Design and Implementation of a Ferrocement Improved Cookstove in Rural Panama

by

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DEDICATION

This work is dedicated to my family who has always supported my goals and vision in life. To my friends who've encouraged me to pursue to best version of myself day-to-day. To all the educators throughout my life who've given a piece of themselves so that I could be better. To my Peace Corps family who were a part of one of the best and most challenging parts of my life.

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ABSTRACT

Household air pollution contributes to the premature death of more than 4 million people annually. Improved cookstoves are one technological intervention that can potentially reduce exposure to household air pollution. However, improved cookstove implementation programs need to consider measures to increase sustainability and promote long-term adoption. The objectives of this research were 1) to develop and implement a new ferrocement cookstove for Peña Blanca, a rural indigenous community in the Ngäbe-Bugle region of Panama, 2) to evaluate its potential sustainability in comparison to the most common cooking technologies observed in the community, 3) to prepare a construction manual for the stove to promote future development, and 4) to provide guidelines for applying a holistic approach to improved cookstove projects.

A bottom-up, community-driven approach to development focused on integration and capacity building was used to design and implement a ferrocement improved cookstove. A survey was administered to 26 households to understand the familial and environmental health of the community as well as knowledge, opinions, and needs related to cooking practices and improved stoves. Finally, the ferrocement stove developed for this study, along with the three stone fire, the *ecojusta* stove model, and a gas stove were evaluated both quantitatively and qualitatively using a sustainability assessment framework developed specifically for improved cookstoves.

The results of this study suggest that design and implementation of an improved cookstove in the field that incorporates community feedback and provides educational opportunities may produce solutions that are more likely to be sustainable and meet users' needs. The process allows for design flexibility to reduce smoke and fuel use while incorporating community preferences such as simplicity and ease of use, ability to control heat, stove features and size.

Results from conducting household surveys emphasize the importance of a community-based development process that focuses on meeting community-specific challenges and needs. Conditions such as extreme poverty and lack of support structures pose significant challenges and shape community opinions regarding cooking technology and practices. In fact, the community's desires in this study differ greatly from that found in the established literature. Specifically, 84% of rural Panamanians from this study felt that reducing smoke indoors was important to them.

Sustainability evaluations of improved cookstove implementation programs in Panama highlighted common strengths in the needs assessment and implementation project life stages. These programs excelled at involving the community in identifying project needs and participating in the construction of stoves. On the other hand, the post-implementation and follow-up life stages were assessed to be weaker as these programs generally do not perform evaluation and monitoring of stove use and adoption after the implementation stage or continue user education. Additional qualitative analysis from this study suggest that the traditional stove may be the most sustainable and appropriate stove technology at this time for the community if combined with improving education related to family health, the environment, and stove use that results in behavior change. This approach may have the potential to fulfill the goals of improved cookstove programs globally through education and behavior change as an alternative approach to implementing an inappropriate technology. Moreover, an improved stove that is developed in the community that uses local materials and provides educational opportunities that focus on caring for resources and improving stove operator skill is more likely to be sustainable than other options.

General guidelines and lessons learned for applying a holistic approach to improved cookstove development in the field include enhancing community understanding through involvement of local leaders, empowering the community in the decision-making process, providing educational opportunities or facilitating the implementation of a technology that is affordable, effective, and that meets users' diverse needs, or both. As well as evaluating sustainability likelihood by utilizing comprehensive tools such as surveys, stove testing, program assessment frameworks, life cycle assessments, and incorporating results from post-project monitoring and evaluation iteratively until needs are met and exposure to household air pollution and deforestation rates are reduced.

The implications of this work are that 1) technology implementation may not be the best solution, similar investments made in education and behavior change may result in equal or greater sustainability early on, 2) the design and implementation of an improved cookstove in the field with high standards for technical design, that reduce emissions, and with flexibility for elements that do not affect performance can result in meeting users' needs better with higher adoption rates, and 3) a more holistic approach to development using available tools is suspected to result in improved cookstove programs that improve human and environmental health while meeting users’ needs for the long-term.

CHAPTER 1: INTRODUCTION

1.1 Motivation

Each year, household air pollution (HAP) due to biomass combustion causes illness that leads to the premature death of more than 4 million people (Koffi, 2013). Common illnesses such as stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer are shown in Figure 1.1 with percentages of premature deaths attributable to each illness. Approximately 3.3% of deaths worldwide are attributable to household air pollution - the largest percent of deaths attributed to a single environmental factor (WHO, 2016).

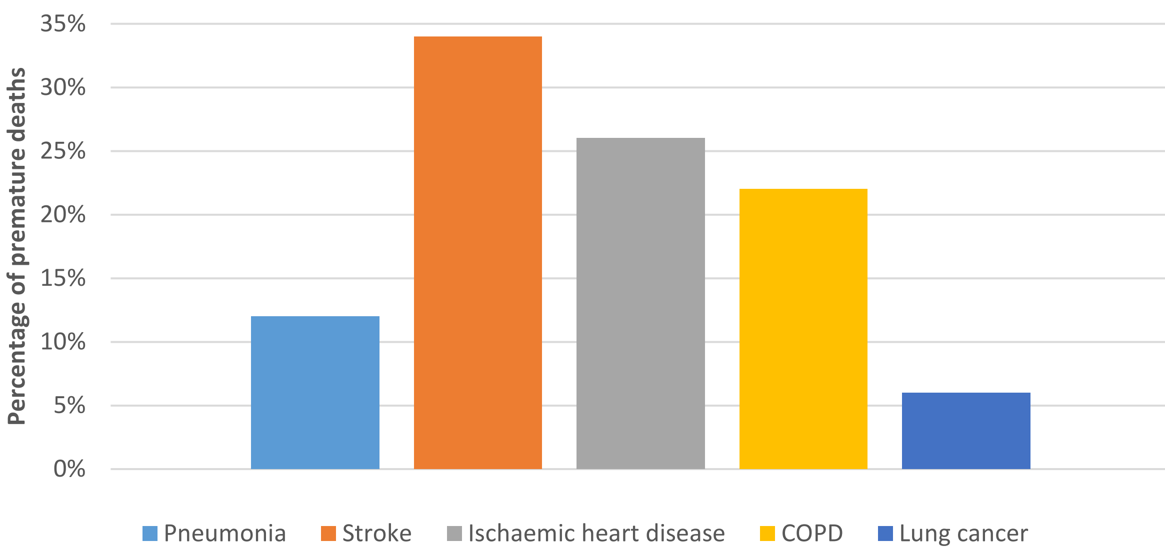


Figure 1.1 World Health Organization data for 2012 showing percentages of the 4.3 million premature deaths attributed to HAP globally by illness.

The World Health Organization (WHO) also names general household air pollution as one of the top 10 health risks and as being responsible for approximately 2.7% of the global burden of disease and 4.3% of DALYs[1]. Often the pollution levels are 100 times higher than established limits for fine particles. Children are most susceptible; more than 50% of pneumonia deaths of children less than five years of age is attributable to this household air pollution (WHO, 2016). In 2016 the updated Global Burden of Disease report (Institute for Health Metrics and Evaluation, 2016) was released citing household air pollution as the fourth leading contributor to the burden of disease behind high blood pressure, alcohol, and tobacco. Because more than half of a person's air intake over a typical life span occurs indoors, improving indoor air quality is vital to reducing the burden of disease (WHO, 2002).

There are also impacts on development and human inequity. Over one third of HAP-COPD related deaths occur in adults in low- and middle-income countries. Women exposed to household air pollution are more than twice as likely to suffer from chronic obstructive pulmonary disease, and approximately 0.7 million die prematurely from stroke associated with household air pollution. Most of the 1.2 billion people globally lacking access to electricity use biomass combustion for lighting resulting in higher pollutant levels in the house and higher possibility for burns and disfigurements. Furthermore, women and children tend to spend considerable time collecting fuel instead of becoming educated or practicing some form of

[1] Disability adjusted life years are the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability (WHO, 2018).

income generating activities (World Bank, 2010). Although those living in poverty are disproportionately affected, household air pollution also has global implications.

Household air pollution also advances global climate change. Pollution from biomass combustion combined with deforestation attributable to fuel needs accelerate climate change which has tremendous public health impacts worldwide (WHO, 2009). These impacts include the chronic illnesses mentioned previously as well as more severe droughts, flooding, storms and heat waves that wreak havoc on populations already struggling to feed their family each day (United Nations, 2015). Furthermore, it is estimated that nearly 80% of the costs associated with climate change such as loss of natural resources as capital, loss of biodiversity, etc. would fall to the developing world (World Bank, 2010).

This thesis research took place in Panama, a country that is affected by climate change, deforestation, inequity and development, and household air pollution. Figure 1.2 below shows three of ten top causes of death in Panama that are associated with household air pollution; all have risen since 2005 (Institute for Health Metrics and Evaluation, 2017).

In Table 1.1, the U.N. Global Alliance for Clean Cookstoves data highlights the potential impact of improved cookstove programs in Panama. These numbers are unlikely to change by 2030 or later without substantial change in policy and action. The role of development workers is vital to make meaningful and lasting changes to this global issue (World Bank, 2010). The traditional cookstove model known as the three stone fire is the most common cooking technology in Panama and is largely responsible for household air pollution.

Table 1.1 Global Alliance for Clean Cookstoves data on household air pollution for Panama 2015. (Global Alliance for Clean Cookstoves, 2016)

Impacts of household air pollution in Panama	Values
Total percent of population using solid fuel for cooking	17%
Total number of people affected by household air pollution	650,000
Total number of households affected by household air pollution	160,000
Total number of deaths attributed to household air pollution per year	630
Total number of child deaths per year	32

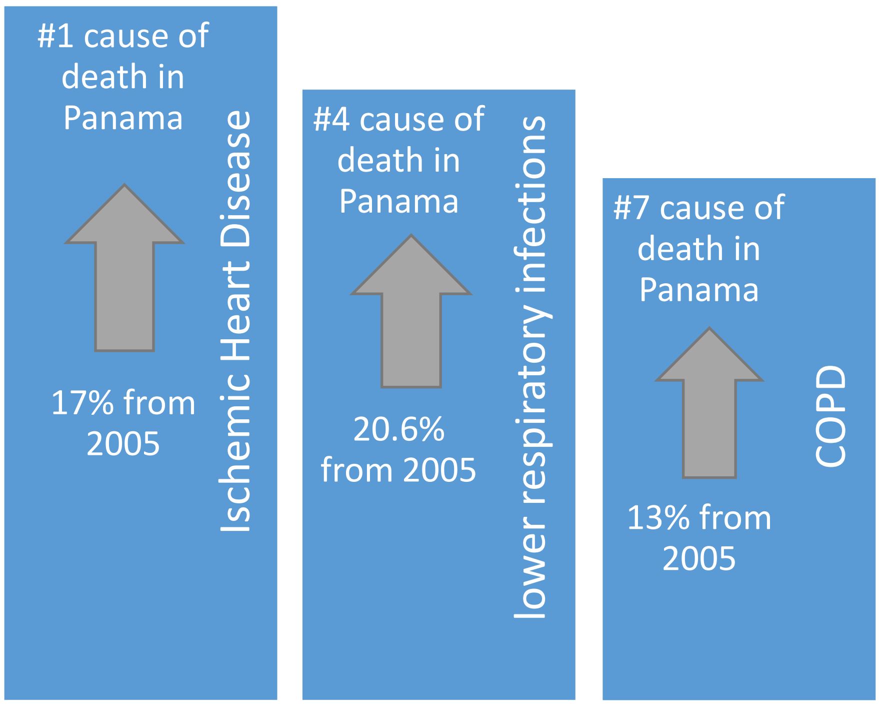


Figure 1.2 Top 10 causes of death by rate in 2015 and percent change, 2005-2015, Panama. (Institute for Health Metrics and Evaluation, 2017)

Efforts to address these environmental and health issues began earlier this decade. The United Nations Global Alliance for Clean Cookstoves formed in 2010 promotes the adoption of 100 million substantially improved stoves by 2020 with regards to combustion efficiency and fuel use to increase energy security in the developing world. In 2016 the effort involved more than 50 countries who included the household air pollution indicators and cleaner cooking technologies in their climate action plans (United Nations, 2016).

The WHO is also currently working with the U.S. Agency for International Development, United Nations International Child Emergency Fund, and World Bank to reevaluate and develop survey questions for the national censuses to better capture information related to fuels and technologies used in the home as well as impacts such as time lost to fuel collection (WHO, 2016). One approach to reducing the burden of disease, slowing climate change, and promoting equality is to improve access and usage rates of improved cookstoves in the developing world setting.

The National Authority of the Environment in Panama (ANAM) currently promotes an improved cookstove called the *ecojusta* in response to this need. Some families in Panama also use gas stoves. The United States Peace Corps is a development organization that now focuses some efforts on improved cooking technology in countries where the need is identified as a national priority, including Panama. The author of this thesis served as a Peace Corps Environmental Health volunteer in Peña Blanca, Panama 2014-2016 as part of the University of South Florida's Masters International Program. The Masters International program is a unique combination of a masters level degree in science (in this case environmental engineering) and a typical Peace Corps service. This combination of education and field experience attracts students with the skills and knowledge capable of applying highly technical problem solving to a real-world scenario. Integrating culture, behavior change, and advanced scientific assessment is how these multi-disciplinary scientists can be part of the solution to solving complex development issues. (Manser et al., 2015; Mihelcic, 2010; Mihelcic et al., 2016; Mihelcic et al., 2006; United Nations, 2015). I observed the needs and cultural responsiveness to cooking technology during my service in Panama, and it is clear from my experience that there is a need for increased focus on improved cooking technology.

Improved cooking technology for the context of this thesis refers to a cookstove which utilizes a fuel, typically biomass, that has increased efficiency and reduces indoor air pollution (Mihelcic et al., 2009). The definition of improved cookstove in this thesis includes cultural appropriateness as an important factor in 'improving' a cooking technology because of the need expressed in the literature suggesting that appropriateness is a leading factor promoting sustainability in technologies in the developing world setting (Bielecki & Wingenbach, 2014; Dickinson et al., 2015; Goodwin et al., 2015; Jan, 2012; Mobarak et al., 2012; Ramirez et al., 2012; Ruiz-Mercado et al., 2011; Simon et al., 2014; Stanistreet et al., 2015; Terrapon-Pfaff et al., 2014).

Appropriateness is meeting the users' cooking, heating, and lighting needs at an affordable cost, respecting cultural norms, and increasing sentiment of ownership and knowledge of the product through education and implementation of the stove (Mehetre et al., 2017). Sustainability is an idea that recognizes the cyclical interaction between humans and the environment. Sustainability in this context wishes to satisfy both the needs of society (present and future) and the stewardship of the environment to promote a healthy and productive today and tomorrow (EPA, 2016). Sustainability must be considered in the many life stages of a development project, especially during the needs assessment, implementation, and monitoring and evaluation stages. The goal of this thesis is to deepen the understanding of the relationship between factors influencing the long-term adoption of improved cooking technology, and to improve the way in which engineers, scientists, stakeholders, and agencies develop and implement improved cookstove programs.

Figure 1.3 Female carrying fuel wood from a long distance. Source: personal photo

1.2 Objectives

One major goal of this thesis was to highlight a holistic approach to sustainability of improved cookstove programs. A holistic approach is one that intends to incorporate many different essential elements in relation to the whole to provide the best solution possible. The following objectives were addressed to provide information to help make recommendations about the most appropriate stove(s) in the Ngäbe-Bugle region in Panama and similar rural regions.

1. Develop and implement a new ferrocement cookstove design to meet the needs and desires of the community.
2. Understand and evaluate the sustainability of the ferrocement cookstove and compare to the *ecojusta* stove, the traditional three stone fire, and gas stove.
3. Develop a construction manual for the ferrocement cookstove.

4. Provide basic guidelines for applying a holistic approach to an improved cookstove project.

This thesis will describe the design and implementation, focusing on improved sustainability, of a ferrocement improved cookstove in Peña Blanca, Ngäbe-Bugle region, Panama. The stove was designed by the author during his experience living in an indigenous community observing the culture and cooking practices associated with the three stone fire. Comparisons of the ferrocement stove are made to the traditional three stone fire, the *ecojusta* model stove that is promoted by the Panamanian environmental authority, *La Autoridad Nacional del Ambiente* (ANAM), and the common gas stove.

I used household surveys to gain information on the knowledge, opinions, and perceptions of the community related to cooking, fuel use, improved stoves, and various other components that may be important to improving the dissemination of improved cooking technology to rural populations. I utilized several tools and quantitative scores to produce rich qualitative evaluations that include social, economic, and environmental factors. The primary tool was a sustainability assessment framework (Ostrom, 2010) applied to the ferrocement stove pilot project and several *ecojusta* projects. I have also asked other Peace Corps volunteers who worked with ANAM to apply the framework to the *ecojusta* project performed in their respective rural Panamanian communities.

This work was done to better understand the process of sustainably implementing improved cookstoves to help reduce the burden of disease for women and children by increasing longevity of fuel, reducing time dedicated to searching for fuel, reducing deforestation of the area thereby protecting environmental resources, reducing household air pollution, and increasing safety in the household. Results will provide information that will be helpful in making recommendations about future improved cookstove projects in Panama and similar developing world situations through a mixed method approach utilizing qualitative and quantitative information. Findings contribute to the established literature on the topic. Additionally, to make the ferrocement a viable stove option and to continue development in the field, a construction manual was created so that the ferrocement stove may be considered for future improvements where testing can be continued.

1.3 Scientific Questions and Hypotheses

The scientific questions and hypotheses of this thesis research are presented here to better understand the purpose and motivation of the objectives of this thesis.

1. *Are the community members aware of the dangers of smoke to their health, is it important to them to reduce smoke in the household and do they connect improved cooking technology with improved health?* My hypothesis was that although smoke reduction was important to them, most people were unaware of the true impacts on their health from household air pollution. I suspect that the connection to improved health through improving cooking technology was also very weak.
2. *Are people aware of human impacts on the local environment?* My hypothesis was that people recognized many uses for trees as more than fuel and would

appreciate reducing deforestation in and around the community. However, I think that anthropogenic impacts to the environment go largely unrecognized.

3. *Is the amount of time for women and children being spent on household chores such as collecting fuel wood and cooking considered a burden?* I hypothesized that yes; most people would feel like gathering fuel wood takes too much time.

4. *What are the reasons people like and dislike the traditional stove and improved stoves?* I expected that people enjoy the traditional stove because of their familiarity with it and ease of use. I suspected that people like improved stoves because it prepares food faster and is cleaner.

5. *What are factors that would influence people to adopt improved cooking technologies in their homes?* I hypothesized that the cost of an appropriate improved stove and availability of fuel would be leading factors in influencing the adoption of improved stoves.

6. *Are the people capable and interested in building the stoves and doing the necessary maintenance?* I suspected that yes, there are people within the community with the knowledge and skills capable of building the stoves, and that households would be willing to contribute time and money to maintain a functional investment.

7. *How do the people feel about access to resources and societal support structures?* I expected that most people feel access to resources is difficult, particularly

resources that exist outside of the community. I believed that many families feel unsupported by the community and the government in their daily lives.

8. *Are there educational opportunities capable of providing inexpensive and effective intervention of indoor air pollution, deforestation, and other associated issues?* I believed that most people are interested in learning about household air pollution, reduction of local deforestation rates, family health, construction and maintenance of improved stoves, and empowering women and girls, and that the educational approach would be an effective and inexpensive way to address these issues.
9. *Is this stove a lasting improvement that is sustainability developed?* I believed that the stove would be considered sustainably developed, as the process to develop and implement the stove consciously followed a development strategy for increasing likelihood of sustainability. I also thought that the stove met most of the functional and cultural requirements of the community, was durable, and the knowledge and skill to build the stove was transferrable to the community making it a lasting improvement.

CHAPTER 2: LITERATURE REVIEW

2.1 The Traditional Three Stone Fire

The traditional cookstove model known as the three stone fire is the most common cooking technology seen in rural Panama. Several key factors are the simplicity of use, reliability, availability of materials. This stove is ubiquitous due to its ability to be constructed nearly anywhere instantaneously, the cost (it's free), and the cultural significance as a place of gathering. This stove, shown in Figure 2.1, is simply three stones, bricks, or logs that elevate a cooking pot above an open fire. Unfortunately, it is inefficient in fuel use and incomplete combustion produces a large amount of smoke that ends up in the household kitchen (MacCarty et al., 2010). This inefficiency results from poor transfer of combustion energy to the cooking pot, significant loss of energy to the stones, air movement around the stove, and poor fuel use practices (Mihelcic et al., 2009). Because of this, local deforestation proliferates as populations increase and demand more from fuel sources. Family safety is at risk as well; household traditional stoves can result in burn injuries, disfigurements, infections, chronic illness, and death (Simon et al., 2014). Thus, improved cookstove programs were developed to decrease the risk to households who rely on biomass as their primary energy source.

Figure 2.1 The traditional three stone fire as seen in Peña Blanca, Ngäbe-Bugle region, Panama. Source: personal photo

2.2 Improved Cookstoves

Access to improved cookstove programs began in the 1970s with the objective of reducing environmental health impacts. In 1990 scientists began to emphasize the connection between stoves and household air pollution, thus popularizing improving cookstoves for the public health benefits. Emissions reduction, slowing deforestation, and saving money and cooking time while improving cooking satisfaction are primary motives for improved cookstove programs. (Urmee & Gyamfi, 2014) As testing of improved cookstoves became common place, some of the fuel-efficient designs were failing to actually reduce emissions and pollutants affecting the users, furthering the need for research in the improved cooking technology sector (Partnership for Clean Indoor Air, 2010).

Early in 2011, experts set new goals of 90% reduction of emissions and fuel savings of 50% over the traditional stove model. The major goal of improving cooking technology is increase success rates of implementation by finding middle ground between technical stove performance and meeting user needs (Simon et al., 2014). It is essential that improved stoves are durable and meet user needs and fit into cultural norms to increase adoption rates so as to reduce household air pollution and deforestation over the working life of the stove (Partnership for Clean Indoor Air, 2010).

2.2.1 Deforestation

In the beginning, one of the major motivations for improved stove programs was to reduce fuel wood use and slow the rates of deforestation. Improved stoves reduce 30% – 50% of the fuel used by the traditional three stone fire (Partnership for Clean Indoor Air, 2010). The need for up to 2 tons of biomass fuel per family each year for basic cooking results from the typical inefficiency of combustion of the three stone fire. This large fuel demand can take up to an hour per day on average to collect; sometimes more depending on deforestation levels and diminishing returns from the fuel source. (Urmee & Gyamfi, 2014) Unfortunately, the inefficient use of biomass though the use of the traditional three stone fire, combined with an unawareness or disregard for scarcity of resources rapidly exhausts the fuel sources available to the most at-risk families in these communities.

According to the Panamanian environmental agency, the average family of four in Panama in 1998 consumed 10.8 kilograms (23.8 lbs.) of fuel wood each day to prepare food. In the year 2000, approximately 186,500 houses used fuel wood as a source of energy, resulting in an average annual consumption of 3,930 kilograms (86,708 lbs.) per family of fuel wood. This usage of wood as fuel leads to an estimated 50,000 hectares of deforestation annually in Panama alone (ANAM, 2014). The Ngäbe-Bugle region of Panama, where resources already have tremendous pressure from the rapidly growing indigenous population, experienced the highest annual rate of deforestation in Panama compared to other provinces between 1990 and 2000 (Pelletier et al., 2012).

Local deforestation has larger impacts as 12%-17% of global greenhouse gases are attributable to forest degradation (Intergovernmental Panel on Climate Change, 2007). Unfortunately reducing deforestation is a bigger challenge than previously imagined in the early days of improved cookstove programs. It has been shown that millions of improved stoves would need to be disseminated to have lasting effects on deforestation rates (Partnership for Clean Indoor Air, 2010). Although reducing deforestation is a vital component, the motivation to disseminate more stoves is also tied to reducing the burden of disease related to household air pollution. Eventually, it was proposed that improved cookstoves be tested to ensure and measure the reduction of key pollutants in the kitchen to ensure this goal was being achieved.

2.2.2 Emissions and Pollutants

Emissions testing is a vital tool for improved cookstove programs that plan to reduce household air pollution. Air pollution consists of chemicals and particles in high enough concentrations to harm humans and other living beings. Air pollution may cause cancer and/or other serious health effects in environmental and ecological systems. Pollutants related to incomplete combustion and often associated with household air pollution from cooking are particulate matter (PM), carbon monoxide (CO), sulfur oxides, and nitrogen oxides (Mihelcic & Zimmerman, 2014). Although many air pollutants affect health in the developing world, PM is most significant due to the ability of fine particles of 2.5 microns or smaller to affect lower airways of the respiratory system. Nearly 50% of pneumonia deaths among children younger than five are due to PM inhaled from household air pollution (WHO, 2016). In addition, household air pollution has been linked to acute lower respiratory infections such as pneumonia, adult chronic obstructive pulmonary disease (COPD), cataracts, blood pressure, ischemic heart disease, lung cancer, and stroke (WHO, 2002). It is important to understand the common pollutants associated with air quality so that one can make meaningful decisions based on emissions data.

Not only should health effects of these pollutants to individuals be considered, but their global impact as well. The combustion of biomass has an adverse impact on global climate change from emissions of greenhouse gases such as carbon dioxide (CO_2,) nitrous oxide (N_2O), and methane (CH_4) which are also emitted from cooking (Smith et al., 2000). Black carbon and CO_2 are the two most important and commonly recognized positive climate-forcing human emissions (Bond et al., 2013). Reducing both these emissions may be among the fastest, least expensive ways to fight global climate change (WHO, 2016). Solid biofuel combustion dominates global black carbon emissions – as much as 42% of total black carbon in India results from inefficient combustion (Kshirsagar & Kalamkar, 2014). Similarly, an improved cookstove program in India estimates saving 0.1-0.2 megatons of CO_2-equivalent[2] per million people in one year, resulting in an 8%-16% reduction in the average per capita CO_2 emissions (Wilkinson et al., 2009).

Fifty of the most common cookstoves throughout the world were compared for fuel use and emissions in the laboratory. This information serves as a useful guide for comparing many potential stove solutions in terms of emissions, time to boil, fuel used, cost, and safety (MacCarty et al., 2010; Partnership for Clean Indoor Air, 2010). The goal of these studies was to provide more detailed information for improved cookstove programs to make informed decisions about choosing the stove most likely to reduce deforestation and household air pollution for the target population.

2.2.3 Emissions Testing

Although emissions testing was outside the scope of this thesis, it is vital that proper emissions testing using the most recent and observed standards occurs as an integral part of improved cooking technology implementation programs. On the global level, Simon et al. (2014) recognizes a lack of accepted standards and testing protocols for improved cookstoves performance. This creates a lack of comparability between improved cookstove technology due to a lack of consensus on data collection methods for the most common tests. The Water Boiling Test (WBT), the Controlled Cooking Test (CCT), the Uncontrolled Cooking Test (UCT), and the Kitchen Performance Test (KPT) in both laboratory and field settings have established methods,

[2] Carbon dioxide equivalents are a " measure used to compare the mass emissions of greenhouse gases to a common constituent, based on the specific gas's global warming potential"(Mihelcic & Zimmerman, 2014).

but frequently are deviated from when actual testing occurs, especially when in the field. It is important that development workers in the improved cookstove field understand modern standards and are consistent with testing methods.

Efficiency is a common term used to describe how well the stove converts fuel to heat energy which reaches the pot for cooking. The WBT is a simple, standard, and easily replicated test typically performed in the laboratory to understand the transfer of energy from fuel to the cooking pot for several types of stoves found throughout the world. The CCT is another lab test developed in parallel with the WBT conducted by preparing a typical local meal chosen by stove testers (i.e. 5 lbs. of rice). The UCT is a field test that allows local stove users to prepare any meal they choose as they desire, using any size pot and operating the stove in local fashion. The KPT is the most extensive field test – a traditional and improved stove are compared side-by-side in the household to see actual fuel consumption while using two qualitative surveys to assess actual cooking behavior. Additional follow up data is collected 3-6 months after implementation (Global Alliance for Clean Cookstoves, 2014).

The Global Alliance for Clean Cookstoves (GACC) has developed, in collaboration with 80 international stakeholders, a temporary standard that states stoves should be rated on four different performance indicators ranging from 0 to 4: 1) total emissions of CO and $PM_{2.5}$, 2) fuel efficiency, 3) indoor air quality for CO and $PM_{2.5,}$ and 4) safety. A rating of 0 indicates a laboratory three stone fire and 4 represents an ideal improved cookstove that meets WHO indoor air quality guidelines. This standard incorporates deforestation and household air pollution as important assessment factors; however, international standards still fail to incorporation appropriateness of stoves and the likelihood of sustainability in internationally accepted standards. Increasing awareness of sustainability and integrating sustainability indicators can help policy makers such as the Global Alliance for Clean Cookstoves simplify, aggregate, and clarify information regarding universally excepted standards for inclusion in the International Organization of Standards (ISO) for improved cookstove programs (Schweitzer & Mihelcic, 2012).

2.2.4 Stove Safety and Durability

Traditionally, improved cookstove design focused primarily on increasing stove efficiency and decreasing emissions (Kshirsagar & Kalamkar, 2014). Then, safety and durability were also recognized as important measurements for improved cookstoves (Ramirez et al., 2012). The Iowa State University Safety Test (Johnson & Bryden, 2015) scores improved cookstoves based on ten field-based characteristics of the stove such as ability to be tipped, access to the fire, surface temperature during operation, and sharp edges (Table 2.1). Each of the ten guidelines incorporates a safety principle, a protocol for testing, and a rating metric for comparison for direct contact hazards. The tests are designed to utilize low-tech, low-cost equipment and incremental measurements to accommodate many types of field testing experiences. More than 100 improved stove designs across 20 countries have been rated and ranked according to this protocol. (Johnson & Bryden, 2015) These ten hazards are rated from 1 to 4 based on likelihood of injury with a rating of 1 corresponding to high likelihood and 4 to low likelihood or unlikely to cause injury. These scores are then multiplied by a weighting factor resulting in a score between 25 and 100. The weighting factor is used to score hazards that can result in greater harm more accurately.

Table 2.1 Ten cookstove safety hazards weighted in the Iowa State University Safety Test.

Hazard	Weighting
Sharp edges and points	1.5
Cookstove tipping	3
Poor fuel containment	2.5
Obstructions near the cooking surface	2
Elevated cookstove surface temperatures	2
Elevated environmental surface temperatures	2.5
Elevated temperature of operational construction	2
Limited or no chimney shielding	2.5
Flames surrounding the cookpot	3
Flames or burning fuel exiting the fuel chamber	4

Durability of stoves is also an important quality to ensure long-term usage of improved cooking technology (Bensch & Peters, 2015). Colorado State University (2014) developed testing protocols for durability of stoves because long-term adoption rates are affected by usability, performance, safety, and user perception. Performance and safety over the life of the stove, durability under normal usage, and perceived quality for the cost are important metrics for determining durability of improved cookstoves (Colorado State University, 2014). Given this information, it is important to utilize a standard when establishing durability ratings of stoves and incorporate that rating into overall stove selection criteria.

In summary, it is important that internationally recognized standards are observed and performed to assess potential for sustainability and reliably compare an improved cookstove that is being considered for large-scale implementation. In the following section, barriers to successful improved cookstove programs are discussed.

2.2.5 Barriers to Successful Cookstove Programs

The need for more efficient, cleaner burning, and safer stove technologies exists to begin to alleviate the burden of disease for women and children who spend the longest periods of time near biomass cookstoves. More than 160 cookstove programs now exist throughout the world. Literature and information regarding the topic is widespread and diverse. In 2014 Kshirsagar and Kalamkar published a review that provides an in-depth look at the history, classification of biomass cookstoves, protocols for stove testing, comparison of stoves, proposed modern design methodology, and barriers to dissemination and adoption (Kshirsagar & Kalamkar, 2014). Barriers to successful dissemination include institutional players (government and non-governmental), policies, economic and social situations, technical quality of stoves, and lack of information and interaction regarding these barriers.

Institutional structures include government agencies, NGO/private partnership organizations, and fully commercial private enterprises. All of which must maintain certain levels of research and development, training resources, monitoring schemes, and sales service through follow-up of programs to overcome many of the barriers to a successful program. Tied to institutional barriers are policy barriers. Often, misguided policy can have an adverse effect on stove programs. Especially when policy directs subsidies to stove manufacturers who are failing to incorporate appropriate design of stoves; removing the consumer from the process. Financial barriers are often one of the most difficult to overcome from the consumer standpoint as an improved cookstove is typically more expensive than traditional stoves, and consumers financial ability and responsibility are rarely considered from the developers' standpoint. Technical quality is also an important barrier to overcome by finding a balance of quality materials, ease of construction, all with low cost so disseminated stoves are attainable and long-lasting (Kshirsagar & Kalamkar, 2014).

Unfortunately providing an improved stove free of cost is no guarantee of high usage. Less than half of households in 26 villages in Peru used stoves which were given to them for free (Agurto & Marcos, 2011). This is often the result of a failure to incorporate social and behavioral components into the selection process for an improved cooking technology. Cultural barriers are gaining attention as stove producers begin to recognize that traditional stoves often serve needs such as lighting, heating, insect repellant, and social gathering points. Finally, the lack of cohesive information on these topics including interaction between stove producers and the targeted audience, especially women, is a significant barrier to success (Mehetre et al., 2017).

2.3 The New Challenge of Improved Cookstove Programs

Approximately 200 million households worldwide have adopted improved stove technologies; over 8 million of these are in Latin America and the Caribbean (World Bank, 2015). However, Urmee & Gyamfi (2014) claimed that most cookstove programs focused only on getting large numbers of stoves into the users' hands and failed to consider local culture, socio-economic situations, and costs and availability of local fuel. Key factors that impede improved cookstove program success include are lack of coordination among cookstove program institutions with top-down planning approaches which fail to consider cultural uses, gender equality, and actual needs of cooking technology. This results in high costs, poor stove design, and lack of education among users (Ramirez et al., 2012).

Unfortunately, designing a more efficient stove in the laboratory is the easier part, the more difficult challenge is designing a stove that is culturally appropriate and desired, affordable, and easily repairable so that it will remain effective over a significant period in the field. Future success of cookstove programs will depend largely on technical parameters of stoves that are consistent with cultural norms, attitudes of the end-users regarding adoption of innovative technologies, and cost. Additionally, success was observed from programs that utilized a 'bottom-up' strategy that involved local stakeholders and promoted participatory interaction within the community to establish a local opportunity of self-sustaining business (Urmee & Gyamfi, 2014).

2.3.1 Cultural Appropriateness

A key item for stove selection and sustained use lies in understanding the needs and opinions of the end users. Because food preparation and stove use are largely cultural activities, simply reducing emissions and slowing deforestation cannot be the only considerations made when implementing a new cooking technology. One way to gain valuable insight into the needs and expectations of the households who will adopt a new cooking technology is by utilizing household surveys to better understand perceptions and behaviors.

Literature suggests that many studies fail to consider stove adoption from the users' perspectives (Bielecki & Wingenbach, 2014; Stanistreet et al., 2015). Results of a study in rural Bangladesh suggest that 47% of study participants value reduction of fuel costs as most important, followed by reduced cooking time (21%), and ability to accommodate more biomass fuel types (14%). Surprisingly, only 9% valued the improvement of indoor air quality. Another main finding in this report reinforced the idea that the improved cookstove design should take into account attributes that the cook and households value, not simply reduction in emissions (Mobarak et al., 2012). This type of information gathering can guide the development and selection process for improved cookstove programs and will likely result in a more successful implementation program. An analysis of a household survey will be a main component to contribute to the body of knowledge of improved cooking technology as part of this thesis.

2.3.2 Education

A vital approach to increasing success of improved cookstove programs involves education resulting in positive behavior change. Behavior change can play a major role in the success of improved cookstove programs (Goodwin et al., 2015). Providing educational opportunities that fit into the cultural context focused on usage of improved stoves, fuel preparation and more efficient use of fuel, and risks associated with household air pollution are key to seeing positive behavior change in an improved cookstove program (Dickinson et al., 2015; Stanistreet et al., 2015; Urmee & Gyamfi, 2014). The best way to facilitate behavior change is to understand the behavior and perceptions of the users/households and provide contextual opportunities for learning inside the community for all age groups.

Once engrained user behaviors are better understood, education programs should be developed to teach households, specifically women, about the impacts of household air pollution on them and their families. Appropriate communication could result in more demand for improved cookstoves resulting in better family health and reducing climate change drivers (United Nations, 2016). It is suggested that behavior change programs, even without incorporating improved cooking technology, have the potential to reduce children's exposure to household air pollution. Preliminary results suggest that behavior change can result in reduction of household air pollution between 31-94% in the field. However, more rigorous studies need to be done particularly to understand how various models of behavior change influence participants to change their behavior in conjunction with quantitative results using real-time household air pollution monitoring (Brendon, 2014).

2.3.3 Social Equity

Education not only has potential to reduce destruction of the environment and the burden of disease for families, but to establish human equity through the empowerment of women and girls. Women and girls in Africa in locations considered to have moderate levels of deforestation spend up to 20 hours per week searching for fuel, typically in dangerous and isolated areas. This results in decreased potential for other tasks such as education and income generation (Simon et al., 2014). Not only do they experience time poverty, but women and children who spend more time near the domestic cooking apparatus are at significantly higher risk of developing illness associated with household air pollution (Stanistreet et al., 2015).

The Global Alliance for Clean Cookstoves believes behavior change education and the empowerment of women entrepreneurs is the future of clean cookstove programs. Empowering women by reducing the time and health burden of cooking, and building skills to produce and maintain improved cookstoves empowers local stakeholders and increase likelihood of success of development projects (United Nations, 2016).

2.3.4 Local Stakeholders

The United Nations, the World Health Organization, and the World Bank all mention stakeholders in current literature. All identify stakeholders as local governments, NGO's, stove manufacturer's, and similar organizations. Although these are undoubtedly important stakeholders, there should be more focus on engaging stakeholders at the local level that include community leaders and end-users. It is believed that by understanding perceptions of local stakeholders like these will lead to improved design of cookstoves and worldwide dissemination. The goal is to identify conflicting viewpoints with key players and recognize critical policy issues that help that can be more effectively managed to ensure likelihood of success of these global programs (Global Alliance for Clean Cookstoves, 2012; United Nations, 2016; World Bank, 2015).

Ramirez et. al (2012) incorporated responses from employees, local promoters, community leaders, and end-users in Honduras to a SWOT-AHP (strengths, weaknesses, opportunities, and threats – analytical hierarchy process) analysis about perceptions of an improved cookstove. They found that the overall perception of local stakeholders in an improved cookstove program in Honduras were largely positive. The top influential factors of all stakeholders were the strengths of smokeless cooking and reducing deforestation and emissions with opportunities for strong management, and the presence of financial resources in an untapped market. There was some focus on the threats of discontinuation of subsidies and a long waiting time to receive the improved stove along with program weaknesses. These weaknesses acknowledge that the stove was incompatible with local cooking habits, was hard to switch on, and end-users disliked spending extra time prepping wood for the improved stove. Additional weaknesses included concern about weekly stove maintenance and portability. An interesting finding from this study suggests that all stakeholders consider forest conservation more important than time and money savings. It is believed that this was a result of recent educational programs with financial incentives promoting forest conservation in Honduras. By spending more time engaging local stakeholders, addressing weaknesses and threats, and focusing on strengths and opportunities; improved cookstove programs likelihood of sustainably can be increased. (Ramirez et al., 2012)

Understanding the primary cook, often females, perspectives and opinions are essential to increasingly likelihood of adoption. While significant efforts to educate the households is quintessential for success of an improved cookstove program. (Mehetre et al., 2017) Ideally cookstove programs will consider these challenges and iteratively plan to improve adoption rates and achieve the goals previously discussed by utilizing a holistic approach to development that includes social equity for local stakeholders. If these considerations are made paramount in improved cookstove programs, sustainability is likely to increase.

2.4 Sustainability

Sustainability considers the interactions of people and the environment and our ability to balance the needs of today with the future (Amadei, 2014). To work toward sustainability with cooking technology, a successful program should include the end users in design considerations and testing, should prove efficiency of a durable model before dissemination, and should involve stoves that are safer and reduce household air pollution when compared to the technology being replaced (Urmee & Gyamfi, 2014). Many stoves performed well in controlled settings or after the initial set-up but failed to provide an actual reduction of household air pollution or household air pollution exposure (Kshirsagar & Kalamkar, 2014). In most projects the efficiencies seen in the laboratory did not translate to the field setting resulting in less than one-third of stoves still in use after five years (Simon et al., 2014).

If the new challenges, namely cultural appropriateness of improved cooking technologies are met and combined with fuel efficiency and reduced emissions, the solution is more likely to be lasting and appropriate. It is vital that future improved cookstove programs consider sustainability throughout the project life cycle and attempt to quantify sustainability initiatives to have lasting effects on public health and the environment. (Ostrom, 2010) In the subsection that follows, several key factors of sustainability in improved cookstove programs are discussed. Included is a framework for measuring sustainability throughout project phases, and the concept of quantifying the environmental impact of improved stoves using a life cycle assessment.

2.4.1 Sustainability Assessment Framework

Integration of sustainability factors- including user input- through each stage of the improved cookstove program is one approach to using quantitative data to strengthen implementation programs. As an example of this, one study in Honduras reported that up to 30% of recipients altered their stove by increasing the combustion chamber size effectively nullifying the efficiency of the stove(Lara, 2010). This is a result of a failure to incorporate users' opinions into the final design of an implemented stove. Vitally important to the sustainability of an improved cookstove program is increasing local capacity, utilizing local resources and available materials to establish a productive market. Educating and empowering people to make informed decisions about improved cookstove adoption, health, energy use, and maintenance also improve ownership and increase likelihood of sustainability (Troncoso et al., 2011).

Pursuing sustainability is an integral part of improved cookstove programs, but how is the effectiveness of this pursuit measured? The sustainability assessment framework was created to provide a road map to assess and increase sustainability of development projects. Originally adapted for water, sanitation, and hygiene projects (McConville, 2006; McConville & Mihelcic, 2007), Ostrom (2010) reassessed and refocused the framework toward assessing sustainability of improved cookstove programs. The sustainability assessment framework developed specifically for improved cookstoves programs is provided in Appendix E. The assessment framework is completed using a checklist comprised of focused questions on sustainability of economic, environmental, and three-tiered social issues including socio-cultural respect, community participation, and political cohesion. The checklist questions bring context and detail in each of five unique life cycle stages adapted from a streamlined life cycle assessment (LCA) including needs assessment, conceptual design and feasibility study, design and action planning, implementation, and operation and maintenance. (McConville & Mihelcic, 2007) The developed framework is represented as a matrix shown in Table 2.2. Each matrix element corresponds to a pairing of one of five project life stages (Table 2.3) with one of five sustainability factors (Table 2.4). Associated with each element of the matrix is a set of four questions or recommendations based on best practices in project management and issues related to the sustainability factors which help evaluate the score for each matrix. Each element is assigned a rating (0-4, where 0 is worst and 4 is best) based on the number of sustainability recommendations completed.

Table 2.2 Matrix of sustainability factors and life-cycle stages. (Adapted from Ostrom, 2010)

	Sustainability Factor					
Life Stage	Socio-cultural Respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	1,1	2,1	3,1	4,1	5,1	20
Conceptual Designs and Feasibility	2,1	2,2	3,2	4,2	5,2	20
Design and Action Planning	3,1	2,3	3,3	4,3	5,3	20
Implementation	4,1	2,4	3,4	4,4	5,4	20
Post-Implementation Follow-up	5,1	2,5	3,5	4,5	5,5	20
Total	20	20	20	20	20	**100**

Table 2.3 Project life cycle stages of the Ostrom Sustainability Framework.

Project life cycle stage	**Explanation**
Needs Assessment	Gather with community and assess demand, resources, and ability to see a project through
Conceptual Designs and Feasibility Study	Assess all potential solutions to the identified need and identify the plans and technologies to be utilized
Design and Action Planning	Choose the appropriate technology with details like schematics and budget, and put a plan into place for success
Implementation	The process of assembling materials pre-construction, a pilot construction project, full construction, and training and education
Operation and Maintenance	Continuing education, use, upkeep and maintenance, monitoring and evaluation and follow up projects

Points then add up across and down the matrix, ultimately the highest possible score for each life cycle stage or sustainability factor is 20 summing to potentially achieve the highest possible overall score for a project of 100 (Ostrom, 2010). This framework was utilized in this thesis research to provide a framework for implementation of the ferrocement style cookstove as well as a post implementation evaluation of several *ecojusta* projects. Recommendations about positive actions taken during the project as well as what should be improved or focused on for future projects is discussed in the results Section 4.3.

Table 2.4 Sustainability factors of the Ostrom Sustainability Framework.

Sustainability factor	**Explanation**
Socio-Cultural Respect	Local traditions, way of life, values, and social structure are examples of understanding socio-cultural norms
Community Participation	Empowering community members to own the process of decision making, beginning with choosing a project, how it is to be implemented, built and maintained
Political Cohesion	Assuring that local, national, and international development goals are aligned to assure ownership and aid at the community level
Economic Sustainability	Assessing that local resources and capacity are in place to ensure a successful project when outside resources are no longer available
Environmental Sustainability	Assuring that natural resources are not destroyed for short term solutions to long term problems

The disconnect between technology, implementation, and continued use of improved cookstoves compromises the Global Alliance for Clean Cookstoves development goal of 100 million households adopting an improved cookstove by 2020 (Global Alliance for Clean Cookstoves, 2012). Ostrom (2010) posits that by considering the social, economic, and environmental issues through the lens of a sustainability assessment framework, greater appropriateness and long-term adoption rates can be more readily achieved.

2.4.2 Life Cycle Assessment

A life cycle assessment (LCA) can be used to obtain a larger picture of a technology's impact on the environment and humans (sustainability). In a LCA, a product is analyzed from cradle to grave; from the extraction of raw materials to transportation, manufacturing, fuel use during the proposed life cycle, until the materials fate – typically discarded or recycled. A LCA can help better understand the impact on the environment and ecology, raw material supply, and human health (Reitinger, 2016). Impact category potentials considered in a typical LCA are acidification, eutrophication, freshwater aquatic ecotoxicity, global warming, human toxicity, photochemical ozone creation, and terrestrial ecotoxicity. Utilization of this powerful tool can reduce environmental degradation and lead to more economic design in the production, use, and end-life of a product.

More than two decades ago, Jungbluth (1997) performed a LCA on stoves and ovens in Switzerland to compare various cooking technologies including a three stone fire and a gas stove. Results suggest that cooking with wood on an open fire has high relative environmental impacts and efficiency of stoves largely determines how severe these environmental impacts. Few LCA's have been performed in a developing world setting (examples include Held et al., 2013 and Naughton et al., 2017). Only one team was identified that has performed a LCA on improved cookstoves in the developing world, but it focused on fuel types specifically and not stove choice (Afrane & Ntiamoah, 2012). This study in Ghana found the annual environmental damage cost per household of fuelwood use was US$36,500. The impact associated with the manufacture of the cookstove was not included since the traditional stove is made of indigenous local materials. Lack of accurate and consistent information for other stove models was considered a limitation in this study. It was found that the impact on humans and the local environment of firewood combustion during the use phase was highest in all categories considered (except for acidification). It is more than ten times greater than that of the nearest 'dirty' fuel and contributes about 78% to human toxicity (Afrane & Ntiamoah, 2012).

Performing a LCA can be a useful undertaking by institutions involved in improved cookstove programs globally. The results can help guide stove selection and identify areas for improvement before mass dissemination. The following section will present a closer look at the *ecojusta* as built by ANAM in Panama in conjunction with Peace Corps to identify specific needs. This case study was used to guide the development of the ferrocement cookstove that is the focus of this thesis.

2.5 Case Study: The Panamanian *Ecojusta*

A e*cojusta* style stove (Figure 2.3) is currently the only one promoted by the Panamanian environmental agency, ANAM. These stoves are made from *baldosa* or tile type clay bricks typically mixed with sawdust and baked in a kiln. These tiles and bricks make up the stove body with an ash insulation chamber between the rocket elbow and the walls. This stove is typically constructed on top of a reinforced concrete table elevated by concrete blocks.

A report on *ecojusta* stove use and durability in Panama was written by a Peace Corps Community Environmental Conservation volunteer, Joan Campau (Campau, 2014). This work was previously unpublished and was made available to me through internal Peace Corps resources. The information presented here is adapted from Campau's work. The information in this report was gathered with assistance from ANAM's engineer Rufino Rivera, from Chitré, Azuero, Panama. Campau worked with ANAM in El Toro, Azuero, Panama (Figure 2.4) on an improved cookstove project where funds were provided by grants through the ANAM agency, the U.S. State Department, and the Peace Corps Participatory Grant Process. A variety of technicians from ANAM, the Peace Corps volunteers, and locals from the communities assisted in the construction of the stoves. Participatory households were required to contribute at least 25% of total materials, cost, and labor.

Campau was the third Peace Corps volunteer in El Toro to complete an improved cookstove project. Because of the community's physical location near the *ecojusta* brick production center in El Limon, District of Santa Maria near Ocú, Panama, rapid adoption of the technology was observed. In the 6 years of Peace Corps presence in the area, more than 50 *ecojusta* stoves have been built; 43 of which are included in the Campau report. The primary objective of the study was to identify how many households have a fully functional stove, and if it is used correctly and regularly by conducting 30-minute interviews and observational analysis in 20 households.

Overall comments suggest that the stoves were not being used as intended. Campau suggests that actual fuel reduction varies significantly based on users' knowledge and skill of operating the stove. Based on observations showing buildup of carbon on the outside of the stove above the fuel entrance and damage to bricks, it was obvious that the fire wasn't being tended as was designed. In Figure 2.3, the combustion chamber can be observed overstuffed with fuel with flames coming out of the front, burning the outer bricks. Additionally, the buildup of ash blocking the grate for air circulation decreases efficiency and releases more pollutants into the indoor environment.

Users also removed the rebar and placed the pot directly onto the stove further damaging the fragile bricks. There was also evidence that some users were extinguishing the fire with water, which does damage to the stove body from rapid cooling of the tiles (Campau, 2014). Many users, 72% (n=20) report fuel savings over the traditional stove, and 44% reported faster cooking times. Only 7% reported reduced levels of smoke indoors. The two most common complaints were that it was difficult to balance two pots on the stove simultaneously (42% of 20) and that the chimney was too tall reducing the heat transferred to the cooking pot (33%). These results provided insight into the successes and failures of the *ecojusta* program in this community during this time.

With the household contribution and recognized ‘improvements’ of the stove; stove use was still varied. Most users (63% of 20) reported using the stove daily. Figure 2.2 shows percentages of households who used the *ecojusta* ‘never or rarely’, ‘approximately once a week’, and ‘daily’. One would hope that with a household contribution and a theoretically improved stove that the daily usage rate would be higher within the community; however, it appears that the *ecojusta* is not totally appropriate for the needs of the community. There is still room for improvement in the stove choice and dissemination of improved cookstoves in Panama.

Campau recommends more education of the household and all potential cooks during construction phase of the stoves. This should include the theory and mechanics of the technology, as well as the difference between the *ecojusta* and three stone fire. Training is needed for the preparation and feeding of fuel into the stove, proper lighting and extinguishing techniques, and regular removal of ash. Similarly, the more the household is involved and invested in the stove the more likely they are to maintain it properly and use it regularly according to Campau. (Campau, 2014)

Surveys like this help to generate ideas for more inspired and appropriate design of improved cookstoves for the rural areas, as well as ways to improve dissemination. One limitation of this report is that the approximate ages of each stove was not recorded.

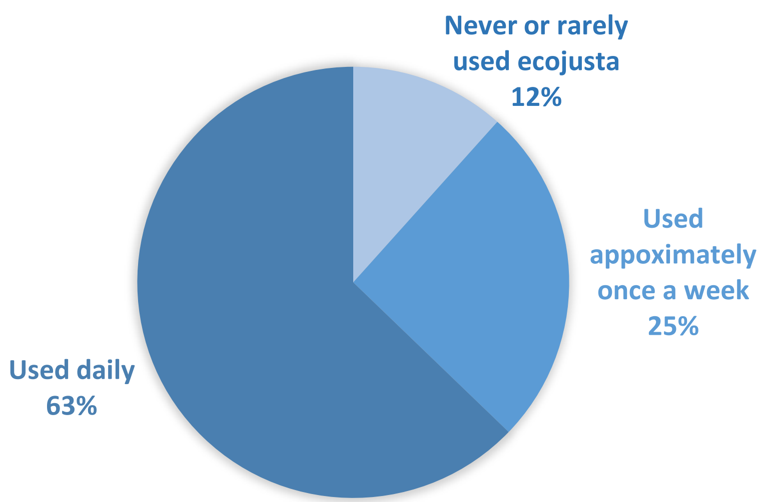


Figure 2.2 Ecojusta cookstove use by households in the Campau survey.

Figure 2.3 *Ecojusta* cookstove as constructed in the capital of the Ngäbe-Bugle region, Panama. Source: personal photo

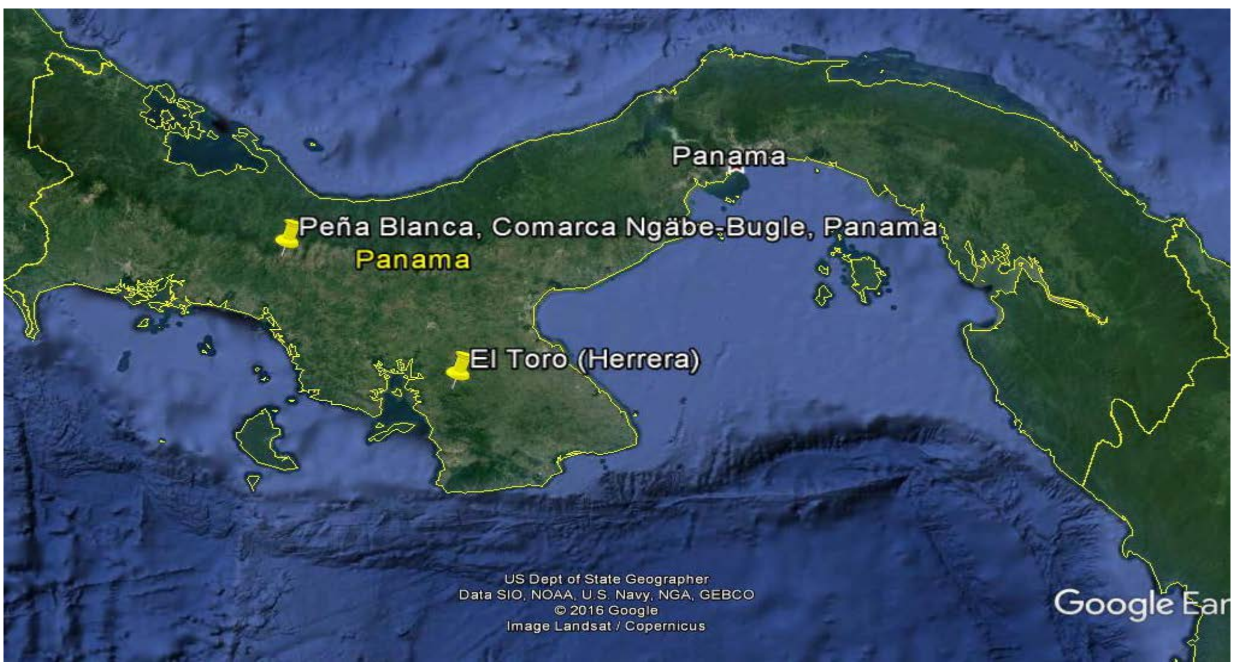


Figure 2.4 Map of El Toro, Herrera, Panama where the author of the *ecojusta* cookstove report lived and worked.

2.6 Literature Summary

Cost is often a barrier in adoption and long-term use in improved cookstove programs. Initial investments to purchase a stove are often higher than monthly income. Additionally, maintenance and care of stoves assumes a cost that traditional stoves rarely do (Kshirsagar & Kalamkar, 2014). Safety is often a key factor for women in adoption of new stoves as childcare and responsibilities in the kitchen often overlap (Simon et al., 2014). Fuel use tends to be a very important factor for both reducing household air pollution and reducing time burden for households in the search for fuel (Anenberg et al., 2013). Staple foods and beverages often take varying amounts of time to cook, making time to boil an important factor in stove choice (Bielecki & Wingenbach, 2014). Additional examples for the literature suggests that cost of the stove, safety, fuel use, and time to boil water are important data to consider when choosing an appropriate stove (Jetter & Kariher, 2009; Kshirsagar & Kalamkar, 2014). The literature also suggests that use of local materials, portability, type of fuel used, combustion type, and number of pots are important considerations for improved stove adoption. As shown in Section 2.3, there are many more key factors when planning to initiate an improved cookstove program, such as community appropriateness, educational opportunities resulting in behavior change, human equity especially for women and children, and inclusion of local stakeholders. The WHO suggests that cookstove programs that hope to reduce the burden of disease related to household air pollution must utilize a combination of interventions that acknowledge these concepts and involve multiple stakeholders, to equitably and sustainably achieve their goals (WHO, 2014).

Cost, estimated fuel use per month, and time to boil for the three stone fire, *ecojusta*, and gas stove are presented in Table 2.5 for a comparison of the three most common cooking technologies observed in rural Panama. This data was obtained from the Partnership for Clean Indoor Air (PCIA) (2010). However, the model of the *ecojusta* constructed by ANAM is different than the model that was tested by the PCIA. Panamanian food culture doesn't include tortillas, so the griddle was replaced with openings above the rocket elbow combustion chamber with square rebar on which to place the cooking pot. Additionally, the typical model has a chimney, but that feature is no longer built in Panama based on my observations and conversations with technicians from ANAM. This means that the elimination of household air pollution has likely not been achieved as intended. No data is available on specific field emissions testing of the *ecojusta* model observed in Panama.

The need for refining efforts in the improved cookstove sector include balancing implementation strategies with prioritization of technical stove performance, cultural compatibility, and the impacts of local versus imported production. The 'top-down' approach largely relies on donor funding and subsidies and tends to perform much worse than those who engaged the end-user and attempted to establish a group with the knowledge to replicate and build the stoves in the community. (Simon et al., 2014) The collapse of projects following the end of donor funding were largely attributed to poor implementation strategies inappropriate technologies, lack of community participation, and lack of training (Urmee & Gyamfi, 2014). An additional challenge associated with sustainable implementation of improved cookstove programs is the concept of 'stove-stacking' or using multiple stove models in the household. This is an observable side-effect of culturally inappropriate and poorly implemented cooking technology (Dickinson et al., 2015). Data have shown that unless the cleanest stoves are adopted and used, few health benefits are actually realized (Simon et al., 2014). If the user can't rely solely on the improved cookstove, the burden of disease related to household air pollution will not be reduced. Seemingly straightforward design considerations such as pot size, size of kitchen, length of time to heat the stove, cost, transfer of knowledge about design and construction, and aesthetics can lead to more successful projects.

Table 2.5 Comparison of cooking technologies considered in this thesis. (Partnership for Clean Indoor Air, 2010)

Stove	**Location**	**Cost**	**Safety Rating (0-40)**	**Fuel use (estimated per month)**	**Time to boil 5L of water (minutes: seconds)**
3 Stone Fire	ubiquitous	NA	21	67 kg	26:42
Ecojusta	Central America	$130	38	35-82 kg	46:42
Gas	Panama	$75 (stove + tank) +$8 per 45 lb. refill of gas ($100/year)	33	8 kg	23:00

The Global Alliance for Clean Cookstoves believes immediate action is needed despite current failures to meet the highest performance standards. There is a need for combined empirical analysis of past and current programs for local user preferences to be matched with effective designs, production, and distribution methods. An integrated approach prior to scale-up of programs with evaluation of both technical (e.g. emissions and exposures) and socio-cultural (adoption and sustained use) factors are critical to future success and sustainability (Simon et al., 2014).

CHAPTER 3: METHODOLOGY

The case study area description, design and implementation of the ferrocement stove, the evaluation of stove sustainability, household survey, sustainability framework application, and stove performance are all discussed in the following sections. The methods utilized during this research are outlined and explained including where results were obtained without following proper methodologies.

3.1 Case Study Area Description

The location of Peña Blanca, shown with a yellow pin in Figure 3.1 was the community in which the author lived and worked during his Peace Corps service from 2014-2016. The indigenous community is medium sized and located in the Ngäbe-Bugle region, district of Müna, in western Panama approximately 400 kilometers from the capital Panama City. This region was established in 1997 and borders the province of Chiriquí to the north and Bocas del Toro to the east. The community is located approximately equidistance northwest from Tole and northeast from San Felix, Chiriquí. The elevation of the community ranges between 2,300 to 3,000 feet (700 to 900 meters) above sea level and is located on the Pacific foothills of the continental divide.

There are two distinct seasons; the dry season (summer) begins in December and lasts until late April/May. During this time rainfall is basically nonexistent and winds are high and consistent leading to an arid and dry environment. In the wet season (winter), winds die down and rainfall is very consistent reaching peak downfall in October resulting in high humidity. Temperatures range from 50°F (10°C) to 95°F (35°C). The indigenous language, Ngäbere is spoken primarily in the community with mid-level Spanish spoken as a secondary means of communication. The first basic schools arrived in the community in the 1980s. Now there are approximately 300 students and 8 teachers who remain in the community during the week while school is in session. The students can earn a scholarship with good grades each semester which is considered part of family income. Currently, Peña Blanca remains without an asphalt road, electricity, phone/internet signal, modern housing, or flush toilets. A properly functioning potable water supply system was installed and is currently being used as of December 2016.

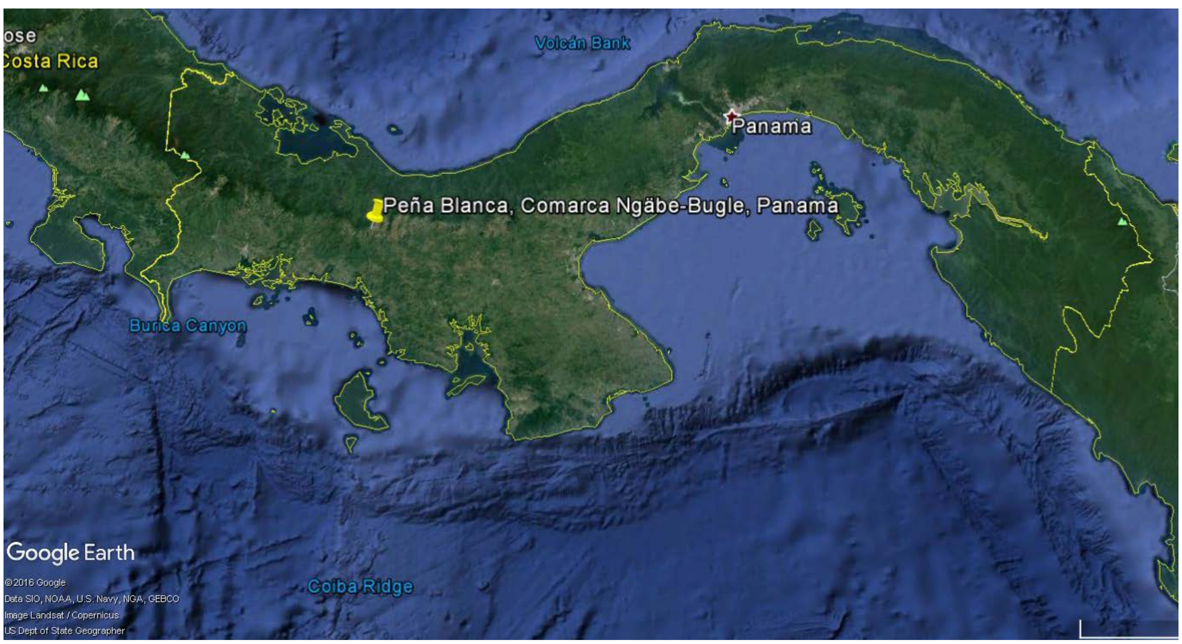


Figure 3.1 Map of Panama with yellow pin on site location of author's Peace Corps community.

Per the community census conducted by the author in 2014, there were 642 permanent residents living in 85 houses. This estimate includes approximately half the houses and corresponding population that live on the fringes of Peña Blanca community center. The community also has a health center, a town hall for meetings, and a church. The primary community activity is subsistence agriculture and harvesting and transport of trees. There is a sizable portion of migrant agriculturalists in the male population between 15 and 50 years of age who leave the community seasonally to harvest coffee and produce from nearby Cerro Punta, Chiriquí. Government programs exist which bring money into the community, and the women have an 'opportunity network' which functions similarly to welfare programs in the United States that contribute to the typical household income.

The provincial capital of Buäbti or Tugri is the neighboring community; therefore, it appears that Peña Blanca will experience large population growth as well as the benefits of development coming to the capital such as roads, lighting, wi-fi, and other government sponsored projects. As of December 2016, ANAM technicians were talking about increasing focus in this region for *ecojusta* implementation. Additionally, that they anticipated beginning to produce the required bricks for the *ecojusta* in the nearby town of Tugri.

3.2 Design and Implementation of a New Ferrocement Stove

The need for improved cookstoves was obvious to me during my stay with a host family as part of my Peace Corps service in Panama. From early morning until late at night women and children spent much of their time near smoky, poorly tended open fires. Additionally, the burden of looking for fuel wood was obvious as I spent much of my time hiking hours with my host family to cut down trees and carry them back to our kitchen where we then used an axe for several more hours to process the wood into useable sizes. I observed the way in which community members set up and operated their three stone fires, the common foods cooked, and the way stoves were used as heating, lighting, preparing traditional medicines, gathering places, and food preservation. These observations led to me to ask many more questions about cooking traditions, opinions, and desires of the households that I visited during my time in the community. I then obtained and reviewed the Campau (2014) case study on *ecojusta* stoves. Campau's comments and observations were considered during the development of the ferrocement improved cookstove that is the focus of this thesis.

I worked with my host family one evening in the kitchen to develop a prototype design of the ferrocement cookstove that is the focus of this thesis. Shortly after, I performed a needs assessment during a community meeting to better understand the interest and commitment of the community to improving their cookstoves through a community-wide project. The initial response to an improved cookstove program was high as many households, particularly women desired a more efficient and cleaner stove. I collected a list of names of those interested and advised them that we would be building the prototype stove at my host family's house shortly. After the prototype stove was built, a pilot project was initiated to refine the design by building four more stoves with the most interested families. These families were asked to contribute some materials and US$5.

The pilot project was jointly funded by the Peace Corps Volunteer Activity Council grant of $120 and the contribution from each of the families who would receive a stove. The cost was calculated based on the average material cost incurred for each stove, regardless of funding source. The Peace Corps Participatory grant was used to subsidize the cost for cement and transportation of materials for the community.

This pilot project was utilized to improve the design of the stove iteratively using community engagement during the prototype construction process. As well as imparting knowledge of stove design and combustion efficiency throughout. The intention was to teach several community members how to build the stoves by building five together as a pilot project. Unfortunately, only three stoves were built due to limitations of time.

3.3 Evaluation of Stove Sustainability

A multi-faceted approach for evaluation of sustainability for improved cookstove projects was taken for this research. The goal was to acknowledge many of the gaps identified in the literature on improved cookstove programs and show that using a holistic approach can result in higher success rates in improved cookstove programs. The methods for the approach to sustainability used in this thesis will be highlighted in the following sections. Beginning with the household survey conducted in the community, the application of Ostrom's sustainability framework for cookstove projects, and assessment of ferrocement stove performance as time permitted.

3.3.1 Household Survey

Household surveys were used to gain information regarding household demographics, knowledge and perceptions related to stoves, cooking practices, effects of smoke exposure, socioeconomics, and demand and willingness to pay for an improved stove and its maintenance, among other relevant information. The survey instrument used was adapted from a baseline survey written and coded by Dickinson et al. (2015). Many questions and answer choices were adapted for this study to suit rural Panama and the lifestyle observed while the study author lived in the community for more than two years. In addition, the survey results from Campau (2014) provided some insight into what issues Panamanians found with the *ecojusta.* Gaps in the Campau survey were acknowledged to build a more robust survey for this thesis by asking more specific questions and focusing responses to important questions regarding appropriateness and users' opinions.

The survey was translated to Spanish primarily, and a Peruvian school teacher living in the area who speaks native Spanish and advanced English verified the translation and provided recommendations for better comprehension for the indigenous population. Sample design targeted the primary cook, 18 years old or older, of the 26 households selected randomly using arbitrarily assigned house numbers from the Peace Corps aqueduct project, and a random number generator in Microsoft Excel.

The survey procedure was to approach the household, ask for permission to enter the kitchen and speak with the primary cook of the household. The purpose of the survey was explained in Spanish and the primary cook was asked if they were interested in completing the survey. A positive response was followed by reading the informed consent form to the respondent and asking for verbal confirmation of consent. Because the Spanish language skills of many of the primary cooks was poor, one woman from the local health committee accompanied me to all surveyed houses to translate the Spanish survey into the native language for clarity and comprehension (Figure 3.2). The household survey is provided in English in Appendix C and in Spanish upon request. All results of the survey included in this thesis were translated from Spanish to English by the author, including direct quotations. Descriptive statistics were generated in Microsoft Excel. Additional analysis was performed through IBM's SPSS Statistics software version 24 (2016). This study was approved by the University of South Florida Institutional Review Boards (IRB) IRB#: Pro00028279. The IRB letter of approval can be found in Appendix D.

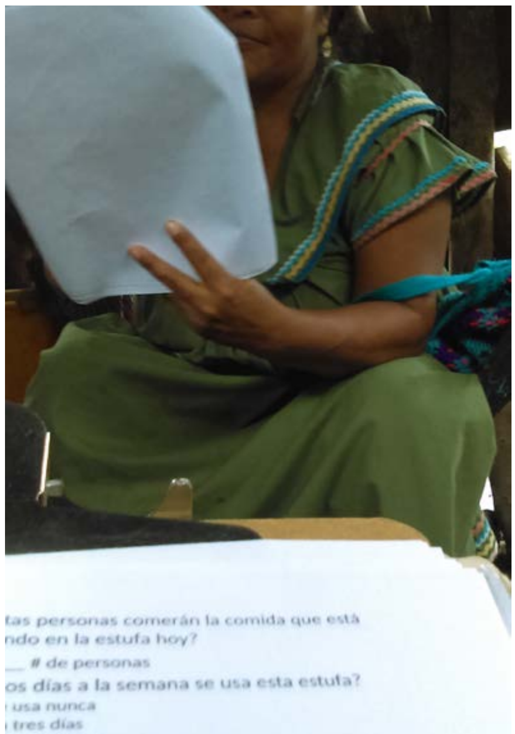


Figure 3.2 A female community counterpart who is president of the local health committee helping the author conduct household surveys. Source: personal photo

3.3.2 Application of the Sustainability Assessment Framework

Both the *ecojusta* and the ferrocement stoves were assessed using an existing sustainability assessment rubric for cookstove development projects (Ostrom, 2010). In section 4.3 I present these analyses along with anecdotal information from several Peace Corps volunteers that built *ecojusta* stoves during their service as well as my analysis of the ferrocement stove pilot project. The details of the questions for each matrix element from Ostrom, 2010 can be found in Appendix F including permissions found in Appendix B.

CHAPTER 4: RESULTS AND DISCUSSIONS

The following sections discuss the results of the household survey, observations made during the ferrocement improved cookstove project in Panama from design to implementation including results of the ferrocement stove performance. Then, the evaluation of the sustainability analysis using the Ostrom (2010) framework for several *ecojusta* projects and the ferrocement pilot project leads to an in-depth discussion of the tool's usefulness and identification of the strengths and weaknesses of both implementation programs.

4.1 Household Survey

Many of this thesis' research questions are focused on understanding the knowledge and perceptions of a community regarding cooking technology, smoke and associated health issues, and the environment. The objective of the survey administered for this study was to understand and evaluate the sustainability of an improved cookstove. This section will present results using descriptive statistics to provide contextual answers to the questions presented in Section 1.3. All results in this section have been translated from Spanish into English by the thesis author, including direct quotes. By utilizing a community counterpart, who was also the president of the local health committee, the quality of these results is expected to be high because the chances of questions being lost in translation was minimized and there was greater trust between survey administrators and respondents.

In the Peña Blanca community center there were approximately 45 houses. This study surveyed 26 households as part of the cookstove survey (58% of the households in the community center). There were 23 females with ages ranging from 23 to 60 and an average age of 40 years old and an education level equivalent between 7^{th} and 8^{th} grade and 3 males ranging from 18 to 52 years old who averaged 30 years old with an education level equivalent to 10^{th} grade who participated. Primarily respondents (n=25) were household caretakers (76%), farmers within the community (12%), or students (8%), while the heads of household (typically males) were lumberjacks (28%), farmers within the community (20%), 8% worked as a farmer outside the community, and 8% held a position as a civil servant.

Among the 26 households lived 51 children between 0 and 5 years old and 99 children between 5 and 18 years old, averaging 5.8 children per household. Respondents were asked to report the sex and ages of additional cooks (other than the survey respondent) in the household; 46 females with an average age of 20 years old and 24 additional males averaging 11 years old help in the kitchen regularly. The average family was found to spend approximately 32.1 hours per week in the kitchen. Typical foods cooked daily include rice, beans, bananas, tubers, corn, coffee, pasta, and smoked meat. Nearly all households (88% of 26) consider the three stone fire their primary stove. This stove is most often located indoors (62% of 26) (three or four walls and a roof), with 23% of the stoves located in a semi-closed environment (two walls with a roof), one stove (4%) is located outside, and one stove is located indoors with no ventilation.

The average monthly spending was nearly \$90 or approximately \$11 per person per month, with the mode monthly spending of \$100. When community members were asked if they had heard of or seen improved cookstoves in the area that use wood, 68% said no, while 27% said they had, and 4% were not sure. When asked who in the household would benefit most from an improved stove, 82% said everyone would benefit, 12% said women, and 8% said children. Notably, no one said men only would benefit the most. Also, 86% of respondents said that the government had never shown interest improving cooking technology in the community which could be a major influencing factor in respondents' awareness of the benefits of improved cooking technology and health.

4.1.1 Do Community Members Connect Improved Cooking Technology with Improved Health?

A primary question to answer in this survey is "d*o community members connect improved cooking technology with improved health?* Based on my experience in the community, I hypothesized that most people are unaware of the health impacts related to household air pollution and the potential that improved cookstoves have to alleviate the associated burden of disease.

The first step is to understand the knowledge and perception of the households about smoke and smoke-related health impacts. When asked directly, most respondents (68%) believed smoke causes health issues (Figure 4.1). The question was repeated later in the survey and got consistent results (Figure 4.2). Slightly more respondents (69%) made the connection that smoke is harmful to their family members (Figure 4.3). Respondents even associated smoke with specifically named health problems including "headache", "general damage", "cold", and "asthma" as shown in Figure 4.4. Survey respondents were asked if they had any symptoms commonly associated with exposure to household air pollution and fuel collecting in the past week (Figure 4.5). Most respondents reported symptoms associated with smoke exposure during the past week: the majority (62%) had a headache, 42% had a sore throat, 38% had a fever, 35% had back pain caused by fuel collection, 31% had dry cough, 19% had blurred vision and eye irritation, 15% had a runny nose and difficulty breathing, 12% had wheezing or whistling in the chest, and 4% had a bloody cough. In fact, only seven respondents (27%) reported having no symptoms in the past week. Then I asked several more questions about health issues related to cooking. Slightly more than a third (38%) said they often had a cough and 42% said that their cough is made worse by cooking smoke. Additionally, 46% said that they often have a whistling or wheezing sound when they breathe and 38% said this wheezing is made worse when they are exposed to smoke. A large amount, 5 out of 7 respondents (71%) over 50 years old, and 60% (n=10) of respondents between 30 and 50 years old said they frequently have wheezing in their chest. All respondents over the age of 50 said that the wheezing worsens when exposed to smoke. This wheezing or whistling is often an indicator of an illness associated with household air pollution. Many respondents (54% of 24) said they often develop a headache during cooking. The majority 71% (n=7) of respondents over 50 frequently have a headache during cooking that recedes once the smoke has cleared. Overall 82% of respondents (n=11) said their headaches get better when they finish cooking. Of the ten respondents who reported having a frequent cough, 90% spent three hours or more a day in the kitchen, and 60% spent between six and ten hours per day in the kitchen. Similarly, of the twelve respondents who frequently have a wheeze, 92% reported spending more than three hours a day in the kitchen with 58% spending between six and ten hours per day in the kitchen. These results are summarized in Table 4.1. This information suggests that the exposure to smoke impacts the respondents of the survey and many are aware of the impacts of cooking on their health.

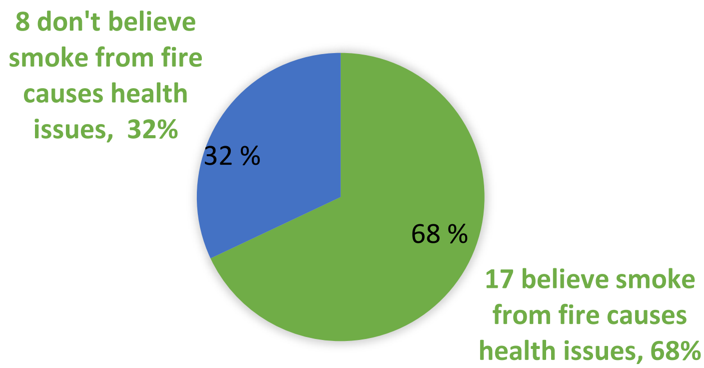


Figure 4.1 Survey result for the question “Does smoke cause health issues?” (n=25)

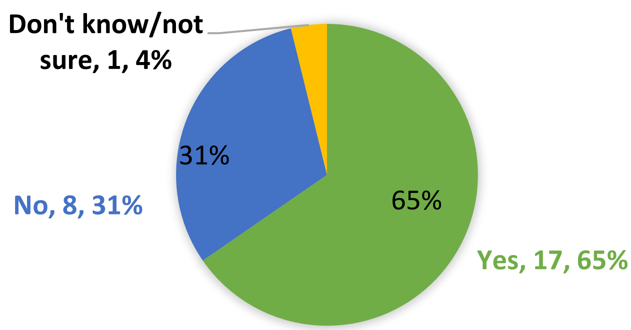


Figure 4.2 Survey result for the question “Do you think smoke from cooking is harmful to your health?” (n=26)

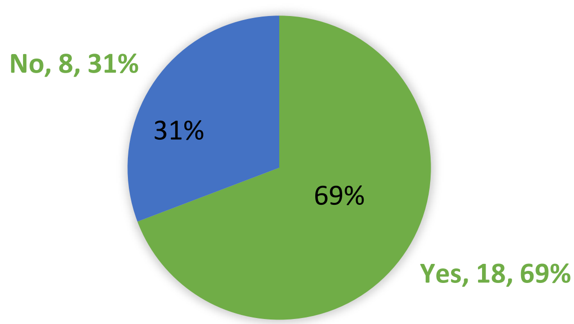


Figure 4.3 Survey result for the question “Do you think smoke from cooking is harmful to your family’s health?” (n=26)

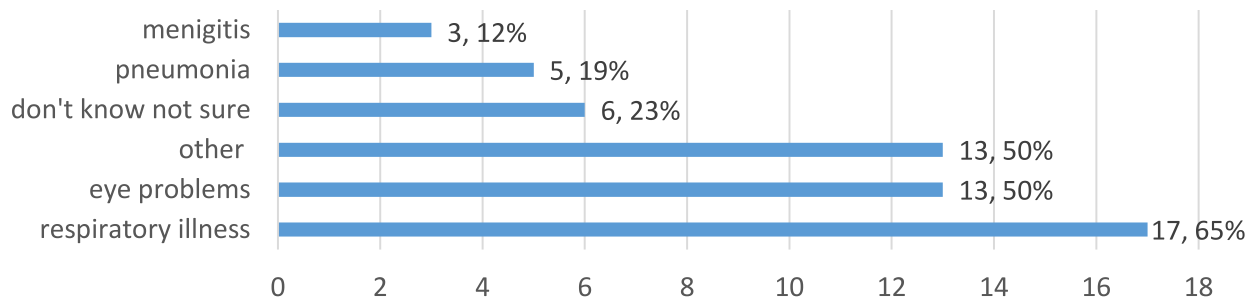


Figure 4.4 Survey result for the question “What health problems do you think are linked to cooking smoke?” (n=26)

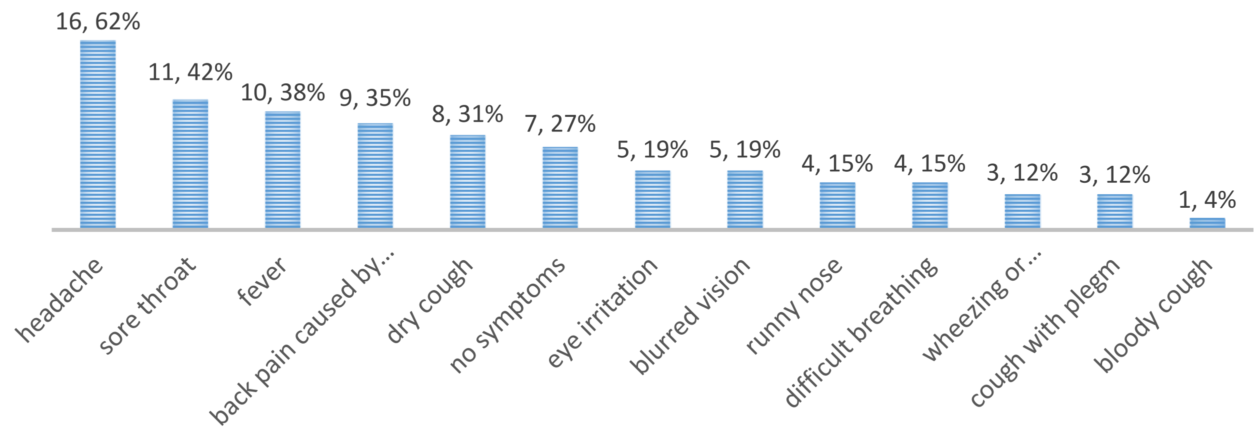


Figure 4.5 Survey result for the question “Did you have any of the following symptoms in the past week?” (n=26)

Table 4.1 Survey results for questions and responses related to smoke exposure symptoms.

Questions related to smoke exposure symptoms	Responses
Do you often have a cough?	Yes (10, 40%) No (15, 60%)
Is your cough caused or made worse by cookstove smoke?	Yes (11, 85%) No (2, 15%)
Do you often have a whistling or wheezing sound when you breathe?	Yes (12, 50%) No (12, 50%)
Is your chest wheezing or whistling caused or made worse by exposures to cookstove smoke?	Yes (10, 83%) No (2, 17%)
Do you often develop a headache during cooking?	Yes (14, 58%) No (0, 0%) Don’t know (10, 42%)
Does the headache get better, worse, or stay the same after you are done cooking?	Better (9, 82%) Worse (0, 0%) Same (2, 18%)

To gain more perspective on community members perception of smoke and other harmful environmental factors, questions were asked about the relative harmfulness of cooking smoke compared to dust from sweeping (Figure 4.6), burning trash (Figure 4.7), and tobacco smoke (Figure 4.8).

Generally, 18 out of 26 (69%) of respondents think dust from sweeping is equal in regards to harm associated with smoke from a fire. The majority of respondents, 24 out of 26 (92%) responded that burning trash is equally or less harmful than burning wood for cooking. Of the two respondents who thought that burning trash is more harmful the wood smoke, one had a middle school level education and one had a high school education.

When asked if tobacco smoke was more harmful than wood smoke, 19 out of 26 (73%) thought smoking tobacco was more harmful. These results may show the power of an educational program. During my time in Panama the Ministry of Health had an ongoing anti-smoking program. Although the program was mostly targeted toward the urban population, the Ministry distributed educational materials about the dangers of tobacco smoke to the rural areas as well. I think this anti-smoking campaign influenced the community to respond that smoke from tobacoo is more harmful than cooking smoke because the results were clearly different from the questions regarding sweeping dust and burning trash. Furthermore, it appears that many community members don’t recognize the dangers of combustion of chemicals such as plastic when burning trash in an indoor environment. As there are no solid waste management plans in place in the community, burning trash is the most common method of disposal of inorganic products. In fact, It was very common to see trash thrown into the creeks and rivers as well, surely arriving downstream to other communities' water supplies.

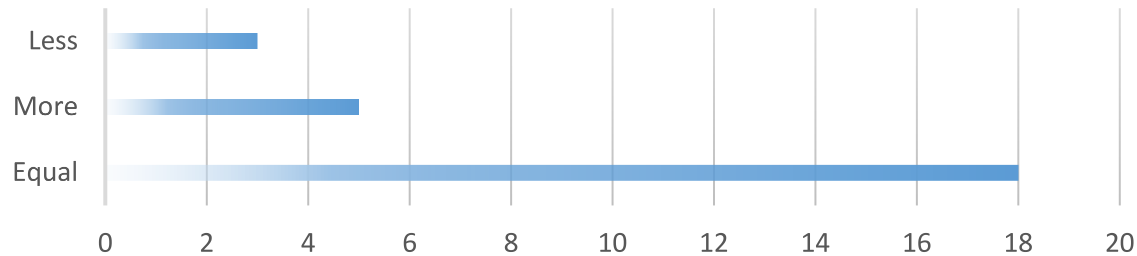


Figure 4.6 Survey result for the question "Is the smoke from cooking more or less harmful than dust from sweeping?" (n=26)

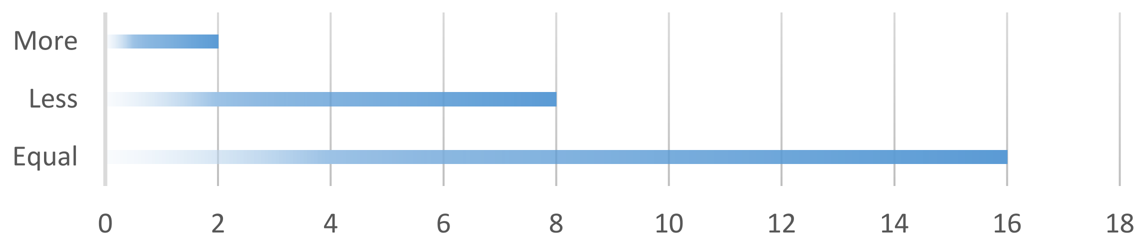


Figure 4.7 Survey result for the question "Is the smoke from cooking more or less harmful than smoke from burning trash?" (n=26)

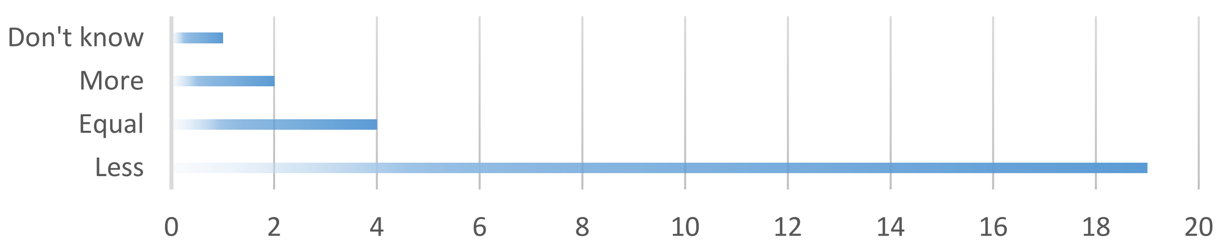


Figure 4.8 Survey result for the question "Is the smoke from cooking more or less harmful than tobacco smoke?" (n=26)

To better understand if community members connected improved cooking technology with improved environmental health, several questions of the survey focused on the topic. Several respondents (n=26) recognized problems with the traditional cookstove such as "lots of smoke (69%), causes health problems (27%), and burns body (27%)". Two households out of 26 (8%) reported that the traditional stove had previously tipped over and burned someone. Out of 25 households, 16 (64%) who said that smoke from cooking causes family health problems also said that reducing smoke was an important factor in improved stove selection. Although one household that acknowledged that smoke causes health problems didn't think reduction of smoke was important in their selection of an improved cookstove.

Although 21 out of 26 (81%) responded that smoke from cooking is more harmful indoors rather than outdoors, when asked about the main benefits of improved cookstoves, few respondents 7 out of 26 (27%) thought that improving their cooking technology would result in fewer health problems (Figure 4.9). This may demonstrate either lack of education on the topic or the survey respondents lack of faith that the improved stove technology could reduce the amount of smoke during cooking.

When asked about their willingness to pay for an improved cookstove, the majority of respondents (15 out of 25, 58%) said they would pay between $1-$10. A small percentage (15%) said they would pay nothing for an improved cookstove, yet 4% said they would pay between $30 and $40 (Figure 4.10). However, because it was suspected that many families weren't financially capable of paying for an improve stove, respondents were asked what materials or services their household would contirbute to improve their cooking technology. Many respondents said they would contribute wood (65% of 26) and sand (62%), while only 35% said they would contirbute labor and only 4% said they would contribute tools, and no one would contribute transportation, bricks, or wiremesh (Figure 4.11). Respondents were then asked if they contributed any of the materials above, how much would they now pay for an improved stove. The percentage of the population who would pay nothing rose from 15% to 38% (n=26) while 42% said they would still pay less than $10, 12% would pay between $11-$20, and only 4% would pay more than $20 (Figure 4.12).

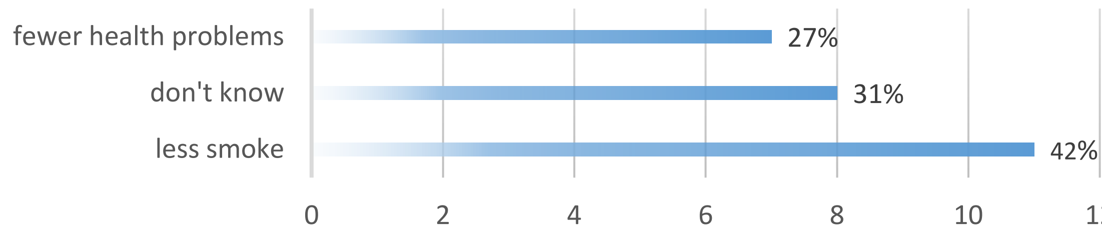


Figure 4.9 Partial survey result for the question "From what you've heard, what are the main benefits of (improved cooking technology)?" (n=26)

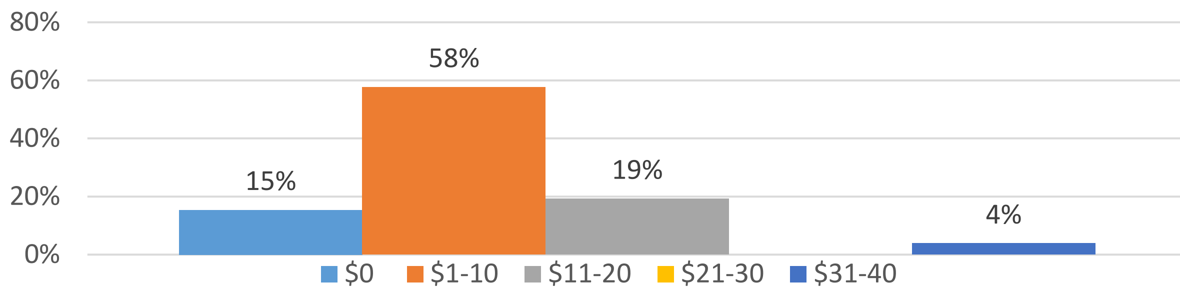


Figure 4.10 Survey result for the question "How much would you pay for an improved cookstove?" (n=25)

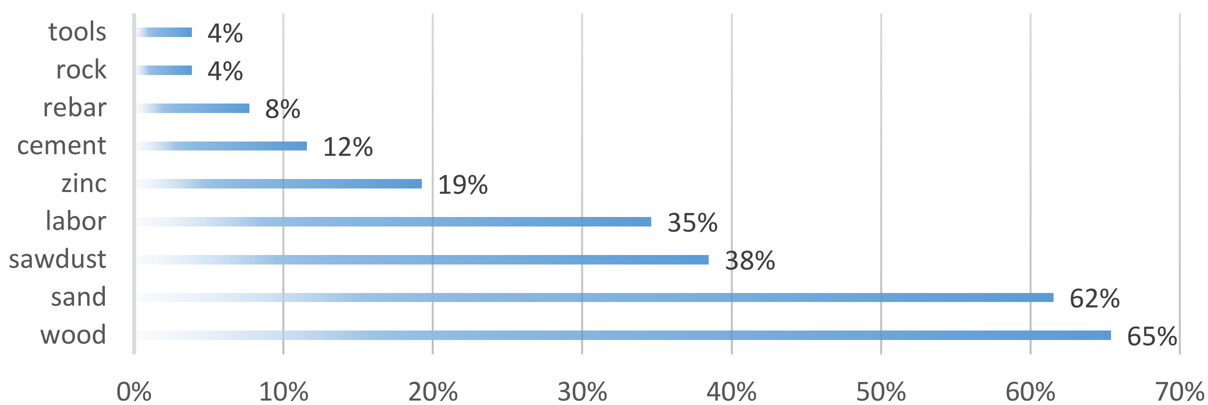


Figure 4.11 Survey result for the question "Are you willing to contribute any of the following to improve your stove?" (n=26)

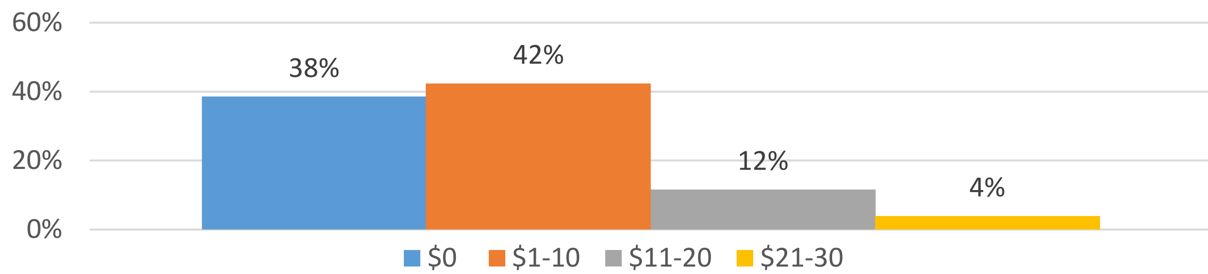


Figure 4.12 Survey result for the question "How much would you pay for an improved cookstove if you contributed some of the materials listed above?" (n=26)

Some users have already invested in an improved cookstove in their household. Of the 10 households that use a gas stove and a traditional stove, four (40%) say they use gas to reduce smoke in the kitchen, and two (20%) use the gas stove because it is safer. Interestingly, two out of 10 households (20%) who already paid for a gas stove said they would pay nothing for an improved cookstove. However, when asked "what would convince you to use only 'improved or gas' stoves", all households (10) that currently use both stoves said that no smoke in the kitchen would convince them, and six households stated safety would convince them to discontinue use of the traditional stove. Half of the households with a gas stove report only using it one day per week while 40% say they use it at least three days per week at a maximum. Users with gas stoves still spend an average of three hours per day processing fuel wood, a reduction of approximately an hour and a half from households with no gas stove. Of these ten gas stove users, 90% said they had cooked with wood in the past month. Additionally, 60% reported spending three or more hours in the kitchen daily.

Most households appear to fail in recognizing that improving the way they use energy and in effect polluting less, could have positive impacts on their health. For example, when asked, 25 of 26 households stated that there is "not good lighting in the house at night", but only one household out of 26 (4%) believed that electricity in the home would improve their lives. This appears to be a failure to recognize that electrified homes could meet users' needs such as cooking, lighting, and heating and move the combustion process for energy for these needs outside of the home resulting in improved indoor air quality.

Although the majority (68%) of respondents (n=26) believe that smoke is harmful to their health, only 27% recognized improved health from improving cooking technology with most respondents not knowing the benefits of cleaner combustion. These results confirm my hypothesis and suggest the need for more education and dissemination of information regarding improved cookstove benefits related to family health.

4.1.2 Are People Aware of Human Impacts on the Local Environment?

The second scientific question of this study was, "*Are people aware of human impacts on the local environment?"* Based on my experience in the community, I hypothesized that most people are aware of the local environment and to some extent, the impact they have on it specifically related to harvest wood for fuel.

Many respondents (n=26) acknowledge the many uses of trees in their environment (Figure 4.13). Shade for people and animals was the most common benefit of trees acknowledged by the community (73% of respondents). Also, 62% of respondents said that trees provide wood and protect water sources, 58% said trees provide food, 46% said trees provide traditional medicine, additionally around 40% of respondents recognized trees as habitat for animals, wind breaks, maintaining soil fertility, and providing clean air.

However, most people (73%) don't recognize that their use of fuel for cooking have any negative effects on the local environment. Specifically, 31% believe their demand for fuel wood has no impact on the environment. Less than a third of respondents (27%) believe that fuel collection contributes to deforestation, climate change, erosion, and air pollution (Figure 4.14). Only five respondents out of 26 (19%) believe that their cooking practices and demand for fuel wood affect air pollution specifically. Of the five that believe their fuel use causes air pollution, three of them are younger than 30 years old; 60% have a high school education and 40% have a middle school equivalent education. No one over the age of 50 (n=7) believes that harvesting fuel wood affects deforestation. However, 86% of those that believe that their use of wood for fuel causes deforestation include six respondents that said chores take too much of their time. The connection between time spent looking for fuel wood and deforestation may be recognized here. Overall, there appears to be a failure to acknowledge that over-harvesting fuel wood will impact the environment.

No respondents over the age of 50 (n=7) believed that human actions have any impact on local weather patterns while 3 out of 5 (60%) of respondents younger than 30 believe in anthropogenic climate change. Only 2 out of 20 (10%) respondents who have education levels equivalent to middle school (two have no official education) or less believe that human actions have impacts on the environment while 50% (n=6) of respondents with a high school education believe that humans impact local weather patterns. Although a large majority of respondents believe humans do not impact climate change (Figure 4.15), nearly all respondents observed some change in the local weather pattern over the past several years, specifically that there was more rain (Figure 4.16). There are 7 (27% of 26) respondents who say that their fuel use affects climate change including 40% (n=7) of those 50 years old or older. Similarly, seven (27% of 26) respondents believe their fuel use affects erosion. Some users responded to an open question about reasons for climate change, responses included: “cutting down trees and smoke in the air”, “humans”, “smoke, dust, and cutting down trees”, “failing to protect plants and trees”, “trash, chemicals, contamination, and cutting trees”, and “sickness and worry”.

Although a small number of respondents were knowledgeable on climate change and anthropogenic impacts to the local environment, largely there appears to be a failure of respondents to connect the impact humans can have on the environment. This could be because of circumstances of poor education and poverty with cause and effect on a large scale being difficult to identify. The impact that fuel wood harvesting has on the local environment could be better understood by the community with properly-framed environmentally focused talks given by the governmental authority on the environment. This understanding would likely create a more pressing desire to upgrade to an improved cooking technology because community members rely heavily on their environment for water and food and the local environment appears to be important to them.

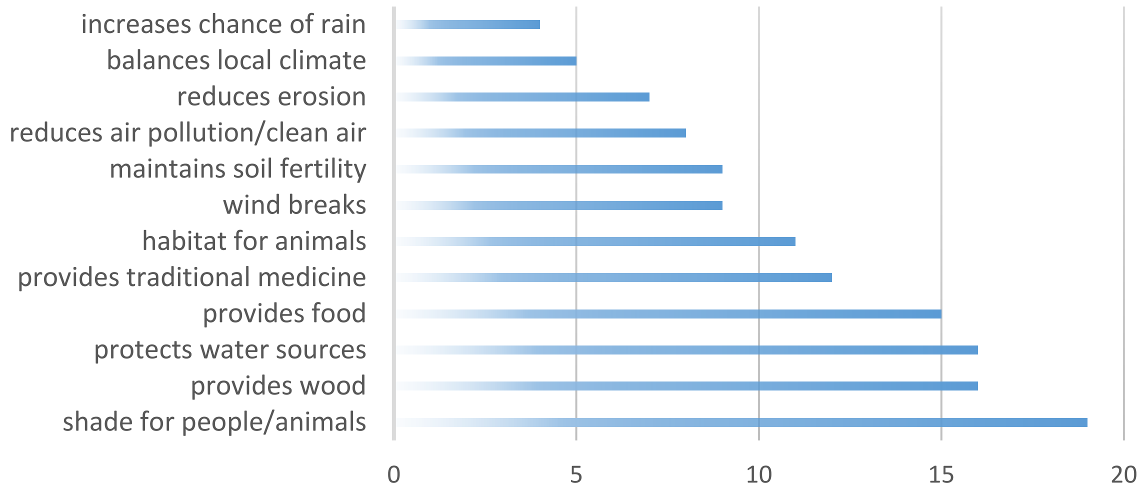


Figure 4.13 Survey result for the question “Other than providing fuel, what are other benefits that trees provide in this area?” (n=26)

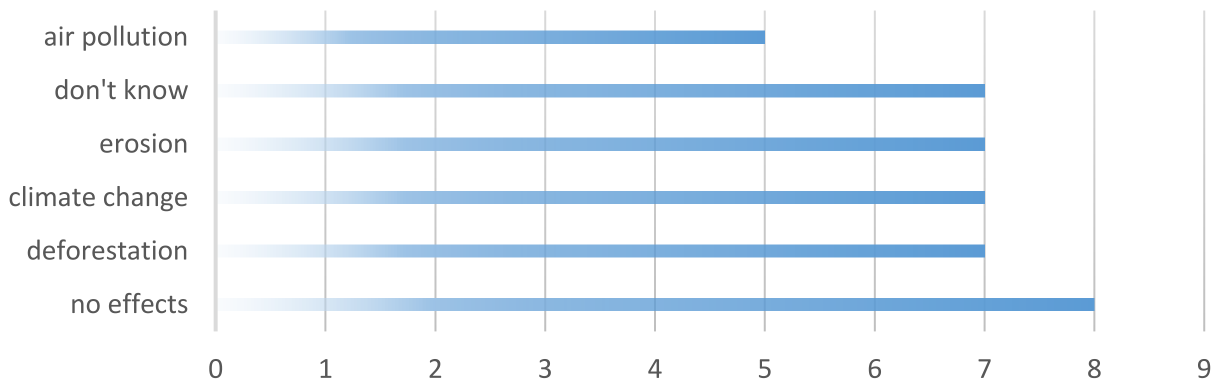


Figure 4.14 Survey result for the question “Do the fuels people use for cooking in this area have effects on the air, water, land, plants, and animals around us?” (n=26)

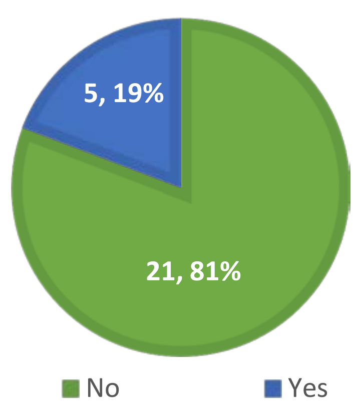


Figure 4.15 Survey result for the question “Do you believe that human actions have any impact on changes in local weather patterns?” (n=26)

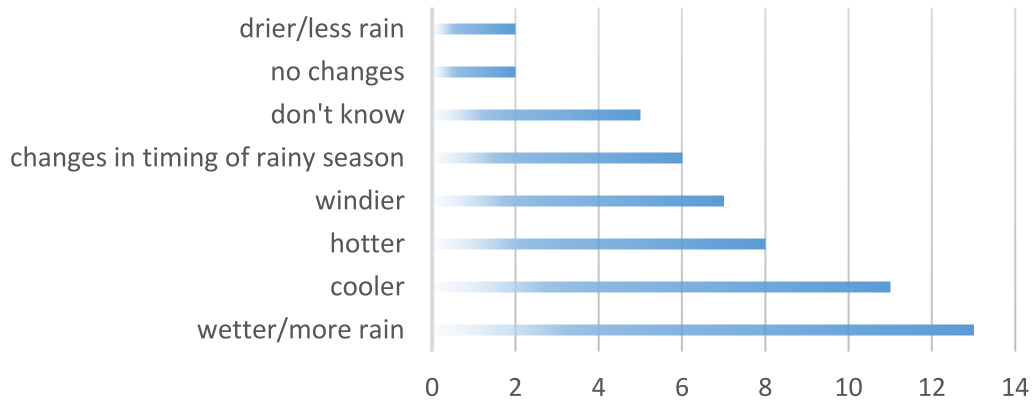


Figure 4.16 Survey result for the question "What, if any, changes have you noticed in local weather patterns over the past several years?" (n=26)

4.1.3 Is the Amount of Time Spent on Household Chores Considered a Burden?

To better understand the perception of time demand of household chores, specifically for women and children, respondents were asked the question "*Is the amount of time for women and children being spent on household chores such as collecting fuel wood and cooking considered a burden?*" Based on my experience in the community, it was hypothesized that most people feel that gathering wood and cooking takes an excessive amount of time and is burdensome as a daily chore.

In general, 38% (n=26) of respondents said they "did not have plenty of free time". Overwhelmingly, the respondents (88% of 26) believed that household chores take too much time (Figure 4.17) with 100% of women between 30 and 50 (n=11) saying chores take too much time. In fact, 14 out of 26 (54%) of respondents reported spending between six and twelve hours a day in the kitchen. Of those 14, 11 (79%) of respondents were older than 30 years old with 71% (5 of 7) of respondents over 50 spending more than six hours per day in the kitchen.

These households quantified that an average of 10 hours per week are spent collecting fuel. Respondents were asked to identify anyone else in the household who typically help with this chore; 22 females with an average age of 31 years old and 47 males with an average age of 28 years old also average 10 hours per week on fuel collection. Many households find it difficult to get fuel wood (Figure 4.18) with 69% stating there is "not always enough fuel". Most respondents (58% of 26) report that they get their fuel from family land, while 23% get fuel from public land, and 19% get fuel from their neighbors' land. Income doesn't seem to play a role in source location of fuel wood for households. Both above and below average income groups report sourcing their fuel from the family, public, and neighbor's land in proportional amounts. This likely suggests that many households have already depleted their fuel wood supply on their property. Often, these households are required to travel far away from home to secure fuel, a trying and sometimes dangerous task. Supporting, 11 respondents (64% of them 30 years old or older) said it is now harder than before to get fuel wood in the area and 2 households had changed fuel type to gas due to difficulty in securing fuel wood. On the other hand, 8 households (31%) had not noticed a change in difficulty of access to fuel while 7 households (27%) thought it now easier to get fuel than in the past. However, five of 12 respondents (42%) who said it was easy to get fuel for cooking also said that their family often doesn't have enough fuel with which to cook.

When asked how important a reduction in fuel use was for choice of improved cookstove, 13 (50%) respondents said a reduction in fuel use was somewhat important, while 8 (31%) said it was a very important factor which suggests that many households (81% of 26) view this chore as a burdensome task. Notably, 24 out of 26 respondents (81%) said they would buy an improved cookstove even if it required more fuel prep time. Overall results suggest that the households do perceive the time demand of household chores, specifically related to cooking, to be a burden.

Many women (9 of 14, 64%) who said that chores take too much time found a women and girls empowerment educational talk less interesting than family health, the environment, and a talk on maintaining cookstoves. Although it may not be recognized, reducing this time burden may be a way to promote women's empowerment which could create additional sources of income for the household by allowing women to create more artisanal goods or grow more crops to sell or eat. Additionally, reducing this time drain for children would allow more time spent studying, doing homework, and potentially helping the adults with some economically positive activity while addressing human equity concerns as identified in the literature.

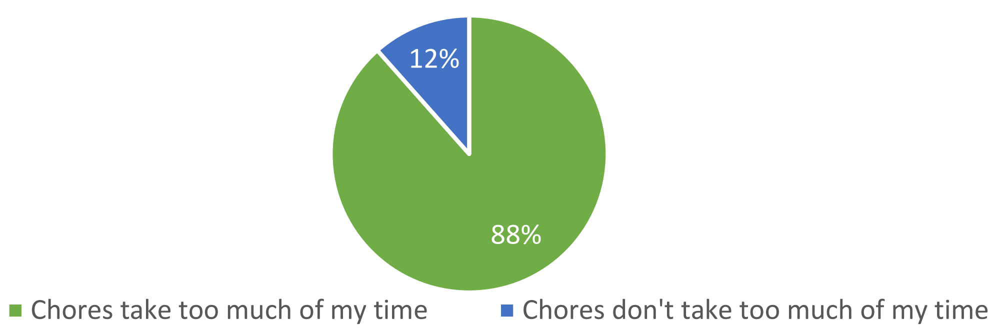


Figure 4.17 Survey result for the question "Chores take too much of my time?" (n=26)

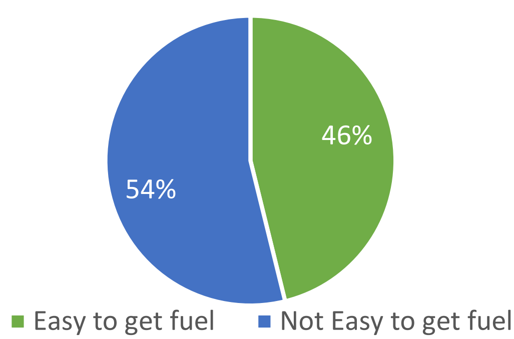


Figure 4.18 Survey result for the question "It is easy or not easy to get fuel?" (n=26)

4.1.4 What are the Reasons People Like and Dislike the Three Stone Fire?

The fourth scientific question is helpful when considering appropriateness of an improved cooking technology: "*What are the reasons people like and dislike the traditional stove and improved stove?"* Based on my experience in the community, I hypothesized that most people enjoy the simplicity and reliability of the traditional stove, while they enjoyed how quickly and cleanly the improved stove prepares food and beverages.

Many users (58% of 26) appreciate the simplicity of the three stone fire and its ability to smoke meat, a very common method of preservation in a community without access to electricity. Large household sizes are also easily supported as the three stone fire cooks significant amounts of food quickly with a large fire. Many households also use their stove as a means of disposal of solid waste, insect repellant, and heating and lighting. Figure 4.19 presents many reasons that people responded to why they like the three stone fire.

On the opposite end of the spectrum, there are many complaints about the three stone fire. Overwhelmingly households complained of the smoke (68%), dirtying of pots and the kitchen area (42%), and difficulty of securing fuel wood (38%). Some unfavorable aspects of the traditional stove are shown in Figure 4.20. Of note, only seven households (27%) said they didn't like the traditional stove because it causes health problems.

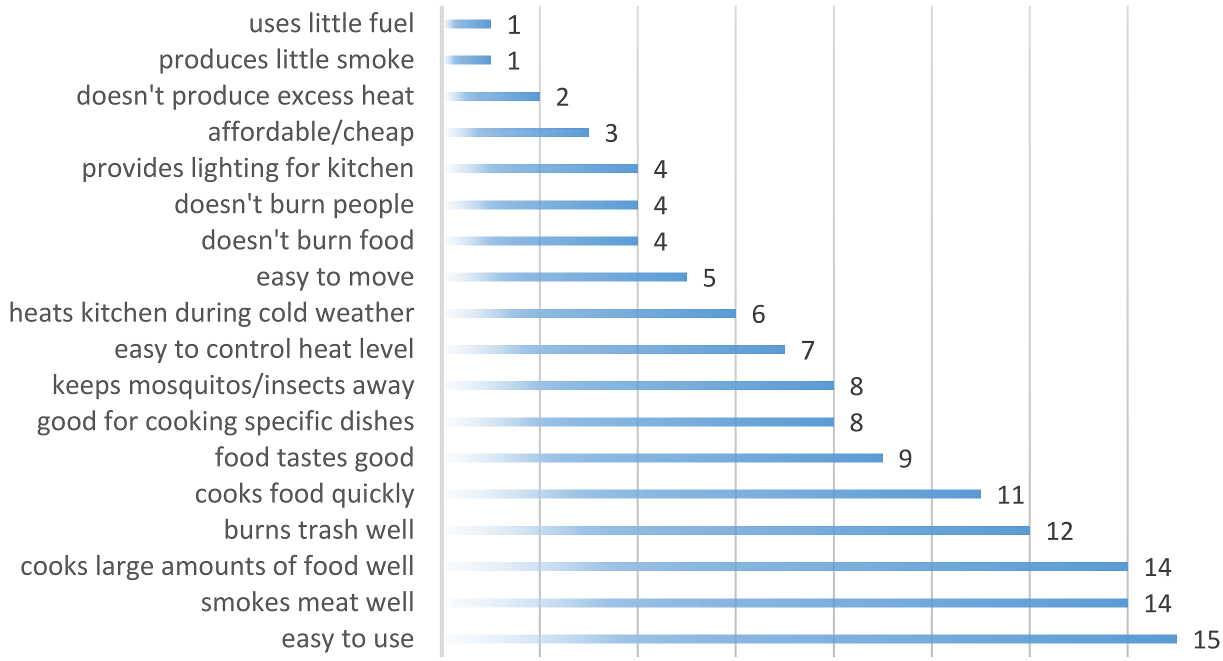


Figure 4.19 Survey result for the question "…reasons people like the three stone fire". (n=26)

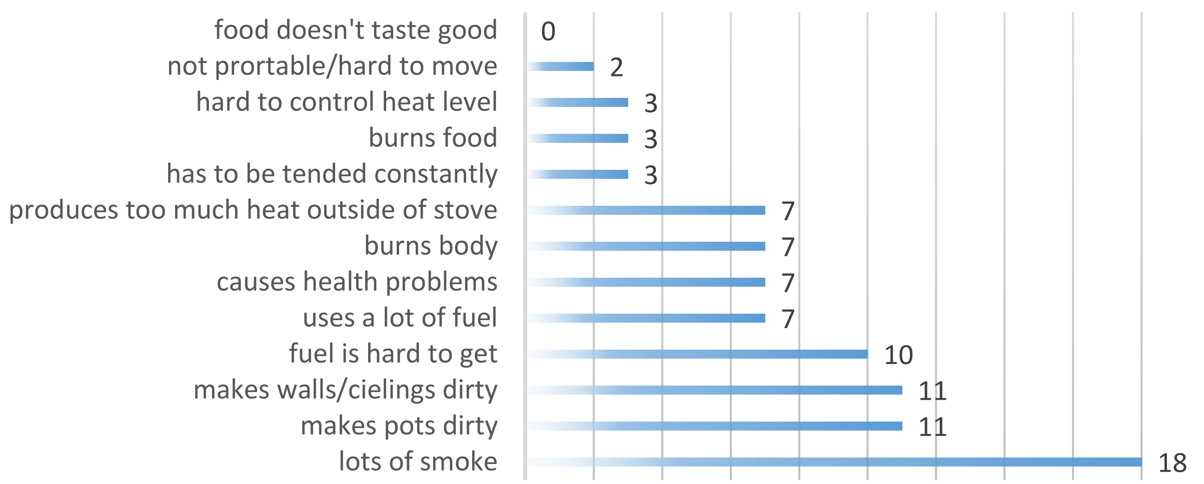


Figure 4.20 Survey result for the question "…reasons people dislike the three stone fire". (n=26)

4.1.5 What are Factors that Would Influence People to Adopt an Improved Cooking Technology?

By better understanding the likes and dislikes of the three stone fire and the gas stove, the appropriateness of an alternative improved cooking technology can be focused in by considering public opinon. By understanding and incorporating responses from question 5, “*What are factors that would influence people to adopt improved cooking technologies in their homes?”,* an implementation program may see more success. It was hypothesized that the cost of an appropriate improved stove and availability of fuel are leading factors in influencing the adoption of improved stoves.

As previously mentioned in Section 4.1.3, a reduction in fuel use is a beneficial characteristic of an improved stove. Figure 4.21 ranks many factors named by the community that would influence adoption of improved cooking technology in their homes. The five most important factors reported for an improved cookstove for this community (n=25) are:

- simplicity and ease of use (92%),
- ability to control the heat (92%),
- pot stablity on the stove (92%),
- size of the stove (88%) with a chimney (68%), and
- reduction in both smoke and fuel use (84%).

A surprising amount of respondents said that previous experience with the stove, safety, portability, and cost were relatively unimportant in their choice of improved cookstove. Safety, cost, and portability were factors specifically mentioned during conversations with my host family while developing the idea for the ferrocement stove which led me to believe them important in the stove design. Less than half (11 out of 25 (44%)) say that safety is an important factor , and about half (12 out of 25 (48%)) said that portabilty was important.

Some community members have an improved stove, a gas stove, that they use in conjunction with their traditional stove. While there were two common problems households found with gas (that it is hard to get, and the stove makes pots dirty), the implication is that many users are satisfied with their gas stoves. The primary reasons community members appreciate their gas stoves are how quickly it prepares food, how little smoke it produces, and how easy it is to use (Figure 4.22). These results provide insight into vital considerations for improving a cooking technology in the community.

I anticipated that cost would be a more important determining factor; however, it ranked as less important to other more technical factors of stove design such as simplicity and size. About half (12 out of 25 (48%)) said that cost was not an important factor for improved stove selection. Supporting this result, 88% of users said they would not be willing to use a community stove to share costs.

The response "has a chimney" appears to be a key factor for most households with 17 out of 25 (68%) saying that it is important that the stove has a chimney; however, it is unclear if the community desires a chimney or not. After speaking with some of the pilot project households, many of them were against having a chimney because they recognized that heat escaped rapidly through the chimney as opposed to the pot or heating the kitchen.

However, a "reduction in smoke" also appeared as a crucial factor, which is typically a function of a chimney for biomass burning stoves. The reduction of smoke was important to 84% (n=25) of the respondents independent of education level. No respondent over the age of 50 (total of 7) said that a reduction in smoke was very important to them, although 71% said that it was somewhat important. On the contrary, only 2 out of 18 respondents (11%) under the age of 50 said that a reduction of smoke was not important while 50% said it was very important.

Interestingly, four out of seven respondents (57%) who don't believe that smoke from cooking causes familial health problems still said that reducing smoke was an important factor in their selection of improved cookstoves. Only one household said that smoke from cooking causes health problems to the family but didn't think reduction of smoke was an important factor for an improved cookstove. Similarly only one respondent said that smoke doesn't bother them and it wasn't important for an improved stove to reduce smoke.

Whenever an improved stove doesn't meet the users' needs completely, stove stacking occurs as observed in the community. Figure 4.23 shows results on why users who use multiple stove technologies do so which is primarily to prepare food faster, produce less smoke, and so that the children can help. Less than half (40% of 10) say that stove stack to avoid smoke. Only two of the ten (20%) users who use both a gas stove and the traditional stove say they do so to use less fuel. While four (27%) of the users that said a reduction in cooking time (n=15) was an important factor for adoption of an improved stove said that they stove stack to prepare food faster. In contrast, 15 out of 26 (58%) said no smoke in the kitchen would convince them to buy an improved stove, while 10 out of 26 (38%) said that availability of fuel and faster cooking times would motivate them to stop stove stacking. However, switching entirely to an improved stove may not solve fuel shortage perceptions, most, 16 of 26 households, (62%) said that availability of fuel was important to their stove choice yet 8 out of 10 (80%) gas stove users said that their family often doesn't have enough fuel with which to cook.

Understanding why users choose to incorporate multiple stoves into their cooking routine is important for developing attributes of an appropriate improved cookstove that can be effectively marketed to the community. Figure 4.24 shows responses to a question asking what factors of an improved cookstove would convince users to fully replace the traditional stove with an improved stove. This action would help achieve the international goals set forth for improved cookstove programs more rapidly by eliminating stove stacking.

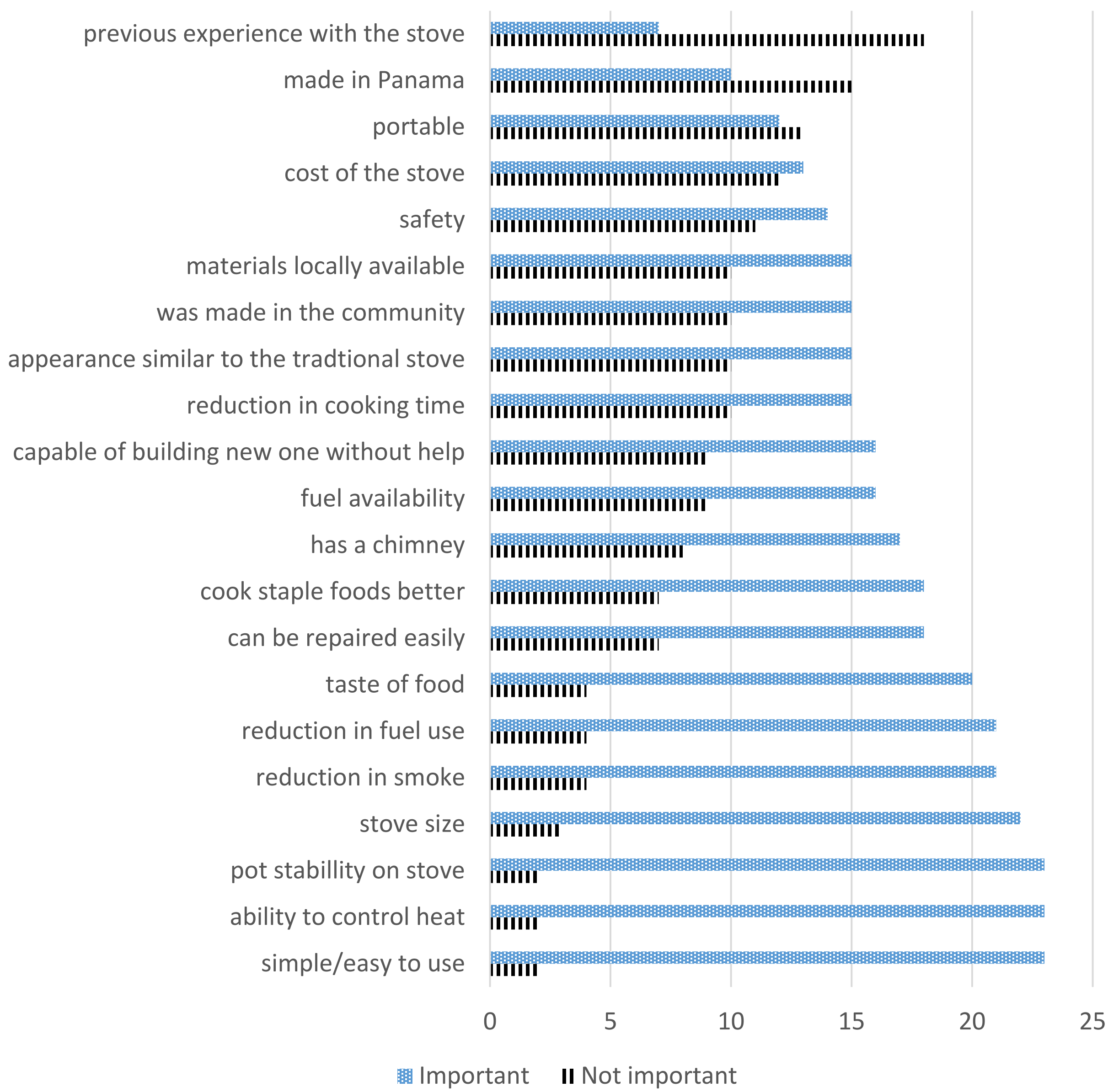


Figure 4.21 Survey result for the question "How important are each of the following factors to your choice of improved stoves?" (n=26)

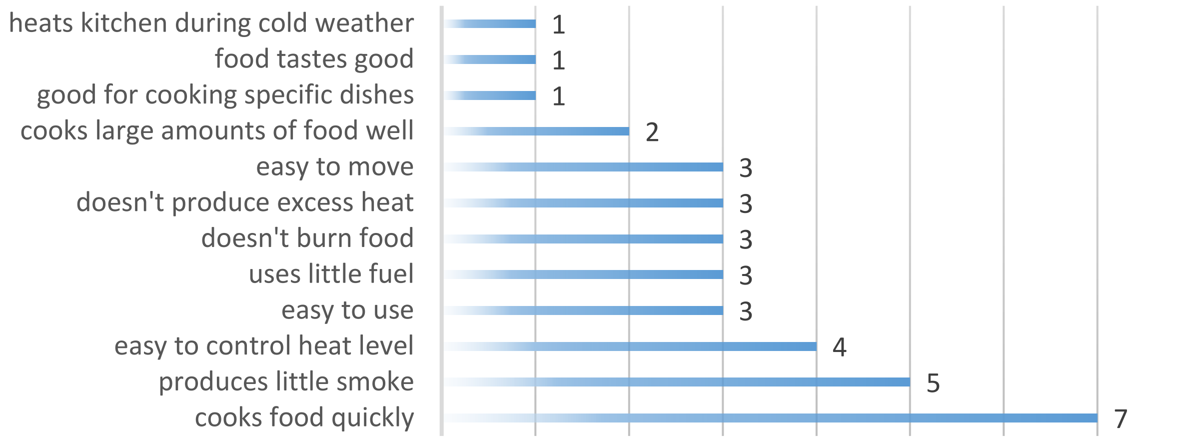


Figure 4.22 Survey result for the question "…reasons people like the gas stove". (n=10)

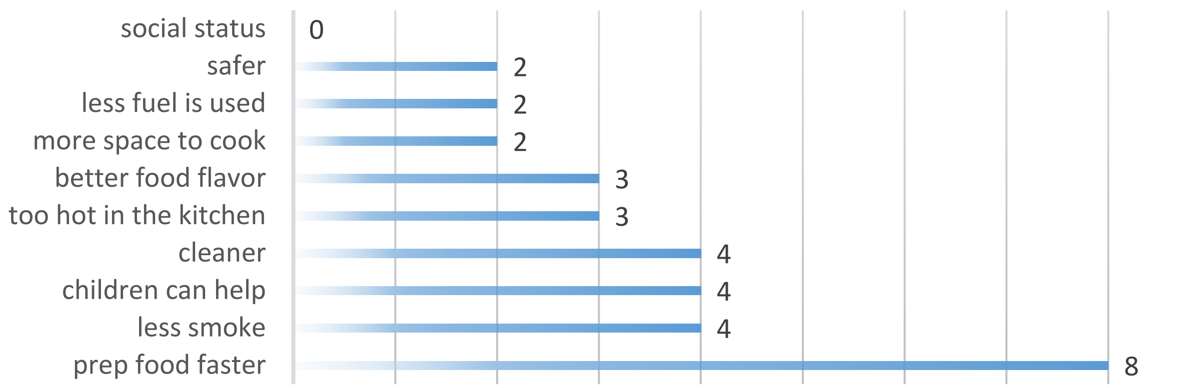


Figure 4.23 Survey result for the question "Why do you use multiple stove technologies?" (n=10)

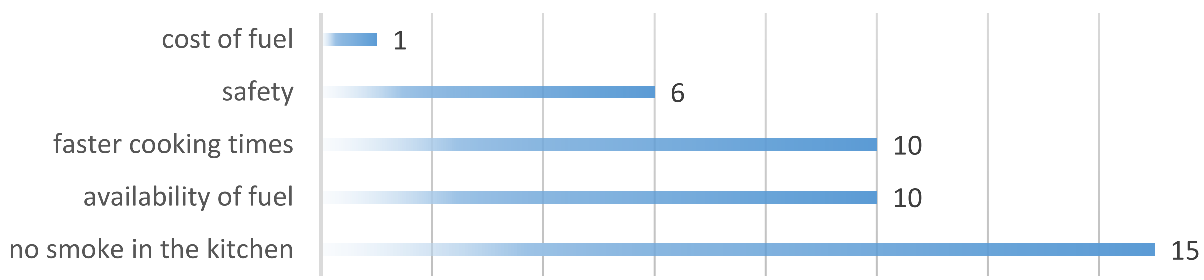


Figure 4.24 Survey result for the question "What would convince you to use only improved stoves or gas?" (n=26)

4.1.6 Are the People Capable and Interested in Building and Maintaining an Improved Stove?

Selecting an appropriate stove based on the desires of the community is vitally important but acknowledging how likely that stove is to be a lasting improvement is also essential. One question that can be asked to better understand the likelihood of long-term viability of the selected stove is question 6 of this study: "*Are the people capable and interested in building the stoves and doing the necessary maintenance?*" I suspected that yes, there were people within the community with the knowledge and skills capable of building the stoves, and that households are willing to contribute time and money to maintain a functional investment.

In Section 4.2.4, Figure 4.21 showed results suggest that the community believes it is important that an improved cookstove can be constructed within the community using local materials. After living in the community for a few years, I personally knew several people with construction skills. One neighbor fabricates his own concrete blocks and sells them for profit within the community, primarily for foundations for new homes. Another community member who worked within the community building frames for houses went to Costa Rica multiple times to learn carpentry skills. Although I had observed these skills within the community, I still asked about construction experience at the household level.

Many respondents either personally had some type of construction experience or a member of the household did; 8% had experience building with wood, 8% had experience building with wood and concrete, and 38% said someone in the household had construction experience (Figure 4.25). Any type of previous construction experience would be beneficial and facilitate the knowledge transfer for constructing an improved cookstove, especially those with wood and concrete experience. Several follow up questions directly asked about knowledge and skills related to cookstove construction. One respondent (n=26) said they already knew how to build an improved cookstove while five said they knew how to maintain an improved cookstove; however, no one knew how to repair an improved cookstove. The results shown in Table 4.2 clearly demonstrate an opportunity to educate and empower the community with skills to improve their household cooking situation.

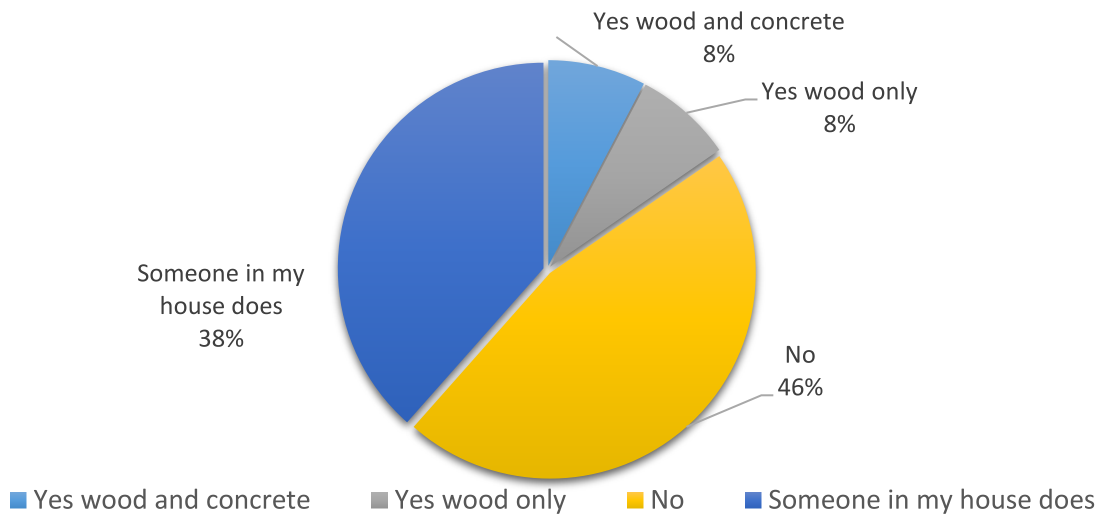


Figure 4.25 Survey result for the question "Do you have any construction experience using wood or concrete?" (n=26)

Table 4.2 Survey results for several questions regarding building, repairing, and maintaining an improved cookstove. (n=26)

Do you know how to build an improved cookstove?	
No	25
Yes	1
Do you know how to maintain an improved cookstove?	
No	21
Yes	5
Do you know how to repair an improved cookstove?	
No	26
Yes	0

Maintenance is essential to longevity and proper functioning of an improved cookstove. A proxy for gauging the communities liklihood of maintaining an improved cookstove asked how much time or money the respondnet would willingly contribute to the care of their investment. The willingness to contribute money and time for monthly stove maintence is shown in Figure 4.26 and Figure 4.27 respectively. While six of the 26 respondents (23%) said they'd contribute no money to maintain their stove on a monthly basis, half of the respondents said they would contribute between $1-$10 monthly and seven of 26 (27%) said they'd contribute more than $11 monthly, more than 10% of their monthly household income. Half of the respondents also reported that they would contribute more than five hours a month to stove maintenance and care with 11 of the 26 (42%) households saying they would spend an hour or less. These results demonstrate an overall commitment of time and monetary resources to maintaining the investment in the improved cookstove, improving the liklihood of sustainability.

One approach that was considered to increase sustainabiltity is to educate and train a willing group of community members to build stoves for interested households. A reasonable percentage of respondents (35%) believe that an entrepreneurial approach could be taken by members within the community to build improved cookstoves (Figure 4.28). I also observed an earnest interest from a small group of men willing to take on this task during the build of the prototype who were excited about the opportunity to learn the skills and make a profit building improved stoves for community members.

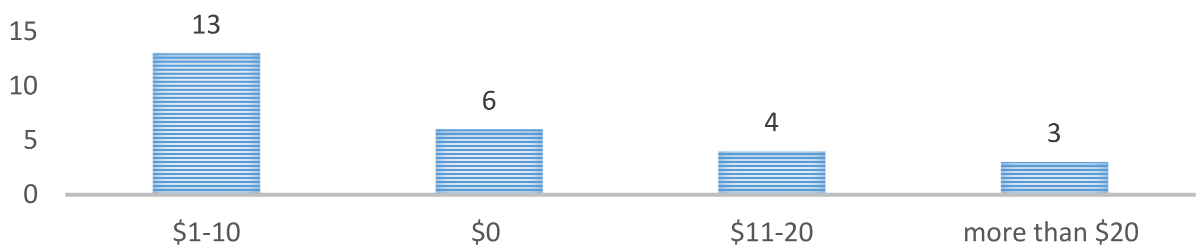


Figure 4.26 Survey result for the question "How much money per month are you willing to contribute to stove maintenance and care?" (n=26)

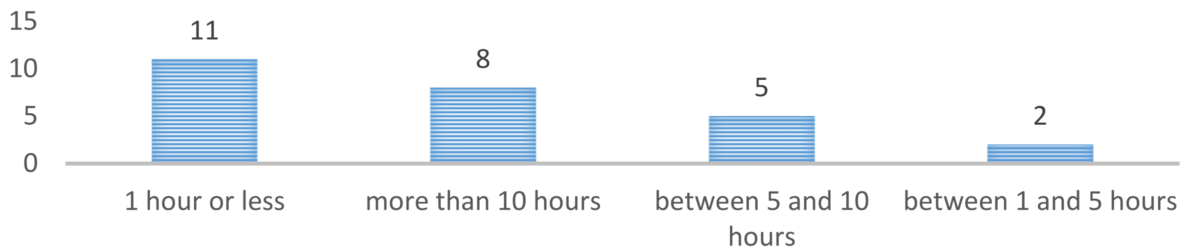


Figure 4.27 Survey result for the question "How much time per month are you willing to contribute to stove maintenance and care?" (n=26)

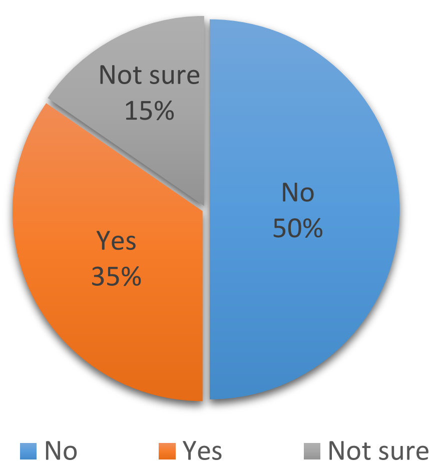


Figure 4.28 Survey result for the question "Do you believe there are groups of people within the community that would be interested in building improved cookstoves as a small business?" (n=26)

There are several advantages to developing a small, consistent group for building stoves. Less time spent retraining and more opportunities for refining and mastering the skills to produce a quality stove, as well as creating an income-generating activity that also increases environmental health within the community are several. However, to facilitate an entrepreneurial upstart, funding is necessary to buy tools and materials. When 26 households were surveyed, 25 said there was no credit available to purchase materials or tools. Only one household surveyed said they had access to a bank account. Similarly, only one household said they had bought livestock or food stocks within the past year with the intention of selling them in the future for profit. The respondent who said someone in their household had access to a bank account also had construction experience and reported that their basic needs were met, this household has potential to support a small business focused on building improved cookstoves inside the community.

A further challenge is regularity and predictability of income. Only four households (15%) reported a regular and predictable income. The majority (58%) said their income was irregular and unpredictable. Notably, 3 out of 4 (75%) of respondents who had regular and predictable income said that there is small buisness potential inside the community for improved cookstoves, while 10 out of 13 (77%) who said 'no' there is no potential for entrepreneurship had irregular and unpredictable income. Suggesting that having an irregular and unpredictable financial situation makes it difficult to establish a reliable group to provide cookstove services inside the community.

Effectively, the community does not yet possess the skills to build and maintain an improved cookstove program without external support; however, there is undeniable interest and with some focused training, the skills could easily be achieved. Unfortunately there still exist economic barriers that could dampen the success of the commuinty in this regard. It may be advisable to incorporate some educational talks regarding financial security and planning to overcome this barrier.

4.1.7 Do the People Feel that Access to Resources is Difficult?

A willingness to build and maintain an improved cookstove is an essential component for reducing household air pollution at the community level; however, despite having the best intentions, there are additional barriers to consider. One such barrier, as mentioned in the previous section, is an irregular and unpredictable income. Another barrier for this community, because of the geographical location and lack of infrastructure, it can be difficult to obtain resources most commonly available outside of the area. Most community members rarely, if ever leave the area, but still rely on basic support structures and outside goods to meet their basic needs. Question 7 of this study, "*How do the people feel about access to resources and societal support structures?"* aims to identify the resources and support structures that exist and the community's perception of their access to them. Feeling that you are supported by community members and the government can facilitate innovation and positive changes within the household (House et al., 1988). However, based on my experience living in the community, I expect that most people feel access to resources is difficult; particularly resources that exist outside of the community. I believe that many families feel unsupported by the community and the government in their daily lives.

Primarily this study sought to understand if, in general, households felt their basic needs were met. While 72% of households (n=25) reportedly have trouble supporting themselves, the majority (92%) of households responded that their basic needs go unmet and the remaining 8%

neither agreed nor disagreed. Of the 24 respondents who said their basic needs go unmet, 14 of them (58%) had above average monthly income (more than $90 per month). This result shows the severity of poverty in the area and how each day can be a struggle to meet the basic needs of the household.

This study also sought to understand perceptions of quantity and quality of local resources. Almost half of the respondents (46% (n=23)) believe that the water is dirty, and it makes them sick. This is a surprising number considering that the community and I had recently completed an improved aqueduct project which featured chlorine disinfection. Next, respondents were asked about food security; 85% (n=23) perceive a food scarcity in their household even though all households have a family farm. Then, 69% said there was not enough fuel for the household's cooking needs. These results show a perceived scarcity of local resources that comprise many families' basic needs.

All households within the community rely at least partially on outside goods for survival, primarily food. So, respondents were asked a direct question about difficulty to access goods outside of the community. Results indicate that many respondents (81% of 25) believe it is difficult to access outside goods and materials. There are many, 18 out of 26 (69%), who say that access to goods outside the community is difficult and there is not always enough food for the family. On my last day in the community, I visited several of the families. One of these community members shared with me a memory from about a decade ago when family members of his passed away due to malnutrition and starvation.

Besides food, water, and fuel, a household's basic needs include access to a health facility and an education. In the 1980's the first school structure was built in the community, and in the early 2000's a health clinic was built. However, 60% of respondents (n=25) still believe they have poor access to health facilities. In 2016, a government project was expanding the school and promising wi-fi. Now, 96% of families (n=26) think their children have good access to education.

It was often observed in the community that there was a reliance on external support structures when basic needs were unmet at the household level. Although humility is often at play, the community, at a familial level, appeared to be bound together in a supportive fashion. However, when asked, only 33% of households (n=24) felt that the community supports them (Figure 4.29). Interestingly, 57% of respondents felt that the government supports them (Figure 4.30). Of those who said the government cares for me and improves my life (n=13), 92% feel their children have access to a good education while only 54% believe they have decent access to health facilities. There were 10 households of 26 (38%) who felt that they were unsupported by both the community and the government, while only 7 households (27%) felt supported by both. There were 5 households (19%) who felt support from the government but not from the community.

I felt that the government was more supportive of the urban Latin communities (as opposed to the rural indigenous) in Panama. For example, historically, the only quality road that was built into the indigenous land was a mining access road, while local road construction was left to community members to achieve by hand. Many households feeling supported by the government could be result of a 2016 initiative where the government proposed to eliminate latrine usage and replace it with 100% sanitary toilet coverage country wide, despite many rural communities' lack of potable water supply. Additionally, government resources were used for construction of a paved road connecting the Pan-American highway to the capital of the indigenous region, Tugri. This plan ultimately intends to electrify those houses nearest the road, even though 96% of 26 households felt that electricity in the house would not improve their lives. I personally find it interesting that the community has less faith in support from within the community than from the government; however, recent attention from the government is apparently improving the relationship between the two.

Some of the results regarding basic needs and access to goods are summarized in Table 4.3. As anticipated, the community largely agrees that access to resources are a considerable challenge even when the resources exist within the community. Having basic needs met, especially clean water and access to health facilities, is incredibly helpful in increasing the likelihood of success for improved cookstove programs (Mehetre et al., 2017). The results of this survey question confirm my hypothesis that the community feels that access to resources is often very difficult and that they feel unsupported in their community; both are significant barriers to consider in an improved cookstove program. Fortunately, there appears to be hope as many respondents feel their children will be well educated, and that the government is paying more attention to their wellbeing.

Table 4.3 Survey results for several questions regarding basic needs and access to goods.

Survey Questions	Number of Respondents (n)	Answered 'Yes'	Answered 'No'	Answered 'Don't Know'
Our household has trouble supporting itself	25	72%	28%	0%
Our household has enough money to take care of our basic needs	25	8%	92%	0%
We always have enough food for the family	23	15%	85%	0%
My family often does not have enough fuel to cook	23	69%	19%	12%
Access to materials and outside goods is difficult	25	81%	15%	4%
My family has access to health facilities	25	40%	60%	0%
My children have access to a good education	26	96%	4%	0%

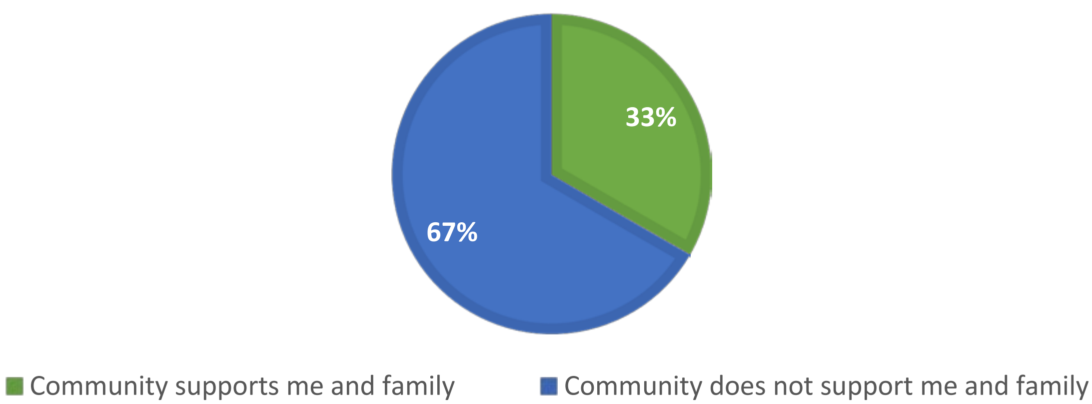


Figure 4.29 Survey result for the question “The community supports me and my family?” (n=24)

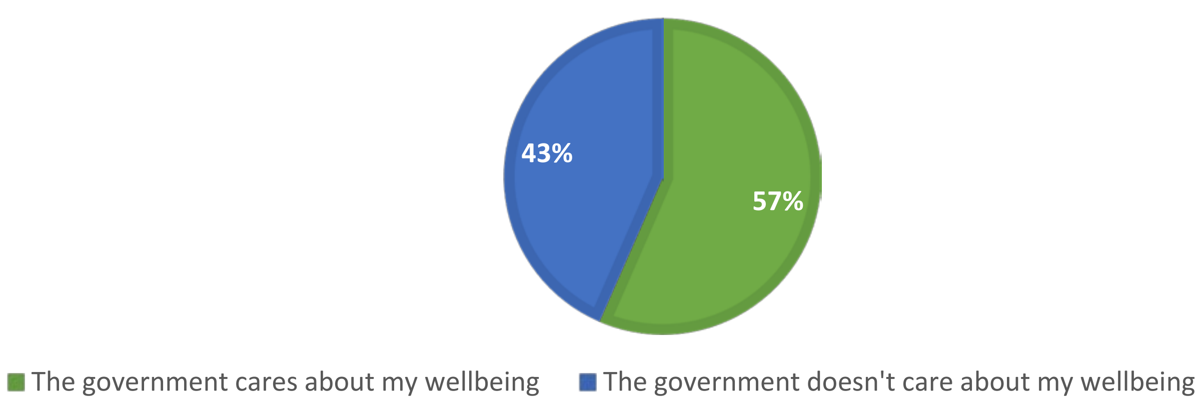


Figure 4.30 Survey result for the question “The government cares about my wellbeing?” (n=23)

4.1.8 Are There Educational Opportunities Capable of Providing Inexpensive and Effective Intervention?

Fortunately, many respondents felt that their children now have access to a good education. Providing educational opportunities to all age groups within a community is a focus of many volunteers Peace Corps Service. Educational talks are commonly used by volunteers to engage communities and inspire behavior change. I believe that the educational approach is an effective and inexpensive way to address many environmental health issues in rural communities. Several talks focused around improved cookstoves and their impacts were proposed as part of the implementation plan for this cookstove project. I think that people would be interested in learning about household air pollution, reduction of local deforestation rates, family health, construction and maintenance of improved stoves, and empowering women and girls.

Five topics were proposed including “Cookstoves 101” which would cover the basics of what makes an improved cookstove ‘improved’, the various essential components of an improved cookstove and what function they serve, and techniques to improve fuel combustion including fuel preparation. ‘Construction and Maintenance of Cookstoves’ would provide more in-depth information regarding constructing and maintaining an improved cookstove including hands-on practice doing both. “Family Health” would cover the basics of how improved cookstoves can help improve family health by focusing on details about household air pollution. “Women and Girls Empowerment” was proposed to highlight opportunities for women and girls in the community such as education and artisanal work when the time burden related to household chores is reduced by improved cooking technology. Finally, “Environment” is intended to educate participants about impacts from the harvesting of fuel wood and combustion and disposal of waste to the local environment, as well as emerging global climate science.

Survey respondents were asked to rate their level of interest in potential educational talks in the community. Table 4.4 shows the number of respondents who rated each topic based on their level of interest with “1” being most interesting and “5” being least interesting. The results in order of most to least interesting are as follows:

1. Family Health
2. Environment
3. Construction and Maintenance of Cookstoves
4. Women and Girls Empowerment
5. Cookstoves 101

Table 4.4 Interest in educational talks ranked by respondents. (1 is most desired, 5 is least desired)

Topic	**1**	**2**	**3**	**4**	**5**
Family Health	12	4	0	0	1
Environment	7	7	1	1	1
Construction and Maintenance of Cookstoves	0	2	7	4	1
Women and Girls Empowerment	0	1	4	5	4
Cookstoves 101	0	3	2	4	7
Total	19	17	14	14	14

Out of 26 households surveyed, 15 (65%) said they enjoyed educational talks including 5 of 7 (71%) of those above the age of 50 and 64% of those between 30 and 50 years old. These age groups likely had poor access to education in their youth and now find educational talks an opportunity to learn more about themselves and their environment. The most households (17 of

26, 65%) were interested in learning about family health with 71% of the 17 choosing family health as the most interesting topic. The second most interesting topic was the environment with 17 households (65%) interested, 37% choose the environment as the most interesting topic including 75% (n=4) of those with a high school education. Regarding construction and maintenance of cookstoves, 14 of 26 households (54%) were interested in learning more about it while 7 (27%) said the topic was in the top three most interesting. Similarly, 14 of 26 households (54%) were interested in learning about women and girls' empowerment. Interestingly, nearly an equal number of men as women (2 men out of a total of 5 respondents) chose women and girls' empowerment as one of the top three most interesting talks. I believe that "Cookstoves 101" was ranked last because the community recently had a very similar educational talk provided by ANAM and me.

This information demonstrates that family health and environment are both interesting and important to the community, while female empowerment appears to be a concept they are unfamiliar with and have yet to gain much interest in, and likely do not associate with improved cookstove programs. Overall, based on these responses, there is interest and a need for education and behavior change within the community on topics related to improved cookstoves. Educational talks could be an effective and inexpensive way to improve the health of the community.

4.1.9 Survey Summary

A household survey is a powerful tool that can be used to assess the appropriateness of a proposed improved cooking technology within a community. In this survey I was able to talk with 58% (n= 45) of the households in the community center. Understanding the knowledge, perceptions, and opinions of the primary stove users can provide valuable insight into selecting the correct approach and technology for the implementation strategy.

In this instance many respondents (68% of 26) acknowledged that smoke from cooking has health impacts, although only 27% specifically said that improved health is related to improving cooking technology. This information is important to understand before beginning an improved cookstove program because if users don't recognize how cooking practices impact their health there will likely be little interest or willingness to participate in an improved stove implementation program. For example, many respondents (58%) were only willing to pay $10 or less for an improved stove even though 73% of all respondents experienced some symptom related to air pollution exposure in the past week. There appeared to be a lack of understanding about the impacts of burning trash on health and the environment. Specifically, that 62% of respondents thought smoke from burning trash equally as harmful as wood smoke and 31% thought it less harmful, while only 2% of respondents that it more harmful than smoke from wood. Overall, these results suggest that the community largely does not connect improved cooking technology with improving environmental health.

Despite many respondents recognizing the benefits of trees to themselves and the local environment (primarily for shade, wood, food, and protecting water sources), largely it appears they failed to connect how human actions can impact the environment negatively. Indeed, 73% of respondents don't recognize their demand for fuel for cooking has impacts on the local environment with only 19% of households realizing that combustion of fuel wood contributes to air pollution directly.

Although the use of the three stone fire is inefficient and causes environmental degradation as well as health problems, many households like their traditional stove because it is easy to use (58%), smokes meat and cooks substantial amounts of food well (54%), and nearly half stated that it burns trash well (46%). However, 69% said they dislike the traditional stove because it produces lots of smoke, makes the kitchen dirty (42%), and that fuel is hard to get (38%). Largely, respondents (88%) felt that household chores specifically related to collecting fuel is burdensome and 81% suggested that a reduction in fuel usage is a key factor in an improved stove technology.

Additionally, over 90% of respondents said simplicity and ease of use, ability to control heat, and pot stability on the stove were principal factors in their choice to adopt an improved cooking technology. Unlike the study in Bangladesh (Mobarak et al., 2012) where only 9% of surveyed respondents valued improved indoor air quality, 84% of respondents (n=26) in this survey said reduction of smoke was an important factor in cookstove selection.

The community felt that being able to use local materials to build and repair the stoves themselves was important. Although only one household knew how to build an improved cookstove, and five respondents knew how to maintain one, more than half (54%) of the community had construction skills related to building an improved cookstove. This included one household that had their basic needs met, access to a bank account, and believed that there was potential for entrepreneurship in the improved stove sector within the community.

However, it was apparent from the results of the survey that overwhelmingly the community felt that access to money, food, fuel, clean water, as well as outside goods and resources was a major challenge. Supporting this statement, 92% of households reported that their basic needs go unmet, and 72% have trouble supporting themselves. Furthermore, there is a lack of strong community support structures in place. Only 38% of all respondents felt supported by both the government and the community. This situation is tantamount to understand the motivations and ability of a community to participate in an improved cookstove program and should be identified as a threat to the success of the program.

Fortunately, there is an interest in learning. Most households (65%) said they enjoy educational talks from experts. Topics about family health, the environment, and constructing and maintaining an improved cookstove were interesting to community members which is a good starting place for an implementation program.

In summary, there is an apparent lack of education surrounding environmental health in the community despite their interest in the topic. Similarly, access to materials, money, and support structures were the largest challenges to overcome in this community for improving success of a cookstove implementation program and should be considered from the developers' standpoint. A mitigation strategy is vital to think-through and develop before devoting time and resources to improving cooking technology in a community such as this.

These results suggest a need to invest time and resources into a comprehensive educational program and assessing those results before implementing a new stove technology. By providing educational talks to the community, interest and demand for an appropriate stove program could increase. There seems to be evidence that educational programs from the government helped to increase awareness of the harm of tobacco smoke suggesting that education is an effective strategy for improving health in the community. These results reinforce educational talks and behavior change as useful tactics for improving household and environmental health.

4.2 Design and Implementation of a New Ferrocement Improved Cookstove

The first objective of this thesis was to develop and implement an improved cookstove in the field setting utilizing results from a household survey of the community and the guidelines set forth in the Ostrom (2010) sustainability framework. The following section will explore the process taken to do so in rural Panama presented through five project life stages: needs assessment, conceptual design and feasibility, design and action planning, implementation, and post-implementation and follow-up.

4.2.1 Needs Assessment

Peace Corps volunteers live and eat in the community, and in this case, with a host family for three months. Figure 4.31 depicts a common occurrence in the kitchen as an infant and teenager watch their mother prepare lunch. During the first three months, in addition to hiking hours into the mountains to retrieve fuel wood, I spent long hours in the kitchen talking and eating with the family. The zinc roof in the kitchen was a dark black from all the particulate matter from the three stone fire. One evening my host sister removed a battery powered lantern that was hanging in the kitchen to clean the black soot darkening the plastic shield around the lightbulb. I used the opportunity to have a conversation about household air pollution with the host family. I asked if they knew why the lantern was covered in ‘black stuff’. They responded that the fire was making things dirty, but clearly had never really thought about the idea in depth. I continued to explain that the same thing was happening to their lungs and eyes from standing around in a smoky kitchen. This conversation prompted my host family to be the first family in the community to express interest in contributing to the design and build of a prototype ferrocement stove.

Figure 4.31 Women and children around a smoky three stone fire. Source: personal photo

After seeing the interest put forth from my host family, I organized a community meeting to assess demand, resources, and ability to do an improved cookstove project in the community. Roughly thirty community members attended the first improved cookstove meeting. There were several components that were acknowledged and discussed by the community during the needs assessment that influenced the design of the prototype ferrocement stove, shown in Figure 4.32. The primary motivation of the community was local materials and a stove that could be constructed by community members. Many community members said access to outside materials was difficult and there was very little money to spend on expensive stoves that they couldn't repair themselves. There was a strong sentiment and desire for the community to show ownership of the process and results. It is important to acknowledge that during the needs assessment phase, I encouraged the attendance and participation of women in the decision-making process. Often, males would dominate the conversations resulting in women who were too shy to share their opinions. To overcome this, for one meeting, I separated men and women into two different rooms to conduct the needs assessment. Then with those results we recombined the two groups. I established ground rules that prioritized presentation of needs from women first, then men followed up. We then combined these needs on a single piece of paper and evaluated each response as a group. The results contributed to Figure 4.32.

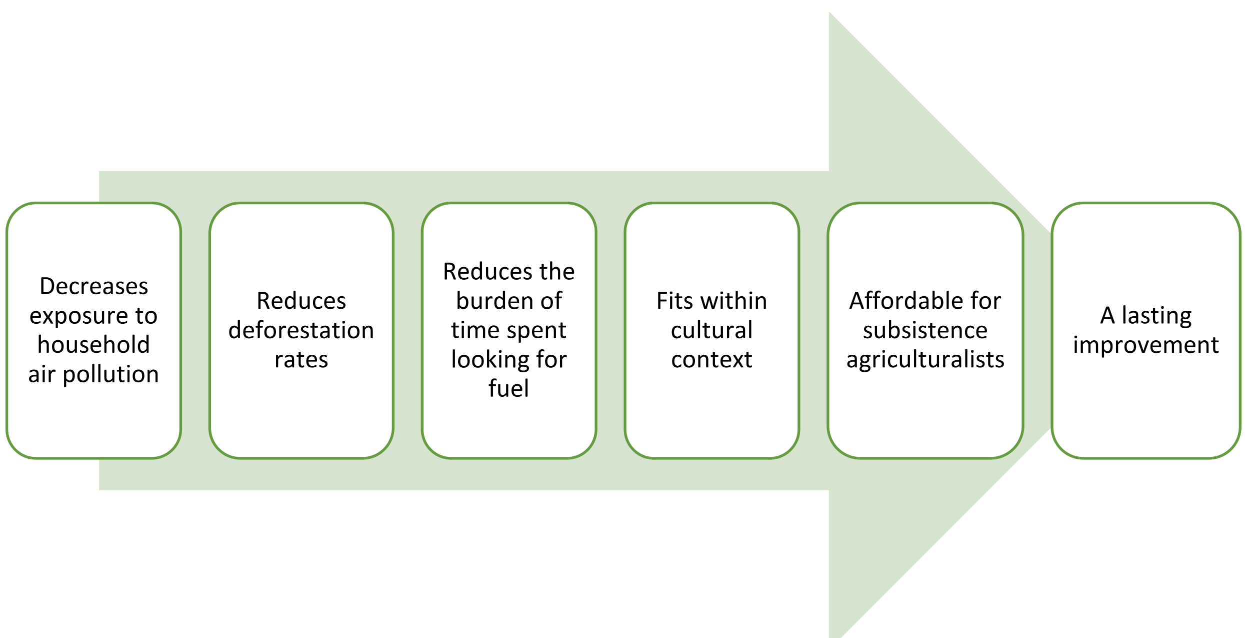


Figure 4.32 Vital components for sustainable improved cookstoves in Panama observed by the author during Peace Corps service.

4.2.2 Conceptual Design and Feasibility

During the conceptual design and feasibility life cycle stage, I brainstormed with my host family to come up with a design that might provide a lasting solution to their cooking needs. The design was intended to be aesthetically pleasing to them yet could still be built with their construction skills using materials that were either available in the community or easily obtained at the nearest hardware store. We assessed potential solutions and decided to incorporate proven methods of cookstove design from Mihelcic et al. (2009) such as pot elevation above combustion chamber (typically 30 – 40 cm) and combustion chamber sizing (12 cm squared) with the ideas and desires to use local materials and construct the prototype in the community. The stove design should theoretically improve ambient air conditions through more efficient heat transfer to the cooking pot resulting in less smoke production (Mihelcic et al., 2009; Partnership for Clean Indoor Air, 2010).

I decided that the application of ferrocement construction techniques to improved cookstoves is plausible because ferrocement structures are strong, water resistant, relatively lightweight, and generally repairable. Ferrocement construction typically involves applying thin layers of mortar (sand, cement, and water) over a layer of woven metal mesh. According to the literature, ferrocement is commonly used as an insulating material against fire damage and performs better than concrete in fire resistance due to low water content within the mixture. Because there is no large aggregate that typically has void space filled with water and moisture, there is higher resistance to cracking from exposure to high temperatures. (Greepala &

Nimityongskul, 2008) The ferrocement style of stove has a high likelihood of being long-lasting and durable because of the material properties.

Designing and constructing a chimney turned out to be one of the more challenging aspects of the ferrocement stove construction. Initially, I proposed to roll zinc into a cylinder and fit it to the draft exit of the stove body with the chimney exit outside of the kitchen. This idea was intended to utilize a material that many families in the community already have available, commonly laying around their properties as it had been removed from their roofs. Unfortunately, bending the zinc in this fashion turned out to be a tedious and imprecise method resulting in lower user satisfaction from the males. Women were particularly interested in problem-solving the chimney issues after I explained that the chimney was the primary stove component that could reduce smoke in the kitchen.

Favorably, the ferrocement design looks and feels much more like the typical three stone fire, a quality that 15 of 26 (58%) of the community mentioned as an important factor for stove adoption. Additionally, the community has experience with construction working with reinforced concrete with the previous Peace Corps volunteer building latrine floors (54% of surveyed households reported having some construction experience). The construction techniques of building a ferrocement cookstove required little leap in knowledge of materials and construction from this previous experience with latrines. Required materials such as cement, rebar, wire mesh, and zinc are readily available in the nearest hardware store to the community at a reasonable cost, although many (81% of survey respondents) say that access to outside goods is difficult.

Fortunately, the community has a very good local source of sand, a primary ingredient by mass in the ferrocement mix.

Portability often came up as a positive attribute during conversation in the needs assessment and during the build of the prototype. Women were more interested than men in stove portability because they wanted to be able to continue using the improved stove during the windy season when households tend to relocate from the primary kitchen. To increase portability of the ferrocement stove, I incorporated from latrine floor designs (Mihelcic et al., 2009) rebar reinforcement in the thin ferrocement base slab with rebar handles protruding vertically out of the slab as shown in Figures 4.33 and 4.34. This enables several people to safely relocate the stove with changes of kitchen location if desired, a crucial factor as 85% of the community often relocates during season changes. Furthermore, the inside of the stove body was designed to be hollow. The cylindrical shaped body allowed for a strong load bearing capacity while reducing stove body mass. This is beneficial not only for portability, but for increasing heat transfer to the cooking pot instead of the stove body.

Before we moved forward with the conceptual design, I reviewed the case study presented in Section 2.5 regarding the *ecojusta* stove projects in another community in rural Panama to broaden the scope of thinking surrounding the development of the ferrocement stove. In contrast to the ferrocement design, the bricks for the ANAM *ecojusta* are produced far from Peña Blanca. This makes it very difficult to access the materials required for construction and nearly impossible to get replacement bricks for vital repairs to ensure proper stove functionality over time. The *ecojusta* bricks are made of clay and sawdust, making them generally weak and irreparable when exposed to the environment. The clay bricks deteriorate if wetted, which is a major problem in Panama where the rainy season lasts for several months of the year and few people live in an enclosed dwelling. The lack of clay in the area prompted the idea of designing a stove which uses no clay. If the household left the ferrocement stove uncovered during the rainy season, it would still be usable or at least easily repaired. Issues with the *ecojusta* are that it is a big, heavy, immovable, and fragile stove. Furthermore, the *ecojusta* is typically cemented to a large concrete block table rendering it immovable. The typical *ecojusta* found in rural Panama is shown in Figure 4.35.

Figure 4.33 Photo of construction of the ferrocement stove showing rebar reinforcement of the base slab. Source: personal photo


Figure 4.34 Photo of construction of the ferrocement stove showing handles for increased portability. Source: personal photo


Figure 4.35 Photo of a typical *ecojusta* in rural Panama. Source: personal photo

4.2.3 Design and Action Planning

For the design and action planning phase, a conceptualized design was agreed upon and sketches were made. The community agreed that a pilot project with five stoves was an effective way to begin. The Peace Corps participatory grant money ($120) was used along with the community contribution ($5 per household, $25 total) to purchase materials for the pilot phase. The materials list and rounded up costs of the items as they were purchased in San Felix, Panama in 2016 is included in Table 4.5. Table 4.5 reflects the costs for a single stove, realistically only about a quarter of the second bag of cement is used. The remaining cement can be resold to recoup some costs or properly stored to make repairs to the stove. Additionally, while constructing the prototype stoves, I was sure to reinforce the idea that most damage to the stove body, if proactively addressed could be easily remedied using the same construction techniques currently being taught and practiced.

Since it's unlikely only one stove will be built, the materials costs should decrease by 10%-30% when purchased in a group setting, sharing cement, excess rebar, transportation costs, and recycling of wood forms. When purchasing materials for five pilot stoves, the ferrocement stove averaged $29 per stove. Even the cost for one ferrocement stove ($50.50) is significantly less expensive than the typical *ecojusta* which reportedly costs about $130 per stove. Despite the relatively inexpensive investment cost for a gas stove ($30), each tank of fuel costs approximately $8 which may serve a household for a month if used conservatively resulting in a yearly fuel cost of nearly $100 or 9% of average yearly income. The average monthly spending including food, clothes, transportation, and entertainment for the households surveyed for this thesis was approximately \$90 or \$11 per person per month. The mode income was \$100, with four households reporting monthly spending greater than \$100. Therefore, to invest in the ferrocement cookstove, only 4.6% of average yearly income would be necessary to buy materials for a single stove (2.7% of average yearly income if multiple stoves are built, forms recycled, and materials and tools are shared). This is roughly half the investment of the *ecojusta* or the gas stove.

Table 4.5 Ferrocement stove materials and costs in Panama in 2016.

Material	**Cost**
2 bags of cement	\$20.00
9 meters of 3/8"(1 cm) rebar	\$12.00
4 pieces of 90 x 120 cm medium opening wire mesh	\$6.00
2 pieces of 10 cm x 120 cm wood (long side)	\$5.00
2 pieces of 10 cm x 90 cm wood (short end)	\$5.00
1 roll (lb.) of tie wire	\$1.00
6 black plastic bags	\$1.50
5 buckets of sifted sand	\$0.00 (local resource)
Sawdust or equivalent filler (46,000 cubic centimeters 12 compacted gallon buckets)	\$0.00 (local resource)
Clean water	\$0.00 (local resource)
Total (for one stove)	**\$50.50**

4.2.4 Implementation

As an approach, the implementation process engaged the community and improved the stove design for appropriateness using community feedback. The first stove build was a great learning experience. Figure 4.36 is a photo showing a community member building the first ferrocement prototype stove outside of his home. I was able to combine education of better stove design and combustion techniques during the construction process with many interested community members. The idea was to revise parts of the design that didn’t function or weren’t ideal to the community with each iteration of the pilot project stove build.

Unfortunately, after the first prototype’s curing period the family got busy and the stove was left unfinished for several months before we could organize a day to finish the concrete work and fit the chimney. According to the survey, 17 out of 26 households (65%) said that having a chimney was a key factor for an improved cookstove. However, while building the ferrocement stove prototype, we learned that the chimney design wasn’t ideal as many community members found it difficult to construct and didn’t believe it would function well. Many community members felt that the chimney would pull heat away from the pot and outside of the house where it was ‘wasted’. The community eventually decided they didn’t want a chimney, which is unfortunate because it is a valuable way to reduce household smoke in the kitchen. This was a very weak part of the design; a better chimney needs to be developed that satisfies the community so that it becomes a desired aspect of the stove and demonstrates efficient cooking despite this ‘wasted’ heat.

Another lesson learned in the first stove construction is that the sides of the stove need to be built higher to accommodate larger fires under the cooking pot to cook food faster. When surveyed 15 out of 26 households (58%) said that cooking food faster was an important function of an improved cookstove. Additionally, the rebar handles need to be higher on the outside of the stoves to facilitate moving the stove with ease.

Figure 4.36 Photo showing community member building the first ferrocement prototype stove outside of his home. Source: personal photo

The second stove built was for a smaller family. A one pot version of the stove with no chimney was requested and built outside of the house under a grass roof hut. The family was satisfied and used the stove regularly. The lessons learned from the first stove were incorporated into the second build. However, there was still self-reported use of the three stone fire and gas stove. The results in section 4.2.6 were generated utilizing this stove.

The third stove we built in the school kitchen because it benefited the entire community. This stove did not have a chimney but was well constructed. However, because it was for the school, the community complained that the stove wasn't big enough for the pots they use to cook meals for the students. In rural Panama, family sizes can vary greatly; therefore, many different sized pots are used. If quickly preparing coffee for a guest, a 10-cm pot is used. If preparing a meal for a family gathering, an 80-cm pot may be used. Results from the case study of *ecojusta* projects in Section 2.5 show that 42% of 20 respondents felt that stove stability was an issue. Results from the survey in Section 4.1 suggest that 23 of 26 households (88%) think pot stability is a crucial factor in improved cookstove design. Stably supporting a wide range of pot sizes continues to be a challenge for many improved cookstoves including the ferrocement design.

4.2.5 Post-implementation and Follow-up

The post-implementation and follow-up phase was very limited as I simply ran out of time in the community to spend time working with members to complete the pilot project. I did talk about operation and maintenance frequently at meetings and during construction; however, there was no time to do follow up monitoring and reporting for the prototyped stoves. Fortunately, operation is very similar to the three stone fire, so the knowledge is there. During meetings and construction, I frequently mentioned the importance of processing fuel into smaller pieces and drying it sufficiently to improve combustion and avoid damaging the stove body by forcing large pieces of wood into the stove. When surveyed, all 24 households who responded said that they would buy an improved cookstove even if it required more fuel prep time, and 22 of 25 households (88%) said that the ability to use smaller pieces of wood would be a benefit to them. However, when asked specifically about training, 22 out of 26 households (85%) said they had never been taught how to burn more efficiently resulting in less fuel use and less smoke.

4.2.6 Ferrocement Stove Project Summary

An improved cookstove project was never requested by the community during the first community needs assessment that I performed at the beginning of my Peace Corps service. The community was very focused on improving their potable water supply which we completed as a primary project in the community. However, gradually the more that I talked of the benefits of improved cookstove projects, more community members showed interest. The follow up volunteer in this community reported to me that during his needs assessment meeting, the community named an improved cookstove project as their primary interest without being prompted by him. This may indicate now that basic water and hygiene needs have largely been met by development projects, the community will focus on improving their indoor air quality. The fact that the community is now requesting an improved cooking technology of their own accord is positive as bottom-up organizing is useful for providing an appropriate and sustainable solution.

In the following sections, I will address each ferrocement pilot project stage and summarize the overall strengths and weaknesses. Chiefly, I think that the needs assessment project life stage was strong in this study. The demand for an improved cookstove came from interest that built within the community through educational talks focusing on cookstoves and health. The design incorporated technical details important for improving combustion alongside characteristics that were specifically mentioned by female community members there were incorporated with male's opinions as well. Not only was an extensive household survey done, but my observations from living and integrating with the community for three years serves as a significant source of information for improved cookstove projects in similar communities in rural Panama.

The conceptual design and feasibility stage of the project was also strong. I was able to evaluate the weaknesses of *ecojusta* projects through the Campau (2014) case study and improve the likelihood of sustainability of the ferrocement stove by considering the sustainability framework to aid in the design process. This lead to a successful design and action planning phase as well. We were able to build a few prototype stoves during a pilot phase and iteratively adjust the design based on community input, intentionally giving a voice to women, the primary stove users. Once a prototype design was approved by community members, the materials availability was confirmed, and costs finalized.

The implementation stage was effective during the pilot project. Many community members got involved, committed resources and time to the project, and capacity building opportunities were utilized through knowledge and skills transfer. Women were encouraged to participate in construction of the stoves to increase ownership and confidence in their abilities to repair the stove when necessary. Additionally, I was successful in increasing transparency between the ministry of environment, ANAM, and the community. This was achieved by inviting ANAM technicians to the community and introducing them to the work and processes we were taking for this stove project, as well as local leaders and contacts.

Unfortunately, as my service as a Peace Corps volunteer neared the end, I was unable to perform important post-implementation and follow-up activities. I attempted to involve the follow-up volunteer as much as possible. Unfortunately, the project transfer was unsuccessful, which is often typical when projects change hands. Still, the demand for improved cookstoves was high in the community after the pilot project. Because of this, I spent many hours during my final three months in the community as a volunteer establishing the relationship between the ANAM and the community. Despite an initial reluctance from the community to involve the government in the cookstove program, I solicited materials for an *ecojusta* stove construction at the school, invited ANAM technicians to facilitate the construction of the *ecojusta* and give an educational talk on the benefits of improved cookstove projects. This interaction fostered an important connection between participants and ANAM, encouraging both groups to continue the program. As of December 2016, when I left the community, *ecojusta* construction at the school had not been completed but all contact information had been passed on to the follow up volunteer as well as the expectation made clear to the community members that it is their responsibility to contact the government agency and continue working on the project.

One strength of the ferrocement cookstove is the design flexibility. By understanding the technical design parameters and construction principles, the design is adaptable to specific community needs and desires and may be an appropriate solution to communities with similar situations to the one studied here. To pass on the information and continue development of the ferrocement stove a construction manual was created in conjunction with this thesis to assist with future construction and education. For details on the construction process and design of the ferrocement stove, the manual is included in Appendix E of this thesis as well as to Peace Corps volunteers alongside the existing *ecojusta* stove manual. Unfortunately, critical emissions, efficiency, and safety testing were unable to be completed on the ferrocement prototype stoves. This is a vital component for understanding the efficacy of a potential improved cookstove and is discussed as a limitation in Chapter 5.

4.3 Sustainability Assessment Framework

An objective of this thesis was to sustainably design and implement a new style of improved cookstove in a rural community by considering cultural appropriateness, involving local stakeholders, increasing political alignment regarding cooking technologies, and being mindful of economic and environmental sustainability. So, for the ninth scientific question in this thesis I asked, "*Is this stove a lasting improvement that is sustainability developed?".* This question will be further addressed in the following sections to evaluate the likelihood of sustainability of the three most common stove technologies seen in the Ngäbe-Bugle region of Panama and the ferrocement stove developed by the author. I hypothesized that because the process to develop and implement the ferrocement stove consciously followed a sustainable development strategy, the stove meets some of the functional and cultural needs of the community. Additionally, it is durable, and the knowledge and skill to build the stove exist within the community so the likelihood of sustainability is high relative to other improved stove implementation programs that fail to consider the pillars of sustainability throughout each project stage.

The five pillars of sustainability mentioned in Section 2.4.1 establish the framework for the details in the following five sections. The observations of the usage of the three stone fire, the ferrocement stove, the *ecojusta,* and the gas stove are the focus of the discussion. The resulting content is based on evidence from my experience living and working in Panama as a Peace Corps volunteer. Then the sustainability framework (Ostrom, 2010) was used to highlight the strengths and weaknesses of the ferrocement stove pilot project and four *ecojusta* projects to assess the likelihood of sustainability.

In Table 4.6, I summarize the four stoves considered in this thesis relative to one another based on the discussions in Sections 4.3.1 through 4.3.5. In this ranking scenario, I believe that the three stone fire is the most sustainable stove because of its ability to meet the needs of the community well and its small environmental impact from stove body materials. The important implication is how appropriate the three stone fire is as a stove technology in this rural Panamanian community in the current situation. For example, many respondents rely on smoking meat to preserve protein when a cow is processed. Not insignificantly, the three stone fire is used to provide lighting and reduce the number of mosquitoes in the kitchen which have direct impacts on safety and health. Furthermore, many women found portability important, notably the three stone fire doesn't need to be portable because it can be rebuilt using rocks that are often much closer and easier to relocate than an improved stove. Unfortunately, due to observed current stove-use practices, it has considerable impacts on family health including burn potential, local and global air pollution, and environmental degradation. With proper education that results in adoption of improved fuel processing and stove operation, the three stone fire can be operated more efficiently. Furthermore, users of the traditional stove could be encouraged to relocate and elevate their traditional stoves, increase ventilation, and limit exposure to smoke-filled environments.

I suggest that the gas stove is the least likely to be sustainable primarily because 100% of users observed with a gas stove still practiced stove staking because the gas stove is unable to entirely meet users' needs. Most obviously, the gas stove is used to quickly prepare coffee for guests. Users are very unlikely to use this stove to prepare meals for the family because the large pot doesn't fit. Furthermore, cooking substantial amounts of food on the gas stove requires significant amounts of fuel that is difficult to get in the community due to access to outside resources and limitations of income. For these reasons I believe the gas stove is unlikely to be a sustainable solution for the community in the current state. It is important to note that situations change and the goal of improving local air quality, user safety, and reducing deforestation should not be abandoned simply because the traditional stove is the most likely to be sustainable in this instance. More details regarding the rankings provided in Table 4.6 are provided in the following sections.

Table 4.6 Stoves observed in Panama rated by sustainability factor based on the author's experience. (lower score is better)

Sustainability Factor	**Stoves Observed in Rural Panama**			
	Three Stone Fire	Ferrocement stove	*Ecojusta stove*	Gas stove
Socio-cultural respect	1	2	3	4
Community participation	1	2	4	3
Political cohesion	1	4	2	3
Economic sustainability	1	2	3	4
Environmental sustainability	3	2	1	4
Average score	1.4	2.4	2.6	3.6

4.3.1 Socio-cultural Respect

Considering local traditions, way of life, values, and social structure are examples of showing understanding of socio-cultural norms. Here, I discuss each stove observed in rural Panama and how it relates to socio-cultural respect. The three stone fire is socio-culturally significant although it may not be recognized by the stove users. As evidence, only one respondent of 26 acknowledged cultural reasons as one of the qualities of the three stone fire that they liked. For example, the three stone fire often becomes a central gathering point in households. The men sit around and chat while the women prepare the coffee and the children manage the fuel, cups, and shew away the animals. It is a source of light and heat for social gatherings. Similarly, many foods are associated with the taste of smoke. Many believe (35% of 26) that the taste of food is better from the three stone fire. Because of this, I said that the three stone fire was the best stove with regards to socio-cultural respect.

The ferrocement stove was developed while spending time with a host family in the kitchen over the course of three months. The stove body aesthetically resembles the traditional look, feel, and size of the three stone fire. While a large part of the design was built around the fact that light and some heat should still be available from an improved stove. The construction and maintenance also require little leap in knowledge from techniques that are known from several of the households because of previous experience building concrete latrines in the area. Part of the development and implementation strategy also considered socio-cultural norms as community meetings were the primary means of communicating the project, raising interest, and developing a group of dedicated community members to be part of a pilot project. The pilot project planned to transfer knowledge by training community members on construction techniques, the key components of improved stoves, and improved combustion knowledge. Because of this, I said that the ferrocement stove was the second best stove with regards to socio-cultural respect.

The argument can be made that since the government agency ANAM has a division in the Ngäbe-Bugle region and employs Ngäbe people, that the understanding of local traditions and core values are inherently considered in the dissemination of the *ecojusta* stove. Although there is a respectable effort from ANAM to improve communication and trust by utilizing indigenous staff for projects in the region, there is still a lack of survey tools used to understand the needs and desires of the communities being served. An example, the *ecojusta* stove evolved from the typical model mentioned in the literature which has a flat grill on top and a chimney. The model seen in Panama has been adapted for traditional foods which tend to be rice, soup, and beans, eliminating the need for the grill top which is a culturally appropriate change. Unfortunately, during this process, the chimney was eliminated as well. A stove with a chimney is more effective at reducing household air pollution. Additionally, because of the stove body materials' nature, it must be located indoors eliminating the opportunity to move the smoke outside of the kitchen. Because of this, I said that the *ecojusta* stove was the third best stove with regards to socio-cultural respect.

Gas stoves have been popularized in Panama as a cooking solution. Not once living in the country for three years did I observe any cooking using electricity. Because of the abundance of gas stoves in the country, the technology is easily implemented in the distant communities as infrastructure such as roadways are developed. Gas fills an important social cooking role because of the ability to prepare a hot cup of coffee very quickly. Because offering a cup of coffee to any guests is customary in Panama, many seek the efficiency, ease, and cleanliness of gas stoves. Unfortunately, the gas stove fails to meet other socio-cultural needs such as providing lighting, space heating, and a central gathering point. This would likely result in stove-stacking in most of the homes using this technology in rural Panama. Because of this, I said that the gas stove was the worst stove with regards to socio-cultural respect in rural Panama.

4.3.2 Community Participation

Empowering community members to own the process of decision making, beginning with choosing a project, how it is to be implemented, built, and maintained is the core of community participation. Here I discuss how each stove relates to the empowerment of community members by fostering participation and decision making.

The three stone fire is the epitome of fostering empowerment and ownership. It is a technology as old as time and everyone has the ability to construct and use the three stone. Similarly, all ages and genders are skilled in operating this stove and community members are prideful of managing a good fire that results in tasty food cooked quickly. Because of this, I said that the three stone fire was the best stove with regards to community participation.

The ferrocement stove during development in a host family kitchen, grew out of conversations and ideas between the host family and myself. Similarly, the prototype was built by a member of the community as I guided him, ensuring that the knowledge and skills were transferred from the conceptual design from the beginning. In this way, the importance of certain design decisions was conveyed while any non-essential design element was flexible and able to be changed by the construction team. After just one community meeting discussing improved cookstoves, the community recognized a need for improved stoves in their own homes. Additional interest and desire grew with time spent giving more detailed talks and workshops about the topic. To illustrate the point, during the first and second volunteers' participatory analysis for community action (PACA) meetings, improved cookstoves didn't make the list of needs that the community had interest in addressing; however, during the third volunteer's PACA meeting, it made the top of the list. Because of this, I said that the ferrocement stove was the second best stove with regards to community participation.

On the other hand, the *ecojusta* stove program fosters little ownership and empowerment of community members. Typically, ANAM representatives arrive in a community, have a meeting and ask for a show of hands of those who are interested in receiving a new stove. The only contribution to be made is ash for insulation and labor, which is better than nothing, but not enough to foster a sense of ownership. Sometimes the community is involved in the construction process resulting in transfer of knowledge and ownership, but this largely depends upon the ANAM representative in charge of the project. Because the stoves already have a set design, are entirely subsidized, and all materials are brought in from a different province, there is little room for community participation. It was observed that most people will accept any 'gift' that requires little effort or contribution regardless if it actually meets the needs of the household. Because of this, I said that the *ecojusta* stove was the worst stove with regards to community participation.

The adoption of gas stoves sees no external promotion or funding in Panama. The household makes the choice of stove, and pays the entire cost including reoccurring fuel costs (although subsidized at the country level). It is noteworthy that based on my observations, the 'wealthier' residents of the community were the most likely to use gas stoves as a cooking technology. Arguably, this situation empowers the household and increases ownership, but it does nothing in terms of increasing community participation and building support structures.

Because of this, I said that the gas stove was the third best stove with regards to community participation in rural Panama.

4.3.3 Political Cohesion

Assuring that local, national, and international development goals are aligned to assure ownership and aid at the community level is evidence of good political cohesion. Here I discuss how each stove relates to political cohesion at the various levels. The three stone fire has no connection to political cohesion, which in this case is positive. Regardless of political change, instability, or pressure, the three stone fire remains a reliable solution to meeting cooking needs. The stove is proven and unchanging in the community regardless of political alignment. Because of this, I said that the three stone fire was the best stove with regards to political cohesion.

Locally, the ferrocement stove was accepted among political leaders in the community. Nationally, ANAM expressed interest in seeing the results of the stove and learning more about it, although changing the political momentum associated with the 'proven' *ecojusta* design would be difficult. I presented the ferrocement stove prototype as an alternative option for isolated communities far from the production zone of the bricks required for the *ecojusta*. Internationally, Peace Corps supported the work done with the ferrocement stove and several volunteers requested information about the stove to build a prototype in their communities. Political cohesion is likely the most difficult and farthest from being achieved aspect of sustainability for the ferrocement stove due to the limited number in existence and lack of a champion in the field promoting the stove. Because of this, I said that the ferrocement stove was the worst stove with regards to political cohesion.

The *ecojusta* on the other hand has the full support from the political realm. Local political entities tend to support the larger governmental agencies and facilitate their projects. Nationally, ANAM has invested time and effort into the local production of the materials, a construction manual, and sending representatives into the field to plan stove projects throughout Panama. Similarly, Peace Corps in Panama concentrates on *ecojusta* stove projects partnering with ANAM when possible. At the international level, the *ecojusta* is a popular stove model for improved stove programs and has the support of the international community as a viable technology. Because of this, I said that the *ecojusta* stove was the second best stove with regards to political cohesion.

There is little involvement on the local political level with regards to the gas stove. However, gas stoves are very politically stable as much of the Panamanian population utilizes gas as the primary fuel source for cooking. Although Panama is an importer of natural gas, prices remain relatively cheap due to subsidies. Internationally and globally, natural gas is a highly political topic. Gas is currently being heavily promoted as an inexpensive and relatively 'clean' transitionary energy source from dirtier fossil fuels to 'green' energy production like solar, wind, and geothermal. Because of this, I said that the gas stove was the third best stove with regards to political cohesion in rural Panama.

4.3.4 Economic Sustainability

Assessing that local resources and capacity are in place to ensure success when outside resources are no longer available is vital to economic sustainability of an improved cookstove project. Here I discuss how each stove relates to economic sustainability with regards to stove costs, time, and natural resources. The three stone fire itself is very economically stable. The stove costs nothing and only one respondent of 26 reported paying for fuel wood, which was very inexpensive relative to other purchases for a typical household. Although there are no direct economic costs associated with time spent looking for fuel wood, there are certain economic concerns, such as loss of health, diminishing returns of fuel wood, and time spent looking for fuel to feed the inefficient three stone fire that could be used productively instead. Additionally, overconsumption of fuel wood in the area leads to land and air degradation as well as global climate change. The loss of healthy forests has long-term economic impacts specifically on air, soils, and water. As this community primarily relies on subsistence agriculture, maintaining forest coverage is vital for a sustainable lifestyle. I said that the three stone fire is the best stove when it comes to economic sustainability because it costs nothing, and fuel is currently available at no cost; however, I recognize that the indirect economic costs mentioned previously are hard to quantify at this level and could easily upset the economic sustainability of the three stone fire.

The ferrocement stove averages about $30 out of pocket expense as many materials and labor can be sourced locally, making it a much more feasible option for many households in the community. Similarly, bags of cement are easily available at the nearest hardware store for less than $10. One bag of cement and sand is all that is needed to maintain the stove in proper working condition for an extended period if proper maintenance occurs through the life cycle of the stove. With regards to the previously mentioned impacts of fuel wood harvesting on the environment, this stove would theoretically slow the degradation of the forests in the area through increased combustion efficiency. Additionally, as households spent less time gathering fuel wood from long and fair, more time could be spent in an economically favorable manner. Additionally, as part of this stoves implementation program, educational talks could improve the economic potential of the community through increasing awareness of environmental sustainability and promoting income generating activities for women and children such as artisanal work. For these reasons, I said that the ferrocement stove was the second best stove with regards to economic sustainability.

The *ecojusta* costs on average $130 per stove, although typically subsidized by ANAM. The issue is that when the stove gets damaged or needs to be relocated, ANAM no longer offers financial support, thus resulting in useless stoves and lost investments. There are no bank accounts or credit available inside the community for replacement materials or stoves when this damage occurs. Similarly, there is no way to produce or obtain the bricks used for the *ecojusta* for a community such as Peña Blanca located a great distance from the production center. Further, coordinating efforts with ANAM is a significant challenge as communication with those outside of the community is difficult. Again, like the ferrocement stove, this stove could slow the impacts of fuel harvesting on the environment and provide more time for households to be economically productive in other ways. Because of this, I said that the *ecojusta* stove was the third best stove with regards to economic sustainability.

Gas stoves have a relatively high initial cost. A typical gas stove costs $30 plus a $65 (one-time capital investment) for the tank. Then a 45 lb. tank refill of gas costs $8 which may last an average family a month. Although having a reoccurring fuel cost may be perceived as a negative aspect of the stove, for the immediate future it is a stable and consistent fuel source. This stove doesn't use wood for fuel, so the community could focus on reforesting with high quality timber which would improve local environmental conditions as well as provide additional economic income if harvested mindfully. Because of the high initial capital investment and the reoccurring fuel costs, I said that the gas stove was the least sustainable stove with regards to economic sustainability in rural Panama. However, like the three stone fire, if the circumstances regarding household income and access to fuel changed, the gas stove could be a more economically sustainable cooking solution because of the potential to maintain the local environment and reduce the burden of disease associated with incomplete combustion.

4.3.5 Environmental Sustainability

Assuring that natural resources are not destroyed for short term solutions to long term problems is the focus of environmental sustainability. Here I discuss how each stove relates to environmental sustainability with regards to stove materials and impacts on the environment due to fuel use. From a stove materials standpoint, the three-stone fire is the most sustainable as it is made of stones and requires no processing of materials to construct or repair nor any transportation of materials. On the contrary, this stove has significant impacts to the local environmental resources as mentioned in the previous section regarding degradation to local air, soil, and water. In my experience, often families would leave a smoldering log in the stove so that they could throw a plastic bag on it to quickly and easily produce a flame for cooking. This type of behavior is likely a result of a lack of education surrounding fire-tending practices and the health impacts of smoke. With users who are uneducated about efficient combustion tending the three stone fire, it is largely inefficient and produces a large amount of smoke and particulate matter due to incomplete combustion. These have global impacts on climate change as combustion byproducts such as heat-trapping gases and black carbon accelerates sea level rise and polar ice melt which will significantly impact Panama and it's many low-lying regions. Because of this, I said that the three stone fire was the third best stove with regards to environmental sustainability.

The ferrocement stove contains materials that have more of an environmental impact such as cement, rebar, metal wire, and sheet metal for the chimney. Again, these materials must be transported from the manufacturer to a store then to the community requiring fossil fuels and trucks. Like the other two wood-burning stoves, the demand for fuel wood causes deforestation, loss of biodiversity through elimination of animal habitats, decreases in soil fertility, and various other impacts associated with unsustainable harvesting of fuel wood. Additionally, wood combustion causes air pollution, albeit theoretically less than the three stone fire. Because of this, I said that the ferrocement stove was the second best stove with regards to environmental sustainability.

Next, the ecojusta that utilizes clay and sawdust are abundant natural resources but require energy to form into useful bricks. Those bricks then get transported requiring fossil fuels and other resources. Cement is then used to assemble the bricks into a useful stove which is often placed on concrete blocks to elevate the stove body. Because the *ecojusta* burns wood, many of the impacts associated with combustion from the previous paragraph apply here, although to a lesser extent than the traditional and ferrocement stoves because of the demonstrated increased efficiency. Because of this, I said that the *ecojusta* stove was the best stove with regards to environmental sustainability.

Finally, the gas stove contains various metals including aluminum and iron, steel for the tank, as well as rubber for hoses and gaskets, and plastics. In addition to the transportation of the stoves (most commonly) from Asia. These processes consume significant amounts of natural resources. Combustion of natural gas is relatively clean at the local level compared to combustion of wood reducing household air pollution. Unfortunately, many practices used to produce gas, specifically fracking (a technique used to extract gas from the natural environment using high-pressure water and chemicals that can result in aquifer contamination) pose other environmental impacts that must be considered. Because of this, I said that the gas stove was the worst stove with regards to environmental sustainability in rural Panama.

Observations made in the previous sections should highlight the overall likelihood of sustainability of three stone fire in this scenario. The other three stoves compared may improve local environmental health, but only if they are fully adopted and stove stacking with the traditional stove ceases to occur, otherwise, overall sustainability will not improve, and few positive health impacts will result. The comment was made that users who are uneducated on efficient combustion techniques poorly operate the traditional stove largely resulting in its inefficiencies. This is the fundamental issue with the sustainability of the three stone fire. Properly framed educational programs associated with significant behavior change could improve this aspect of the three stone fire.

4.3.6 *Ecojusta* Sustainability Framework Summaries

In the following paragraphs, four *ecojusta* stove implementation programs facilitated by Peace Corps volunteers were analyzed using the sustainability assessment framework (Ostrom, 2010). Projects ranged from building two stoves with ten community members to building 80 stoves for roughly 100 houses, resulting in implementation of 153 *ecojusta* stoves. Because each evaluation is subject to the person who performed the analysis, the overall scores from these matrices are not as important as the general trends observed. For example, post-implementation and follow-up sections consistently received low scores in this evaluation suggesting the project stage as one for improvement.

Dillon Robertson lived in Chepo de Las Minas, Herrera. During his service he built 80 stoves through two projects. The first was a pilot project resulting in 17 stoves. According to Robertson, ultimately around 100 households were involved including some households that were previously part of a rocket stove project. The rocket stove project was an attempt by local families to create the bricks in the community instead of buying ANAM's factory bricks. Unfortunately, due to poor craftmanship those bricks crumbled rendering the stoves useless. This project concluded in the year prior to Robertson's arrival with only three of the original thirty stoves still functional. This is important to consider as one of the important factors mentioned in Peña Blanca was the ability to produce stoves locally using local materials.

Robertson rated his *ecojusta* stove project based on his experience with ANAM and the community. The numerical scoring of the sustainability matrix is presented in Table 4.7. It is important to highlight actions that Robertson identified as weak points of this implementation program. Robertson noted that social preferences and traditions associated with household energy use, cooking practices, and indoor air pollution were not identified. Similarly, the level of health education in the community was not determined. He also said that what the community members want from the stoves and expect from the project were not evaluated and no alternatives were presented for community feedback. There was also a failure to understand the local economy and market for improved stoves.

Table 4.7 Robertson's numerical evaluation of the sustainability matrix for *ecojusta* projects in Panama. (0= worst, 4=best)

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	2	3	2	3	3	13
Conceptual designs and feasibility	3	2	4	4	3	16
Design and action planning	2	1	3	3	4	13
Implementation	3	4	4	4	1	16
Post-implementation follow-up	2	2	4	1	3	12
Total	12	12	17	15	14	70

Gender equity and health education topics were not explored with the community, and virtually no post-implementation and follow up took place. The strong points of this project were focused on involving people in the implementation of the stove, which is standard practice in Peace Corps projects. Additionally, political cohesion scored well because Robertson worked closely with ANAM in implementing the stoves in this community.

Jay and Jennifer LaRoche served in Las Barretas de Olá, Coclé. This community had approximately 300 permanent residents. They helped build stoves for 26 families, averaging five people per family, benefitting roughly 130 people. The numerical scoring of the sustainability matrix is presented in Table 4.8. It is important to highlight actions that the LaRoche's identified as weak points of this implementation program. Overall there was a lack of consideration for equity, community input, sustainability of resources, and post-project support including monitoring and evaluation.

Table 4.8 LaRoche's numerical evaluation of the sustainability matrix for *ecojusta* projects in Panama. (0= worst, 4=best)

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	4	4	3	4	2	17
Conceptual designs and feasibility	3	4	2	2	2	13
Design and action planning	3	2	1	2	3	11
Implementation	3	2	4	4	4	17
Post-implementation follow-up	2	3	3	0	0	8
Total	15	15	13	12	11	63

The LaRoches scored low the political cohesion during the design and action planning stage because the project leaders of the partner institution, ANAM, did not clearly define the plan, roles, or responsibilities. Similarly, there was a 'set it and forget it' approach to this project, according to LaRoche. Once the stoves were built, there were no efforts to build capacity at the local level, determine conditions of the stoves, actual results, or continue working with the community to improve the economic and environmental situations. The LaRoche's did however do an excellent job integrating themselves and involving the community in the needs assessment and implementation project stages which follows the Peace Corps approach to development well.

Chrissy Miresse served in Tierra Prometida, Panamá este. Miresse contributed to the construction of 45 stoves benefitting approximately 350 people during her time in Panama. The numerical scoring of the sustainability matrix is presented in Table 4.9. It is important to highlight actions that Miresse identified as weak points of this program. During the conceptual design and feasibility stage, Miresse reports working with a community leader as a liaison throughout the project, typical for Peace Corps volunteers; however, the project goals weren't clearly defined or understood by the community at large, there were no feasible alternatives presented, and the community members were not involved in formally selecting a design based on their needs and preferences. Similarly, Miresse worked within the traditional structure of community projects per the Peace Corps approach; however, the resource contributions and benefits were not equitably divided. Additionally, there was not sufficient time planned for health education regarding household air pollution, and there was a lack of gender equity and capacity building during the project resulting in a low score for the design and action planning – socio-cultural respect element of the matrix. As previously mentioned, the post-implementation and follow up project stage often gets left behind once construction of stoves nears completion. This often results in a failure to continue capacity building, monitoring the efficacy of the intervention, and ensuring that future demand is met by the program. Likewise, the environmental concerns related to biomass combustion largely go unaddressed during and after the project.

Table 4.9 Miresse's numerical evaluation of the sustainability matrix for *ecojusta* projects in Panama. (0= worst, 4=best)

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	4	4	2	4	2	16
Conceptual designs and feasibility	4	1	4	3	3	15
Design and action planning	1	2	3	3	2	11
Implementation	3	3	4	4	4	18
Post-implementation follow-up	2	2	1	1	1	7
Total	14	12	14	15	12	67

Julian Navarez lived in Cabecera de Cochea, Chiriqui. During his service he built two *ecojustas* in town that involved 10 people. The numerical scoring of the sustainability matrix is presented in Table 4.10. Unfortunately, Navarez was unable to provide specific comments regarding his project, but again post-implementation and follow-up and the design and action planning stages were weak. However, the economic sustainability of this project was the lowest score of the sustainability factors, unlike the other *ecojusta* projects. It is possible that Navarez required more economic buy-in from the community and depended less on ANAM to subsidize the stoves. This type of decision is often left up to the volunteer if it is decided that it would improve community participation and foster a greater sense of ownership with project participants.

Table 4.10 Navarez's numerical evaluation of the sustainability matrix for *ecojusta* projects in Panama. (0= worst, 4=best)

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	2	3	3	1	2	11
Conceptual designs and feasibility	2	1	2	1	1	7
Design and action planning	1	2	2	1	1	7
Implementation	2	2	3	2	3	12
Post-implementation follow-up	1	1	0	1	2	5
Total	8	9	10	6	9	42

To further evaluate the strengths and weaknesses of the *ecojusta* stove programs implemented by ANAM and Peace Corps, I averaged the results from the previous four matrices to get a relative idea of which areas are strong and which are weak in terms of likelihood of sustainability. I then color-coded the table using a three-color scale with the midpoint at the 50th percentile where red is the worst and green is best for easily identifying the overall strengths and weakness uncovered during these projects. This data is presented in Table 4.11. In the following paragraph, I discuss the weakest and strongest elements identified from the *ecojusta* projects.

From the averaged matrix scores for the *ecojusta* projects, the design and action planning scores are low, specifically in the socio-cultural respect and community participation categories. This is one of the major weakness with ANAM's program. Often, they arrive to a community with a technology (the *ecojusta)* already in mind and take little time to evaluate community understanding related to the project or solicit input from them. Also lacking is an effort to educate the community on the stove, the basics of combustion, and health affected by household air pollution. Additionally, there is little accountability to the community, once a stove project is promised, the product is often built for households regardless of labor or materials contribution. This is often the case because of the demand for a quota to be realized. Furthermore, there is often little done to increase gender equity, even though the women are almost exclusively the users of the stoves. For example, from my experience, there are no educational opportunities provided that focus on empowering women to be part of the decision making regarding stoves, fuel, or finances. Additionally, when ANAM discusses the benefits of improved cookstoves, lacking is information on how women and children that are less burdened by gathering and prepping fuel and cooking can spend time on artisanal work, education, farming, or helping their partners in their daily work. Likewise, capacity building in the community isn't given the time and attention that is necessary to create a lasting change in behavior because once stove construction is completed, the communication between implementor and recipient ends.

Table 4.11 The average of the *ecojusta* stove sustainability matrix scores highlighting the areas for improvement for the implementation program. (0 = worst(red), 4 = best(green))

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	3	3.5	2.5	3	2.25	14.25
Conceptual designs and feasibility	3	2	3	2.5	2.25	12.75
Design and action planning	1.75	1.75	2.25	2.25	2.5	10.5
Implementation	2.75	2.75	3.75	3.5	3	15.75
Post-implementation follow-up	1.75	2	2	0.75	1.5	8
Total	12.25	12	13.5	12	11.5	61.25

Unsurprisingly, post-implementation and follow-up scores are the worst, specifically in the economic and environmental sustainability categories. Based on these projects it appears that very little thought is given to stove projects after construction is complete. I believe this is a two-fold issue. From the community standpoint, they are excited and ready to use their new stove and get back to their daily activities. From the implementers position, they often have other projects to work on or simply run out of time and resources dedicated to a specific community. Unfortunately, this stage is vital in assessing whether the intervention was successful and iteratively providing information for improving future projects.

The political cohesion during the implementation stage received a very high score among the projects. This reflects a good connection between the local (community), national (ANAM), and international (Peace Corps) groups. This is a very positive aspect because it increases support across the dynamic political spectrum and increases likelihood of success of the project. Similarly, the community participation during the needs assessment received high scores. I believe this reflects a focused Peace Corps volunteer who is well trained to integrate, conduct participatory needs assessments, evaluate stakeholders' expectations, and accompany the community through the process by working closely with local leaders.

The economic sustainability during implementation had high scores as well. Again, nearly all Peace Corps volunteers who seek funding for projects utilize a standard Peace Corps participatory grant process that establishes specific guidelines for training, capacity building, community involvement, record keeping, and budgeting to increase likelihood of project success and transparency in the community.

At times, the strengths and weakness of these projects can depend heavily upon the quality of the interaction between the community, the Peace Corps volunteer, and the representatives of ANAM. If there is a strong working relationship, projects can be done very well and achieve a high likelihood of sustainability. If there is a weak working relationship, the community can often fall through the cracks of the larger political powers at play with overarching goals failing to be realized. The major takeaway from the analysis of these projects is that the community should be at the top of the decision-making hierarchy (a bottom-up approach) which would turn upside down the current situation (the top-down approach). By doing this, more time is spent engaging local stakeholders, investing in educational opportunities, inspiring behavior change, and equitably empowering the community to embrace the significance of an improved cookstove project. The intended results should be verified post-implementation to assure that the program is achieving its goals and that the community adopts the behavior change resulting in improved public health and well-utilized political and natural resources.

4.3.7 Ferrocement Stove Sustainability Framework Summary

Section 4.2 elaborates in detail the development and implementation of the ferrocement stove during my service as a Peace Corps volunteer. Here I will discuss specific strengths and weaknesses from the experience framed in the context of the Ostrom (2010) sustainability framework. The numerical scoring of the sustainability matrix is presented in Table 4.12 while more details regarding scoring of individual elements can be found in Appendix F. There were three ferrocement style stoves built during my service in Peña Blanca, one at my host family household, one in the community's school kitchen, and another for a family in Cerro Gallina, a community similar to Peña Blanca in the Ngäbe-Bugle region where a fellow Peace Corps volunteer was serving. Building a second prototype stove in another community increased feedback and community participation in the region.

The first prototype stove was built at my host family's house which was located on the main road through the community. Many residents stopped by that location and saw my host family and I building the stove. This encouraged many to ask questions and watch the process, leading to community input and educational opportunities during the process. Several requests for a second community meeting for the stove project resulted from this visibility. This increased awareness of the project and allowed it to grow based on community interest and excitement. Meetings such as this that are requested by the community rather than prescribed by the Peace Corps volunteer are often better attended.

Table 4.12 Author's numerical evaluation of the sustainability matrix for the ferrocement stove pilot project in Panama. (red, 0 = worst, green, 4 = best)

Life Stage	**Socio-cultural respect**	**Community participation**	**Political cohesion**	**Economic sustainability**	**Environmental sustainability**	**Total**
Need assessment	4	4	3	4	4	19
Conceptual designs and feasibility	4	3	4	4	2	17
Design and action planning	4	2	0	2	1	9
Implementation	4	2	4	3	3	16
Post-implementation follow-up	0	2	0	0	0	2
Total	16	13	11	13	10	63

Building a third stove at the school kitchen in Peña Blanca was an excellent decision. It was inclusive of all community members as nearly all had children who attend the school. This provided high visibility of the project to all ages and education levels and encouraged many more community members to gain interest in the project, specifically women as many volunteered to cook at the school in rotations. Socio-cultural respect and community participation were important focus areas during the needs assessment and conceptual design and feasibility stages. This exposure strengthened the community desire and participation in the project. Additionally, it strengthened the political cohesion across the project life stages as well by incorporating the school and gaining the support of local political leaders.

Originally, I solicited ANAM technicians to participate in building and developing the ferrocement stove. Unfortunately, ANAM only had capacity and interest in building *ecojustas* in the community. This lack of support for the stove resulted in a low score for the design and action planning – political cohesion element. It was a significant challenge to align the political powers in the community due to past circumstances where government agencies promised improvements for the community and failed to deliver leading to a general distrust. Eventually, we solicited the support of ANAM to build an *ecojusta* beside the ferrocement stove in the school kitchen, so community members could use both and provide feedback on aspects of each stove that they enjoyed. The first half of the stove got built in one day, a follow-up work day was scheduled but ANAM failed to make the appointment. Despite these set-backs, 57% of survey respondents felt that the government supports them. This effort increased political cohesion and socio-cultural respect during the implementation stage.

Often this process happens in reverse, where ANAM will target a community for a stove project and arrive unsolicited. In this situation, interest was built at the community level, supported by the local political leader and Peace Corps volunteer. Then when ANAM's help was solicited, the connections were even stronger, and the community had a basic understanding of stoves and a desire to learn more. Ideally community members will continue to use both stoves in the school and facilitate discussion of improved cooking technologies. Ultimately the goal would be to work together to build several stoves in the community that best fits the needs and desires of the project participants. This is an example of flipping the hierarchy upside down as mentioned in the previous section.

The implementation stage of the project was going well and included several community meetings co-facilitated by ANAM. Building a stove at the school encouraged involvement of women in the decision-making process by evaluating the prototype. I trained a few local leaders in construction techniques and key design components. I facilitated communication between the community and ANAM while continuing to involve them with the pilot projects. Unfortunately, because the extension of my service rapidly ended, I was unable to complete the pilot project.

Ultimately, the project stayed on budget and those initial investors who did not receive a stove, had their $5 contribution returned. Sadly, I was unable to perform any post-implementation follow-up resulting in a very poor score in the post-implementation follow-up project stage.

Both the *ecojusta* project and the ferrocement project had their lowest scores in the post-implementation and follow up stage. Although these projects ended differently for unlike reasons, ultimately the results are the same. The community loses out on continuing education, support for environmental health programs like reforestation, and the reinforcing of positive behavior change. Also missing is an outlet for continued feedback of stove appropriateness.

The design and action planning stages were also weak. Often when a project gets off the ground, the pace is hectic. The organization, careful planning, and feedback loops proposed between the community and the varying levels of political involvement begin to fall apart. Budgets and time can dwindle resulting in a failure to build capacity and consider long-term success of the project.

This reinforces the idea that these stages of the project are difficult and should be thoroughly considered with action plans developed prior to beginning a cookstove project. Specific action plans with all parties' responsibilities clearly outlined, amount of budget allocated and remaining, and a checklist that is unique to the project should help ensure that economic and environmental sustainability will result for the local stakeholders once the political parties are removed.

The strengths of the ferrocement project include a strong involvement at the community level, specifically a continuing needs assessment that is integrated into the stove design. Multiple options of improved stove were considered by the community. The varying levels of political organizations came together within the community. Similarly, the community was held responsible for contributing to the project and increasing their capacity to build and maintain the stoves. Opportunities were also provided for gender equity throughout the pilot project specifically at the school as women were encouraged to interact with and discuss the stove with other community members in a public space and were later asked for their feedback for improving the design. In the end, many strengths were shared between the ferrocement and *ecojusta* projects because of the approach to development utilized by Peace Corps volunteers.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Cooking technology has developed significantly from the origins of the three stone fire. Since the 1970s scientists and development workers have been attempting to improve cooking technology to reduce adverse impacts to humans and the environment from inefficient combustion. The goals of improved cookstove technology include: reducing deforestation, reducing or eliminating household air pollution, increasing stove user safety, and improving stove durability. More recently, due to program failures, advances to improve user satisfaction, increase adoption rates, involve local stakeholders, focus on the bottom-up approach, improve efficiency, and reduce global environmental impacts while better meeting specific users' needs have been recommended.

This thesis evaluates the development and implementation of a new type of ferrocement improved cookstove in rural Peña Blanca, Ngäbe-Bugle region, Panama that focuses on meeting users' needs while remaining durable and reducing environmental impacts, resulting in a more sustainable and appropriate solution to goals presented above. The research included a holistic approach to improving cookstove development projects by considering a project through the lens of five pillars of sustainability (socio-cultural respect, community participation, political cohesion, economic sustainability, and environmental sustainability) over five project life stages: needs assessment, conceptual design and feasibility, design and action planning, implementation, and post-implementation and follow-up. A community-wide household survey was utilized to provide insights into the knowledge, opinions, and desires of a rural indigenous community about health, the environment, and basic needs and preferences related to cooking and improved cookstove technology. Additionally, the sustainability assessment framework by Ostrom (2010) was used to compare the ferrocement improved cookstove developed in this study to the most common stoves seen in rural Panama (particularly the *ecojusta* stove) and provide insights into the strengths and weaknesses of the development strategies observed. Additionally, a construction manual for the ferrocement cookstove was developed so that interested parties can build and improve upon the design. Finally, in this section, basic guidelines for a more holistic approach to an improved cookstove project are presented to assist development workers in increasing the likelihood of sustainability of their improved cookstove projects.

The remaining paragraphs of this chapter summarize the development of an improved cookstove as part of achieving objective one of this thesis: to develop and implement a new ferrocement cookstove design to meet the needs and desires of the community. The community and the thesis author designed and implemented the stove using Ostrom's (2010) assessment framework to guide the process through the project stages of development to increase the likelihood of project sustainability. The design process incorporated community member feedback iteratively through a pilot project attempting to both meet user needs and improve technical performance. The details of this process can be seen in Section 4.2.

The ferrocement design evolved aesthetically from the traditional stove and operates similarly so that no leaps in knowledge are required to properly utilize the technology.

Furthermore, the cost and materials of the improved technology are affordable and accessible to the community, incorporating local materials when possible. The design of the ferrocement stove, specifically the use of the mostly enclosed combustion chamber and hollow stove body is thought to increase efficiency resulting in decreased emissions into the indoor air environment. Also, the technology will likely be safer to use because of containment of the fire and the reduction of heat lost to touchable surfaces, as well as the requirement to build the improved stove on an elevated table. The stove design was intended to be more portable and durable than other options available in the area. Longevity is suspected to increase due to the durability of materials used and the ease of repair due to simplicity of construction. Portability is encouraged by providing handles and reducing concrete volume through ferrocement construction of the hollow stove body.

Weaknesses in the ferrocement stove design are primarily the lack of chimney and pot stability for large diameter cooking pots. To address issues associated with the chimney, specifically difficulty of construction and user perception, several recommendations are provided: 1) use a more flexible material to shape the chimney that is still durable, 2) use ferrocement construction techniques to construct the chimney, or 3) locate the stove outdoors in a well-ventilated area, focus on improving combustion techniques, and provide educational demonstrations of chimney efficacy by allowing users to compare stoves with and without a chimney side by side. Recommendations on improving pot stability on the stove are as follows: 1) adjust the stove side wall height to allow the pot to sit deeper into the combustion chamber and 2) round or indent the stove body and groove the ferrocement to improve friction between the stove body and pot providing a better fit.

The pilot project was proposed to include a focused educational series. These educational talks would provide valuable information to the participants regarding family and environmental health, operation and maintenance of the improved cookstove, gender equality, and financial resiliency among other topics that may emerge during the educational process.

Specifically, the family health educational program would incorporate interactive and high-energy demonstrations of how family health can be impacted by household air pollution. For educational opportunities to be successful in this setting, difficult and complex issues, especially cause and effect, must be broken down into comprehensible pieces that are relatable through images and stories. Each unsafe component of the traditional stove should be discussed as it relates to family members specifically that women spend more time around the stove and are responsible for keeping a fire going all day, how can women reduce their exposure and still fulfill this role. Simple solutions include increased ventilation in the kitchen, moving the common gathering location further away from the fire, and extinguish smoldering fuel. Similarly, exploring the role of children in cooking and highlighting that young children are often at higher risk for burns, scalds, etc. For the environmental educational talk, participants would be asked to draw and tell stories about how trees benefit them and their environment. Then show the effects of deforestation for the local environment and how it directly impacts their livelihood. This should be followed up by actionable items including consciously reducing fuel harvesting and use, establishing a local committee that cares for the environment. These local committees should organize reforestation days and provide updates to community members about environmental health to keep people engaged and actively combating deforestation. This topic can incorporate gender equity talks that highlight the contributions of women in the household and encourage males to show their appreciation. Furthermore, demonstrating the importance of educating females so that they can be part of educating the children in the household, increasing the value of the household in the long run. The value of women and children with more time for education and income-generating activity should be demonstrated both culturally and financially to increase likelihood of success. To address costs and meeting basic needs with regards to finances, a basic household accounting educational talk should be provided. This provides an opportunity for households to create a monthly budget by demonstrating how to keep track of their monthly income and expenses, as well as highlighting opportunities to save money. For example, many households buy individual packets of coffee daily instead of buying in bulk which would reduce yearly expenses significantly and allow for investment in an improved cookstove. Regarding education surrounding cookstoves, it would be beneficial to have several improved cookstove models available to the population in one demonstration kitchen so that users can see, touch, and try their options and provide feedback about the likes and dislikes of each. Furthermore, it is important to demonstrate the fuel savings and reduction of smoke in the kitchen to increase buy-in from residents. One example of this is by placing a curtain or similar between a traditional stove and improved stove and allow users to experience the favorable conditions in the kitchen with an improved cookstove. Each educational opportunity should demonstrate how participants can incorporate what they have learned into their daily lives and the anticipated benefits made clear.

The goal of the educational component of the program is to provide community members with exciting, inspiring, and relatable information that encourages behavior change. A well-designed educational program considers users education levels and daily responsibilities to achieve maximum attendance and leave participants excited about the next opportunity. When the situation is as such, participants animatedly discuss what they've learned with their family and friends after the program has ended. Participants who complete courses can be rewarded with certificates, food, recognition in the community or in some other way that is valued or prideful. This experience should be inclusive, empowering, and rewarding.

In summary, the objective to develop and implement an improved cookstove in the field setting was achieved largely through a pilot project as time permitted. As shown here, time, trust, and understanding are essential for developing an appropriate solution in the field. Without the support of the community it's unlikely any lasting solution can be realized. More than half of the respondents of the household survey said that a stove that was made in the community using local materials that had an appearance like the traditional stove was important to them, and about half of the users stated that cost was important. Unfortunately, no improved technology is free. There must be some level of financial support, and the more levels of financial support the more likely the success of the project. This project had financial support from the community of approximately 10% direct financial, an additional 10% equivalent material contribution, and 20% time as labor contribution combined with a grant from the Peace Corps for materials and transportation. Survey results indicated that only 4% of respondents would pay between US$30 and $40, the approximate cost of the ferrocement stove when built as part of a larger project. More than half (58%) said they would pay between $1-$10 suggesting that some households would assume some of the financial burden of an improved cookstove program. Overall, the survey results showed that 96% of respondents wouldn't pay full price for the least expensive improved stove currently available to them (i.e., the ferrocement option). Nor would they share an improved stove with neighbors to reduce the costs. This level of buy-in requires significant subsidies to be successful in the location of this study. This creates an interesting challenge for developers to meet the needs and desires of rural communities to provide an appropriate stove with high adoption rates that is also affordable and functional. The likelihood of project success could've been increased with financial or labor support from the Panamanian government. Further improvements to the design and implementation process can be made by conducting a survey before and after the pilot project to assess the effectiveness of the design, educational materials, and reassess community knowledge and opinions regarding cooking technology.

To achieve the second objective of this thesis: to understand and evaluate the sustainability of the ferrocement cookstove and compare to the *ecojusta* stove, the traditional three stone fire, and a gas stove, a household survey adapted from Dickinson et al. (2015) and the Ostrom (2010) sustainability assessment tool were used. The survey included 26 households from the community center, representing approximately 58% of the population.

Section 2.3.1 discussed results from a literature review of some household studies in rural communities. The findings of previous research (Mobarak et al. 2012) were very different from results from the household survey conducted as part of this study in rural Panama. Specifically, only 9% of rural community members in Bangladesh specified improved indoor air quality as an important factor in their choice of improved cookstoves while 84% of rural Panamanians from this study felt that reducing smoke indoors was important to them. Furthermore, the Mobarak et al. (2012) study found that survey respondents valued a reduction in fuel costs most whereas this study found stove simplicity and ease of use as most important. This fact reinforces the importance of performing community-based surveys. It is essential to understand the local needs and perceptions to provide an appropriate technology that has any hope of being a solution that will be adopted by the community for the long term.

Nine scientific questions used to support the development of the improved cookstove project were presented in Section 1.3. Eight of the nine questions were intended to be answered with the household survey. The first question of the survey was "*Are the community members aware of the dangers of smoke to their health, do they connect improved cooking technology with improved health, and is it important to them to reduce smoke in the household?"* Survey results indicated that many respondents (68%) believe that smoke is harmful to their health and the health of their families. With regards to stove selection and health, only 27% of respondents thought that improving their cooking technology would result in less smoke and fewer health problems associated with household air pollution and an equal number associated their three stone fire with causing health problems. Many users (84%) said a reduction in smoke was an important factor in their choice in adopting an improved cookstove. While (58%) responded that they would discontinue use of the three stone fire if smoke was totally removed from their household by an improved cookstove. Overall, these results may suggest a lack of faith in improved cookstoves to reduce the amount of smoke in the kitchen and health problems associated with that smoke, or simply a lack of awareness surrounding the issue.

The second question of the survey was "*are people aware of human impacts on the local environment?*" Most (73%) didn't believe that their use of fuel for cooking has any negative effects on the environment. Specifically, only 19% stated that their cooking practices and demand for fuel wood directly affects air quality. These respondents tended to be younger and more educated than others in the survey. An equal number of respondents (19%) reported believing in climate change at the local level despite reported observations of changes in the local environment by half of all respondents, most commonly that it is wetter due to increased rainfall. Overall, respondents with a higher education level tended to believe more in climate change as 50% of those with a high school education and only 10% of those with middle school education or less believed in climate change.

The third question in this survey focused on respondents' perception of the time spent on household chores: "*Is the amount of time for women and children being spent on household chores such as collecting fuel wood and cooking considered a burden?*" Resoundingly, yes, 88% of respondents reported that household chores take too much of their time. In addition to the 10 hours per week reportedly spent collecting fuel, 54% of respondents stated spending between six and twelve hours a day in the kitchen.

To guide the decision-making process for improving cooking technology in this community, question 4, "*what are the reasons people like and dislike the traditional stove and* *improved stove"* and question 5, "*what are factors that would influence people to adopt improved cooking technologies in their homes"* were asked. Many respondents like their traditional stove because it is "easy to use, smokes meat, and cooks substantial amounts of food well". Moreover, approximately a third of respondents stated more practical uses of the three stone fire such as "burns trash well, keeps bugs away, heats the kitchen during cold weather, and provides lighting". The most common complaints of the three stone fire include "lots of smoke, makes pots/walls/ceilings dirty", and that fuel is "hard to get". Approximately a third stated that the three stone fire "uses a lot of fuel, causes health problems, burns the body, and produces too much heat outside of the stove". More than 84% of respondents agree that primarily, they want an improved stove that is "simple and easy to use with the ability to control the heat" that also provides pot stability for their various sized cooking pots. More than three quarters of respondents also said that stove size was important and a reduction in both smoke and fuel use were important.

As many of the households (60%) wanted a stove that could be constructed with local materials, it was important to understand if users are *"…capable and interested in building the stoves and doing the necessary maintenance".* In response to the sixth question in this study, about half of the households surveyed claimed that they had some construction experience using either wood and/or concrete. This experience is vital to building many of the styles of improved cookstoves, specifically the ferrocement and *ecojusta* stoves. Establishing a group of interested and capable individuals within the community would increase the likelihood of success and ability to meet demands. About one third of respondents stated that they believed there were community members capable of establishing a cookstove building and servicing start-up within the community. However, access to credit and finances to support this group of individuals entrepreneurial effort is lacking as only one household reported having regular and predictable income and access to a bank account. The success of a stove program in the community may be achievable as responses indicate that the community is interested and may be capable of building and maintaining the stoves within the community. However, these findings suggest a strong need for educational opportunities that should not only be technical in nature (i.e. stove construction and repair) but should include ways to improve financial resiliency (i.e. budgeting, utilizing income generating opportunities, etc.) to increase the likelihood of a long-term success.

There are significant challenges that if not identified and properly understood, could be catastrophic to the success of an improved cookstove program in rural communities. The seventh question in this study, "*how do the people feel about access to resources and societal support structures",* seeks to understand some of these critical challenges. In general, the large majority (92%) of respondents felt their basic needs go unmet and 72% have trouble supporting themselves. Even those with above average income (58%) contend with these daily struggles. Indeed, 85% of households are self-reportedly food insecure, 69% do not have enough fuel for their daily cooking needs, and 46% were concerned that their water is dirty and causing them sickness. All households, based upon my observations, rely partially on food from outside of the community to meet their needs. Still, 81% of respondents stated that access to goods and materials from outside the community is difficult. These results suggest that this community may need additional focus on overcoming these important challenges before an improved cookstove program could achieve success. In fact, this information suggests there may be other development strategies that are better suited for a rural community in this situation.

One such strategy is focusing on educational opportunities and behavior change. Education resulting in behavior changes is cited in the literature as one of the more promising modern development approaches. (Dickinson et al., 2015; Goodwin et al., 2015; Stanistreet et al., 2015; Urmee & Gyamfi, 2014) Additionally, Campau's (2014) study on *ecojusta* projects reported that a reduction in fuel use and household air pollution depended more on users' knowledge and skill in operating the stove rather than stove type.

The eighth question in this survey asks, "*are there educational opportunities capable of providing inexpensive and effective intervention?*" In this community, 65% of respondents said they enjoyed educational talks, including 71% of those above the age of 50. For this project, I specifically asked about interest in five potential topics to be covered through educational talks in the community. Respondents ranked them as follows:

1. Family Health
2. Environment
3. Construction and Maintenance of Cookstoves
4. Women and Girls Empowerment
5. Cookstoves 101

I gave many educational talks in the community during my Peace Corps service, and they were often well attended with many questions. I often observed behavior changes related to topics I covered at educational talks inside the household, specifically related to hand washing. Furthermore, I observed the potential for word-of-mouth type spread of information as community members who were not in attendance at the educational talk would later come to me with their own questions. The results of the survey and field experience suggest that education focused on behavior change has strong potential to impact rural communities and create observable change in personal and environmental health.

In addition to utilizing the Ostrom (2010) sustainability assessment framework to guide the design and implementation of the ferrocement stove, I also used it to evaluate the strengths and weaknesses of the ferrocement cookstove implementation process after the pilot project (Section 4.3.7). Similarly, I asked several Peace Corps volunteers to evaluate their *ecojusta* projects that were completed in other rural communities in Panama jointly with the Panamanian national environmental agency, ANAM (Section 4.3.6). A distillation of these sections comprises the following three paragraphs.

Largely because of my integration and interactions with the community, the ferrocement stove scored well with respect to socio-cultural respect, community participation, and economic sustainability through the framework. This resulted in strong scores for the needs assessment, conceptual design and feasibility, and implementation stages of the project. The strengths of this project highlight the involvement of the community from building interest in improving family health at the household level to providing feedback on stove design and implementation strategies through stove prototyping. The project struggled during the design and action planning stage due to concerns over pot stability and chimney design. Furthermore, the post-implementation and follow-up stage was poorly considered due to limitations of time.

Like the ferrocement stove project, the *ecojusta* projects did well during the needs assessment and implementation stages. This pattern reflects the development strategy often used during improved cookstove programs. Initially, there is involvement of the community to assure that there is a need for an improved technology. Then, as demand rises, the stoves are constructed as quickly as possible for as many households as will participate until the resources are gone. Often resulting in a failure to consider most of the important life stages in the assessment framework. In this case, the design and action planning stage was poorly evaluated as many recognized that the *ecojusta* was chosen as the most appropriate technology by the implementors, not the community. Furthermore, the process rarely provided stove schematics and budgetary plans to community members to promote an inclusive success of the project.

As for the sustainability factors, the political cohesion of the *ecojusta* projects is very strong as it is supported by local, national, and international political organizations. Also, the socio-cultural respect in the *ecojusta* projects echo the efforts put forth by ANAM and the Peace Corps volunteers to work within the community. To implement the maximum number of stoves based on the assumption that the largest impact can be made in this fashion to family and environmental health is in error. Environmental sustainability was the biggest weakness identified for *ecojusta* projects in this study. Primarily this suggests that long-term environmental degradation will continue due to lack of education resulting in behavior changes that reduces fuel harvesting and increases stove performance through operator skill.

Both projects overlap in significant ways, the approach used by Peace Corps volunteers is people centered with the idea that the process is the product. The idealized knowledge transfer is participatory and inclusive and achieved through capacity building from the bottom-up that focuses on the long-term vision. This is reflected in both evaluations receiving strong scores in the needs assessment and implementation phases particularly with socio-cultural respect.

The shared weaknesses were clearly in the post-implementation and follow-up phases particularly in the environmental sustainability category. This is very common in development projects that are more focused on implementing technologies than developing the human resources and inspiring behavior changes. Without sufficient dedication to educating the communities, I suspect that many of the human and environmental health goals will go unrealized as inefficient fuel use will continue resulting in household air pollution and deforestation. However, a strong focus in post project evaluation and monitoring is necessary to confirm this suspicion.

To compare the ferrocement stove with the three other stoves observed in the community, I incorporate engineering judgement alongside experience in the field to provide a qualitative discussion of the stoves most likely to be sustainable for this rural community. The details of this discussion are in Section 4.3, and the following four paragraphs summarize these opinions.

Based on my knowledge, I believe that the gas stove is the least sustainable stove option for this community. Primarily because this stove doesn't meet users' needs entirely which most likely will result in stove stacking. Literature suggests that households that stove stack rarely achieve the health benefits associated with cleaner combustion (Simon et al., 2014). Furthermore, the reoccurring fuel costs associated with gas equate to a yearly cost more than the household monthly average income. This financial demand places additional pressures on households that already struggle to meet their basic needs. Additionally, the environmental impacts associated with producing gas and distributing it to this rural community are driven by non-renewable resources, mainly fossil fuels that have significant environmental impacts at the global level.

I believe that the *ecojusta* stove is more sustainable than the gas stove, but less than the ferrocement and three stone fire. The ferrocement and *ecojusta* stoves were closely ranked for likelihood of sustainability. The primary difference between the two is the ferrocement stove is more durable, portable, and could be repaired easier than the *ecojusta.* Furthermore, the costs associated with the *ecojusta* are considerably higher than the ferrocement or three stone fire, and no further design improvements are being made based on community feedback.

Overall, I ranked the ferrocement stove as the second most likely to be sustainable in the community. This is primarily due to the holistic process of development undertaken that is the focus of this thesis. The bottom-up approach creates more informed users resulting in a grassroots demand for improving cooking technology. The outcome is a more appropriate solution developed through high socio-cultural respect and community participation. Moreover, the ferrocement stove seems to be affordable for a rural community that faces extreme poverty. As mentioned above, it uses local materials and thus can generally be repairable by members of the household. The ferrocement stove needs more development and testing to ensure that it is meeting the goals of reducing indoor air pollution and deforestation.

Finally, I suspect the three stone fire is the most sustainable stove for a rural community in a situation similar to one observed here. The obvious issue with the three stone fire is its impact on human and environmental health. However, this stove is very adequate at meeting users' varying needs while requiring no additional fossil fuels or non-renewable resources to construct or operate. An important result to consider is that 85% of survey respondents had never been taught how to use less fuel and create less smoke through more efficient combustion practices such as using dry wood that has been processed into smaller pieces to facilitate combustion and how to maintain an efficient fire through fuel moderation and protection from wind. Furthermore, although many respondents felt that smoke was harmful to them, I believe that few of them understand why it is harmful or how they can reduce their exposure resulting in fewer health issues. I believe more reductions in household air pollution and environmental degradation will be achieved if the human and monetary resources that are typically dedicated to implementing a technology were focused on providing educational opportunities and inspiring behavior change.

Ultimately, there is no one perfect solution, however it is important that each stove option for an implementation program be considered within the context of increasing sustainability and evaluated for the short and long-term using tools as available. There is also greater need to consider the potential to make an impact in these communities by following the most appropriate approach to development. The current zeitgeist of cookstove implementation programs focuses largely on reducing exposure to household air pollution by improving combustion efficiency of technology. We need to contemplate more seriously the socio-cultural roles that traditional cooking technologies fulfill. By taking sufficient time to evaluate each community's' unique situation, one may find that, in fact, a new stove technology may not be the most economical or sustainable solution. A better approach may be to spend more resources improving education and skills related to increasing combustion efficiency of the traditional stove, managing local resources, and improving personal and familial health through behavior change.

Objective three of this thesis was to develop a construction manual for the ferrocement cookstove so that the stove could be utilized for other applications either in the field or the lab. Appendix E contains the construction manual developed to achieve this objective. Hopefully practitioners find value in the process and design flexibility and continue improvements.

Finally, objective four of this thesis was to provide basic guidelines for applying a more holistic approach to an improved cookstove project. I provide recommendations as part of this objective to support development workers in achieving the sustainable development goals related to energy and public health. The United Nations Global Alliance for Clean Cookstoves encourages the adoption of 100 million substantially improved stoves by 2020 with regards to combustion efficiency and fuel use to increase energy security in the developing world (United Nations, 2016). However, I believe that this frames a solution without properly considering the problem.

Ultimately, I suggest that better education regarding efficient combustion, mitigating indoor air pollution, and sustainable harvesting and processing of fuel wood should become the central focal point of improved cookstove programs for rural communities like Peña Blanca. By not implementing an improved cooking technology that is likely to fail, more resources can be devoted to building capacity of the community members at the household level. This type of capacity building combined with a focus in behavior change can result in better human and environmental health without the risky investment and environmental burden of inappropriate cooking technologies.

Several guidelines to incorporate for refining the approach to improving family and environmental health are as follows:

1. Gain community trust by integrating or showing honest intention to help them solve their needs. Perform needs assessments by empowering them to contribute and brainstorm. Act as a facilitator.
2. Perform a community survey, ideally working with established local leaders to achieve best results.
3. Carefully consider the results of the survey and the needs assessments.
4. Evaluate the approach. Decide if educating is the best method, if there is an existing technology that meets users' needs and is aligned with local and national political powers, or if there is an opportunity to develop or modify a technology that is more appropriate.
5. If a technology is chosen to be implemented, evaluate the likelihood of sustainability using data from community surveys, emissions testing, safety and durability tests, the Ostrom sustainability assessment framework, and life cycle assessments.

6. Follow the Ostrom sustainability framework to guide development and implementation of the appropriate technology. Be sure to perform post-implementation and follow-up and observe behavior change.
7. Perform another community survey and needs assessment to understand satisfaction and verify adoption rates incorporating these results into the iterative process.

Many iterations of this process may be necessary to ensure that best practices are being performed and that the goals of reducing or eliminating exposure to household air pollution and impacts to the environment are being achieved.

5.1 Limitations and Recommendations

The author during the development of this work had many ideas on how to improve success of the program and assure that solutions presented were likely to reduce emissions, reduce environmental impacts, incorporate users' needs and opinions, and ultimately be sustainable. Unfortunately, significant challenges presented themselves during the work that prohibited a complete success. The most significant challenges for this study were time and access to resources. Part of working with a community at the grassroots level is respecting daily and seasonal schedules and lifestyles. Many families have daily priorities that are placed above developing an improved cookstove and at times, essential community members work a job outside of the community. Similarly, as a Peace Corps volunteer there is a limited time within the community. Furthermore, access to resources such as electricity, communication, stove testing equipment, and stove materials proved to be major obstacles to the success of this study.

One notable condition of this study was the level of integration of the researcher into the community. Although being well integrated can often provide a deeper understanding of the community, it is also a limitation. Specifically, many community members understood the role of a development worker and may have been inclined to tailor their responses to study questions to receive the benefits often associated with development projects, particularly in this case, a subsidized improved cookstove. After several years in the community, many members were aware of my intentions and some are inclined to say what they expect I want to hear, as opposed to their honest opinions. Furthermore, the sample size of the study was a limiting factor. Although a majority of the community center was surveyed, there are approximately 85 households in the community and 26 were surveyed. The role of the researcher and the sample size are important to consider as results from this survey vary significantly from results found in the literature on improved cookstove programs.

In addition, several specific and important objectives of this work were unable to be accomplished. The following paragraph describes the proposed but incomplete tasks. A household survey was conducted after the design and implementation of the ferrocement stove. Ideally this survey would have been conducted before this process to guide the design and after implementation to assess success. Additionally, to assure that the stove design will last and reduce fuel use and household air pollution, it is important to demonstrate cooking efficiency, safety, and durability equal to or greater than the most common cookstoves currently in use. A variety of tests may be used, but I recommend the most up-to-date water boiling test and kitchen performance test that provides data on particulate matter and carbon monoxide to determine pollutant emissions using equipment such as Aprovecho's Portable Emissions System (PEMS) (Aprovecho Research Center, 2016; Partnership for Clean Indoor Air, 2010). Details regarding a variety of stove performance tests are discussed in Section 2.2.3. Moreover, the use of personal monitoring units to collect data on actual fuel use and exposure would be beneficial to include in further studies. To evaluate for safety, the author recommends the Iowa State University Safety Test (Johnson & Bryden, 2015). For durability, the Colorado State University (2014) durability test is the most modern assessment tool. As the importance of consistency in modern assessment tools is becoming more recognized, it is important to conduct research on the most up-to-date testing protocols that have scientific consensus before beginning a stove implementation program.

One approach used in this study was building the ferrocement stove and the *ecojusta* side by side so that users could have hands-on experience with both styles and better inform the decision-making process. I would suggest this idea be further pursued, particularly with a stove model that had a chimney to increase the desire for a chimney on the selected stove technology to improve indoor air quality.

Another proposed and important evaluation that is recommended for the future is to conduct a life cycle assessment (LCA) of the various stove technologies being considered including the traditional stove. A LCA can provide insight into principal factors during the production, use, and disposal of cooking technologies. Specifically answers to the question, "*Is the embodied energy associated with production, transportation, fuel usage during lifetime, and* *disposal of improved cookstoves truly offsetting the environmental impact from fuel efficiency improvements"* would provide vital insights into program management and decision making.

In conclusion, at the global level, there remains a need for improved cookstove development projects to consider their likelihood of success and sustainability. Even more so, to consider if implementing a technology that is unlikely to meet users' specific needs is a better approach than investing time and resources into education and behavior change activities. These programs in rural Panama appear to be performing well in the needs assessment and implementation phases of the projects, but still need crucial work in the post-implementation and follow-up phases. There remains a need to confirm high user satisfaction and adoption rates, as well as a reduction in household air pollution and deforestation while providing continuing educational opportunities that result in positive behavior changes related to improving health and managing environmental resources and impacts. This work demonstrates that it is possible to develop a more appropriate solution to improved cookstove program goals at the community level by considering users' knowledge, perceptions, and needs.

LIST OF REFERENCES

Afrane, G., & Ntiamoah, A. (2012). Analysis of the life-cycle costs and environmental impacts of cooking fuels used in Ghana. *Applied Energy, 98*, 301-306. doi:http://dx.doi.org/10.1016/j.apenergy.2012.03.041

Agurto, A., & Marcos, M. (2011). *Improved stove adoption in the Northern Peruvian Andes.* (Text). Retrieved from https://open.library.ubc.ca/collections/24/items/1.0071618

Amadei, B. (2014). Sustainability and Development for All *Engineering for Sustainable Human Development* (pp. 489-492): American Society of Civil Engineers.

ANAM. (2014). *MANUAL PARA LA CONSTRUCCIÓN Y MANTENIMIENTO DE LA ESTUFA ECOLÓGICA*. Retrieved from www.anam.gob.pa.

Anenberg, S. C., Balakrishnan, K., Jetter, J., Masera, O., Mehta, S., Moss, J., & Ramanathan, V. (2013). Cleaner Cooking Solutions to Achieve Health, Climate, and Economic Cobenefits. *Environmental Science & Technology, 47*(9), 3944-3952. doi:10.1021/es304942e

Aprovecho Research Center. (2016). Portable Emissions Monitoring System (PEMS). Retrieved from http://aprovecho.org/portfolio-item/portable-emissions-monitoring-system/

Bensch, G., & Peters, J. (2015). The intensive margin of technology adoption - Experimental evidence on improved cooking stoves in rural Senegal. *Journal of health economics, 42*, 44-63. doi:10.1016/j.jhealeco.2015.03.006

Bielecki, C., & Wingenbach, G. (2014). Rethinking improved cookstove diffusion programs: A case study of social perceptions and cooking choices in rural Guatemala. *Energy Policy, 66*, 350-358. doi:10.1016/j.enpol.2013.10.082

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. doi:10.1002/jgrd.50171

Brendon, R. B. (2014). Behavioural Change, Indoor Air Pollution and Child Respiratory Health in Developing Countries: A Review. *International Journal of Environmental Research and Public Health, Vol 11, Iss 5, Pp 4607-4618 (2014)*(5), 4607. doi:10.3390/ijerph110504607

Campau, J. (2014). *Ecojusta Stove Use and Durability, Corregimiento El Toro*.

Colorado State University. (2014). Cookstove Durability Protocol.

Dickinson, K. L., Kanyomse, E., Piedrahita, R., Coffey, E., Rivera, I. J., Adoctor, J., . . . Wiedinmyer, C. (2015). Research on Emissions, Air quality, Climate, and Cooking Technologies in Northern Ghana (REACCTING): study rationale and protocol. *BMC public health, 15*(1), 126. doi:10.1186/s12889-015-1414-1

EPA. (2016, 10/2016). Learn About Sustainabilty. Retrieved from https://www.epa.gov/sustainability/learn-about-sustainability#what

Global Alliance for Clean Cookstoves. (2012). *Enabling Markets Worldwide*. Retrieved from http://cleancookstoves.org/resources_files/alliance-second-annual-report-enabling-markets-worldwide.pdf

Global Alliance for Clean Cookstoves. (2014). The Water Boiling Test Version 4.2.3: Global Alliance for Clean Cookstoves.

Global Alliance for Clean Cookstoves. (2016). Panama - Health. Retrieved from http://cleancookstoves.org/country-profiles/107-panama.html

Goodwin, N. J., O'Farrell, S. E., Jagoe, K., Rouse, J., Roma, E., Biran, A., & Finkelstein, E. A. (2015). Use of Behavior Change Techniques in Clean Cooking Interventions: A Review of the Evidence and Scorecard of Effectiveness. *Journal of Health Communication, 20*(sup1), 43-54. doi:10.1080/10810730.2014.1002958

Greepala, V., & Nimityongskul, P. (2008). Structural integrity of ferrocement panels exposed to fire. *Cement and Concrete Composites, 30*(5), 419-430. doi:http://dx.doi.org/10.1016/j.cemconcomp.2007.08.007

House, J. S., Umberson, D., & Landis, K. R. (1988). Structures and Processes of Social Support. *Annual Review of Sociology, 14*(1), 293-318. doi:10.1146/annurev.so.14.080188.001453

Institute for Health Metrics and Evaluation. (2016). *Rethinking Development and Health: Findings from the Global Burden of Disease Study*. Retrieved from

Institute for Health Metrics and Evaluation. (2017). Health data for Panama. Retrieved from http://www.healthdata.org/panama

Intergovernmental Panel on Climate Change. (2007). *Climate Change 2007: Synthesis Report*. Retrieved from Geneva, Switzerland: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf

Jan, I. (2012). What makes people adopt improved cookstoves? Empirical evidence from rural northwest Pakistan. *Renewable and Sustainable Energy Reviews, 16*(5), 3200-3205. doi:http://dx.doi.org/10.1016/j.rser.2012.02.038

Jetter, J. J., & Kariher, P. (2009). Solid-fuel household cook stoves: Characterization of performance and emissions. *Biomass and Bioenergy, 33*(2), 294-305. doi:http://dx.doi.org/10.1016/j.biombioe.2008.05.014

Johnson, N. G., & Bryden, K. M. (2015). Field-based safety guidelines for solid fuel household cookstoves in developing countries. *Energy for Sustainable Development, 25*, 56-66. doi:http://dx.doi.org/10.1016/j.esd.2015.01.002

Koffi, E. (2013). *Household Energy for Cooking Project Design Principles*. Paper presented at the Energy and Mining Board Discussion, Washington DC. http://cleancookstoves.org/binary-data/RESOURCE/file/000/000/377-1.pdf

Kshirsagar, M. P., & Kalamkar, V. R. (2014). A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. *Renewable and Sustainable Energy Reviews, 30*, 580-603. doi:http://dx.doi.org/10.1016/j.rser.2013.10.039

Lara, C. (2010) *Conversations with Claro Lara/Interviewer: T. Ostrom*.

MacCarty, N., Still, D., & Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy for Sustainable Development, 14*(3), 161-171. doi:http://dx.doi.org/10.1016/j.esd.2010.06.002

Manser, N. D., Naughton, C. C., Verbyla, M. E., Prouty, C., Orner, K., & Mihelcic, J. R. (2015). Improving the Global Competency of Graduate Engineers Through Peace Corps Partnership and Long-term International Service.

McConville, J. R. (2006). *Applying Life Cycle Thinking to International Water and Sanitation Development Projects.* (Master of Science in Environmental Engineering Thesis), Michigan Technological University, Michigan Technological University. Retrieved from http://cee.eng.usf.edu/peacecorps/5%20-%20Resources/Theses/Assessment/2006Mcconville.pdf

McConville, J. R., & Mihelcic, J. R. (2007). Adapting Life-Cycle Thinking Tools to Evaluate Project Sustainability in International Water and Sanitation Development Work. *Environmental Engineering Science, 24*(7), 937-948. doi:10.1089/ees.2006.0225

Mehetre, S. A., Panwar, N. L., Sharma, D., & Kumar, H. (2017). Improved biomass cookstoves for sustainable development: A review. *Renewable and Sustainable Energy Reviews, 73*, 672-687. doi:http://dx.doi.org/10.1016/j.rser.2017.01.150

Mihelcic, J. R. (2010). The Right Thing to Do: Graduate Education and Research in a Global and Human Context. (Downey, G.L., and Beddoes, K. eds., San Francisco: Morgan & Claypool Publishers), 235-250.

Mihelcic, J. R., Fry, L. M., Myre, E. A., Phillips, L. D., Barkdoll, B. D., & Carter, J. (2009). Field Guide to Environmental Engineering for Development Workers: Water, Sanitation, and Indoor Air: American Society of Civil Engineers.

Mihelcic, J. R., Naughton, C. C., Verbyla, M. E., Zhang, Q., Schweitzer, R. W., Oakley, S. M., . . . Whiteford, L. M. (2016). The Grandest Challenge of All: The Role of Environmental Engineering to Achieve Sustainability in the World's Developing Regions. *Environmental Engineering Science, 34*(1), 16-41. doi:10.1089/ees.2015.0334

Mihelcic, J. R., Phillips, L. D., & Watkins, D. W., Jr. (2006). Integrating a Global Perspective into Education and Research: Engineering International Sustainable Development. *Environmental Engineering Science, 23*(3), 426-438. doi:10.1089/ees.2006.23.426

Mihelcic, J. R., & Zimmerman, J. B. (2014). Air Quality Engineering *Environmental Engineering: Fundamentals, Sustainability, Design*: Wiley.

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, 109*(27), 10815-10820. doi:10.1073/pnas.1115571109

Ostrom, T. K. (2010). *Considering sustainability factors in the development project life-cycle : a framework for increasing successful adoption of improved stoves.* (Master of Science thesis), Michigan Technological University. Retrieved from http://digitalcommons.mtu.edu/etds/503

Partnership for Clean Indoor Air. (2010). *Test Results of Cookstove Performance*. Retrieved from http://www.pciaonline.org/resources/test-results-cook-stove-performance

Pelletier, J., Codjia, C., & Potvin, C. (2012). Traditional shifting agriculture: tracking forest carbon stock and biodiversity through time in western Panama. *Global Change Biology, 18*(12), 3581-3595. doi:10.1111/j.1365-2486.2012.02788.x

Ramirez, S., Puneet, D., Robert, B., & Adrian, G. (2012). Perceptions of stakeholders about nontraditional cookstoves in Honduras. *Environmental Research Letters, 7*(4), 044036.

Reitinger, C. (Ed.) (2016). Salem Press.

Ruiz-Mercado, I., Masera, O., Zamora, H., & Smith, K. R. (2011). Adoption and sustained use of improved cookstoves. *Energy Policy, 39*(12), 7557-7566. doi:http://dx.doi.org/10.1016/j.enpol.2011.03.028

Schweitzer, R. W., & Mihelcic, J. R. (2012). Assessing sustainability of community management of rural water systems in the developing world. *Journal of Water Sanitation and Hygiene for Development, 2*(1), 20-30. doi:10.2166/washdev.2012.056

Simon, G. L., Bailis, R., Baumgartner, J., Hyman, J., & Laurent, A. (2014). Current debates and future research needs in the clean cookstove sector. *Energy for Sustainable Development, 20*, 49-57. doi:http://dx.doi.org/10.1016/j.esd.2014.02.006

Smith, K., Uma R., Kishore V., Lata K., Joshi V., Zhang J., . . . Halil M. (2000). Greenhouse Gases from Small-scale Combustion Devices in Developing Countries, Phase IIa: Household Stoves in India. *EPA-600/R-00-052*.

Stanistreet, D., Hyseni, L., Bashin, M., Sadumah, I., Pope, D., Sage, M., & Bruce, N. (2015). The Role of Mixed Methods in Improved Cookstove Research. *Journal of Health Communication, 20*(sup1), 84-93. doi:10.1080/10810730.2014.999896

Terrapon-Pfaff, J., Dienst, C., König, J., & Ortiz, W. (2014). How effective are small-scale energy interventions in developing countries? Results from a post-evaluation on project-level. *Applied Energy, 135*, 809-814. doi:http://dx.doi.org/10.1016/j.apenergy.2014.05.032

Troncoso, K., Castillo, A., Merino, L., Lazos, E., & Masera, O. R. (2011). Understanding an improved cookstove program in rural Mexico: An analysis from the implementers' perspective. *Energy Policy, 39*(12), 7600-7608. doi:http://dx.doi.org/10.1016/j.enpol.2011.04.070

United Nations. (2015). *The Millennium Development Goals Report*. Retrieved from http://www.undp.org/content/dam/undp/library/MDG/english/UNDP_MDG_Report_2015.pdf

United Nations. (2016). *2016 Progress Report Clean Cooking: Key to Achieving Global Development and Climate Goals*. Retrieved from http://cleancookstoves.org/resources/reports/2016progress.html

Urmee, T., & Gyamfi, S. (2014). A review of improved Cookstove technologies and programs. *Renewable and Sustainable Energy Reviews, 33*, 625-635. doi:http://dx.doi.org/10.1016/j.rser.2014.02.019

WHO. (2002). *World Health Report: Reducing Risks, Promoting Healthy Life*. Retrieved from

WHO. (2009). *The Energy Access Situation in Developing Countries*. Retrieved from http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Sustainable%20Energy/energy-access-situation-in-developing-countries.pdf

WHO. (2014). *Indoor air quality guidelines: household fuel combustion*. Retrieved from http://www.who.int/indoorair/publications/household-fuel-combustion/en/:

WHO. (2016). Household air pollution and health [Fact Sheet] (pp. Fact sheet N°292).

WHO. (2018). Metrics: Disability-Adjusted Life Year (DALY). Retrieved from http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

Wilkinson, P., Smith, K. R., Davies, M., Adair, H., Armstrong, B. G., Barrett, M., . . . Chalabi, Z. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *The Lancet, 374*(9705), 1917-1929. doi:10.1016/S0140-6736(09)61713-X

World Bank. (2010). *Development and Climate Change*. Retrieved from http://siteresources.worldbank.org/INTWDR2010/Resources/5287678-1226014527953/WDR10-Full-Text.pdf

World Bank. (2015). *The State of the Global Clean and Improved Cooking Sector* (96499). Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf

APPENDIX A: LIST OF ABBREVIATIONS

ANAM – La Autoridad Nacional del Ambiente (Panama's national authority of the environment)

GACC – Global Alliance for Clean Cookstoves

HAP – Household air pollution

COPD – Chronic obstructive pulmonary disease

WHO – World Health Organization

DALY – disability adjusted life year

LCA – life cycle assessment

PM – particulate matter

CO – carbon monoxide

CO2 - carbon dioxide

N2O - nitrous oxide

CH4 - methane

WBT - Water Boiling Test

CCT - Controlled Cooking Test

UCT - Uncontrolled Cooking Test

KPT - Kitchen Performance Test

ISO - International Organization of Standards

SWOT-AHP - strengths, weaknesses, opportunities, and threats – analytical hierarchy process

APPENDIX B: COPYRIGHT PERMISSIONS

Below is permission for the use of the Ostrom Sustainability Assessment Framework in Chapters 2, 3, and Appendix E.

Josh Donegan <joshdonegan@gmail.com> Fri, Feb 16, 2018 at 8:39 AM
To: [redacted]

Good morning Travis, my name is Josh Donegan, I'm a student at the University of South Florida with Dr. Mihelcic. I was in Peace Corps as well in the Masters international program and doing my thesis on improved cookstoves. I wanted to use part of your sustainability Matrix checklist in my appendix. But I need your written permission to do so. would you mind if I did so? If not, Please provide written permission to include. Thanks , hope all is well.

Travis Ostrom [redacted] Fri, Feb 16, 2018 at 9:39 AM
To: Josh Donegan <joshdonegan@gmail.com>

Josh,
Good to hear from you.
You are welcome to use any part of the sustainability matrix, checklist, or any other material from my thesis in your work.
Please let me know if there is any other information or help I can offer.
I'd be interested to read your thesis when your finished. Say hi to Mihelcic for me.
Best of luck,
Travis

APPENDIX C: HOUSEHOLD SURVEY IN ENGLISH

This survey was sufficiently adapted from Dickinson et al., 2015 for use in this study.

Appropriateness of Improved Cookstoves -- Air Quality and Health Impacts in Panama

Study - Pro00028279

Oct. 10th 2016

Fill out prior to beginning interview:

Survey Information:

Household Number: [ ]

Is this household a **replacement** for another household that was selected for the study but could not participate?

- ☐ Yes → Enter the Household Number for the household being replaced: ___________________
- ☐ No

If the survey is not completed, please indicate the reason why?

[ ] Interviewee seriously ill, cannot reschedule
[ ] Interviewee refused to be interviewed
[ ] Interviewee decided to stop before finishing interview
[ ] Interviewee absent
[ ] Other, specify _____________________

Mark the time you started and finished the interview. If the survey required a second visit, mark the start and finish time of that interview, and so on.

	First visit	Second visit
Date (dd/mm/yy)	___/___/___	___/___/___
Time start		
Time stop		
Total minutes		

1

I. INFORMED CONSENT

INTRODUCTION

Hello, my name is ______. I am working with the University of South Florida, and the Peace Corps from the United States. We are doing a study about cooking, air quality, health, and other issues in this area. We do not plan to talk to all residents in this area, but have selected several to participate in this study. You are one of those selected to participate, if you are willing. **I would like to speak with the person in this household who does the most cooking.**

STUDY PROCEDURE

We are interested in learning about people's perceptions and opinions concerning the cookstoves, fuels, common foods, and cooking practices. This survey will take less than one hour to complete. If you decide to participate in this survey, we will need to record the location of your household on a map. Finally, I would like to take a few pictures of your cooking area.

VOLUNTARINESS

Taking part of this study is completely voluntary. You have every right to refuse to participate. If you should refuse, you will not suffer any consequences.

WITHDRAWAL

If you chose to participate in this study, you have the right to withdraw from it at any point in time without any consequences to you. You can also refuse any study procedure that you are not comfortable with. *You are free to skip any questions you do not wish to answer or to stop at any time. You may ask the researchers any questions you have at any time.*

COMPENSATION

You will not be paid for your participation in this study.

CONFIDENTIALITY

We will be using household numbers randomly generated to identify the survey. Your name will not be associated

QUESTIONS

If you have any questions concerning the study, you can contact Josh Donegan at (507) 6773-4231 or Dr. Jaimie Corvin at the University of South Florida.

ORAL CONSENT OF PARTICIPANT

Do you agree to participate in this study?

- ☐ Yes
- ☐ No

II. ROSTER

Respondent information:

1. What is the highest level of school you have completed? ***(Read options; single response)***

- ☐ Never attended school
- ☐ First year
- ☐ Second year
- ☐ Third year
- ☐ Fourth year
- ☐ Fifth year
- ☐ Sixth year
- ☐ University
- ☐ Other (specify)
- ☐ Don't know

2. During the last 12 months, what are your primary daily activities? (***Check all that apply)***

- ☐ Student
- ☐ No work – disabled
- ☐ No work – too old/retired
- ☐ No work – unemployed
- ☐ Housewife
- ☐ Agriculture / farm in the community
- ☐ Agriculture / farm outside the community
- ☐ Public servant (e.g., teacher or nurse)
- ☐ Civil servant
- ☐ Casual worker
- ☐ lumberjack
- ☐ Self-employed – trader
- ☐ Self-employed – artisan
- ☐ Self-employed – other: ____________
- ☐ Other (specify): ________________

Head of Household information:

3. During the last 12 months, what was the head of household's MAIN activity? ***(Read options; single response)***

- ☐ Student
- ☐ No work – disabled
- ☐ No work – too old/retired
- ☐ No work – unemployed
- ☐ lumberjack
- ☐ Housewife
- ☐ Agriculture / farm
- ☐ Public servant (e.g., teacher or nurse)
- ☐ Civil servant
- ☐ Casual worker
- ☐ Self-employed – trader
- ☐ Self-employed – artisan
- ☐ Self-employed – other: ____________
- ☐ Other (specify): __________________
- ☐ Not applicable

Other Cooks' information:

4. Other than yourself, who else cooks in this household? ***(Enter N/A if there are no other cooks in the household)***

	Sex	Age
Cook 1		
Cook 2		
Cook 3		
Cook 4		
Cook 5		

Children's information:

5. Total number of children under five currently living in this household: _____________
6. Total number of children between five and eighteen currently living in this household: __________

III. PRIORITIES

Now I'd like to ask about challenges or problems you face in your daily life.

7. Do you agree or disagree with the following statements about your daily life?

	1 Disagree	2 Neither Agree nor Disagree	3 Agree
Our household has enough money to take care of our basic needs.	☐	☐	☐
All of my family members are in good health.	☐	☐	☐
A smoky kitchen bothers me			
Our household has poor access to health facilities	☐	☐	☐
Having an electricity connection at our household would greatly improve our lives.	☐	☐	☐
Smoke from my cooking fire causes health problems for me or my family.	☐	☐	☐
Our drinking water is often dirty and makes us sick.	☐	☐	☐
Household chores like cooking and cleaning take too much of my time.	☐	☐	☐
It is easy for our household to get fuel for cooking.	☐	☐	☐
We have good lighting for our home at night.	☐	☐	☐
Access to materials and outside goods is difficult	☐	☐	☐
My children have access to a good education	☐	☐	☐
Our household has trouble supporting itself	☐	☐	☐
We always have enough food for the family	☐	☐	☐
The community supports me and my family	☐	☐	☐
My family has a high education level	☐	☐	☐
It is difficult to communicate with people outside the community	☐	☐	☐
The government cares for my well-being and works to improve my life	☐	☐	☐
I have plenty of free time	☐	☐	☐
My family often does not have enough fuel to cook with	☐	☐	☐

IV. COOKING PRACTICES

Now I'd like to ask you a few questions about your cooking practices. Could I please see the area in your house where you cook?

8. How many **three stone / traditional stoves** do you use to cook for this household?

   _____________ *Number of stoves*

   ________________hours per day spent using this stove

9. How many **LPG/Gas stoves** do you use to cook for this household?

   _____________ *Number of stoves*

   ________________hours per day spent using this stove

10. How many **other stoves** (not traditional stoves or coal pots) do you use to cook for this household?

______________ Number of stoves

_________________hours per day spent using this stove

11. Do you use multiple types of stoves?
- ☐ Yes
- ☐ No

12. Which is your favorite stove?
- ☐ Three stone/ Traditional stove
- ☐ LPG/Gas stove
- ☐ Other stove

13. Why do you use multiple stove technologies? **(Check all that apply)**
- ☐ To prepare food faster
- ☐ Need more space to cook
- ☐ Less fuel is used
- ☐ It is safer
- ☐ Less smoke
- ☐ Social status
- ☐ My children can help cook
- ☐ It is too hot in the kitchen
- ☐ Cleaner
- ☐ Better flavors of food

14. What would convince you to use only 'improved stoves or gas'?
- ☐ Cost of fuel
- ☐ Availability of fuel
- ☐ Safety
- ☐ Faster cooking times
- ☐ No smoke in the kitchen

15. Please indicate the most common foods and beverages prepared in your home and how long they are prepared on a daily basis
    a. Rice ___lbs x ___hours per day
    b. Beans ___lbs x ___ hours per day
    c. Coffee ___lbs x ___ hours per day
    d. Tubers ___lbs x ___ hours per day
    e. Leafy Vegetables ___lbs x ___ hours per day
    f. Bananas___lbs x ___ hours per day
    g. Boiled meat ___lbs x ___ hours per day
    h. Smoked meat ___lbs x ___hours per day
    i. Fried foods___lbs x ___ hours per day
    j. Pastas ___lbs x ___ hours per day
    k. Fruit ___lbs x ___ hours per day
    l. Roasting/toasting rice/coffee ___ lbs x ___ times per day
    m. Vegetables / soup___ lbs x ___ times per day
    n. Corn/maize___ lbs x ___ times per day
    o. Other ___ lbs x ___ times per day

ENTER STOVE TYPE: ________________

a) Does this stove appear to be the primary stove?
   Yes No

b) *(Observe)* Where is this stove located?
- ☐ Outdoors (no roof)
- ☐ Indoors (3 or 4 walls, roof)
- ☐ Semi-closed (2 walls with roof)
- ☐ Other

c) ***(Observe for INDOOR STOVES)*** How is the kitchen or cooking area ventilated? ***(Check all that apply)***

- ☐ No ventilation
- ☐ Open eaves
- ☐ Open windows
- ☐ Open door
- ☐ Other:__________
- ☐ Not applicable

d) Is this stove located in the same place all the time, or do you move the stove?

- ☐ Always in the same place
- ☐ We move the stove

e) When do you move this stove? ***(Read options)***

- ☐ Seasonally
- ☐ Daily
- ☐ Occasionally / Depending on the weather
- ☐ Whenever the stove is used (e.g., stove stored indoors but used outdoors)
- ☐ Other:____________________
- ☐ Not applicable

f) Do you use this stove to cook food… ***(Read options; Check all that apply)***

- ☐ For your own household
- ☐ For other households in the community
- ☐ For households in different community
- ☐ To sell commercially

g) What is this stove typically used to cook? ***(Check all that apply)***

- ☐ Rice
- ☐ Beans
- ☐ coffee
- ☐ Tubers
- ☐ Leafy vegetables
- ☐ Bananas
- ☐ Boiled meat
- ☐ Smoked meat
- ☐ Vegetables / soup
- ☐ Fried foods
- ☐ Corn / Maize
- ☐ Porridge
- ☐ Roasting coffee/rice
- ☐ Fruits
- ☐ Pastas
- ☐ Other: ______________

h) What fuel is being used NOW? ***(Check all that apply)***

- ☐ Twigs/leaves
- ☐ Medium sized wood
- ☐ Large pieces of Wood
- ☐ Charcoal
- ☐ Corn cobs
- ☐ Dung
- ☐ Kerosene
- ☐ Plastic bags/trash
- ☐ Other: ____________

i) How many people will eat the food that is being cooked on this stove today?

______ Number of people

j) How many days per week is this stove used?

- ☐ Not used at all
- ☐ One to three days
- ☐ Four to six days
- ☐ Every day

k) Has this stove ever?

- ☐ Tipped over
- ☐ Caught fire (or spread fire in the kitchen)
- ☐ Burned someone
- ☐ Caused other type of injury

l) Which members of the household would build/move or maintain this stove?

- ☐ Mothers
- ☐ Daughters
- ☐ Fathers
- ☐ Sons

m) Who typically uses this stove?

- ☐ Respondent
- ☐ Other person in this household → Sex/Age: ________________
- ☐ Other person from a different household

n) What do you like about this stove? ***(Unprompted)***

- ☐ Affordable/cheap
- ☐ Easy to use
- ☐ Good for cooking specific dishes
- ☐ Cooks food quickly
- ☐ Produces little smoke
- ☐ Uses little fuel
- ☐ Few health problems
- ☐ Smokes meat well
- ☐ Food tastes good
- ☐ Doesn't burn food
- ☐ Doesn't burn body
- ☐ Easy to control heat level
- ☐ Doesn't produce heat outside of stove
- ☐ Easy to move
- ☐ Keeps mosquitos/insects away
- ☐ Provides lighting in the kitchen
- ☐ Burns trash well
- ☐ Heats the kitchen during cold weather
- ☐ Other: __________________
- ☐ Not applicable
- ☐ Good for cooking multiple dishes

o) Any problems you have with this stove?

- ☐ Produces a lot of smoke
- ☐ Makes pots dirty from soot
- ☐ Makes walls/ceiling dirty from soot
- ☐ Has to be tended constantly while cooking
- ☐ Uses a lot of fuel
- ☐ Fuel is hard to get
- ☐ Causes health problems
- ☐ Food doesn't tastes good
- ☐ Burns food
- ☐ Burns body
- ☐ Hard to control heat level
- ☐ Produces heat outside of stove
- ☐ Combustion chamber too small/fuel doesn't fit
- ☐ Not portable / hard to move
- ☐ Other: ________________

ENTER STOVE TYPE: _______________

p) Does this stove appear to be the primary stove?
Yes No

q) *(Observe)* Where is this stove located?
- ☐ Outdoors (no roof)
- ☐ Indoors (3 or 4 walls, roof)
- ☐ Semi-closed (2 walls with roof)
- ☐ Other

r) ***(Observe for INDOOR STOVES)*** How is the kitchen or cooking area ventilated? ***(Check all that apply)***
- ☐ No ventilation
- ☐ Open eaves
- ☐ Open windows
- ☐ Open door
- ☐ Other:__________
- ☐ Not applicable

s) Is this stove located in the same place all the time, or do you move the stove?
- ☐ Always in the same place
- ☐ We move the stove

t) When do you move this stove? ***(Read options)***
- ☐ Seasonally
- ☐ Daily
- ☐ Occasionally / Depending on the weather
- ☐ Whenever the stove is used (e.g., stove stored indoors but used outdoors)
- ☐ Other:____________________
- ☐ Not applicable

u) Do you use this stove to cook food… ***(Read options; Check all that apply)***
- ☐ For your own household
- ☐ For other households in the community
- ☐ For households in different community
- ☐ To sell commercially

v) What is this stove typically used to cook? ***(Check all that apply)***
- ☐ Rice
- ☐ Beans
- ☐ coffee
- ☐ Tubers
- ☐ Leafy vegetables
- ☐ Bananas
- ☐ Boiled meat
- ☐ Smoked meat
- ☐ Vegetables / soup
- ☐ Fried foods
- ☐ Corn / Maize
- ☐ Porridge
- ☐ Roasting coffee/rice
- ☐ Fruits
- ☐ Pastas
- ☐ Other: _______________

w) What fuel is being used NOW? ***(Check all that apply)***
- ☐ Twigs/leaves
- ☐ Medium sized wood
- ☐ Large pieces of Wood
- ☐ Charcoal
- ☐ Corn cobs
- ☐ Dung
- ☐ Kerosene
- ☐ Plastic bags/trash
- ☐ Other: _____________

x) How many people will eat the food that is being cooked on this stove today?

______ Number of people

y) How many days per week is this stove used?
- ☐ Not used at all
- ☐ One to three days
- ☐ Four to six days
- ☐ Every day

z) Has this stove ever?
- ☐ Tipped over
- ☐ Caught fire (or spread fire in the kitchen)
- ☐ Burned someone
- ☐ Caused other type of injury

aa) Which members of the household would build/move or maintain this stove?
- ☐ Mothers
- ☐ Daughters
- ☐ Fathers
- ☐ Sons

bb) Who typically uses this stove?
- ☐ Respondent
- ☐ Other person in this household → Sex/Age: ________________
- ☐ Other person from a different household

cc) What do you like about this stove? ***(Unprompted)***
- ☐ Affordable/cheap
- ☐ Easy to use
- ☐ Good for cooking specific dishes
- ☐ Cooks food quickly
- ☐ Produces little smoke
- ☐ Uses little fuel
- ☐ Few health problems
- ☐ Smokes meat well
- ☐ Food tastes good
- ☐ Doesn't burn food
- ☐ Doesn't burn body
- ☐ Easy to control heat level
- ☐ Doesn't produce heat outside of stove
- ☐ Easy to move
- ☐ Keeps mosquitos/insects away
- ☐ Provides lighting in the kitchen
- ☐ Burns trash well
- ☐ Heats the kitchen during cold weather
- ☐ Other: __________________
- ☐ Not applicable
- ☐ Good for cooking multiple dishes

dd) Any problems you have with this stove?
- ☐ Produces a lot of smoke
- ☐ Makes pots dirty from soot
- ☐ Makes walls/ceiling dirty from soot
- ☐ Has to be tended constantly while cooking
- ☐ Uses a lot of fuel
- ☐ Fuel is hard to get
- ☐ Causes health problems
- ☐ Food doesn't tastes good
- ☐ Burns food
- ☐ Burns body
- ☐ Hard to control heat level
- ☐ Produces heat outside of stove
- ☐ Combustion chamber too small/fuel doesn't fit
- ☐ Not portable / hard to move
- ☐ Other: ________________

ENTER STOVE TYPE: _______________

ee) Does this stove appear to be the primary stove? Yes No

ff) *(Observe)* Where is this stove located?
- ☐ Outdoors (no roof)
- ☐ Indoors (3 or 4 walls, roof)
- ☐ Semi-closed (2 walls with roof)
- ☐ Other

gg) ***(Observe for INDOOR STOVES)*** How is the kitchen or cooking area ventilated? ***(Check all that apply)***
- ☐ No ventilation
- ☐ Open eaves
- ☐ Open windows
- ☐ Open door
- ☐ Other:__________
- ☐ Not applicable

hh) Is this stove located in the same place all the time, or do you move the stove?
- ☐ Always in the same place
- ☐ We move the stove

ii) When do you move this stove? ***(Read options)***
- ☐ Seasonally
- ☐ Daily
- ☐ Occasionally / Depending on the weather
- ☐ Whenever the stove is used (e.g., stove stored indoors but used outdoors)
- ☐ Other:____________________
- ☐ Not applicable

jj) Do you use this stove to cook food... ***(Read options; Check all that apply)***
- ☐ For your own household
- ☐ For other households in the community
- ☐ For households in different community
- ☐ To sell commercially

kk) What is this stove typically used to cook? ***(Check all that apply)***
- ☐ Rice
- ☐ Beans
- ☐ coffee
- ☐ Tubers
- ☐ Leafy vegetables
- ☐ Bananas
- ☐ Boiled meat
- ☐ Smoked meat
- ☐ Vegetables / soup
- ☐ Fried foods
- ☐ Corn / Maize
- ☐ Porridge
- ☐ Roasting coffee/rice
- ☐ Fruits
- ☐ Pastas
- ☐ Other: _______________

ll) What fuel is being used NOW? ***(Check all that apply)***
- ☐ Twigs/leaves
- ☐ Medium sized wood
- ☐ Large pieces of Wood
- ☐ Charcoal
- ☐ Corn cobs
- ☐ Dung
- ☐ Kerosene
- ☐ Plastic bags/trash
- ☐ Other: _____________

mm) How many people will eat the food that is being cooked on this stove today?

______ Number of people

nn) How many days per week is this stove used?
- ☐ Not used at all
- ☐ One to three days
- ☐ Four to six days
- ☐ Every day

oo) Has this stove ever?
- ☐ Tipped over
- ☐ Caught fire (or spread fire in the kitchen)
- ☐ Burned someone
- ☐ Caused other type of injury

pp) Which members of the household would build/move or maintain this stove?
- ☐ Mothers
- ☐ Daughters
- ☐ Fathers
- ☐ Sons

qq) Who typically uses this stove?
- ☐ Respondent
- ☐ Other person in this household → Sex/Age: _______________
- ☐ Other person from a different household

rr) What do you like about this stove? ***(Unprompted)***
- ☐ Affordable/cheap
- ☐ Easy to use
- ☐ Good for cooking specific dishes
- ☐ Cooks food quickly
- ☐ Produces little smoke
- ☐ Uses little fuel
- ☐ Few health problems
- ☐ Smokes meat well
- ☐ Food tastes good
- ☐ Doesn't burn food
- ☐ Doesn't burn body
- ☐ Easy to control heat level
- ☐ Doesn't produce heat outside of stove
- ☐ Easy to move
- ☐ Keeps mosquitos/insects away
- ☐ Provides lighting in the kitchen
- ☐ Burns trash well
- ☐ Heats the kitchen during cold weather
- ☐ Other: ____________________
- ☐ Not applicable
- ☐ Good for cooking multiple dishes

ss) Any problems you have with this stove?
- ☐ Produces a lot of smoke
- ☐ Makes pots dirty from soot
- ☐ Makes walls/ceiling dirty from soot
- ☐ Has to be tended constantly while cooking
- ☐ Uses a lot of fuel
- ☐ Fuel is hard to get
- ☐ Causes health problems
- ☐ Food doesn't tastes good
- ☐ Burns food
- ☐ Burns body
- ☐ Hard to control heat level
- ☐ Produces heat outside of stove
- ☐ Combustion chamber too small/fuel doesn't fit
- ☐ Not portable / hard to move
- ☐ Other: __________________

FUEL USE

16. Which of the following fuels have you used to cook food **in the past month**? ***(Read options; check all that apply)***

- ☐ Wood
- ☐ Charcoal
- ☐ Corn cobs
- ☐ Dung
- ☐ Kerosene
- ☐ LPG/gas
- ☐ Trash/Plastic
- ☐ Have you used any other fuels in the past month? (Fill in) ___________________

17. How long is spent on an average day processing fuel wood (i.e. cutting, chopping, storing at the house hold, drying)

_____________hours per day
_____________days per week

18. Who typically does this fuel processing?

	Sex	Age
Person 1		
Person 2		
Person 3		
Person 4		
Person 5		

19. If more time was needed to process fuel for an improved stove would this deter your desire for an improved stove?

- ☐ Yes
- ☐ No
- ☐ Not sure

20. Would the ability to use smaller pieces of wood be a benefit to you?

- ☐ Yes
- ☐ No
- ☐ Not sure

21.

22. Where do you get your fuel?

- ☐ Public land
- ☐ Family land
- ☐ Neighbor's land
- ☐ Not sure

23. In the past few years in this area, has there been any change in the availability of fuel for cooking? ***(Unprompted; check all that apply)***

- ☐ Yes, it has become harder to find fuel
- ☐ Yes, it has become easier to find fuel
- ☐ Yes, we have changed the types of fuel we use
- ☐ No
- ☐ Other: ____________________________________

V. KNOWLEDGE AND PERCEPTIONS

24. Do you have any construction experience using wood or concrete?

- ☐ Yes
- ☐ No
- ☐ Someone in my household does

25. Do you think smoke from cooking is harmful to your health?

- ☐ Yes
- ☐ No
- ☐ Don't know/not sure

26. Do you think smoke from cooking is harmful to your family's health?

- ☐ Yes
- ☐ No
- ☐ Don't know/not sure

27. What health problems do you think are linked to cooking smoke?
(Unprompted – check all that are mentioned)

- ☐ Eye problems
- ☐ Respiratory illnesses
- ☐ Pneumonia
- ☐ Meningitis

- ☐ Other: ______________________
- ☐ Don't know/not sure

28. Is the smoke from cooking more or less harmful than the dust from sweeping?

- ☐ More harmful
- ☐ Less harmful
- ☐ Equally harmful
- ☐ Don't know

29. Is the smoke from cooking more or less harmful than smoke from burning trash?

- ☐ More harmful
- ☐ Less harmful
- ☐ Equally harmful
- ☐ Don't know

30. Is the smoke from cooking more or less harmful than tobacco smoke?

- ☐ More harmful
- ☐ Less harmful
- ☐ Equally harmful

31. Is the smoke from cooking more or less harmful indoors than outdoors?

- ☐ More harmful
- ☐ Less harmful
- ☐ Equally harmful
- ☐ Don't know

32. Do the fuels people use for cooking in this area have effects on the air, water, land, plants, and animals around us? ***(Unprompted – check all that are mentioned)***

- ☐ Deforestation/loss of trees
- ☐ Air pollution
- ☐ Climate change / changes in weather
- ☐ Erosion
- ☐ No effects
- ☐ Other: ______________________
- ☐ Don't know

33. Other than providing fuel, what are other benefits that trees provide in this area? ***(Unprompted – check all mentioned)***

- ☐ Provide habitat for animals
- ☐ Provide shade for people/animals
- ☐ Reduces pollution / provides clean air / improves air circulation
- ☐ Provides food (like mangoes, other fruits)
- ☐ Provide wood for building
- ☐ Provides traditional medicine (herbs, roots, bark, leaves)
- ☐ Balance / stabilize / the local environment or climate
- ☐ Provides wind breaks
- ☐ Protects the local watersheds, rivers and streams
- ☐ Reduces soil erosion
- ☐ Maintains soil fertility / provides fertilizer or organic matter
- ☐ Increases chances of rain
- ☐ Other: ______________________
- ☐ Don't know/not sure

34. What, if any, changes have you noticed in local weather patterns over the past several years? ***(Unprompted – check all mentioned)***

- ☐ No changes
- ☐ Wetter/more rain
- ☐ Drier/less rain
- ☐ Changes in timing of rainy season / Less predictable rains
- ☐ Hotter
- ☐ Cooler
- ☐ Windier
- ☐ Other: ______________________
- ☐ Don't know / not sure

35. Do you believe that human actions have any impact on changes in local weather patterns?
- ☐ Yes
- ☐ No

36. If any changes mentioned in previous question: Why **do you think** these changes are occurring?
(Enter 88 for not applicable.)

VI. DEMAND FOR NEW STOVES AND WILLINGNESS TO PAY

37. Have you heard of or seen any new cookstoves in this area that use wood?
- ☐ Yes
- ☐ No
- ☐ Don't know/not sure

38. Where did you hear about or see these stoves? ***(Check all that apply)***
- ☐ Community meeting
- ☐ Friend
- ☐ Relative
- ☐ At river
- ☐ Store
- ☐ Public meeting outside community
- ☐ Another household in community
- ☐ Another household outside community
- ☐ Church group
- ☐ Women's group
- ☐ Government agency
- ☐ Peace Corps volunteer
- ☐ Other: ____________________
- ☐ Not applicable

39. From what you've heard, what are the main benefits of this technology? ***(Unprompted)***
- ☐ Cheaper
- ☐ Faster cooking
- ☐ Less smoke
- ☐ Less fuel use
- ☐ Fewer health problems
- ☐ Food tastes good
- ☐ Easy to use
- ☐ Doesn't burn food
- ☐ Doesn't burn body
- ☐ Easy to control heat level
- ☐ Easy to construct/maintain
- ☐ Portable
- ☐ Not as hot (around the stove)
- ☐ Other: ________________________
- ☐ Don't know
- ☐ Not applicable

40. From what you've heard, what are the main problems with this technology? (***Unprompted)***
- ☐ Expensive
- ☐ Slower cooking
- ☐ More smoke
- ☐ More fuel use
- ☐ Food tastes worse
- ☐ Hard to use
- ☐ Easy to control heat level
- ☐ Can't be used for heating home
- ☐ Difficult to construct or maintain
- ☐ Other: _______________________________
- ☐ Don't know

41. How important are each of the following factors to your choice of improved stoves?

	1 Not important	2 Somewhat important	3 Very important
Reduction in smoke	☐	☐	☐
Reduction in fuel use	☐	☐	☐
Reduction in cooking time	☐	☐	☐
Cost of the stove	☐	☐	☐
Whether or not the stove was made in Panama	☐	☐	☐
Appearance similar to the traditional stove	☐	☐	☐
Whether or not the stove was made in the community	☐	☐	☐
Fuel availability	☐	☐	☐
Safety i.e. non-tippable, protection from burns	☐	☐	☐
Is simple and easy to use	☐	☐	☐
Is portable	☐	☐	☐
Can be repaired easily	☐	☐	☐
Materials are locally available	☐	☐	☐
Capability of building a new one without outside help	☐	☐	☐
Cooks staple foods better	☐	☐	☐
Has a chimney	☐	☐	☐
Taste of food	☐	☐	☐
Ability to control heat level	☐	☐	☐
Stove size	☐	☐	☐
Pot stability on stove	☐	☐	☐
Ease of use	☐	☐	☐
Previous experience with the stove	☐	☐	☐

42. Would you be willing to use a community stove in order to share the costs?

☐ Yes daily
☐ Yes weekly
☐ Yes monthly
☐ No

43. Have you ever been taught about how to burn more efficiently (use less fuel/less smoke)?

☐ Yes
☐ No
☐ Don't remember

44. Do you know how to build an improved cookstove?

☐ Yes
☐ No

45. Do you know how to repair an improved cookstove?

☐ Yes
☐ No

46. Do you know how to maintain an improved cookstove?
- ☐ Yes
- ☐ No

47. How much money per month are you willing to contribute to stove maintenance and care?
- ☐ $0
- ☐ $1-10
- ☐ $11-20
- ☐ More than $20

48. How much time per month are you willing to contribute to stove maintenance and care?
- ☐ 1 hour or less
- ☐ Between 1 and 5 hours
- ☐ Between 5 and 10 hours
- ☐ More than 10 hours

49. Who in the household would benefit most from an improved stove?
- ☐ Women
- ☐ Children
- ☐ Men
- ☐ Everyone

VII. SOCIAL NETWORKS

50. Does your family spend time together in the kitchen?
______hours per day
______days per week

51. Has the government shown interest in improving cooking technologies in your community?
- ☐ Yes
- ☐ No
- ☐ Not sure

52. Do you enjoy educational talks?
- ☐ Yes
- ☐ No

53. Which educational talks would you like to have offered in order of most interesting to least interesting **(Number from 1 to 5)**

__ Environment (How improved cookstoves can help keep fuel sources plentiful and nearby, as well as protect your water source)

__ Family health (What are the effects of cooking smoke on my family and how does it make us sick)

__ Women and Girls empowerment (How improved cookstoves can free make women and girls healthier and more productive in school and life)

__ Cookstoves 101 (What does improved cookstove mean and what are the basics of more efficient cleaner cooking)

__ Construction and Maintenance of cookstoves (How to build an improved cookstove and take care of it so that it lasts)

__ Other: ________

VIII. SOCIOECONOMICS

	Yes	No	Don't know
54. Does anyone in your household have access to a bank account?	☐	☐	☐
55. Is there any credit offered to buy construction materials or tools?	☐	☐	☐
56. In the past year, have you purchased livestock or food stocks with the intention of selling them in the future for more money?	☐	☐	☐

57. What is the average monthly spending in your household? (Including food, clothes, transportation, and entertainment) ____________ balboas
58. Do you believe there are groups of people within the community who would be interested in building improved cookstoves as a small business?
- ☐ Yes
- ☐ No
- ☐ Not sure

59. Is your income regular and predictable?
- ☐ Regular and predictable
- ☐ Regular but unpredictable
- ☐ Irregular but predictable
- ☐ Irregular and unpredictable

60. How much would you pay for an improved cookstove ***(Unprompted)***
   - $0
   - $1-10
   - $11-20
   - $21-30
   - $31-40
   - Other:_______

61. Are you willing to contribute any of the following to improve your stove? (circle all that apply)
   - ☐ labor
   - ☐ wood
   - ☐ sand
   - ☐ rock
   - ☐ zinc
   - ☐ sawdust
   - ☐ wire mesh
   - ☐ rebar
   - ☐ cement
   - ☐ bricks
   - ☐ materials transport
   - ☐ tools (saw, trowel, pliers, machete, etc.)

62. How much would you pay for an improved cookstove if you contributed some of the materials listed above?
   - $0
   - $1-10
   - $11-20
   - $21-30
   - $31-40
   - Other:_______

IX. HEALTH: Now I'd like to ask some questions about your health and the health of children in this household.

Health Questions for Respondent:

63. Did you have any of the following symptoms in **the past week**? ***(Read answers; Check all that apply)***

- ☐ Runny nose
- ☐ Sore throat
- ☐ Difficulty breathing
- ☐ Wheezing or whistling in the chest
- ☐ Dry cough
- ☐ Cough with phlegm
- ☐ Back pain caused by fuel collection
- ☐ Bloody cough
- ☐ Eye irritation
- ☐ Blurred vision
- ☐ Fever
- ☐ Burns from cookstove
- ☐ No symptoms **(GO TO 69)**

64. Do you often have a cough?

- ☐ Yes
- ☐ No **(GO TO 65)**
- ☐ Don't know **(GO TO 65)**

65. Is your cough caused or made worse by cookstove smoke?

- ☐ Yes
- ☐ No
- ☐ Don't know/ not sure

66. Do you often have a whistling or wheezing sound when you breathe?

- ☐ Yes
- ☐ No **(GO TO 67)**
- ☐ Don't know **(GO TO 67)**

67. Is your chest wheezing or whistling caused or made worse by exposures to cookstove smoke?

- ☐ Yes
- ☐ No
- ☐ Don't know/ not sure
- ☐ Not applicable

68. Do you often develop a headache during cooking?

- ☐ Yes
- ☐ No **(GO TO 69)**
- ☐ Don't know **(GO TO 69)**

69. Does the headache get better, worse, or stay the same after you are done cooking?

- ☐ Better
- ☐ Worse
- ☐ Same
- ☐ Don't know/ not sure
- ☐ Not applicable

70. Do you typically carry your child while cooking?

- ☐ Yes → How old is this child? ________________ months
- ☐ No

71. Are you currently pregnant?

- ☐ Yes → How many months have you been pregnant? ________________ months
- ☐ No
- ☐ Don't know / not sure

THANK RESPONDENT AND END SURVEY

APPENDIX D: IRB APPROVAL LETTER

UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

November 16, 2016

Josh Donegan
Civil and Environmental Engineering
Tampa, FL 33612

RE: **Exempt Certification**
IRB#: Pro00028279
Title: Appropriateness of Improved Cookstoves -- Air Quality and Health Impacts in Panama

Dear Mr. Donegan:

On 11/16/2016, the Institutional Review Board (IRB) determined that your research meets criteria for exemption from the federal regulations as outlined by 45CFR46.101(b):

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF HRPP policies and procedures.

Please note, as per USF HRPP Policy, once the Exempt determination is made, the application is closed in ARC. Any proposed or anticipated changes to the study design that was previously declared exempt from IRB review must be submitted to the IRB as a new study prior to initiation of the change. However, administrative changes, including changes in research personnel, do not warrant an amendment or new application.

Given the determination of exemption, this application is being closed in ARC. This does not limit your ability to conduct your research project.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John Schinka, Ph.D., Chairperson
USF Institutional Review Board

APPENDIX E: FERROCEMENT STOVE CONSTRUCTION MANUAL

Ferrocement Improved Cookstove Construction Manual

This is a simple manual intended to facilitate the reproduction of a ferrocement improved cookstove as developed by Josh Donegan (joshdonegan@gmail.com) as part of a masters thesis titled "Design and Implementation of a Ferrocement Improved Cookstove in Rural Panama"

This process was developed in December of 2016.

Table E1 Materials required to build the ferrocement improved cookstove.

Material	**Cost**
2 bags of cement	\$20.00
9 meters of 3/8"(1 cm) rebar	\$12.00
4 pieces of 90 x 120 cm medium opening wire mesh	\$6.00
2 pieces of 10 cm x 120 cm wood (long side)	\$5.00
2 pieces of 10 cm x 90 cm wood (short end)	\$5.00
1 roll (lb.) of tie wire	\$1.00
6 black plastic bags	\$1.50
5 buckets of sifted sand	\$0.00 (local resource)
Sawdust or equivalent filler (46,000 cubic centimeters 12 compacted gallon buckets)	\$0.00 (local resource)
Clean water	\$0.00 (local resource)
Total (for one stove)	**\$50.50**

This is the cost for one stove, if materials, forms, and tools are shared, the stove may cost as little as \$29.

Tools Needed:

Hacksaw with extra blades – tools

Trowels - tools

pliers with wire cutters- tools

IMPORTANT: Build formwork on top of a table or the preferred destination of the cookstove, although the stove is somewhat portable, this will save effort and allow full concrete strength to develop in place. Be sure the supporting structure will support at least 200 pounds to prevent failure. If the supporting structure will allow mortar to pass through, a plastic bag should be used beneath the forms and rebar to keep all mortar in place. For more tips on performing construction work in a field setting see Chapter 7 of Mihelcic, J. R., Fry, L. M., Myre, E. A., Phillips, L. D., Barkdoll, B. D., & Carter, J. (2009). Field Guide to Environmental Engineering for Development Workers: Water, Sanitation, and Indoor Air: American Society of Civil Engineers.

SUSTAINABILITY TIP: If building multiple stoves, the garbage bag forms used in Step 11 can be replaced by durable cloth forms, in Panama we used cloth forms that were previously used to build sand filters for a water project. These forms (Figure E4) were sewn by local women in the community.

Construction Steps (approximately 6 hours not including cure time):

1. Nail together the long sides and short ends of the wooden forms in a rectangle allowing the nails to protrude from the outside of the form to facilitate removal. Make sure the short ends are INSIDE the long side so that the total width is 90 cm.
2. Cut rebar:
    - 4 pieces of 90 cm (short body)
    - 1 piece of 118 cm (long body)
    - 4 pieces of 75 cm

3. Bend 4 pieces of 75 cm rebar to make handles, 2 bends at 30 cm each to make an open square type handle
4. Lay 118 cm long body rebar piece length-wise down the center of the stove body inside the wooden form
5. Lay 4 pieces of 90 cm short body rebar equally spaced across and on top of the long body rebar piece
6. Fit four handles (bent 75 cm rebar) between the 4 pieces from step 5 bordered by the wooden form
7. Use approximately 20 cm pieces of tie wire to tie all overlapping rebar at the connections, including handles

The result of steps 1-7 should look similar to the photo in Figure E1.

Figure E1 Rebar reinforcement for base slap, handles, and proper form setup.

IMPORTANT: Leave a 20 cm gap between the two innermost sheets of metal mesh during Step 9 for the combustion chamber.

8. Cut 4 pieces of 90 x 120 cm medium opening wire mesh

9. Place 2 pieces of wire mesh flat on top of the rebar base. Fold each piece of outermost mesh (near the forms) up to form a vertical wall approximately 10 cm in height and 3 cm from the rebar handles. Then flatten out the mesh along the bottom and fold again leaving approximately 21 cm between the two vertical mesh walls for the combustion chamber so that the remaining wire mesh of both pieces rises vertically from the bottom as seen in the photo below.

IMPORTANT: Be sure that sufficient wire mesh is available to wrap a 22 cm diameter cylinder filled with sawdust or similar filler.

10. Prepare to place concrete
    a. Wet forms
    b. Mix concrete and fill base up to 3-4 cm thickness
    c. Can use small aggregate (volume ratio 3:3:1) to save cement or just sand and cement (3:1).
    d. Wait at least 4 hours for surface to dry before beginning next step

Steps 9-10 should look like the photo in Figure E2 as you are constructing the base slab. Notice the wire mesh protruding from the concrete and the wetted forms.

Figure E2 Ensuring the proper amount of wire mesh is protruding while beginning to pour to base slab.

Once the concrete base is dry to the touch you can begin Step 11. Be sure to keep concrete moist and out of wind and direct sunlight for best results.

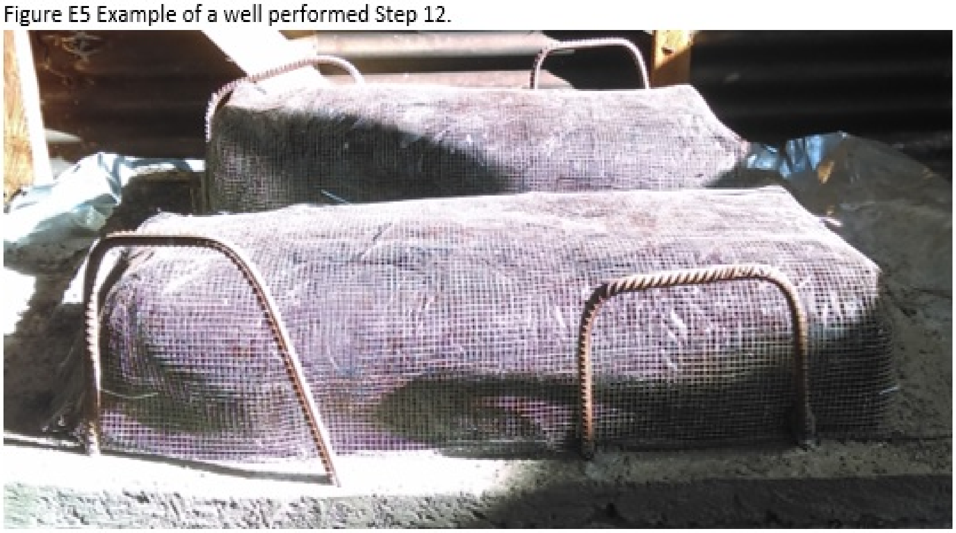
11. Remove wood forms.
12. Fill 2 plastic garbage bags with approximately 46,000 cubic centimeters (or 12 compacted gallon buckets) of sawdust or similar filler.
    a. Tie shut garbage bags and pack filler into shapes of cylinders with approximate diameter of 22 cm
    b. Place filled plastic bag forms and wrap the remaining metal mesh around the forms to form a cylinder with height approximately 20 cm, leaving a 20 cm gap in the middle between the two forms.
    c. Tie overlapping metal mesh using tie wire preferably at the base. Be sure the trim or fold flat excess tie-wire as it creates difficulties when applying the ferrocement coating in Step 12a.

IMPORTANT: If the stove is likely to be moved or the filler is to be recycled, it is best to leave an opening in the wire mesh so that the filler can be removed to reduce the weight of the stove. These openings can later be patched with wire mesh and mortared closed. See Figure E3 as an example.

Figure E3 Placing the cylindrical forms on the base slab and tying the wire mesh together for Step 12.

Figure E4 Example of the reusable cloth forms and leaving an opening to remove them after applying ferrocement layers to the wire mesh cylinders.

Figure E5 Example of a well performed Step 12.



13. Mix mortar: sand and cement (3:1) and cover the wire mesh as seen in Figure E6.
    a. Use ferrocement application technique to achieve thin layers of ferrocement pushing the mix into the wire mesh.
    b. It's best to cover it all at once; however, if there are spots that cannot be covered in the first layer, mesh should be left exposed to apply second layer.
14. Cover and let cure for at least one week preferably two weeks, being sure to keep the concrete wet or moist during curing process to reduce cracking and increase strength.

Figure E6 A community member putting finishing touches on the stove body after removing the cloth forms and filler.

15. To increase draft around fuel wood, place spare wire mesh into the combustion chamber as seen in Figure E7 to elevate the fuel off the slab.

Figure E7 Example of wire mesh being used as a grate for fuel to increase combustion efficiency.

16. Use stove and improve upon design for greater appropriateness for the users.

APPENDIX F: SUSTAINABILITY FRAMEWORK DETAILS

The framework developed by McConville (2006) and Ostrom (2010) is represented as a matrix accompanied by an associated checklist. Each matrix element corresponds to a pairing of one project life stage with one sustainability factor. Associated with each element is a set of four recommendations based on best practices in project management and issues related to the sustainability factors. Each element, its four sustainability recommendations, and sample rhetorical questions are included in the checklist. The rhetorical questions provide detail and context to the suggestions. Each element is assigned a rating (0-4) based on the number of sustainability recommendations completed. For each of the five project life stages, five matrix elements, with associated sustainability factors, must be evaluated to determine the score for that stage. The highest possible score for each life cycle stage or sustainability factor is 20. The highest possible overall score for a project is 100.

Table F1 Sustainability matrix for the Sustainability Assessment Framework.

Sustainability Factor						
Life Stage	Socio-cultural Respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	1,1	2,1	3,1	4,1	5,1	20
Conceptual Designs and Feasibility	2,1	2,2	3,2	4,2	5,2	20
Design and Action Planning	3,1	2,3	3,3	4,3	5,3	20
Implementation	4,1	2,4	3,4	4,4	5,4	20
Post-Implementation Follow-up	5,1	2,5	3,5	4,5	5,5	20
Total	20	20	20	20	20	**100**

The author’s scoring for the ferrocement stove sustainability is shown in parentheses following each question below. For example, “(1)” means the author self-evaluated and confirmed the action was undertaken. If there is no “(1)” that means the author did not perform the task. The results are summarized in Table 4.12 in Section 4.3.7.

The matrix element 1,1 covers Needs Assessment and Socio-cultural Respect.

- Identify past experiences with cooking technologies and attitudes toward them. (1)
- Identify social preferences and traditions associated with household energy use, cooking practices, and indoor air pollution. (1)
- Determine the level of health education in the community. (1)
- Recognize differences in gender/age in cooking, fuel collection, and HAP exposure. (1)

The matrix element 1,2 covers Needs Assessment and Community Participation.

- Conduct a participatory needs assessment at the local level to determine local development priorities. (1)
- Integrate yourself into the community and “accompany” them through the process. (1)
- Identify stakeholders and community leaders. (1)
- Determine what community members want from the stoves and expect from the project. (1)

The matrix element 1,3 covers Needs Assessment and Political Cohesion.

- Conduct a situational analysis of regional and national issues such as political structure and stability, government policies, and foreign aid.

- Ensure the proposed project is consistent with regionally identified development priorities and plans. (1)
- Research the history of NGO and government projects in the area. (1)
- Establish communication lines with existing NGO and/or government institutions in the area. (1)

The matrix element 1,4 covers Needs Assessment and Economic Sustainability.

- Understand the local economy and the market for improved stoves. (1)
- Understand the economic burden associated with cooking, fuel use, and IAP. (1)
- Identify sources of monetary and non-monetary resources within the community. (1)
- Assess the general community willingness-to-maintain and willingness-to-pay for fuel and improved stoves, in both monetary and non-monetary terms. (1)

The matrix element 1,5 covers Needs Assessment and Environmental Sustainability.

- Identify local environmental resources. (1)
- Collect baseline data and data on climate and Determine how environmental resources are used and controlled, and by whom. (1)
- Identify potential environmental concerns at the local and regional level. (1)
- Determine local, national, and international understanding of and concern for environmental problems and the willingness to correct them. (1)

The matrix element 2,1 covers Conceptual Designs/Feasibility and Socio-cultural Respect.

- Consider designs which meet the needs and expectations of users and make noticeable improvements. (1)

- Assess how the proposed stove technologies fit into traditional household practices, including gender roles. (1)
- Investigate feasibility of health education programs. (1)
- Recognize why biases exist towards certain technologies by donors and/or locals. (1)

The matrix element 2,2 covers Conceptual Designs/Feasibility and Community Participation.

- The project goals are clearly defined and understood by the community and development workers. (1)
- Work with leaders who can act as community liaisons throughout the project. (1)
- Present several technically feasible alternatives for community evaluation and feedback. (1)
- Community members modify and formally select a design based on their needs, preferences, and an understanding of the constraints involved in the selection process.

The matrix element 2,3 covers Conceptual Designs/ Feasibility and Political Cohesion.

- Develop a working relationship with all interested and pertinent partner organizations, including at least one that is based in the host country. (1)
- Use lessons learned from the plans and designs of other organizations on similar projects (past and present). (1)
- Consider ways to provide follow-up to the project. (1)
- Ensure project fits within local, national, and international context. (1)

The matrix element 2,4 covers Conceptual Designs/Feasibility and Economic Sustainability.

- Consider the logistical feasibility of implementing, operating, maintaining, and replacing each conceptual design. (1)
- Consider implications for the local economy and stove market and how economic capacity can be built for each conceptual design. (1)
- Assess the specific willingness-to-maintain and willingness-to-pay for each improved system (how much people value each option). (1)
- Conduct an economic feasibility assessment to evaluate long-term project viability based on cost estimates, projected operation and maintenance costs, community willingness to pay, the need for outside resources, and the availability of outside funding. (1)

The matrix element 2,5 covers Conceptual Designs/Feasibility and Environmental Sustainability.

- Assess the capacity for sustainable fuel use in the geographic area.
- Investigate feasibility of environmental awareness and rehabilitation activities. (1)
- Be sure to select a design which makes a significant and noticeable difference.
- Conduct an environmental impact analysis for each alternative. (1)

The matrix element 3,1 covers Design/Action Planning and Socio-cultural Respect.

- Plan sufficient time for health education. Empower people to make good choices about exposure to IAP, health, and household energy use. (1)
- Work with the traditional structure and schedule of community projects. (1)
- Confirm resource contributions and benefits are equitably or acceptably divided. (1)
- Explore options for increasing gender equity in project roles and capacity building. (1)

The matrix element 3,2 covers Design/Action Planning and Community Participation.

- Community input is solicited in refining the selected technical design. (1)
- Final technical design is understood and approved through a process of community consensus.
- Community members are involved in identifying and sequencing tasks that will be incorporated into an action plan. (1)
- The community members and development workers understand and approve of the timeline and responsibilities laid out in the action plan.

The matrix element 3,3 covers Design/Action Planning and Political Cohesion.

- The roles and responsibilities of partner institutions are defined in a detailed action plan, including financial commitments and a timeline.
- People in charge of construction and training are qualified and clear on the plans.
- Follow-up tasks, such as project M&E, are defined and execution of subsequent projects is discussed.
- Final project design and action plan are presented to and agreed upon by partner institutions and local, regional, and/or national level authorities.

The matrix element 3,4 covers Design/Action Planning and Economic Sustainability.

- Verify costs and availability and develop an action plan for resource procurement. (1)
- Finalize budget, contributions, and schedule based on demand, local costs, available resources, and commitments. (1)
- Plan sufficient time for O&M training.

- Plan actions to build capacity of the stove market and promote stoves.

The matrix element 3,5 covers Design/Action Planning and Environmental Sustainability.

- The final project design minimizes ecological disturbance, energy use, and waste emissions.
- The project design uses existing, renewable and/or recyclable local resources. (1)
- The action plan considers the long-term availability and seasonality of resources.
- Finalize an environmental education and rehabilitation plan to address environmental issues.

The matrix element 4,1 covers Implementation and Socio-cultural Respect.

- Conduct health education activities. (1)
- Encourage the involvement of all participants, particularly women, throughout the construction process. (1)
- Ensure high quality construction. Be inflexible and precise with critical components of the design, but flexible with non-crucial changes. (1)
- First implement a small number of stoves. Then use public gatherings to address concerns and build confidence before continuing with the rest. (1)

The matrix element 4,2 covers Implementation and Community Participation.

- Involve the community in revisions of the action plan, program changes, and problem solving.
- Ensure community members manage and carry out much of the implementation process themselves. (1)

- Train local leaders in the new techniques and technology that are introduced. (1)
- Ensure community members are clear on the O&M requirements and schedule.

The matrix element 4,3 covers Implementation and Political Cohesion.

- Supervise work (quality control) and push for fulfillment of responsibilities from partners. (1)
- Inform partner institutions of the start of construction, project milestones and major changes. (1)
- Invite government and institutional representatives to the project and make connections between organizations and the community. (1)
- Partners are reminded of follow-up responsibilities, future plans are confirmed, and any needed baseline data is collected. (1)

The matrix element 4,4 covers Implementation and Economic Sustainability.

- Conduct training, promotion, and capacity building according to action plan.
- Recheck the quality of materials and equipment during resource procurement and the quality of the finished project. (1)
- Monitor and document spending and contributions throughout the project implementation phase. (1)
- Draft final report on the budget and share with community members and partner organizations. (1)

The matrix element 4,5 covers Implementation and Environmental Sustainability.

- Restore any areas disturbed during construction. (1)

- Take precautions to avoid and minimize environmental impacts during implementation. (1)
- Conduct environmental education and rehabilitation activities. (1)
- Demonstrate the difference the technology has made at the household level.

The matrix element 5,1 covers Post-Implementation Follow-up and Socio-cultural Respect.

- Monitor whether or not the stoves continue to be used as intended. If not in proper use, determine issues.
- Address immediate issues and potential future ones.
- Continue health education programs and monitor choices people make about exposure to HAP, health, and household energy use.
- Reassess how gender/age roles affect the proper use and perceived benefits of the system.

The matrix element 5,2 covers Post-Implementation Follow-up and Community Participation.

- Unite the community to share experiences, provide support, and agree on next steps.
- The community assists with follow-up activities. (1)
- Conduct a participatory evaluation to get community feedback and suggestions for improvements. (1)
- The community has the capacity to conduct O&M.

The matrix Element 5,3 covers Post-Implementation Follow-up, Political Cohesion.

- Get feedback from project partners and stakeholders.

- Invite stakeholders and officials to an opening ceremony. Discuss with them future collaborations and continuation of efforts.
- Participating institutions carry out agreed upon roles in providing postimplementation follow-up.
- Share impact and monitoring reports and project evaluations with partner institutions and community.

The matrix element 5,4 covers Post-Implementation Follow-up and Economic Sustainability.

- Continue building the capacity of the local household energy (stove) market.
- Determine the actual impacts of the project.
- Monitor fuel use, maintenance, repair, and replacement of stoves.
- Ensure a mechanism to meet future demand.

The matrix element 5,5 covers Post-Implementation Follow-up and Environmental Sustainability.

- Work to further increase efficiency of technologies.
- Reassess local awareness of and willingness to address environmental concerns.
- Reassess environmental concerns and evaluate project impacts.
- Continue environmental education and rehabilitation efforts.

ABOUT THE AUTHOR

Josh Donegan graduated from Tennessee Technological University with a Bachelor of Science in Civil/Environmental Engineering in 2012. He then attended the University of South Florida as a National Science Foundation Scholar in the Masters International Program. As part of the program he was an active Peace Corps Volunteer in the Water and Sanitation Hygiene sector in Panama from June 2014 to December 2016. Josh currently works as an environmental engineering consultant primarily in the wastewater industry. He is an active member of the Water Environment Federation and hopes to play a role in providing clean water to the world for the foreseeable future.