentioned sickness as the reason that causes students to miss 5 days or less of school, with only 1% or less reporting staying home to help with chores or earning income.
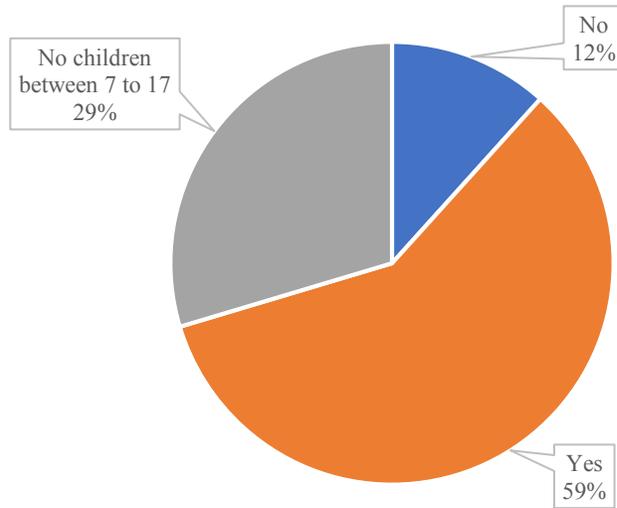
Figure 3 - School attendance of children between 7 and 17 years old
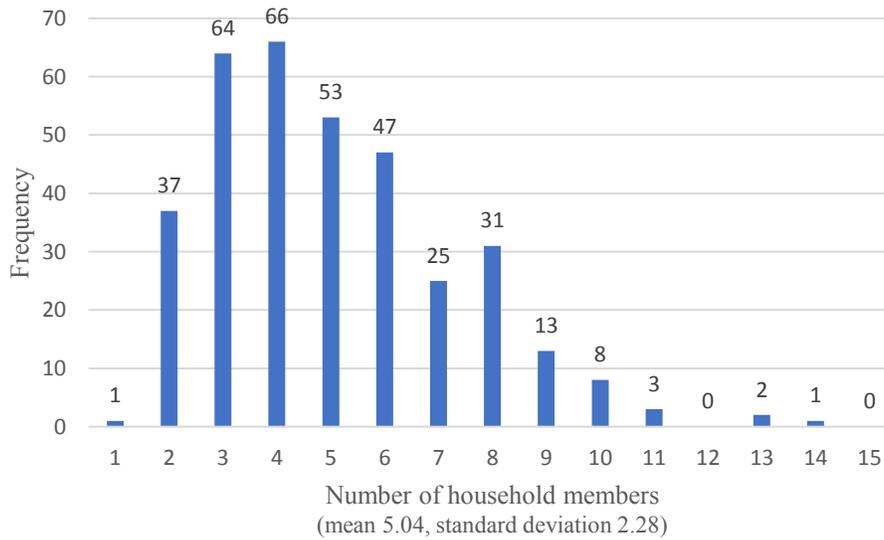
Figure 4 - Distribution of household size
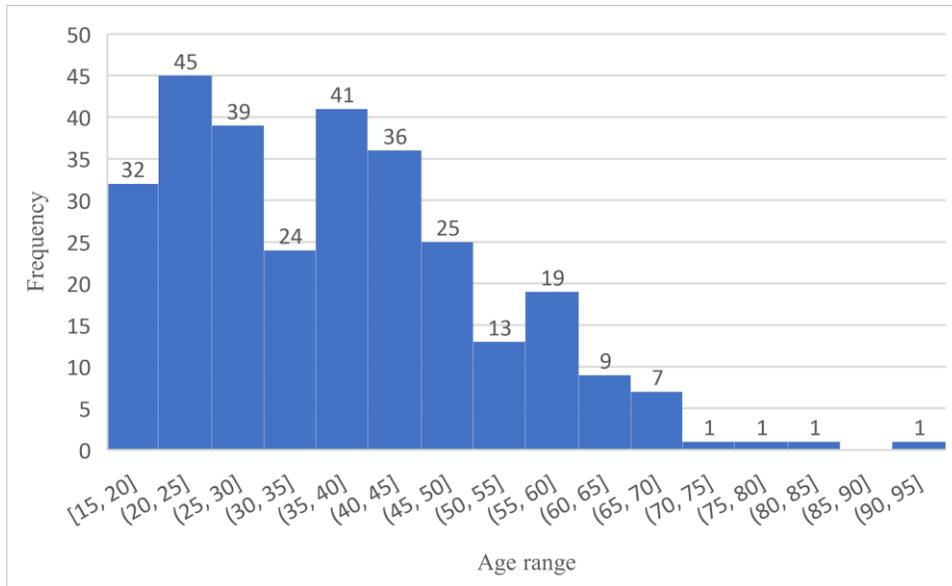
Figure 5 - Distribution of the age of main cooks
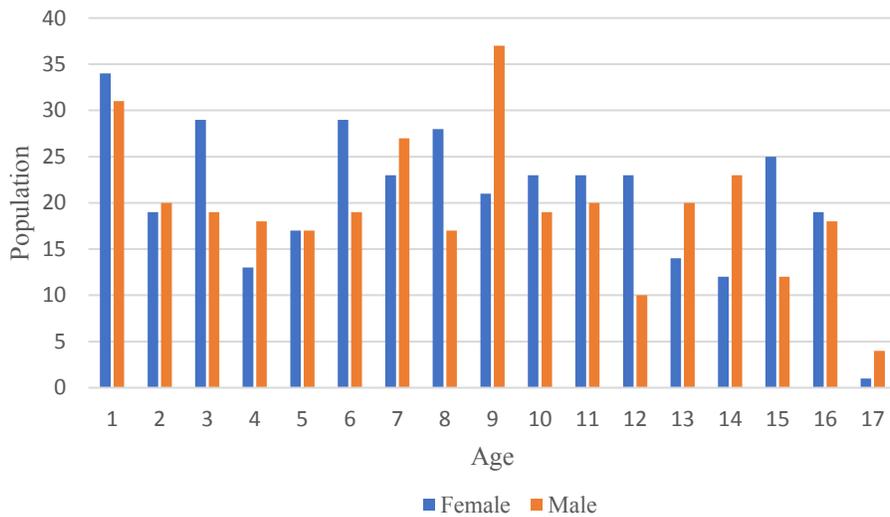
Figure 6 - Distribution of children by age and gender
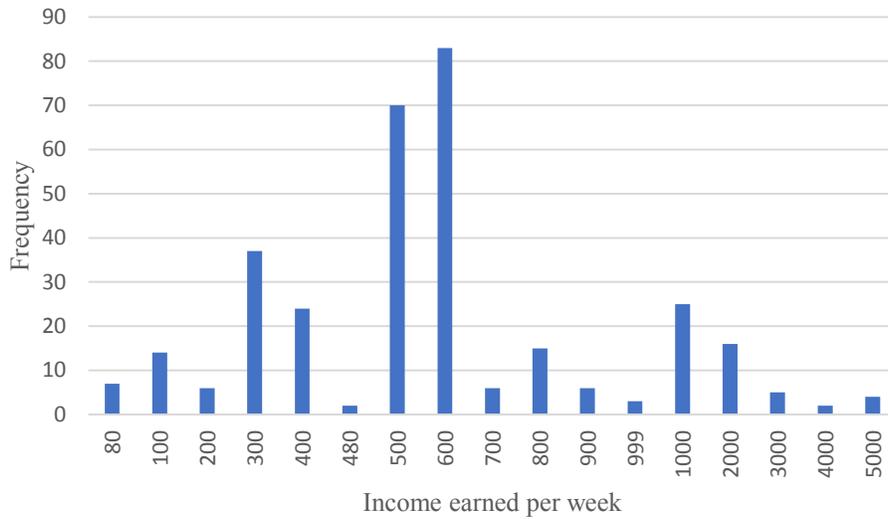
Figure 7 - Distribution of stated income earned by main income earner per week in winter (HNL)
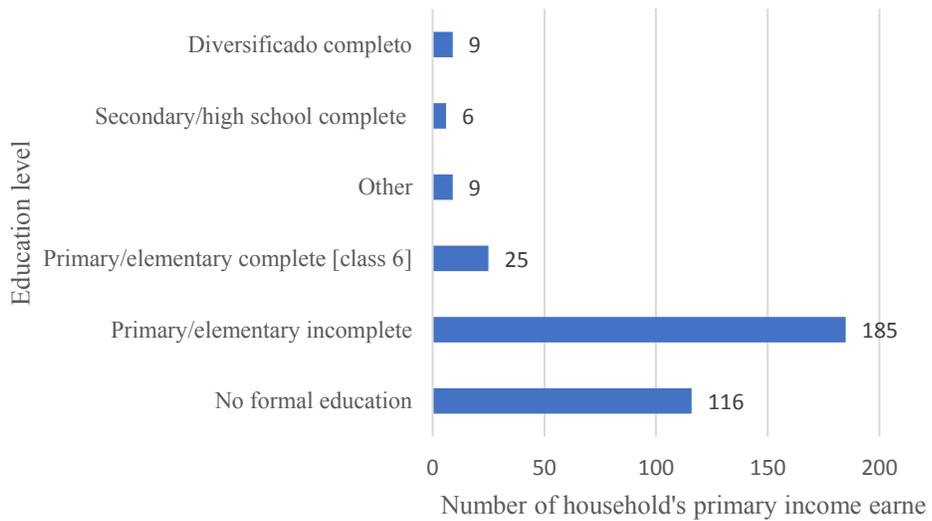
Figure 8 - Highest level of education of household's primary income earner
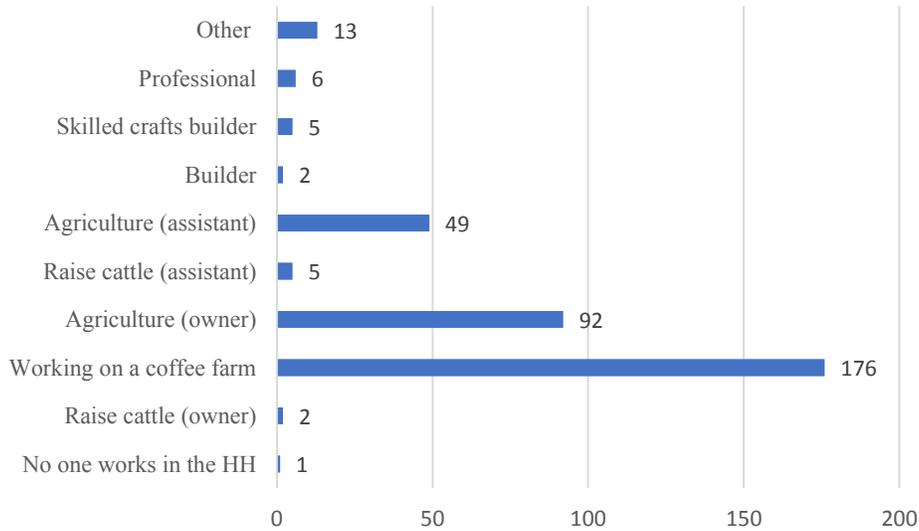
Figure 9 - Distribution of income earners based on sources of income
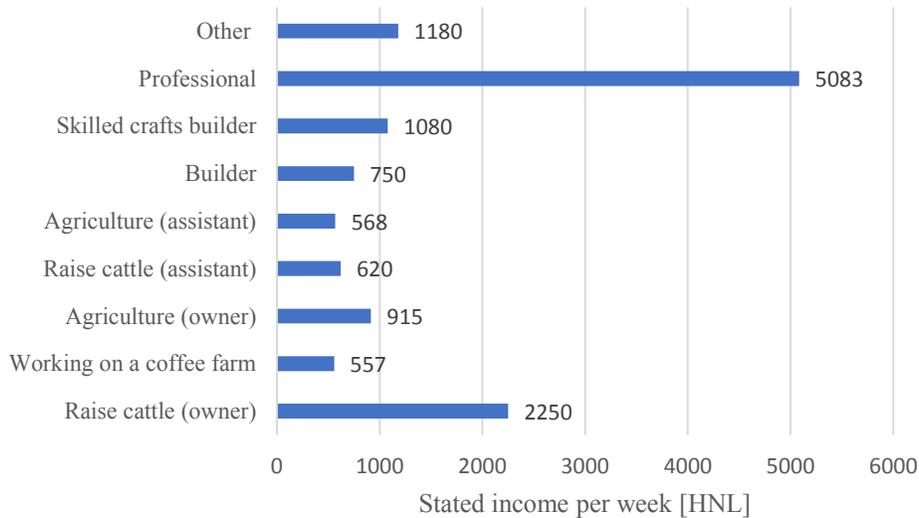
Figure 10 - Distribution of average income generated based on income source

Stove experience

The participating households in this study received an Ecocina cookstove after or at the time of the baseline survey. This provided them with approximately two months of opportunity to experience cooking with a new device in advance of the follow-up survey that elicited their experiences with the Ecocina. In the baseline, 97% of respondents mentioned the traditional Plancha as their primary stove (and at least 50% or more reported cooking each of their staple

foods including tortillas, beans, rice, meat, and coffee/tea on it) and only 10% of the sample had another stove choice. Only 2 households reported use of LPG as a primary stove and 6 as their secondary stove. Households reported fast cooking, cooking of multiple dishes simultaneously, and conserving heat/getting very hot as the favorite aspects (in order) of their current primary cooking method. The worst aspect identified by far was producing too much smoke. Approximately 32%, 24%, 38%, 61%, and 88% reported using their current stove for additional services such as insect repellant, lighting, making animal feed, warming bath water, and making medicine, respectively, in addition to typical cooking processes. Only 2.9% report using open fires or other biomass devices for a business.

The households reported that the husband is responsible for fuelwood collection in 64% of households, followed other (8.7%), self (8%), male children (7.6%), and female children (0.29%). Of fuelwood collecting households, 67% do so daily and 20% do so weekly, while the majority (69%) do so on foot and the rest use a horse or mule with packs. Typically this is done at the same time as other chores in 24.7% of households and takes an average of 3.0 hours (standard deviation of 2.7 hours). Fuelwood is stored outside in 61% of households, inside in 32%, and by the stove in 6% of homes. Approximately 28% of households report challenges with the fuel getting wet, 14% that it is difficult to access, and only 3% that it might get stolen. At the time of the baseline survey, only 14% of households report purchasing wood. Those who purchase report an average cost of 1462 HNL (standard deviation of 1944) per trip.

In the follow-up visit, the Ecocina was observed to be in usable condition in nearly 90% of the houses. In more than 80% of the households Ecocina was either alight or had signs of recent use by the time of the surveyor's visit. For 85% of the respondents, Ecocina was the primary stove at the time of follow-up survey. This may be somewhat over-reported as only 73% reported using the Ecocina at least once per week, and 59% using it 7 days per week. The traditional plancha was still present in 30% of households, and 60% of households reporting using a single stove and 37% reporting using two stoves each week. For the primary stove, 75% reported using it for 3 meals per day and 18% for two. As a whole, 25% of households reported using two stoves at the same time on occasion, typically (68%) three times or less per week, to cook two dishes at the same time (80%), when in a rush (8%), or when cooking for large numbers (5%). Between 85% and 87% of respondents selected the Ecocina as the stove they use to cook each of their staple dishes including tortillas, beans, rice, tamales/tomalitos, nixtamal, and hot drinks. Fuel collectors reported spending an average of 4.9 hours per trip (deviation of 10.6 hours), and the 7% (down from 14% at baseline) of fuel purchasers reported spending an average of 823 HNL (deviation of 1113 HNL) per trip.

The considerable up-take of the Ecocina is likely to be the result of multiple improvements that households perceived. First, 80% of the respondents mentioned that cooking with Ecocina requires less time than before. Figure 11 illustrates how they spent the time they saved by faster cooking practice. Second, for 80% of the households the level of efforts required for cooking such

as fuel preparation, lighting the fire, tending it, and managing the food was significantly less than before when they cook with Ecocina. Third, 95% of the households claim that since they received Ecocina they use less firewood than before. The surveyors asked respondents to show them a rough comparison of the amount of firewood they used to consume before adopting Ecocina and afterward. Surveyors' observations in comparing the saved firewood is presented in Figure 12. The weighted average of the surveyors estimates indicates 37% less firewood is consumed than during the baseline. Less consumption of firewood could lead to less firewood collection effort and less time for the firewood harvest trips. In average the time that households spent to collect wood reduced by 11.3%. Figure 11presents how the time saved by adopting the Ecocina was spent.

The survey also asked households direct questions regarding what they liked and what they think needs to be improved about the Ecocina. Over 98% of users reported the Ecocina as very easy (93%) or somewhat easy (5%) to use, and all but 1 respondent believed it was equally (13%) or more safe (87%) than their traditional method. Based on the responses presented in Figure 13, faster cooking practice and less fuelwood consumption are the most frequently chosen responses regarding what they liked about the Ecocina. Whereas in Figure 14 respondents suggest that adding chimney, material issues, and size of the stove have room for further improvements.
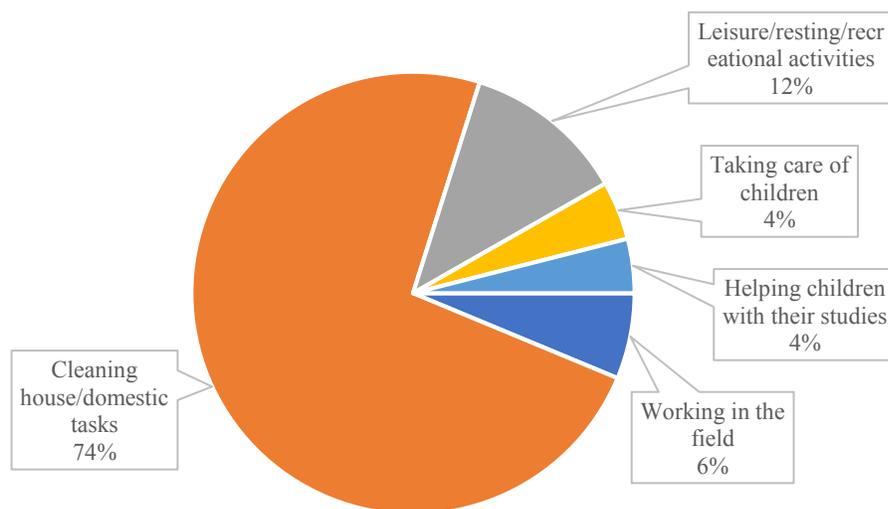
Figure 11 - Households' stated activities that they spent the time they saved by cooking faster using Ecocina
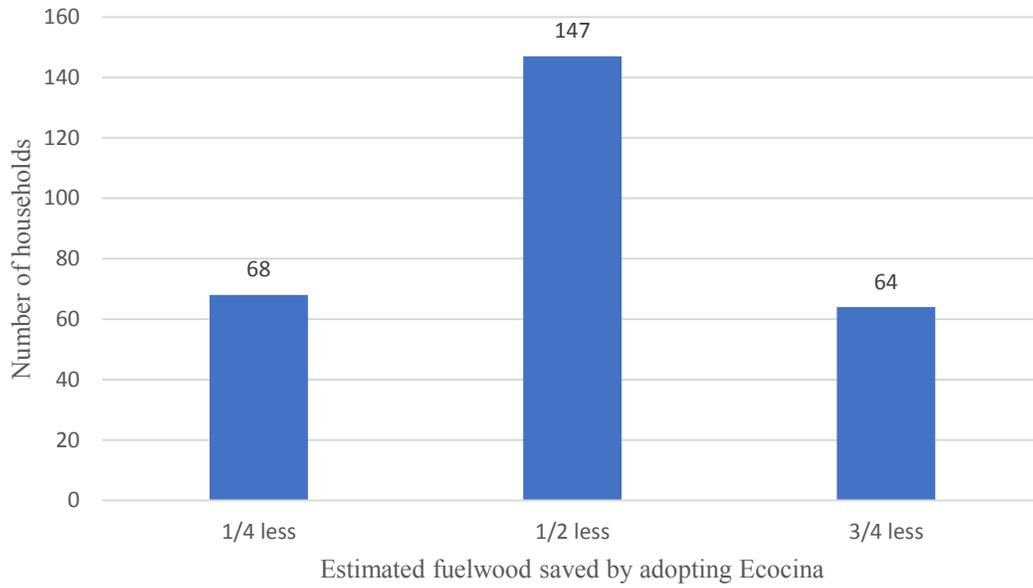
Figure 12 - Fuelwood saved estimated by surveyors.
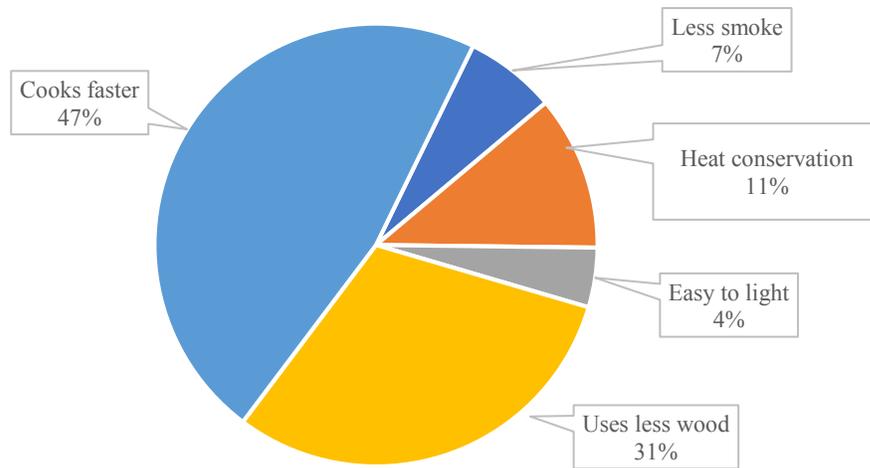
Figure 13 - Stated benefits of using Ecocina
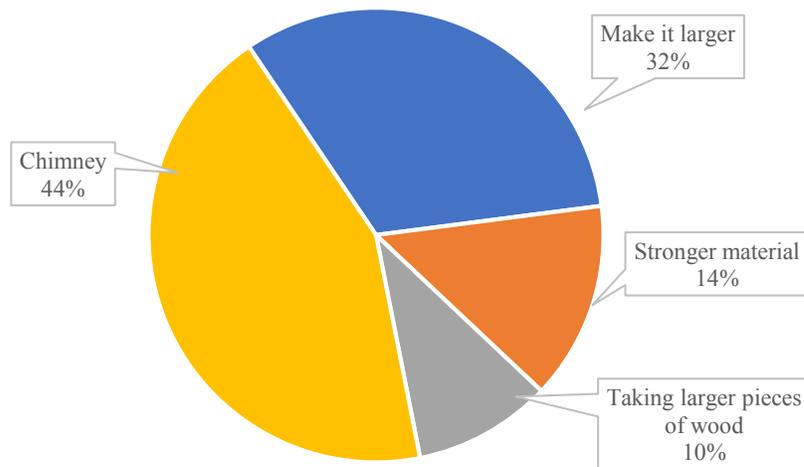
Figure 14 - Stated potential improvements to the Ecocina

Health and safety

This study asked households about any health related issues they had in the 6 months prior to the baseline. Then, in the follow up survey, respondents were asked if the households had any of such experiences since they changed their cooking practices. Figure 15 illustrates that both main cook and her family have experienced significant improvements in their self-reported health. Based on their reports, experiences of burning reduced by 88%, eye irritation by 92%, coughing and sneezing by 85%, chest pain by 93%, shortness of breath by 89%, irritation of nose and throat by 89%. In addition, 76% of respondents also reported feeling more safe since adopting the Ecocina, with 12% reporting less safe. However it is important to note that self-reports are subject to biases (Adams et al, 1999; Mortel and Thea, 2008), and the time frame of using the Ecocina was only 2 months relative to the 6 months asked in the question. Nevertheless, results indicate that households perceive health improvements by adopting the Ecocina. This leads to a positive attitude for using the stove and motivates other households for adopting Ecocina as well.
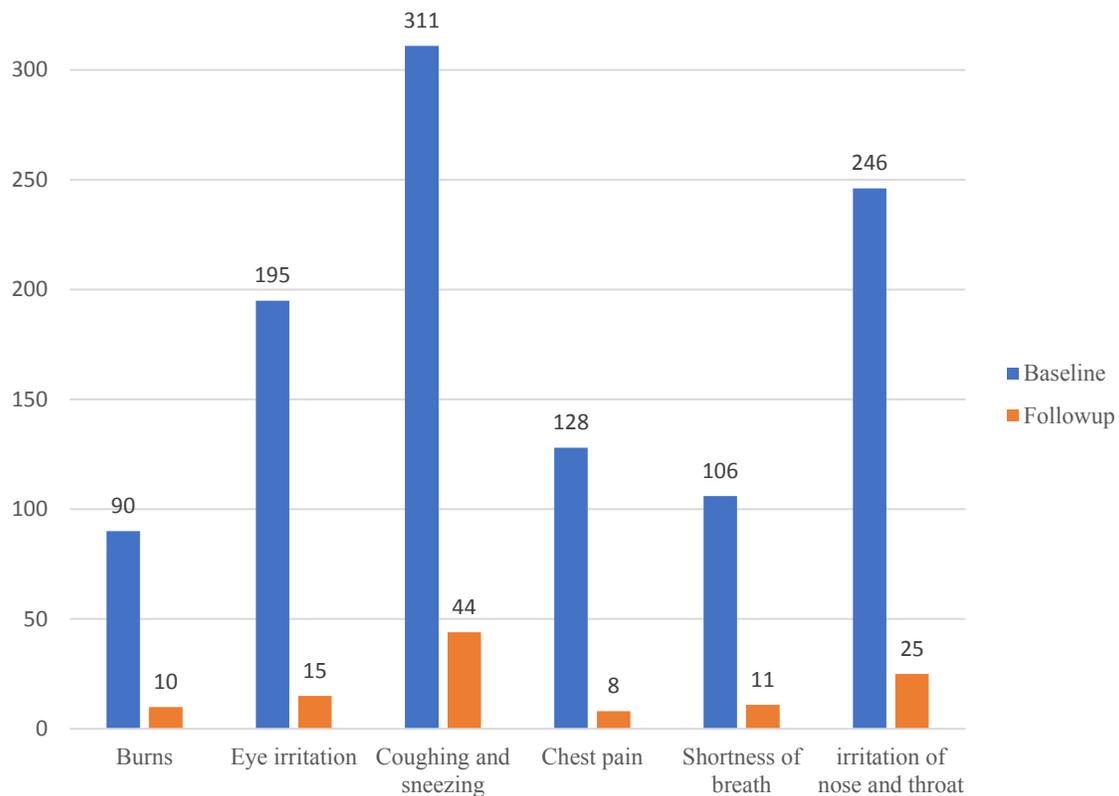
Figure 15 - Households self-reported health and safety risks before and after adoption to Ecocina

The Theory of Planned Behavior

The TPB results present the contribution of each of the three categories of attitude toward behavior, social pressure, and perceived behavior control to the intention of using improved cookstoves. For each building block of TPB, three to five questions were asked to capture multitude of beliefs related to that category. Responses of each question were designed to be simple and understandable for the respondents, at the same time to capture a range of options based on requirements of the Likert scale. The responses were coded from '1' for representing 'strongly disagree' or equivalent to '5' for representing 'strongly agree' or equivalent. Multiple regression analyses were used to find most relevant attributes with the highest model significance (Hankins, French, and Horne, 2000). Table 5 presents the changes in the regression coefficients from baseline to follow-up. Regression analysis is conducted using ordered logistics regression and coefficients are presented in odds ratios. Therefore, the coefficients are not directly comparable to each other. The values indicate how higher levels of each category increase the likelihood of higher intentions to cook more meals with the Ecocina.

Table 5 - Results of the theory of planned behavior
(Robust standard errors are in parenthesis. *p < 0.1. **p < 0.05. ***p < 0.01)

CATEGORY	BASELINE	FOLLOW-UP
ATTITUDE TOWARD BEHAVIOR	-2.87** (1.283)	4.76*** (1.315)
SOCIAL PRESSURES	-0.16 (0.189)	0.91* (0.505)
PERCEIVED BEHAVIOR CONTROL	0.45* (0.231)	1.56** (0.708)
MODEL SIGNIFICANCE (CHI^2)	7.57*	15.56***

The results indicate that attitude toward adopting the Ecocina improved considerably from the baseline to the follow-up. In the baseline, the value for the coefficient related to attitude toward behavior was negative (-2.87). This means that in general respondents' attitude was not in favor of cooking with improved cookstoves. However, in the follow-up, the attitude became significantly positive (4.76). This indicates that respondents are likely to cook more meals with the improved cookstoves because their individual experiences were satisfactory enough to persuade them to change their behavior in favor of using the Ecocina. The social pressure attribute followed a similar trend but is not likely to be significant in altering the intention for cooking in the baseline due to a lower relative strength and level of statistical significance. The coefficient for social pressure became significant and positive in the follow-up suggesting that users felt more social pressure to cook more meals with the Ecocina. One explanation could be that users had no previous experience of different cooking device in the baseline. Therefore, they did not perceive any social pressure regarding change of practice. However, the social pressure became significant when they could observe other households' behavior regarding use of the Ecocina. Perception of the control respondents felt regarding changing their behavior is positive and significant in both models. This suggests that respondents do not perceive any hindrance for changing their behavior to cook more meals with the Ecocina.

Social Impact and Social Networks

This project also carried out two social network studies to capture role of the community in adoption of Ecocina, as well as how the introduction of the Ecocinas affected social trust. The first study measured the changes in households' attitude regarding some influential actors in the community before and after intervention. Influential actors include doctors, teachers and NGOs/government officials. Figure 16 (a-c) illustrates that the level of trust to such actors has improved from baseline to follow-up. This indicates that the bonding social capital (i.e. level of trust) as reported by the households has improved after the stove intervention.
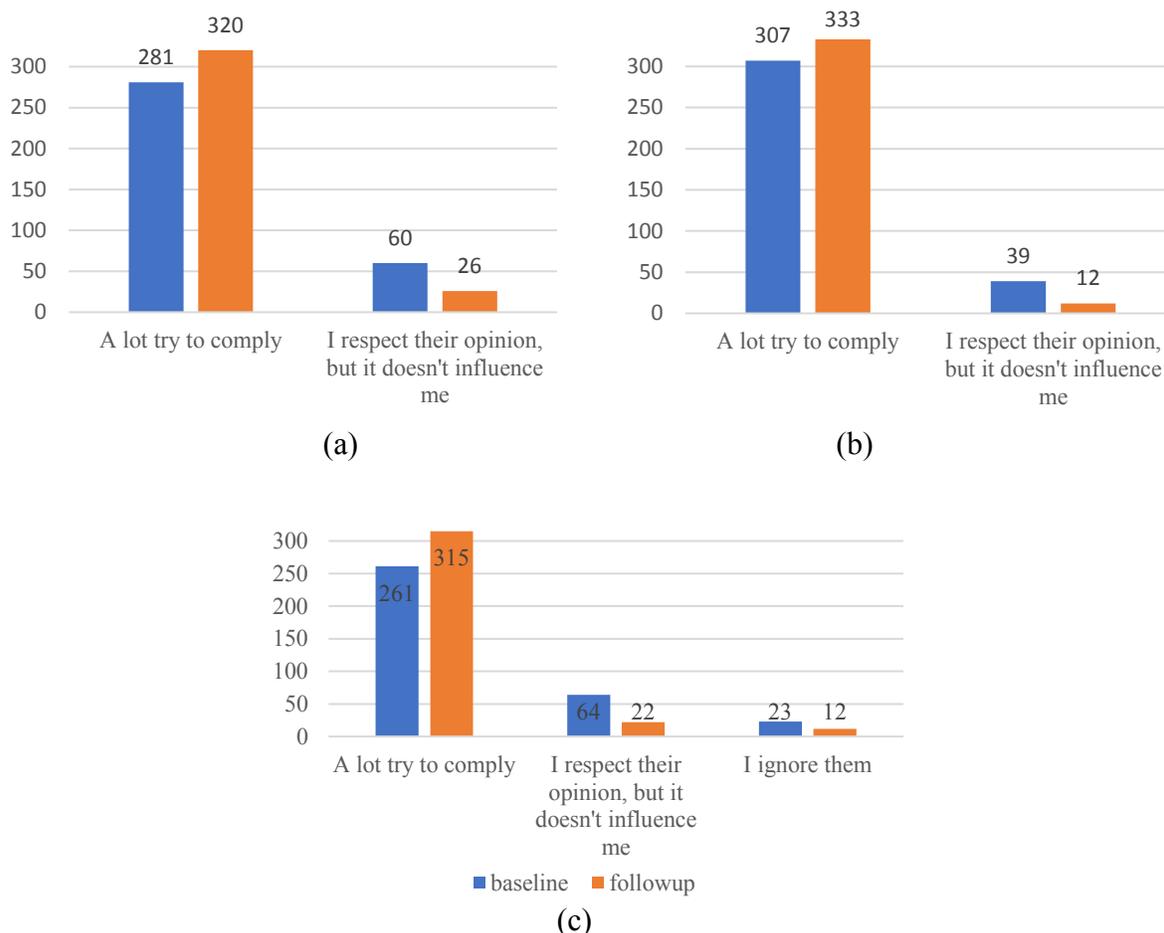
Figure 16 - Change in stated level of trust for (a) NGOs/government officials, (b) Doctors, (c) Teachers from baseline to follow-up

In the second aspect of social networks, social maps of the two villages were developed. The generated networks presented in the Figure 17 are egocentric networks extracted from name generator questions in the baseline survey. Through this study, the influential households in the community that have relatively more respect in the community can be identified. Figure 17 presents the map of the network in two villages and Table 6 presents importance of the community members. Ideally, there would be greater links between groups of nodes such that greater connections within the community were identified. In this case, it is possible that not a large enough proportion of community members was sampled, or the sampling technique was not applicable to the social network mapping. Another possible explanation is that regarding the stoves, there are not very strong social ties in the community. However, given the current social mapping results, a solid explanation for the discrete map presented below cannot be drawn. Further studies are required to reveal the structure of community ties and actors for recognition of most influential actors.
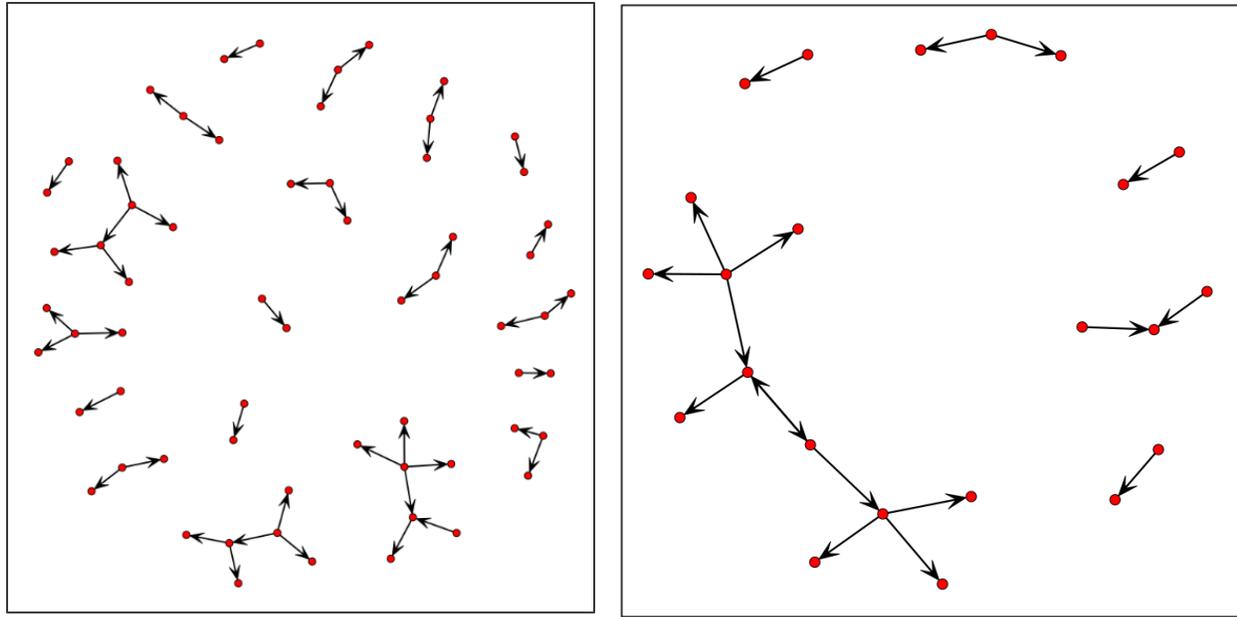
Figure 17 - Social map of actor in the survey in two sample villages.

Table 6 - Degree-centrality and betweenneess centrality of network actors

Name	Degree	Betweenness	Name	Degree	Betweenness
Ca Mor	4	7	Su Agu	4	0
Ma Mar	4	9	De Vid	3	2
Ma Ber	4	0	El Esc	3	0
Ma Ele	3	8	El Ald	3	0
Hu Gut	2	0	Fl Mil	3	2
Ti Mar	2	0	On San	3	2
Ba Ama	1	0	Vi Cha	3	0
Cl Per	1	0	Ad Vor	2	0
Cr Mar	1	0	An Yod	2	0
Cr Mar	1	0	Be Lic	2	0
Do gar	1	0	Er Esc	2	0
Eu Mar	1	0	Ma Mon	2	0
Gl Mad	1	0	Mi Gar	2	0
			pr Yol	2	0
			Xa Flo	2	0

Conclusions and Future Work

This study evaluated the impact of introducing improved cookstoves in 400 households in rural Honduras using a comprehensive approach. In the study at least 1,765 community members were affected by introducing Ecocina, nearly 40% of whom are children 17 years old or younger. Overall, households' experience using the Ecocina was satisfactory because nearly 85% of participant households were cooking their main meals with this stove every day two months after receiving it. The households identified burning less firewood than traditional stoves and open fire along with saving time for cooking practices as major benefits of the Ecocina. In 80% of the houses the Ecocina was visible with signs of recent usage.

For 80% of the beneficiaries, the level of the effort for cooking, the time it takes, and firewood consumed was reported as decreased when using the Ecocina compared to their traditional practices, which was a traditional Plancha stove in 97% of the households. More than 98% of users stated that using Ecocina is easy or somewhat easy for cooking practices. For all but one user, the Ecocina was perceived to be equally (13%) or more safe (87%) than traditional methods. On average, the time for trips to collect firewood was reduced by 11.3%. Health and safety showed significant improvements, with 90% of respondents reporting 85-93% reductions in burns, eye irritation, coughing, sneezing, chest pain, and nose and throat irritation.

Applying the Theory of Planned Behavior to analyze behavioral considerations of adopting cookstoves revealed that adopting the Ecocina significantly improved the user's attitude toward the behavior of cooking with an improved stove, moving from -2.87 in the baseline to 4.76 in the follow-up. This indicates that in general respondents' attitude was not in favor of cooking with improved cookstoves initially but after two months of using the stove, their individual experiences were satisfactory enough to persuade them to change their behavior in favor of using the Ecocina. In addition, TPB analysis revealed that households felt a social obligation to use the Ecocina because others in the community members were doing so as well.

This study also mapped the social network of stove-related influential actors in the target community hoping the results of social networks can be used by project leaders to improve implementation strategies to achieve higher adoption rates. However, the methods used in this study were inconclusive and a more robust surveying technique exclusive to social mapping is recommended for future studies.

The considerable improvements that households reported regarding time saving, health and safety and firewood consumption may be overstated to some extent. Future work should include quantitative evaluations through sensors and other rigorous monitoring techniques for verification of these conclusions. In addition, a long-term monitoring and evaluation study is recommended to capture more settled experiences, changes in behavior and social impacts of any technology implementation project.

Acknowledgments

References

Adams, A., Soumerai, S., Lomas, J., & Ross-Degnan, D. (1999). Evidence of self-report bias in assessing adherence to guidelines. *International Journal for Quality in Health Care*, *11*(3), 187–192. https://doi.org/10.1093/intqhc/11.3.187

Adrianzén, M. A. (2014). social capital and improved stoves usage decisions in the Northern Peruvian Andes. *World Development*, *54*, 1–17. https://doi.org/10.1016/j.worlddev.2013.07.004

Ajzen, I. (1985). from intentions to actions: A theory of planned behavior. In *Action Control* (pp. 11–39). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-69746-3_2

Ajzen, I. (1991). The theory of planned behavior. *Orgnizational Behavior and Human Decision Processes*, *50*, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Ajzen, I. (2013). Theory of planned behaviour questionnaire . Measurement instrument database for the social science. Retrieved from http://www.midss.org/sites/default/files/tpb.construction.pdf

Albarracín, D., Johnson, B. T., Fishbein, M., & Muellerleile, P. A. (2001). Theories of reasoned action and planned behavior as models of condom use: A meta-analysis. *Psychological Bulletin*, *127*(1), 142–161. https://doi.org/10.1037/0033-2909.127.1.142

Armitage, C. J., & Conner, M. (2001). Efficacy of the theory of planned behaviour: A meta-analytic review. *British Journal of Social Psychology*, *40*(4), 471–499. https://doi.org/10.1348/014466601164939

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change*, *5*(3), 266–272. https://doi.org/10.1038/nclimate2491

Bailis, R., Ezzati, M., & Kammen, D. M. (2005). Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. *Science*, *308*(5718). Retrieved from http://science.sciencemag.org/content/308/5718/98/tab-pdf

Bamberg, S., & Schmidt, P. (1998). Changing travel-mode choice as rational choice: *Rationality and Society*, *10*(2), 223–252. https://doi.org/10.1177/104346398010002005

Barnes, D. F., Openshaw, K., Smith, K. R., & Van Der Plas, R. (n.d.). What makes people cook with improved biomass stoves? A comparative international review of stove programs. Retrieved from http://documents.worldbank.org/curated/en/738011468766789505/pdf/multi-page.pdf

Boldero, J. (1995). The prediction of household recycling of newspapers: The role of attitudes, intentions, and situational factors1. *Journal of Applied Social Psychology*, *25*(5), 440–462. https://doi.org/10.1111/j.1559-1816.1995.tb01598.x

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., … Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres*, *118*(11), 5380–5552. https://doi.org/10.1002/jgrd.50171

Chen, W., Collins, A., Cummings, R., Ke, T., Liu, Z., Rincon, D., … Yuan, Y. (2011). Influence maximization in social networks when negative opinions may emerge and propagate. In *SIAM International Conference on Data Mining* (pp. 379–390). ociety of Industrial and Applied Mathematics. https://doi.org/10.1137/1.9781611972818.33

Coleman, J., Katz, E., & Menzel, H. (1966). *Medical innovation a diffusion study*. Indianapolis: Bobbs-Merrill Co. Retrieved from http://www.worldcat.org/title/medical-innovation-a-

diffusion-study/oclc/565386

Conner, M., & Armitage, C. J. (1998). Extending the theory of planned behavior: a review and avenues for further research. *Journal of Applied Social Psychology*, *28*, 1429–1464. https://doi.org/10.1111/j.1559-1816.1998.tb01685.x

Francis, J. J., Eccles, M. P., Johnston, M., Walker, A., Grimshaw, J., Foy, R., … Kaner, E. (1988). constructing questionnaires based on the theory of planned behaviour a manual for health services researchers Retrieved from http://openaccess.city.ac.uk/1735/1/TPB%2520Manual%2520FINAL%2520May2004.pdf

Godin, G., & Kok, G. (1996). The theory of planned behavior: A review of its applications to health-related behaviors. *American Journal of Health Promotion*, *11*(2), 87–98. https://doi.org/10.4278/0890-1171-11.2.87

Hankins, M., French, D., & Horne, R. (2000). Statistical guidelines for studies of the theory of reasoned action and the theory of planned behaviour. *Psychology & Health*, *15*(2), 151–161. https://doi.org/10.1080/08870440008400297

Hanna, R., Duflo, E., & Greenstone, M. (2016). Up in smoke: The influence of household behavior on the long-run impact of improved cooking stoves. *American Economic Journal: Economic Policy*, *8*(1), 80–114. https://doi.org/10.1257/pol.20140008

Hanneman, R. A., & Riddle, M. (n.d.). Concepts and measures for basic network analysis. In *The SAGE Handbook of Social Network Analysis* (pp. 340–369). 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom : SAGE Publications Ltd. https://doi.org/10.4135/9781446294413.n24

Jeuland, M. A., Bhojvaid, V., Kar, A., Lewis, J. J., Patange, O., Pattanayak, S. K., … Ramanathan, V. (2015). Preferences for improved cook stoves: Evidence from rural villages in north India. *Energy Economics*, *52*, 287–298. https://doi.org/10.1016/j.eneco.2015.11.010

Johnson, N. G., & Bryden, K. M. (2012). Energy supply and use in a rural West African village. *Energy*, *43*(1), 283–292. https://doi.org/10.1016/j.energy.2012.04.028

Kempe, D., Kleinberg, J., & Tardos, É. (2005). Influential nodes in a diffusion model for social networks (pp. 1127–1138). Springer Berlin Heidelberg. https://doi.org/10.1007/11523468_91

Klöckner, C. A. (2015). *The Psychology of Pro-Environmental Communication*. London: Palgrave Macmillan UK. https://doi.org/10.1057/9781137348326

Lewis, J. J., & Pattanayak, S. K. (2012). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives*, *120*(5), 637–45. https://doi.org/10.1289/ehp.1104194

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., … George, S. (2013). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*, 2224–2260. https://doi.org/10.1016/S0140-6736(12)61766-8

Marsden, P. (2011). Survey methods for network data. *The SAGE Handbook of Social Network Analysis*. Retrieved from https://books.google.com/books?hl=en&lr=&id=2chSmLzClXgC&oi=fnd&pg=PA370&dq=peter+marsden+survey+methods+for+network+data&ots=GTU7V2uFvt&sig=9824aEKuMCfJHSyh0fS4Dgi69gQ

Mobarak, A. M., Dwivedi, P., Bailis, R., Hildemann, L., & Miller, G. (2012). Low demand for nontraditional cookstove technologies. *Proceedings of the National Academy of Sciences of*

the United States of America, *109*(27), 10815–10820. https://doi.org/DOI 10.1073/pnas.1115571109

Mortel, V. de, & Thea, F. (2008). Faking it: Social desirability response bias in self-report research. In *The Australian Journal of Advanced Nursing*. Retrieved from http://search.informit.com.au/documentSummary;dn=210155003844269;res=IELAPA

Nordlund, A. M., & Garvill, J. (2002). Value structures behind proenvironmental behavior. *Environment and Behavior*, *34*(6), 740–756. https://doi.org/10.1177/001391602237244

Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. *Nature Geoscience*, *1*(4), 221–227. https://doi.org/10.1038/ngeo156

Ramirez, S., Dwivedi, P., Ghilardi, A., & Bailis, R. (2014). Diffusion of non-traditional cookstoves across western Honduras: A social network analysis. *Energy Policy*, *66*, 379–389. https://doi.org/10.1016/j.enpol.2013.11.008

Robins, G. (2015). *Doing social network research : network-based research design for social scientists.*

Rogers, E. (2002). Diffusion of preventive innovations. *Addictive Behaviors*, *27*(6), 989–993. https://doi.org/10.1016/S0306-4603(02)00300-3

Rudel, T. K. (2013). The national determinants of deforestation in sub-Saharan Africa. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *368*(1625), 20120405. https://doi.org/10.1098/rstb.2012.0405

Shankar, A., Johnson, M., Kay, E., Pannu, R., Beltramo, T., Derby, E., … Petach, H. (2014). Maximizing the benefits of improved cookstoves: moving from acquisition to correct and consistent use. *Global Health, Science and Practice*, *2*(3), 268–74. https://doi.org/10.9745/GHSP-D-14-00060

Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., … Rehfuess, E. (2014). Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Chennai) College Park Kurt Straif (International Agency for Research on Cancer Sophie Bonjour (World Health Organization GenevaThe Health Effects Institute Annu. Rev. Public Health*, *35*, 185–206. https://doi.org/10.1146/annurev-publhealth-032013-182356

Valente, T. (1995). Network models of the diffusion of innovations. Cresskill New Jersey Hampton Press 1995. Retrieved from https://www.popline.org/node/287430

Whittington, D., Jeuland, M. A., Barker, k, & Yuen, Y. (2012). Setting priorities, targeting subsidies among water, sanitation, and preventive health interventions in developing countries. *World Development*, *40*(8), 1546–1568. https://doi.org/10.1016/J.WORLDDEV.2012.03.004