METHODS FOR GENERATING MARKET INTELLIGENCE FOR IMPROVED COOKSTOVE DISSEMINATION: A CASE STUDY IN QUETZALTENANGO, GUATEMALA

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BY

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ABSTRACT

METHODS FOR GENERATING MARKET INTELLIGENCE FOR IMPROVED COOKSTOVE DISSEMINATION: A CASE STUDY IN QUETZALTENANGO, GUATEMALA

TIRIAN MINK

Today there are 2.4 billion people exclusively dependent on the combustion of low quality biomass fuels in open fires and inefficient traditional stoves for household cooking. When compared to higher quality fuels and modern technologies, these methods come with many negative and avoidable consequences in the areas of public health, global climate change, environmental degradation, and poverty. Improved Cookstoves (ICS) can be a part of the solution to many of these widespread problems. ICSs, when properly designed and utilized, can improve public health, reduce global warming and deforestation, and help the world's poorest families climb out of the poverty trap. ICS dissemination efforts have been underway since the 1970s with limited success, and today there is a growing interest and focus on tapping into the power of the market to distribute ICSs throughout the world. While the market presents a prodigious opportunity for increasing the penetration of ICS worldwide, there are a number of barriers that have inhibited this pathway from becoming a viable alternative to donation-based dissemination models. In this thesis I identify and discuss many of these barriers and focus on information gaps that are inhibiting key players in ICS manufacturing and marketing sectors from more effectively designing, manufacturing and marketing stoves.

Through the lens of the Doña Dora ICS case study in Quetzaltenango, Guatemala, I demonstrate a set of tools and methods to estimate economic viability using tradition financial metrics including net present value, internal rate of return, time to payback and benefit to cost ratio. One of the outcomes of this work is the Cookstove Calculator, a dynamic spreadsheet tool. With this tool, and a short household survey, cookstove manufacturers and marketing programs can quickly analyze the feasibility of an investment in any stove for any family. The Cookstove Calculator can also be combined with data from a random household survey to estimate total market demand. In this thesis I demonstrate this tool and these methods to estimate that the Doña Dora ICS is a net positive investment for roughly 40,000 households in rural Quetzaltenango. I also show how these tools and methods can be used to identify critical thresholds in stove parameters, such as fuel savings, sales price, and product lifetime that determine investment viability.

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Of course this work would not have been possible without my Guatemala partners at AIDG and Xelateco. The seeds for this project were planted over three years ago, late one evening on the steps of the bell tower at Swarthmore College. There I had a candid conversation with my friend Cat Laine and her husband Peter Haas, the directors of AIDG. I thank them for paving my path to Quetzaltenango, and for the work that they continue to do. I thank Steve Crowe, who created the umbrella under which I was able to carry out this work. I owe a special gratitude to Daniel Buchbinder. Daniel and I worked hand-in-hand to design and implement the household survey that is the foundation of this thesis. We made a great team, and I look forward to working with him on future projects.

I want to acknowledge my two sisters. Astara's strength and inner beauty cannot be matched by anyone on this earth. I could not be more proud of what she has accomplished in the last two years. I see much of myself in her. It has also given me great pleasure to see my little sister Aumbria grow up to be a beautiful woman and loving mom. I thank them both for being cornerstones of my first 35 years of life. I also want to acknowledge my big brother Adrian. Although he left us too soon, he will always live on in our hearts. I want to especially thank my grandmother Vivian. She is a manifestation of loving kindness, even when she sternly orders me to climb down from the top of the apple tree. One of my best and earliest memories in life is sitting on her lap by the fire as we stared at the Milky Way; both of us were in absolute wonder.

Most importantly, I thank the hundreds of people in Quetzaltenango who opened their homes and shared their time and perspectives with us during the field work phase of this project. We had a lot of questions, and interviewees were gracious and patient with us. Without their hospitality, this thesis would not be possible.

I save the greatest gratitude for my eccentric and loving parents Ronald and Victoria. Dad taught me that feeling and giving love is the highest purpose of the human experience. Mom taught me to see the world with my heart, to listen to the voices of the trees, and to believe in fairies. She allowed me to learn from my own mistakes, no matter how painful, and always encouraged me to be true to my inner voice. Above all I thank them both for teaching me about unconditional love.

I dedicate this to them, and to the 2.4 billion people who depend on the burning of wood, charcoal and other biomass fuels for household cooking.

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1 INTRODUCTION

For at least 790,000 years humanity has congregated around the hearth to cook food and gather warmth from the heat of an open fire (Human Origins Initiative, 2011). Creating energy for cooking from biomass is simple and as ancient as humanity itself, and began as combustion by means of an open fire (see Figure 1). Only in the relatively recent past did humans start to transition away from the open fire in favor of more advanced methods. Today billions of people have access to cleaner and more efficient means of cooking and heating the home that utilize technologies and higher quality fuels such as natural gas and electricity (UNDP, 2004). But many have been left behind. Today there are 2.4 billion people exclusively dependent on biomass for household cooking with an expected increase to 2.6 billion by the year 2030 (World Health Organization 2005, IEA 2004). The associated fuel consumption for household cooking represents nearly 10% of total global primary energy consumption (UNDP, 2004). Unfortunately, this timeless method for cooking and heating is very inefficient when compared to modern technologies and comes with many negative and avoidable consequences to public health, global climate change, environmental degradation, and poverty.

Broad negative health effects are associated with exposure to indoor air pollution from inefficient combustion of fuel; these are distributed disproportionately to women and children (World Health Organization, 2005). Fifty-nine percent of the annual 1.5 million premature deaths from indoor air pollution occur in females while fifty-six percent occur in children under five years old (World Health Organization, 2005).

Figure 1: Woman and her stove in San Marcos, Guatemala. *Photo source: Tirian Mink 2010.*

These deaths are caused by exposure to products of incomplete combustion (PICs) from burning solid fuel in the home (World Health Organization, 2005) ranking it 8th in the leading causes of death in the Global South (Bailis et al. 2004).

The health effects from exposure to these pollutants can be both acute and chronic, resulting from both discrete and prolonged exposure to PICs (Figure 2). Studies have found that exposure to PICs from stoves negatively impacts child development, respiratory and cardiovascular health, while increasing the risk of premature death (Schwartz 1996; Bice, et al. 2009; Smith 2006; Smith-Sivertsen, et al. 2009).

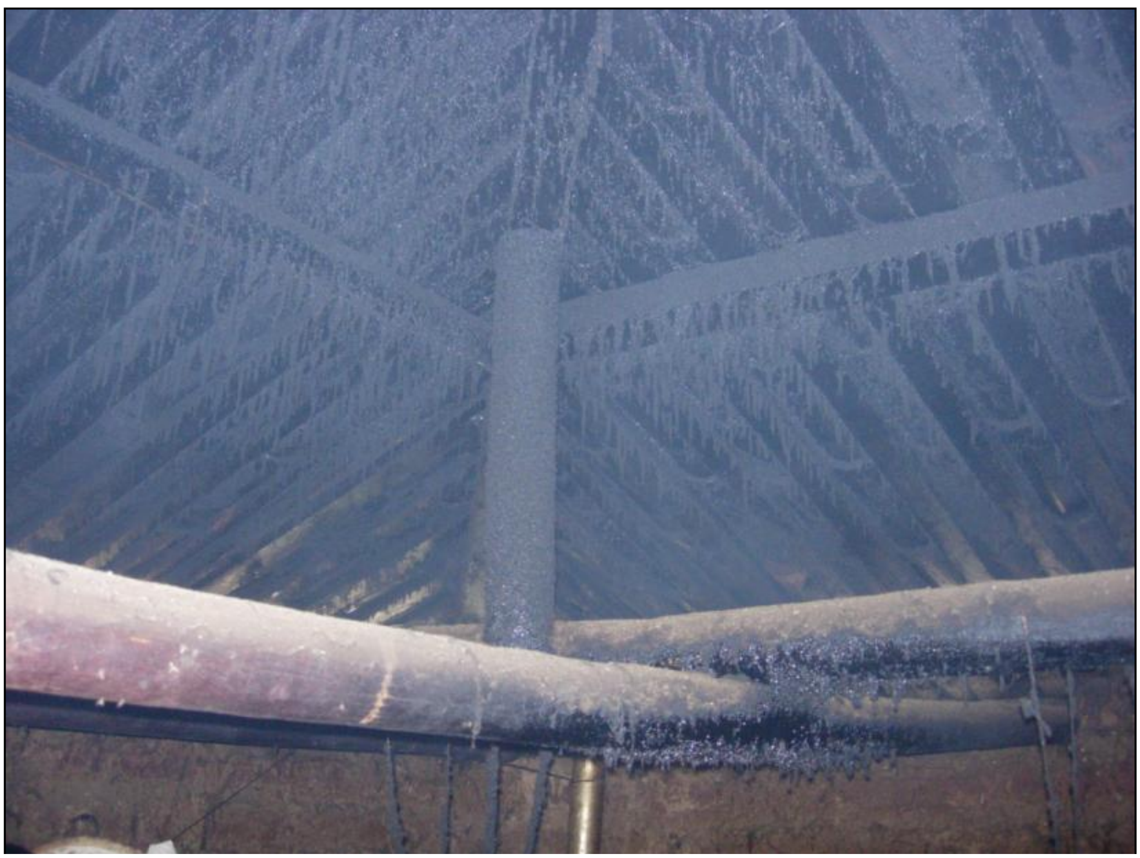

Figure 2. Deposits of PICs concentrated on the roof of a home in southern Mexico. This is a common occurrence in homes that use open fires for cooking and heating. *Photo source: Tirian Mink 2010*

Incomplete combustion in unimproved cookstoves is also a major source of greenhouse gas (GHG) emissions and black carbon (BC), a powerful global warming agent. Woodfuel emits approximately double the CO_2e per unit of fuel energy when compared to LPG (Gomez & Watterson, 2006), therefore efficiency improvements directed at biomass cooking technologies can have a greater impact than those directed at LPG cooking technologies. In fact roughly 13% of global anthropogenic carbon emission is estimated to come from domestic use of biomass fuels for cooking (UNDP, 2004). BC (e.g. soot) is an aerosol and common by-product of incomplete combustion. Due to its short atmospheric residency time (less than two years) and high radiative forcing characteristic, the estimated global warming impact of BC is 680 times that of CO_2 over a 100 year time horizon (Bond & Sun, 2005).[1] Beyond global warming, BC emissions are also significantly contributing to the melting of the Arctic and Himalayan glaciers. The absorption of solar radiation by BC particle deposited on ice and snow has led to a 0.5-1.0 °C local warming in the Arctic (Ramanathan & Carmichael, 2008) and is responsible for at least 30% of the glacial melt in the Himalayas (Menon et al. 2009).

[1] BC is not currently listed in the Intergovernmental Panel on Climate Change inventory of global warming constituents. Nevertheless, studies have demonstrated that it is playing a significant role in climate change and the melting of the glaciers (Bice, et al., 2009). Some are arguing that its inclusion in a common framework for mitigation of climate change would be consistent with the United Nations Framework Convention on Climate Change with estimates that it has a global warming potential of 680 times that of CO_2 on a 100 year timescale (Bond & Sun, 2005). Others argue that due to its short atmospheric residency time of less than two years it cannot be easily included in traditional mitigation strategies (Bice, et al., 2009).

Lack of access to higher quality fuels and more efficient cooking technologies is also part of the poverty trap, a condition in which various structural and institutional barriers prevent those in poverty from acquiring the means to move beyond poverty (Sachs, et al., 2004). In this context, access is inhibited by many factors: limited purchasing power, lack of access to capital or financing, limited availability of products near the home, restricted accessibility of appropriate fuel types at affordable prices, lack of knowledge and understanding of potential health and financial benefits, and culturally inappropriate stove design (see Section 3.3 for a thorough discussion of factors affecting accessibility of improved cookstoves). The upshot is that many people who stand to realize significant financial benefit from higher quality fuels and cooking methods are not able to access them due to these barriers.

Improved Cookstoves (ICS) can be a part of the solution to many of these widespread problems. ICSs are nearly as heterogeneous as the populations they serve; they can take any shape or size, but in order to be defined as “improved” a stove must perform well in two core areas: fuel efficiency and indoor air quality. ICSs, when properly designed and utilized, are improving public health, reducing global warming and deforestation, while helping poor families escape the poverty trap.

Numerous studies have demonstrated that ICSs reduce exposure to carbon monoxide and particulate matter (Granderson et al. 2005; Schwartz 1996; Smith 2006; Smith, et al. 1994; Smith 1987; WHO 2005). Ongoing studies in Mexico have found that the Patsari cookstove reduces the emission of harmful PICs by more than 75%, fuel consumption by more than 50%, and is eagerly adopted by beneficiaries (Masera, et al.

2005). Results from randomized trials in San Marcos, Guatemala demonstrated that beneficiaries of ICSs have significantly reduced carbon monoxide exposure and respiratory symptoms when compared to a control group that continued to use open fires (Smith-Sivertsen, et al., 2009).

During the last decade many studies have revealed that replacing traditional cooking methods with properly designed ICSs can significantly abate the process of global warming and climate change through reductions in emissions of GHGs and BC (Bailis, et al. 2004; Bice, et al. 2009; Bond and Sun 2005; Johnson et al. 2010). For example, studies that have modeled the abatement potential of successful ICS interventions in Mexico have demonstrated that 3.9 MT of CO_2e can be abated annually by the Patsari cookstove (Johnson et al. 2010); making it one of the most fiscally efficacious pathways for combatting global warming (Bond and Sun 2005). In fact, in terms of reducing global warming potential, few other measures can have a greater impact in terms of carbon abated per dollar invested. Estimates of the cost range from 0.30 to 11 USD per ton of CO_2 equivalent abated for this simple technology (Bond and Sun 2005).

ICS interventions can also dramatically improve household economies and provide immediate financial benefit to cash-strapped families. For example, a financial cost-benefit analysis has demonstrated that the *Patsari* cookstove represents a viable option for improving living conditions of the poorest inhabitants of rural Mexico with benefit-cost ratios estimated to be around 10:1; financial benefits come mainly from fuelwood savings (53%) and reduced health impacts (28%) (Garcia-Frapolli, et al., 2010).

In response to this unambiguous and massive need, hundreds, if not thousands of programs have mobilized to disseminate ICSs throughout the world since the 1970s. The question of how to design effective ICS dissemination programs is therefore of critical concern if we are to be effective in our efforts.

Dissemination efforts have been underway since the 1970s with limited success, and there is need for a comprehensive review of dissemination methods (Álvarez, et al. 2004). For the most part, the history of cookstove dissemination programs has a pattern of dependency on donors for funding and non-governmental organizations (NGOs) and government agencies for distribution (Álvarez, et al. 2004). Yet today there is a growing interest and focus on tapping into the power of the market to increase penetration of ICSs throughout the world (see Section 3.4 for a discussion of market-oriented approaches to distribution of renewable and energy efficient technologies). In fact the Global Alliance for Clean Cookstoves (GACC), a public-private partnership sponsored by the United Nations Foundation, was recently formed with the goal of "creating a thriving global market for clean and efficient household cooking solutions" by working with "public, private, and non-profit partners to help overcome the market barriers that currently impede the production, deployment, and use of clean cookstoves in the developing world" (Global Alliance for Clean Cookstoves, 2010).

The primary objective of this thesis is to demonstrate a methodology that can be used to support these goals by generating market intelligence that is useful for filling in critical information gaps that are inhibiting key players in ICS manufacturing and marketing sectors from more effectively designing, manufacturing and marketing stoves.

Using these methods in a case study of the Doña Dora ICS in Quetzaltenango, Guatemala, I predict the total number of households for which an investment in this product is net positive.

The process and scope of this work for this thesis were driven by the needs of the clients: Appropriate Infrastructure Development Group (AIDG) and Xelateco.[2] AIDG is a non-governmental organization with projects in Guatemala and Haiti. Their mission is to incubate small businesses entering the appropriate technology sector through financial support in the form of grants and loans, business and marketing training, and ongoing technology research and development. Xelateco is a small business located in Quetzaltenango, an urban center in the highlands of western Guatemala. Started in 2005, Xelateco was AIDG's first project and currently manufactures biodigestors, water pumps, solar water heaters, micro-hydroelectric systems and improved cookstoves.

During the summer of 2010, I worked closely with AIDG and Xelateco to design and implement a random household survey in order to generate information around their product, the Doña Dora improved cookstove. The survey was designed to collect a wide range of information about potential Doña Dora consumers to characterize their household energy use patterns, associated financial expenses, preferences towards product modifications, and financial feasibility. Some of this information was initially used by AIDG and Xelateco to guide the redesign of the Doña Dora in 2010. Now it is

[2] In the fall of 2010, AIDG restructured their Guatemala operations. Through this process, the Quetzaltenango office and some of its staff registered as a separate non-profit under the name Alterna; AIDG transferred responsibility for Xelateco and the Doña Dora to Alterna. AIDG now operates from their office in nearby Antigua, and continues their work in business incubation.

being used to inform the ongoing marketing strategies as the newly redesigned Doña Dora is being introduced to the market for the first time.

In Chapter 2, Background, I present contextual information that is relevant to the project. I begin by providing a brief summary of Guatemalan demographics, followed by a discussion of the high level of dependence that rural Guatemalan families have on biomass for a wide range of services, particularly as an energy source for household cooking. I then explore the relative contribution that household fuelwood consumption has on the rapidly declining forest resource in the country compared to other drivers of deforestation. In this chapter I will also present a brief history of improved cookstove stove dissemination efforts that have been ongoing in Guatemala since the 1970s. I conclude the chapter by introducing the partner organizations, Appropriate Infrastructure Development Group and Xelateco, and discussing the key contextual issues that provided the impetus for this project.

In Chapter 3, Literature Review, I discuss the broader issues that surround the movement to distribute improve cookstoves throughout the world. I begin the chapter with a discussion about why research and funding into ICS interventions has been lacking given the magnitude of the associated public health and environmental consequences. I then address the factors and dynamics that influence household fuel and technology choices with a review of the "fuelwood ladder" and "fuel stacking" theories. I introduce a more inclusive definition of "access" that is useful for generating a more comprehensive understanding of the barriers that inhibit ICS dissemination programs. I also explore the historical and contemporary issues behind the push for market-based methods for allocating renewable energy and energy efficiency services to the world's poorest and most underserved populations. In this chapter I identify some of the challenges to, and opportunities for, using the market, and attempt to define some of the characteristics of an effective market-based approach. Finally I discuss how household gender dynamics are an important dimension when attempting to understand the processes that influence how decisions are made in the household with respect to the purchase of an ICS.

In Chapter 4, Methods, I present the methods that I employed in the case study of the Doña Dora ICS in Quetzaltenango, Guatemala. I begin the chapter by presenting the Cookstove Calculator, a dynamic spreadsheet tool that facilitates rapid financial feasibility analyses for ICS products. I then define the economic metrics and underlying assumptions that are the foundation of the methodology. This includes a description of the method used for estimating how "real benefits" are quantified in the economic model. I provide a framework for estimating *avoided fuelwood expenditure* for ICS marketing programs. Finally I present a step-by-step example of how I used these methods in the case study.

In Chapter 5, Life in Rural Quetzaltenango, I combine results from the household survey with a review of recent literature to illuminate some of the conditions of household life in rural Quetzaltenango. I characterize demographics, household energy use, energy use in the kitchen, and household expenditures related to energy use. I present primary data describing the houses people live in, the materials used in construction, and the ownership rates of cropland and farm animals. I also present results that shed light on individual perspectives on the relationships between fuel consumption and environment, family health and energy use. I conclude this chapter by presenting my findings on gender and purchasing power and comparing these results to other studies on the subject.

In Chapter 6, Market Demand Analysis Results, I present the results of the market demand analysis. I estimate financial feasibility separately for two subgroups in our sample: households that purchase all fuelwood, and households that purchase and collect fuelwood. Based on these results I make inferences about the wider population and estimate the total number of households in rural Quetzaltenango for which the investment in the Doña Dora ICS is net positive. In this chapter I also present distribution plots, confidence intervals, and box plots of the results for each subgroup and briefly discuss the significance of the distribution pattern across the subgroups. I conclude the chapter by presenting the Cookstove Calculator's automatically generated sensitivity plots for eight input parameters in order to demonstrate the sensitivity of financial metrics to incremental changes in input parameter values.

In Chapter 7, Discussion, I discuss how the results of the market demand and financial feasibility analyses, and associated sensitivity analyses, can be utilized and interpreted by key stakeholders in the cookstove market sector, including individual households, micro-financing institutions, marketing programs, and manufacturers. I discuss the lessons that are relevant to each stakeholder group. Through this discussion I hope to demonstrate the power of this methodology for filling in critical gaps in market intelligence, and how by filling those gaps certain market failures may be alleviated. This is followed by a brief conclusion.

2 BACKGROUND

In this chapter I will present background information that is relevant to the project. I will begin by providing brief summary of Guatemalan demographics, followed by a discussion of the high level of dependence that rural Guatemalan families have on biomass for a wide range of services, particularly as an energy source for household cooking. I then explore the relative contribution that household fuelwood consumption has on the rapidly declining forest resource in the country compared to other drivers of deforestation. I will also present a brief history of improved cookstove dissemination efforts that have been ongoing in Guatemala since the 1970s. I conclude the chapter by introducing the partner organizations, Appropriate Infrastructure Development Group and Xelateco, and discuss the key contextual issues that provided the impetus for this project.

2.1 Guatemala

Guatemala is located in the Central American subtropics, covers 108,889 square kilometers and shares borders with Belize, Mexico, Honduras and El Salvador (Figure 3)(CIA, 2010). The population of approximately 14.5 million people is racially diverse and includes 22 Mayan ethnic groups, mestizos, Garifunos, and people of direct European decent (Instituto Nacional de Estadisticas, 2010). The official language is Spanish; however each indigenous ethnic group and the Garifunos have their own language. In contrast to other countries in Latin America, Guatemala has, to a large extent, bucked the trend of urbanization, with only 49% of the population currently residing in urban areas (Instituto de Agricultura, Recursos Naturales y Ambiente, 2009).[3] Although access to basic necessities has improved in recent years, there is still widespread poverty with a GDP per capita of $5,200 (2010), roughly half of the average for Central America and the Caribbean (CIA, 2010).[4] Wealth is unevenly distributed throughout Guatemalan society with approximately 10% of the population accounting for 40% of consumption (CIA, 2010). Poverty, which is widespread with over half the population living below the poverty line, is particularly acute among indigenous groups (38% of the total population). Within this segment of the population, 76% live in poverty and 28% live in extreme poverty (CIA, 2010). In Guatemala as a whole, a staggering forty-three percent of children under five years old suffer from chronic malnutrition (CIA, 2010).

[3] Percentage of population residing in urban areas for other Central American and Caribbean countries in 2010: Belize 52%, El Salvador 64%, Honduras 52%, Nicaragua 57%, Costa Rica 64%, Panama 75%, Cuba 75%, Jamaica 52%, Haiti 52%, Dominican Republic 69% (CIA, 2010).

[4] Based on 2010 estimates.

Figure 3: Political map of Guatemala (source: Map Cruzin 2011).

2.1.1 Dependency on biomass as an energy source

There is a high level of dependence on biomass as an energy source throughout many sectors of the Guatemalan economy and society. It is estimated that 74% of the country's population is directly dependent on forest resources, not only as a fuel source, but also for food, medicine and construction materials (Instituto Nacional de Estadisticas, 2002). In fact 82.5% of all primary energy consumption in the country is from biomass, of which 90.3% is derived exclusively from wood (Banco Nacional de Guatemala, 2009). The remaining 17.5% comes from hydropower and geothermal (6.8%) and fossil fuels (10.6%) (Banco Nacional de Guatemala, 2009). At the household level an estimated 67% of families (households) rely on wood energy (fuelwood and charcoal) to prepare their meals (see Figure 4) (United Nations System of Guatemala, 1999). This is particularly true for rural families in Guatemala. In Quetzaltenango, Guatemala, where our study took place, urban residents are consuming an average of 0.9 m^3 per person per year of fuelwood, while rural residents are consuming nearly four times that amount at 3.5 m^3 per person per year (Instituto de Agricultura, Recursos Naturales y Ambiente, 2009). This rural-urban fuel-type dichotomy follows a global pattern where only 20% of urban households are primarily dependent on fuelwood for domestic energy compared to 76% of rural households (Hammond et al. 2007).

Figure 4: Woman stacking fuelwood that was just delivered to her home in San Marcos, Guatemala. *Photo source: Tirian Mink 2010*

2.1.2 The declining forest resource

Forests coverage has been in a steady state of decline in Guatemala since 1970. Between 1970 and 2005 the total forest stock (standing trees) in Guatemala has decreased by an estimated 35% (by volume) - an average of 1% per year. This was accompanied by an estimated 72% decrease in forest stock per capita due to simultaneous increase in population (Banco Nacional de Guatemala, 2009). Consequently wood products increased in value as measured by national economic indicators (Banco Nacional de

Guatemala, 2009). Between 1980 and 2005, the estimated value of a cubic meter of Guatemala's existing forest stock increased 219% (corrected for inflation), with an average growth rate of 4.6% per year (see Appendix B) (Banco Nacional de Guatemala, 2009).[5]

The fact that the large majority of Guatemalan households are heavily dependent on this rapidly declining resource as their primary energy source brings forth the question about whether household fuelwood consumption is driving deforestation in Guatemala. Due to the informal (and mostly illegal) nature of the fuelwood market, data that quantifies its contribution towards deforestation is coupled with a large degree of uncertainty. Nevertheless one study estimated that fuelwood consumption in Guatemala contributes to annual losses of 2,460 hectares of tree cover (Comision Centroamericana de Ambiente y Desarollo , 1999), which when compared to estimates of the total annual losses of 65,000 hectares between 1990 and 2005, accounts for only 4% of the total deforestation (Instituto de Agricultura, Recursos Naturales y Ambiente, 2009). These statistics suggest that fuelwood harvesting and consumption are not the primary drivers of deforestation. This would be consistent with the conclusions of extensive studies on the subject in South Asia which led to the rejection of the "fuelwood gap theory" of the 1970s and 1980s. The fuelwood gap theory warned that fuelwood harvesting from forest

[5] In 1980 there was an estimated 948,453,433 cubic meters of standing forest stock that was estimated to be worth 2,271,003,704 GTQ representing a value of 2.4 GTQ per cubic meter. By 2005 there was an estimated 698,434,711 cubic meters of standing forest that was estimated to be worth 5,330,204,767 GTW representing a value of 7.6 GTQ per cubic meter(Instituto de Agricultura, Recursos Naturales y Ambiente, 2009).

lands was driving unsustainable rates of deforestation (Asia-Pacific Forestry Commission 1997). Dire predictions of the collapse of the forests in Nepal due to overharvesting of fuelwood turned out to be false. In fact, fuelwood harvesting was discovered to be largely sustainable, while the primary driver behind deforestation was land use changes, namely clearing lands for agriculture (Asia-Pacific Forestry Commission 1997). This is consistent with what appears to be happening in Guatemala over the last 60 years, where forest lands are quickly being replaced by crops (Figure 5).

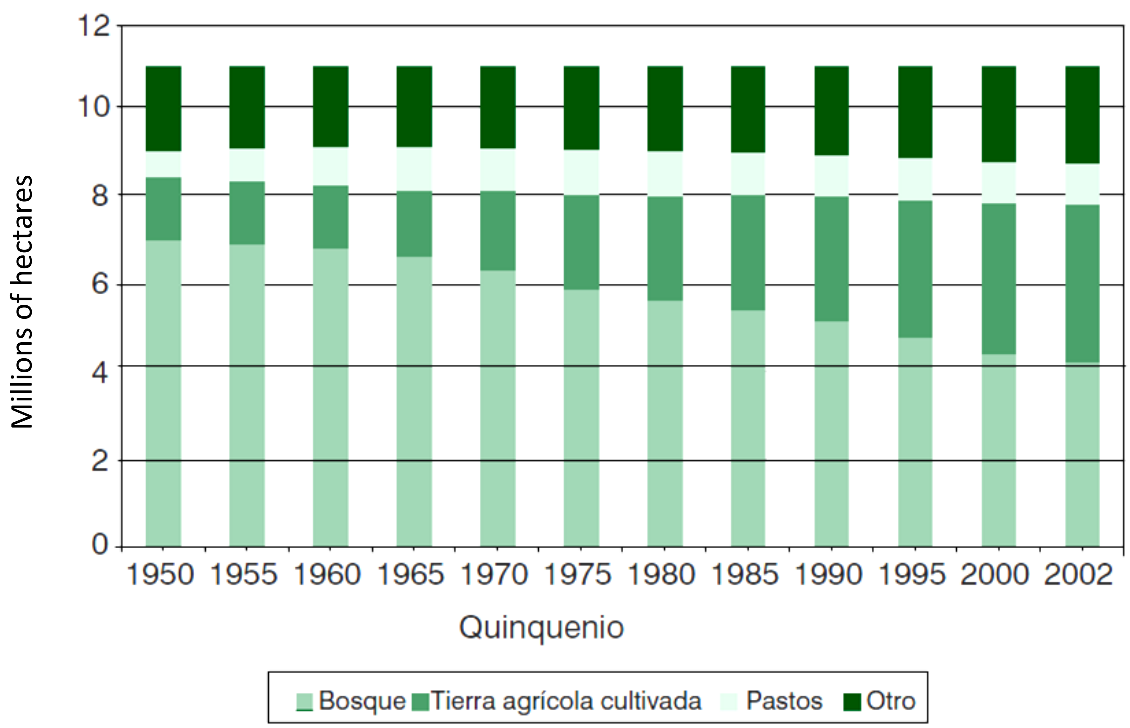

Figure 5: Total land coverage for forests (*bosque*), crops (*tierra agricola cultivada*), pasture (*pastos*) and other (*otro*) in Guatemala between 1950 and 2002. (Graph source: *Instituto de Agricultura, Recursos Naturales y Ambiente* 2009, p.79)

2.1.3 The History of Stove Dissemination Efforts in Guatemala

Stove dissemination efforts have been ongoing in Guatemala since at least 1976 and can be characterized in two stages that are associated with the introduction of technologically innovative models (Álvarez et al. 2004).[6] The Lorena stove is one of these models and is considered by many to be the ancestor of modern ICSs. Distinct from other ICSs in its simplicity of design and ease of adoption, the Lorena is made almost entirely out of rammed earth; this stove was highly successful in improving public health by diverting emissions out of the kitchen via a chimney. The metal *plancha* stove, with many variations, is another ICS model that has been distributed widely throughout Guatemala according to Álvarez et al (2004). Our survey found that in rural Quetzaltenango, 85% of respondents had some variation of the metal *plancha* stove (see Section 5.3 for more information).[7] It is distinct from the Lorena in that it is usually, though not always, built with brick and/or cement, with a sealed rectangular sheet metal cooking surface (see Figure 20). The construction often includes removable rings that allow a pot to be inserted into the combustion chamber for more direct contact with the fire. Like the Lorena, this stove when properly designed and maintained, can successfully direct the smoke out of the kitchen via a chimney resulting in improved indoor air quality.

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[6] *Fundación Solar*, a Guatemalan non-governmental organization, was hired by the Energy Sector Management Assistance Program (ESMAP) of the United Nations and World Bank to review the history of stove efforts in Guatemala.

[7] This estimate is derived from a stratified random block survey conducted in Quetzaltenango in July 2010. See Section 4.3 for more details

While both of these stove designs have been demonstrated to improve indoor air quality when properly designed and maintained over their lifetimes, field and laboratory studies have concluded that they do not necessarily increase fuel efficiency (Granderson et al. 2005; Gill 1987). In fact, studies have shown that the Lorena stove does not necessarily increase fuel efficiency when compared to the open fire and certainly performs poorly when compared to other improved stove models (Mäkelä, 2008). This might be attributed to the high thermal mass of the stove body, but may also be a function of the lack of standardization in the construction process, which leads to high variability in end product.

There have been several national conferences on ICS dissemination efforts in Guatemala, the first of which was the 1977 First Regional Conference of Stove Experts. According to Álvarez et al., the period from 1976-1980 was the inception period for stove design and dissemination in Guatemala. During the period of 1980-1986 there was large scale dissemination of the Lorena with national level support coming from the Guatemalan Ministry of Energy and Mines. Between 1986 and 1993 there was a loss of momentum due to various technical and organizational challenges within stove programs. Many users abandoned their stoves and tangible benefits were illusive. Between 1993 and 2001 there was a resurgence in the stove dissemination effort, this time with a focus on commercialization of improved stoves to harness the power of the market to better address user’s needs and improve quality. New stove models were designed to be portable, durable, and mass produced.

2.2 AIDG

There are two partner organizations that I worked closely with throughout the fieldwork phase of this project: Appropriate Infrastructure Development Group (AIDG) and Xelateco. AIDG is a non-governmental organization with projects in Guatemala and Haiti. Their mission is to incubate small businesses to enter the appropriate technology sector. Entrepreneurs and skilled workers are assisted in developing micro-manufacturing businesses that provide local impoverished communities with renewable energy power systems and appropriate technology solutions for basic needs such as potable water, sanitation, heating and cooking, and efficient use of fuel. AIDG provides small startup businesses with seed capital, training, and access to a wide network of resources including technical business training, tested product designs, partner organizations and academic institutions (Lee, 2009).

2.3 Xelateco and The Doña Dora Improved Cookstove

Xelateco is a small business located in Quetzaltenango, in the highlands of western Guatemala. Started in 2005, Xelateco was AIDG’s first project and currently manufactures biodigestors, water pumps, solar water heaters, micro-hydroelectric systems and improved cookstoves. In September 2007, AIDG initiated a project to design and commercialize an ICS through Xelateco. Numerous designs were considered through a participatory design process in which target stove users as well as Xelateco technicians were actively involved from the beginning (Lee, 2009). The first marketing strategy involved close collaboration with two pilot communities: San Alfonso and San

Lorenzo (Lee, 2009). This was all in the context of a larger community outreach strategy on the part of AIDG within these communities to identify specific needs beyond ICSs. Communities transferred their knowledge and preferences to AIDG and Xelateco through structured and unstructured interviews. AIDG and Xelateco conducted educational workshops and stove demonstrations, and through this process significant barriers were identified. An unstructured market demand analysis revealed that the upfront cost of the stove was an insurmountable barrier for the large majority of community members (Lee, 2009). Feedback from community members showed that 30 years of donation based stove dissemination models in Guatemala had instilled expectations that ICSs would continue to be distributed for free (Lee, 2009). The product of this effort was the predecessor of the Doña Dora ICS; initially named, "*El Rocket Box*." After two years on the market, *El Rocket Box* had not become a success. Fewer than 100 had been sold and users were not satisfied with the product.

Motivated by lackluster sales and insufficient revenue, AIDG and Xelateco set out to double down their efforts on their improved cookstove product. In the summer of 2010 they launched a project to redesign the cookstove, and create a new marketing strategy in an effort to make it a cornerstone of a profitable business model. Focus groups were conducted to elucidate user preferences and several crucial modifications were made to both the combustion chamber and the shell. The Doña Dora is an improvement over *El Rocket Box,* in more than just name. The Doña Dora has a larger combustion chamber, tile shelves on the sides for setting pots or cooking utensils, and a heat shield around the chimney to protect from burns. It is also mounted on a sturdy fabricated metal table (see Figure 6).

My role in the project was to work with staff, volunteers and interns to implement a random household survey in order to generate information about user preferences, willingness and ability to pay, and total market demand for the Doña Dora ICS (see Section 4.3). I also assisted in developing methods to evaluate the effects of design modifications on the performance of the Doña Dora using modified versions of Controlled Cooking and Water Boiling Tests.

Figure 6. The Doña Dora cookstove. *Photo: Malcolm Gribble. July 2010.*

3 LITERATURE REVIEW

With this chapter I aim to illustrate the broader contextual issues that surround the movement to distribute improve cookstoves throughout the world. I begin by addressing reasons why research and funding into ICS interventions has been lacking considering the magnitude of the associated public health and environmental problems. I then address the factors and dynamics that influence household fuel and technology choices with a review of the "fuelwood ladder" and "fuel stacking" theories. I introduce a more inclusive definition of "access" that is useful for generating a more comprehensive understanding of the barriers that inhibit ICS dissemination programs, and I present an example of a cookstove program that addresses these issues by a employing a systemic approach that integrates several of the mechanisms that define the political economy of access to cookstoves. After that I explore the historical and contemporary issues that are the impetuses for the emphasis on market-based methods for allocating renewable energy and energy efficiency services to the world's poorest and most underserved populations. I also identify the challenges and opportunities to using the market and define some of the characteristics of an effective market-based approach. Finally I discuss how household gender dynamics are an important dimension of processes that influence how decisions are made in the household with respect to the purchase of an ICS.

3.1 Mundane science

Considering that we have known about the problems associated with unimproved cooking practices for at least 40 years, why has there been so little progress so far? In their seminal article *The Virtues of Mundane Science*, Kammen and Dove (1997) argue for increased funding for research into ICSs and other “mundane” topics throughout the world. Although the phrase “mundane science” (*applied science*) did not become widely adopted into the vernacular of the scientific and development communities, the central thesis of the article was considerably poignant at the time and remains relevant today. They point out that despite the fact that acute respiratory infections, malnutrition, diarrhea, malaria, and measles account for 71% of the 12.2 million deaths in children under five years old, support for work on these topics is weak relative to their importance (Kammen & Dove, 1997, p. 12). With respect to energy development research, this bias manifests as a disproportionate focus on advanced combustion systems, commercial fuels, and large centralized power facilities, even though half the world’s population relies on biomass for the majority of their energy needs (Kammen & Dove, 1997, p. 11).

Despite the funding disparity, research into the effect of ICS interventions has led to advances in understanding beyond the direct impacts on fuel use, indoor air pollution, and household economics. Work on ICSs has contributed to the ongoing development of innovative methodologies such as participatory rural appraisal techniques, gender sensitive and open-ended interviewing, and new theories of networking (Kammen & Dove, 1997, p. 14).

According to Kammen and Dove, there are “five fallacies” that have contributed to this lack of attention. The first is that applied science is anti-scientific in spirit, a misconception than arose from mainstream scientists’ lack of interest in applied science.

This led to the marginalization of applied science and resulting “fringe” status. The second is the concept that the greatest overall returns come from “basic” research rather than “applied” research. The underlying false assumption here is that there is a diametric opposition between investments in basic versus applied science (e.g. with a pool of limited funds, increased funding for one area would result in decreased funding for the other). To the contrary, they argue that funding for research has traditionally been tied to the prospect of practical applications that may result from the work. For example, support for research into geological sciences increased dramatically after the discovery of untapped reserves of hydrocarbons below the surface of the earth. The third fallacy is that applied science is simply an application distinct from (and potentially in conflict with) basic research. This misperception may be an artifact of post-World War II research and development policy in the US which emphasized basic research as the driving force behind technological progress and applied research “invariably drives out pure” (Kammen & Dove, 1997, p. 38). The fourth is that the outcomes from development projects are inherently technological rather than sociological. Although development efforts in the Global South have generally failed to assist the poor and protect the environment, analysts have largely faulted implementation processes or misaligned project objectives (Kammen & Dove, 1997, p. 39).

Finally, applied science is thought of as having more to do with society than science. The large majority of research related to the Green Revolution, for example, was focused on food production rather than storage and distribution systems because “the former is considered science while the latter is not – even though as much as 40% of some harvests are lost to spoilage, corruption, and inadequate infrastructure" (Kammen & Dove, 1997, p. 39).

Today there is renewed interest being generated by global warming mitigation strategies and new research that is definitively linking disease and death to indoor fuel use (Schwartz 1996, Smith 2006, Smith, et al. 1994). Furthermore, there is now a process in place for cookstove programs to receive carbon offset credits, potentially opening the flood gates to global capital.

3.2 The fuelwood ladder and fuel stacking theories

Understanding the factors that determine how fuels and cooking technologies are selected and accessed by households is useful when designing and evaluating cookstove dissemination programs. Researchers have often attempted to explain the dynamics of household energy use and household economics through the "fuelwood ladder theory," which characterize the factors that influence household decisions about whether to switch or substitute between different fuel types (Smith, et al. 1994, Smith 1987). A common interpretation of this theory is that increases in family incomes drive a transition from less efficient, less expensive, and higher polluting fuels (e.g. dung, wood, charcoal) towards more efficient, more expensive, and cleaner burning fuels (e.g. LPG, electricity)(Smith, 1987). Theoretically, increases in household income allow a family to move up the ladder, abandoning inefficient and dirty technologies for more expensive and cleaner ones. According to Barnes and Willem (1996), moving up the ladder is associated with an improvement in social status. Even when taking into account economic and social factors, what emerges from this theory is the concept that there is linear evolution up the energy ladder (Barnes & Willem, 1996). In other words, as households adopt higher quality fuels and more advanced cooking technologies, they abandon lower quality fuels and traditional cooking methods. However, the fuel ladder theory is being challenged by scientists who argue that it does not accurately characterize the process of fuel and technology switching, especially with respect to household cooking.

In contrast, the multiple fuel model proposed by Masera et al. (2000) describes the process of fuel switching as being dependent on four essential factors in the face of resource scarcity or uncertainty:

1. Conditions that affect access to different fuels and cooking technologies
2. Technical characteristics of cookstoves and cooking practices
3. Cultural preferences
4. Health impacts

Using data from three Mexican states and one village, Masera et al. demonstrate that rural households do not “switch” but rather “stack” fuels (Masera et al. 2000). As new fuels and technologies are adopted, traditional fuels and technologies are rarely abandoned. Their research suggests that households do not perceive one technology type as clearly better than another; different technologies possess different attributes that are positive and negative depending on the circumstances. They argue that this change in perspective regarding the process of fuel switching and technology adoption is essential for being able to accurately characterize rural energy demand and for framing policies that will promote sustainable resource usage (Masera, et al. 2000).

Masera et al. conclude that simple measures used to characterize household energy use and stove selection are often largely inaccurate, and that the linear fuel switching model leads to overestimates of benefits in cases where a variety of stoves and fuels are being used simultaneously. In essence, according to Masera et al., the multiple fuels model assumes that the technologies and fuels used in the kitchen are determined by a group of factors that are fluid and dynamic, leading to mixing and stacking of fuels and technologies, rather than a more linear process of switching. Understanding the dynamics of fuel switching and stacking is critical for designing successful ICS interventions, as well as for accurately evaluating the success of an existing program.

3.3 Understanding accessibility of ICSs

Understanding all the factors that influence accessibility of ICSs in very poor communities is important for effectively characterizing the challenges to cookstove dissemination efforts. The term "access" is commonly used by property and natural resource analysts in the context of defining who has the right to access or make use of property and resources. In this context, access would be defined simply as the right to benefit from things (Ribot & Peluso, 2003). When trying to understand the factors that determine the accessibility of cleaner and more efficient cooking technologies, a more inclusive definition is helpful. Ribot and Peluso (2003) make the following proposal:

access is more than merely having the “right to benefit from things;” it is having the “ability to derive benefits from things” (p. 151).

In their view, access can be thought of as a web with strands that extend in an outward direction from the individual who is located at the center. The strands are the factors (mechanism, process, or relationship) that have influence over an individual’s ability to derive benefit from a resource (Ribot and Peluso, 2003, 153). In this web, the potential cookstove beneficiary is located in the central node; the cookstove is located in some other coordinate. Accessibility is determined by the individual’s capacity to successfully negotiate the strands that separate them from the ability to derive benefit from the product. The mechanisms that define access to an ICS are numerous, and have some overlap with the factors that affect technology and fuel switching and stacking. All of the following mechanisms and/or conditions must be in proper alignment with the idiosyncratic situation of each household seeking access to an ICS:

- purchasing power and availability of credit
- willingness/ability to pay
- availability of products near the home
- accessibility of appropriate fuel types
- knowledge and understanding of potential health and financial benefits
- cultural appropriateness of the technology
- intra-household social relations and their influence on decision making

The nodes of the web are often occupied or controlled by entities that exist outside of the autonomy of the household. These may be institutions, organizations or individuals, and households must successfully negotiate with them in order to have access to something. Because of this, individual identity and social relations "are central to virtually all other elements of access" (Ribot & Peluso, 2003). Each entity (gatekeeper) has their own agenda that may or may not be aligned with the intentions of the resource seeker. In the context of an ICS supply chain, a consumer may be separated from a product by several entities including manufacturers, distributors, NGOs, marketing programs, and micro-financing institutions. In order to truly understand what determines an individual's access to an ICS we must consider the network of interactions and relationships that exist between the individual and the resource.

In Michoacan, Mexico, the Interdisciplinary Group of Rural Appropriate Technology (GIRA) has been addressing these complexities with a systemic approach that integrates several of the mechanism that define the political economy of access for their target population of the Patsari cookstove. Masera et al. (2005) discuss how their projects have evolved from being narrowly focused on stove production and sales to a more integrated systemic approach involving technology innovation, market development, cookstove dissemination packages, support to micro-enterprise development, monitoring and evaluation, and outreach activities (Masera et al. 2005). This systemic approach resonates well with the access theory proposed by Ribot and Peluso. GIRA has identified mechanisms of access that complement and reinforce each other. By integrating several of these into a single programmatic system, GIRA has made progress towards generating a confluence of goals between occupants of nodes that previously may not have been aligned. Aligning the agendas of several key nodes in the web of access should theoretically increase the accessibility of cookstoves to the population while creating a more sustainable program.

Fuels also play a role in determining accessibility of cooking technologies. For example, while LPG is regularly available in Guatemala, the high price severely limits its usage in poor households to small tasks such as heating water for coffee or warming up previously cooked food. Because the cost is prohibitive, people can own an LPG cylinder and associated burners without having the ability to benefit from them. Álvarez et al. (2004) made the observation that access to firewood is correlated with the degree of urbanization; to wit, the closer the community is to an urban center, the more likely its residents will be purchasing fuelwood rather than collecting. This suggests that fuelwood scarcity may be more acute in urban areas where many are forced to purchase because of the inaccessibility of forests. It seems logical that fuelwood accessibility is dynamically linked to forest resource accessibility. The accessibility of forest resources to the average Guatemalan villager is almost certainly steadily declining as scarcity continues to increase (see Section 2.1.2), suggesting that the average Guatemalan is working harder, and/or spending more money each year, to obtain their fuelwood. By taking into account all of the factors that influence accessibility of ICSs to very low income people, cookstove dissemination efforts can be more effectively designed to address the underlying barriers.

3.4 Kitchens at the base of the pyramid: an untapped market?

Given the inaccessibility of improved cooking technologies to the billions of people who need them, the question then becomes how to most effectively distribute them. Over the past 30 years, renewable energy technology projects and investments have transitioned from the fringe to the mainstream of sustainable development (Martinot, et al. 2002). Over this time, donor agencies and government programs have developed and disseminated more than 220 million ICSs in developing countries (Martinot, et al. 2002). The Organization for Economic Co-operation and Development estimated that between 1980 and 2000 there were 3 billion dollars worth of development assistance for renewable energy projects (cited in Martinot, et al. 2002). However most of these projects achieved only modest results and were largely unsustainable (Martinot, et al. 2002). This lack of tangible results led to widespread disillusionment within donor groups towards renewable energy projects. This coincided with a call for market-oriented approaches with a focus on commercial viability, income generation, technology transfer and local capacity building (Hammond, et al. 2007; Polak 2011; Garcia-Frapolli, et al. 2010; Dhungel 2009; Barnes and Willem 1996; Prahalad and Hart 2002; Martinot, et al. 2002). There are significant opportunities for market based dissemination models to deliver renewable and energy efficient technologies and services to the very poor, but there are also considerable challenges that have thus far inhibited this pathway from being an effective alternative to donation-based models. In this section I discuss some of the most important factors that illuminate the opportunities and challenges to market-oriented approaches to disseminating improved cookstoves.

3.4.1 Scalability

One of the key advantages that market based dissemination models have over donation models is scalability. Donation based models are largely dependent on a fixed amount of capital and operate within budgets that are managed by government bureaucrats and donor agencies. In contrast, market based programs for ICS dissemination can access the multi-billion dollar demand from the fuelwood for cooking market (Hammond, et al. 2007). Theoretically energy efficiency technologies such as improved cookstoves can free up a portion of that money by offsetting some fuel demand associated with the status quo technology.

Prahalad and Hart (2002) make the case that very low income people have purchasing power that can lead to profitable returns for companies. They argue that this can be achieved if companies can commercialize and effectively market products that meet the needs of this segment of the population. Prahalad and Hart characterize the global economy in terms of a pyramid in which consumers are placed into tiers based on their annual per capita income. At the very top of the pyramid are the 75-100 million affluent Tier 1 consumers from around the world. In the middle of the pyramid, in Tiers 2 and 3, are poor consumers in developed nations and the burgeoning middle class in the developing world. Tier 4 in the pyramid, often referred to as the Base of the Pyramid

(BOP), is populated by the 4 billion people who have an annual income of less than $1,500 based on purchasing power parity in US dollars.

New empirical measures of the aggregate purchasing power of this population suggest opportunities exist for market-based approaches to better meet their needs while increasing their productivity and incomes (Hammond, et al. 2007). In Africa, Eastern Europe and Latin America, for example, energy ranks third in BOP household expenditures behind food and housing. Across all measured countries, households in the base of the pyramid spend an average of 9% of their household budgets on energy, representing an average yearly expenditure of $379 (Hammond, et al. 2007).

These energy budgets are relevant to ICS marketing programs particularly in rural parts of Africa, Asia and Latin America, where fuelwood is the main source of energy for cooking. In rural Guatemala, for example, 86% of rural households use fuelwood for cooking, while only 29% of urban households use fuelwood for cooking (INE 2002). The survey conducted by me and colleagues from AIDG and Xelateco in Quetzaltenango, Guatemala, indicates that the average yearly household expenditure on fuelwood is $222.[8] Due to the fact that the large majority of the $433 billion in annual BOP energy expenditures are dedicated to fuelwood for cooking, effective ICS programs that reduce fuelwood consumption have the potential to offset a portion of this and liberate these funds to create purchasing power that can go towards ICSs.

[8] See Section 4.3 for a description of the survey methodology.

Despite this scalability, market-based dissemination methods have natural limits. Many people cannot afford even a modestly priced ICS because their incomes are simply too low. While micro-credit loans and other creative mechanisms can increase affordability in some cases (see below for further discussion), this approach will not extend affordability universally. In short, the free market will not be able to deliver renewable energy and energy efficiency products and services to people who truly *cannot* afford them, and these very low income people are among those who are most in need. This limitation can be lessened with well-directed subsidies that lower the cost for a cookstove for households that do not have sufficient purchasing power. This has precedent in the world's most prolific stove programs in China and India; as of 2004, these programs had distributed 18 million and 150 million units, respectively (Álvarez, et al. 2004).[9] In China there is a well-directed soft subsidy from the government in the form of training and technical assistance to stove designers and producers.[10] The goal of the subsidies is to promote commercialization of stoves and ensure that consumers have access to quality products and services. In India, there is a 50% subsidy that is paid directly to stove producers, who in turn sell their stoves directly to consumers (Álvarez, et al. 2004). By using well-directed subsidies for ICSs, governments can leverage the market to more effectively address the needs of their most marginalized constituents.

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[9] Results from surveys suggest that two thirds of the stoves in the India program were either not fully adopted or abandoned completely. Reasons cited for not adopting stoves were that stoves did not save fuel and were of poor quality (Martinot, et al. 2002).

[10] The term "soft subsidy" refers to support for technical capacity building, institutional development, and other non-hardware related costs (Harvey 1996).

Another limitation to the scalability of the market is the upfront cost barrier. Not all of the money that very low income people spend on energy is available at once for large purchases. Household energy expenditures are spread out over the entire year while the cost of a cookstove must be paid in advance. Micro-financing can address this problem by providing small loans that can spread the cost over time. By spreading the cost out over time, some or all of the payments can be made directly from the savings that are generated from the higher efficiency stove.

3.4.2 Natural feedback mechanism

Another advantage that market-based models have over donation models is that well-functioning competitive markets have a natural feedback mechanism to regulate quality of product and service. If the conditions of a well-functioning competitive market are present, products that perform poorly would be driven out of the market by better products. For example, consumers clearly would demand stove A over stove B if they knew stove A out-performed stove B (all other things being equal). In contrast, donation-based models must purposefully build mechanisms into their programs in order to generate feedback from consumers. There are examples of donation-based cookstove dissemination programs that incorporate surveys to measure end-user satisfaction (Masera, et al. 2005), but most programs lack this component. Omar Masera, president of the Mexican Bioenergy Network, made this point in a letter to the Mexican Secretary of Social Development, who is in charge of the Mexican National Stove Program:

"Beneficiaries have no voice in the process and must take what they are offered even if the stove is not appropriate for their cooking practices. There are no follow up, monitoring or evaluation programs to measure effectiveness" (Masera 2010).

This has often led to poor quality or inappropriate stoves being distributed by individuals and organizations that have little incentive to meet minimum standards of quality.[11,12]

3.4.3 Market failure

Despite the advantages that market-based dissemination methods have, there are significant obstacles that have thus far inhibited the market from being an effective pathway for distributing renewable energy and energy efficiency products and services to the world's poorest communities. Market failure is one of these obstacles. In order to

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[11] See Zinacantan case study in Appendix for illustrative example.

[12] In Chiapas, Mexico, where nearly 3 million people cook with biomass, there are at least 20 distinct ICS programs operating. By far the biggest player in Chiapas is the Mexican federal government which has committed to disseminating 500,000 countrywide with perhaps 15,000 a year being allocated to Chiapas. Unfortunately, according to Dr. Omar Masera, President of the Mexican Bioenergy Network, the 126,596 stoves that have been disseminated (as of July 2010) through this program have failed to provide benefits to families who have received them. If this is true, the one billion Pesos (83 million USD) being invested in the National Stove Program are in danger of being wasted, or in the words of Dr. Masera: the program is… "*vaccinating many families against technologies that have been demonstrated to be useful..*." (Masera 2010) The faults of the government program are systemic. Stoves do not need to meet basic performance standards to be considered "improved." Stoves do not meet the basic requirements of functionality, durability, and safety. Stoves are not designed to meet the needs of rural families. The stove producers do not have experience in design, manufacturing, quality assurance or dissemination of these products. Stoves are being distributed by NGOs without requisite experience with the technology. Beneficiaries have no voice in the process and must take what they are offered even if the stove is not appropriate for their cooking practices. There are no follow up, monitoring or evaluation programs to measure effectiveness (Masera 2010).

effectively utilize the market to disseminate stoves to very low income people, there must be a competitive and functioning market present that can be accessed by consumers who can benefit from ICSs. Unfortunately, remote villages and rural areas are often far from well-functioning competitive market places. Certain conditions must be present before a well functioning competitive market can emerge. In the words of Hackett (2006) the conditions require that:

1. There are well defined and enforceable property rights that characterize the ownership of resources, goods, and services.
2. There is a functioning market institution that governs how buyers and sellers interact.
3. There are many buyers and sellers, each of which is small relative to the overall market.
4. Buyers and sellers are unable to collude and form organizations that can affect market prices.
5. There are no positive or negative externalities.
6. There is potential low cost entry for new buyers and sellers.
7. Transaction costs are sufficiently low to not inhibit mutually beneficial transactions.
8. Accurate and reliable information on quality, availability, pricing, and location of goods and services is available at low cost to market participants.

Market failure occurs when one or more of the conditions for a well-functioning competitive market are not met in a substantial way (Hackett 2006). In poor and rural communities in the developing world many of these conditions are not met. New Institutional Economics (NIE) emerged from within the framework of neo-classical economics in an effort to explain some pervasive inadequacies in the latter's ability to explain the mechanisms that often cause market failure, especially in the context of less economically developed countries (Harriss, et al. 1997). NIE theorists proposed that interventions should be implemented to create institutions that could effectively lower transaction costs, govern property rights, and optimize division of labor to increase productivity (Harriss, et al. 1997; Bardhan 1989).

The conditions that lead to market failure are pervasive in isolated rural villages, where there are logistical challenges such as lack of basic infrastructure (roads and public transportation) that inhibit the delivery of products and services to the market. According to Hammond et al. (2007), most very low income people do not have bank accounts or access to financing mechanisms. They live in informal settlements and often do not have title to their land, and lack access to telecommunications, water and sanitation services, electricity and basic healthcare. Very low income people are forced to trade their goods and labor to local employers or middlemen who exploit them. One of the results of these conditions is that very low income people often pay a penalty in the form of higher prices for lower quality goods or services.[13]

While all of these conditions represent substantial barriers to market-oriented approaches to disseminating ICSs, my research is primarily focused on addressing the last condition in the above list, the accessibility of information regarding quality,

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[13]A recent study in Kenya found, for example, that households that lack access to grid electricity pay 150 times more for a unit of lighting service than do households that have grid electricity powered lighting (Mills and Jacobson 2008). For the 1.6 billion people who lack access to grid electricity, burning kerosene or another petroleum based fuels is the only choice in order to illuminate their homes after the sun sets.

availability, pricing and location of goods and services to market participants. I suggest that "adequate information" implicitly includes information regarding benefits (welfare) that consumers will realize from the procurement of a good or service. This information is currently not available to most market participants, representing a substantial barrier to the emergence of a well-functioning competitive cookstove market. With respect to a theoretical purchase of an ICS, benefits can only be understood after careful analyses are conducted at the individual household level. Accurate estimates of household financial benefits that can be generated through the purchase of an ICS can only be quantified with cost-benefit analyses that include information specific and unique to each household and stove.[14] Some parameters prove difficult to quantify, particularly monthly fuel savings. Accurate estimates of monthly fuel savings are needed in order to estimate avoided expenditures on fuelwood. Monthly fuelwood savings for a given household are dependent on the relative performance of the proposed ICS compared to the current cooking technology that is being used in the home. Without accurate estimates of this parameter and/or the technical capacity to conduct an analysis of this nature, information on financial feasibility will be unavailable to consumers and cookstove marketing programs. Bad information or no information necessarily results in uninformed decisions by market participants. This may cause market failure because individuals may either forgo making a purchase that would have benefited their household or proceed to make a purchase that will result in sub-optimal outcomes for their household.

[14] These parameters are examined in depth in Section 4.4

Access to accurate and reliable information regarding the potential household financial costs and benefits from the purchase of an ICS will increase the efficiency of resource allocation in the ICS marketplace. This may translate into more cookstoves being adopted by households that can afford and benefit from them and fewer purchases being made by those who cannot afford it. Adequate information in this area will allow stove marketing programs to be more informed about their actual market demand, to better understand their customer base, and to more effectively design their marketing programs. With this information in hand, stove manufacturers can more effectively invest their research and development funds in order to improve the feasibility of purchase for as many customers as possible (see Section 7.4 Lessons for Manufacturers).

3.5 Intra-household gender dynamics

In Section 3.4, I discussed some of the barriers to market-oriented approaches to disseminating ICSs. There are other factors that further complicate efficient allocation of ICSs to consumers. The role that gender dynamics plays in intra-household economic decision making processes is an important factor that influences whether a household will purchase an ICS product. For example, if the father of the house is the primary income provider and decision maker for household purchases, then a split incentive dynamic may exist regarding purchases that benefit other members of the household disproportionately. In Guatemala women are traditionally responsible for cooking and therefore would benefit the most from the purchase of an ICS. The most obvious of these benefits are improved indoor air quality, cleaner and more efficient kitchens, and reduced time spent collecting fuelwood. One can imagine that this perceived benefit to the women of the house may not necessarily incentivize the purchase of an ICS in the case that the man of the house has primary control of the purse strings. This is just one example that simplifies dynamics that tend to be complex. But it highlights the importance of considering the role of intra-household dynamics in a range of purchasing decisions, including those related to investments in cooking technologies and fuels.

Children and women can often be seen carrying heavy loads of firewood throughout rural Guatemala (Figure 7), where women are primarily responsible for the majority of household tasks including cooking, cleaning, and raising the children. Although these activities are arguably equally as burdensome as the work men are doing, they are usually unremunerated subsistence activities. There is a question then as to whether women have sufficient purchasing power to buy an ICS even when their household has adequate purchasing power; women may not possess enough influence in investment decisions to lead to a purchase.

There is a fallacy when economists and development practitioners consider the household unit as a black box in which decisions are made to maximize the overall household utility. Many microeconomic studies treat the household as if it were an individual. This simplification of the household, a complex and dynamic entity, can sometimes be useful for analytical purposes, but it limits and misguides our understanding of how decisions are made inside the home (Doss, 1996). As a result of this revelation, it has become more common in the recent past for economists to characterize the role that intra-household gender dynamics play in economic decision making processes (Doss, 1996).

Figure 7: Woman and child carrying fuelwood in Quetzaltenango. *Photo source: Rob Gradoville 2010*

Gender based divisions may exist within the household unit that affect allocation of decision making power and income transfer (Miraftab, 1996). For example, it is found that in the western highlands of Guatemala, women who devote a significant amount of their time to remunerated activities do not necessarily acquire commensurate decision making power with respect to non-food household expenditures. Increased household income resulting from the participation of women is largely spent on male goods, affecting women's ability purchase food and domestic technology (Katz, 1995). In Section 5.5, I present primary data on the subject of gender and purchasing power in the home that is derived from our household survey in Quetzaltenango.

4 METHODS

In light of the host of opportunities and challenges to creating effective market-based dissemination efforts for ICSs, there is a need for reliable and repeatable methods for generating regionally specific information for cookstove products and markets. In this chapter I present methods that can be applied to market based cookstove dissemination programs in a wide range of contexts. One application of these methods is to analyze the economic feasibility of a cookstove purchase from the perspective of an individual household. This information can help guide stove marketing programs and micro-financing institutions in their effort to identifying customers that will benefit financially from the purchase of an ICS. It can additionally be used to identify individuals or households that would require subsidies. These methods can also be used to analyze aggregate survey data from regional market demand analyses that can inform stove programs about the potential size and magnitude of a local market for a particular ICS product.

I begin the chapter by presenting the Cookstove Calculator, a dynamic spreadsheet tool that facilitates rapid financial feasibility analyses for ICS products. I then define the economic metrics and underlying assumptions that are the foundation of the methodology. This includes a description of the method used for estimating how “real benefits” are quantified in the economic model. I provide a framework for estimating avoided fuelwood expenditure for ICS marketing programs. Finally, I present a step-by-step example of how to implement this methodology using a case study of the Doña Dora ICS in Quetzaltenango Guatemala.

4.1 Cookstove Calculator

The Cookstove Calculator is an Excel-based dynamic spreadsheet tool that allows for rapid analysis of traditional economic metrics to measure investment viability. This tool is the product of a collaborative effort between me and my colleague Ruben Garcia in the Energy, Environment and Society graduate program at Humboldt State University. The spreadsheet tool accepts a range of configurable parameters including monthly fuel expenditure, fuel savings multiplier, discount rate, fuel escalation rate, stove lifetime, stove capital cost, capital subsidy percentage, carbon offset value, and operation and maintenance expenditures. The financing option allows the user to input financing term (months) interest rate (%) and down payment. The output includes a year-by-year net cash flow table (Figure 9), net present value, internal rate of return, time to payback, and benefit to cost ratio (Figure 8).

Sensitivity plots of key parameters are generated automatically for each individual analysis, allowing the user to observe the sensitivity of financial metrics to incremental changes in input parameters (Figure 10 and Figure 11). This functionality is particularly useful when there is a significant amount of uncertainty around the values of input parameters.

Input Parameters	Value
Purchase Year	2011
Cookstove Lifetime (years)	8
Capital Cost (curr/stove)	1,525
Discount Rate (%)	7.00%
Monthly Fuel Expenditure (curr/mo)	220
Fuel Savings (%)	30%
Fuel Savings Multiplier (%)	100%
Fuel Escalation Rate (%)	5.30%
Currency Exchange (curr/US$)	8
Maintenance Cost (curr/yr)	60
Carbon Offset (tCO2-e/stove-year)	3.90
Carbon Offset Price (curr/tCO_2-e)	80
Capital Subsidy (%)	10%

Financing Option	
Financing Option (yes/no)	no
Financing Term (months)	36
Annual Interest Rate (%)	24.00%
Down Payment (GTQ)	300
Payments Due	0

Results		
Output Metric	**Value**	**$US**
NPV (ROI in curr)	5,252	$657
Time to Payback (years)	2.0	2.0
Discounted Time to	2.2	2.2
Benefit/Cost Ratio	4.0	4.0
IRR	59.5%	59.5%
Monthly Payment (curr)	0.00	$0.00
Monthly Benefit	66	$8.25

Carbon Benefit		
tCO_2-e	**Local Curr**	**$US**
31.2	2,496	$312

Sensitivity Analysis

March 2011, Created by Tirian Mink and Ruben Garcia, Humboldt State University

Figure 8: The Cookstove Calculator 1.11 with five sections: Input Parameters, Financing Option, Results and Carbon Benefit.

Net cash flow table (US$)							
YID	*Year*	*Real Costs*	*Real Benefits (avoided costs)*	*Net Annual Real Cash Flow*	*Discounted Net Annual Cash Flow*	*Undiscounted Accumulated Net Cash Flow*	*Discounted Accumulated Net Cash Flow*
0	2011	$171.56	$0.00	-$171.56	-$171.56		
1	2012	$7.50	$39.00	$31.50	$29.44	-$140.06	-$142.12
2	2013	$7.50	$148.77	$141.27	$123.39	$1.21	-$18.73
3	2014	$7.50	$154.59	$147.09	$120.07	$148.30	$101.34
4	2015	$7.50	$160.72	$153.22	$116.89	$301.52	$218.23
5	2016	$7.50	$167.17	$159.67	$113.84	$461.18	$332.07
6	2017	$7.50	$173.96	$166.46	$110.92	$627.64	$442.99
7	2018	$7.50	$181.11	$173.61	$108.12	$801.26	$551.10
8	2019	$7.50	$188.64	$181.14	$105.43	$982.40	$656.53
9	2020	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
10	2021	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
11	2022	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
12	2023	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
13	2024	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
14	2025	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
15	2026	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
16	2027	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
17	2028	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
18	2029	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
19	2030	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53
20	2031	$0.00	$0.00	$0.00	$0.00	$982.40	$656.53

Figure 9: The Cookstove Calculator 1.11 net cash flow table.

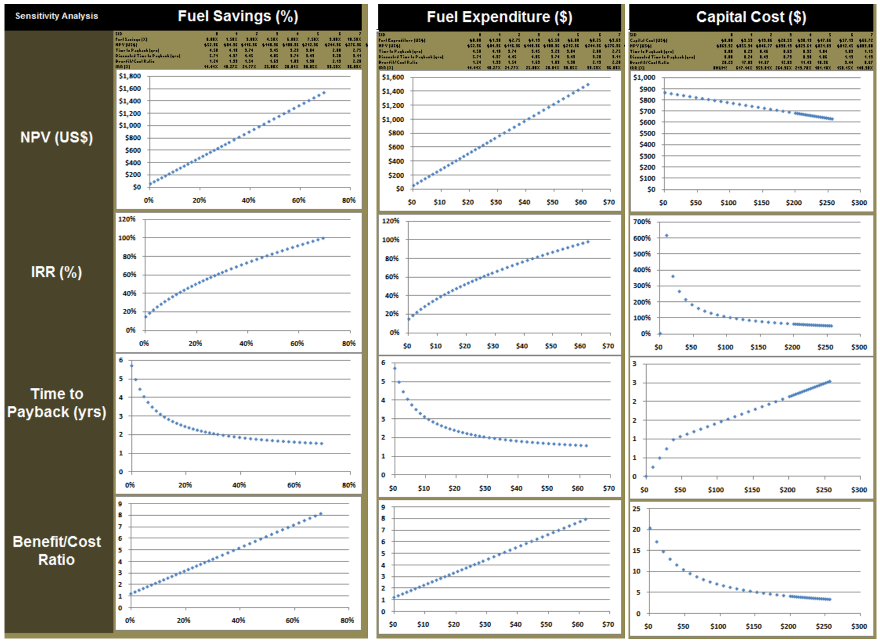

Figure 10: Cookstove Calculator 1.11 with sample sensitivity plots for fuel savings, monthly fuel expenditure and capital cost.

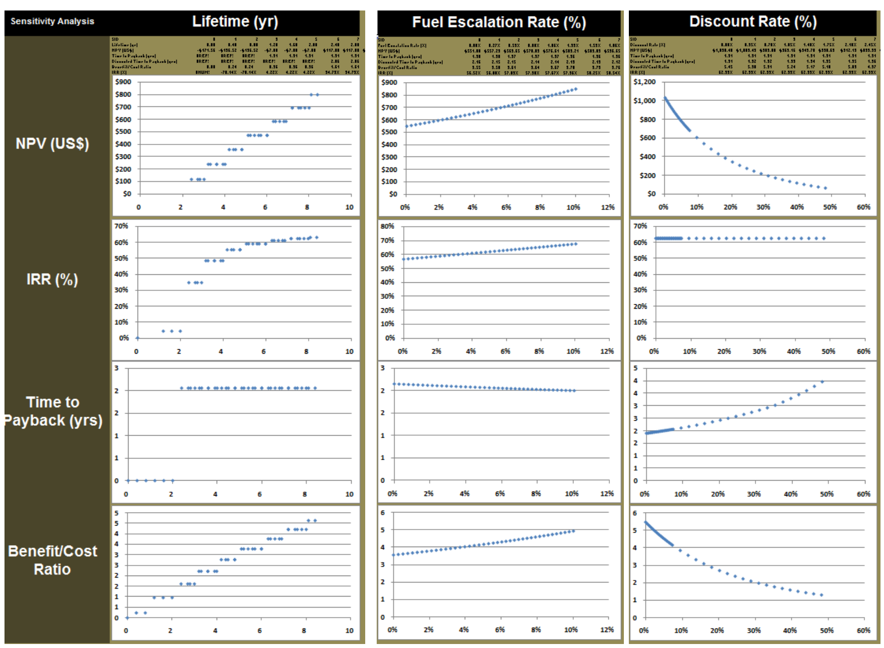

Figure 11: Cookstove Calculator 1.11 with sample sensitivity plots for lifetime, fuel escalation rate and discount rate.

4.2 Definitions of economic metrics and underlying assumptions

The net present value of a time series of cash flows is defined as the sum of the present values of the individual cash flows.

Equation 1

$$NPV = \frac{NB_0}{(1+r)^0} + \frac{NB_1}{(1+r)^1} + \frac{NB_2}{(1+r)^2} + \cdots \frac{NB_n}{(1+r)^n}$$

where

NB_0	=	net benefit 0 years from present
r	=	discount rate
n	=	end of project lifetime (years from present)

4.2.1 Internal rate of return

Internal rate of return (IRR) is the discount rate that solves Equation 1 for an NPV of zero. Often referred to simply as the rate of return, this metric is used to evaluate the desirability of an investment or project. The higher the project's IRR the more desirable it is to undertake the project.

4.2.2 Time to payback

Time-to-payback and discounted time-to-payback are estimates of the period (years) that will be required for the undiscounted and discounted accumulated net cash flows to reach zero. This is the period of time that will theoretically transpire before the initial upfront capital investment and accumulated ongoing operation and maintenance costs will be offset by the real benefits or avoided costs generated from the project.

4.2.3 Benefit to cost ratio

The benefit-to-cost ratio is the quotient of the NPV of total benefits and NPV of total costs over the lifetime of the project:

Equation 2

$$Benefit\ to\ cost\ ratio = \frac{NPV\sum_{i=o}^{n} NB_i}{NPV\sum_{i=o}^{n} NC_i}$$

where

NPV	=	Net present value
NB_0	=	Net benefit 0 years from present
NC_0	=	Net cost 0 years from present
n	=	End of project lifetime (years from present)

4.2.4 Real Benefits

Equation 3

$$real\ benefits = Exp_{wf} * FS * FSM$$

where

Exp_{wf}	=	Total household monthly woodfuel expenditure for cooking
FS	=	Percentage of fuelwood savings generated by ICS over existing cooking technology
FSM	=	Fuelwood savings multiplier

4.2.5 Avoided fuelwood expenditure

Estimating financial benefits from the purchase of an ICS is as difficult as it is integral in the economic feasibility analysis. In the case of an ICS, all direct financial benefits come in the form of avoided expenditures on fuelwood. I do not include non-direct benefits, such as avoided Disability Adjusted Life Years (DALYs) and marginal cost of avoided time spent collecting fuelwood, that are often included in estimating overall benefits for ICS programs. These may be real and significant benefits. For example, an estimated loss of over 38.5 million DALYs has been attributed to cooking with open fires, approximately 3.5% of the global disease burden (Smith K. , 2006). However, including DALYs and avoided time spent collecting fuelwood in the financial analysis introduces uncertainty in the final results (Hutton and Haller 2004, Hackett 2006) and could lead to estimates of benefits that are higher than actual benefits. This is because financial benefits are not automatically generated from reductions in DALYs and avoided time spent collecting fuelwood. In rural Quetzaltenango, there is no certainty that time saved can be translated into financial benefit because people do not necessarily have access to income generating activities.

The accuracy of avoided fuelwood expenditure (direct benefits) estimates will to a great extent determine the accuracy of the feasibility analysis. To estimate direct benefits from a stove purchase we must know fuelwood savings (FS), monthly fuel expenditure (Exp_{wf}), and fraction of fuelwood savings that translates into avoided expenditures (FSM) (Equation 3). In the absence of reliable estimates for these inputs, the resulting outputs of the analysis are not reliable.

Monthly fuel expenditure is an estimate that can be obtained by interviewing a household member who is knowledgeable about the household fuelwood budget. This is the least complicated parameter to estimate. It can be achieved through simple field surveys that can be implemented by a representative of the organization that is marketing the stoves.

The Kitchen Performance Test (KPT) has emerged as the standard method for estimating fuel savings (Bailis, et al. 2007; Granderson, et al. 2005). This test works well for estimating the effect a stove will have on total household fuelwood consumption, but it is resource and time intensive. The KPT includes both qualitative and quantitative surveys. Bailis et al. (2007) recommend that the qualitative surveys be conducted in 30-100 households depending on the size of the target population. The number of quantitative surveys that must be completed depends on the percent reductions that are being tested for and the variance of the results. For example, a paired-test designed to detect 30% reductions in fuelwood consumption requires testing 20 households, first with their old stove and then with the new stove, for a total of 40 tests (Bailis, et al. 2007).

The fuelwood savings multiplier (FSM) is the fraction (between zero and one) of fuelwood savings that will translate into avoided woodfuel expenditures. The rationale behind this parameter is that household reductions in fuelwood consumption may not translate fully into reductions in fuelwood expenditures. For households that purchase the large majority of their fuelwood it makes sense that the FSM would be close to one, meaning that nearly all of the reductions in fuelwood consumption would translate into reductions in fuelwood expenditure. For households that participate in regular collection of fuelwood, it is possible that the FSM will be less than one. This is because for these households, reductions in fuelwood consumption have the potential to offset both fuelwood purchasing activities as well as fuelwood collection activities. If the fuelwood savings were split evenly between offsetting fuelwood collection activities and fuelwood purchasing activities, then the FSM would be 50%.[15] The best method for quantifying FSM is to conduct household surveys that quantify fuel sourcing methods (purchase versus collect) as well as household perspectives on the relative effect of reductions in fuelwood consumption on household collection and purchasing activities. This can be done as an add-on to the KPT qualitative surveys or as a component of a direct marketing program survey.

4.2.6 Value of carbon offsets

There is currently considerable effort being spent on developing methodologies for quantifying the total carbon offsets of cookstove programs (Garcia-Frapolli, et al. 2010, Johnson, et al. 2010). Other stove programs have estimated CO_2e savings of 3.9 MT per year per stove. At this level of CO_2e offsets, even modest prices on abated carbon ($6 - $10 per MT) would add a revenue source ($23 – $39 per stove per year) that could be used to help improve the economics for all households. Sensitivity of financial feasibility results to price of carbon is presented in Section 6.1.7.

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[15] This is true regardless of the relative quantities of purchased and collected fuelwood. For example, if the FSM is 50% and fuel savings are 100kg per month, then 50kg would be offset from the collected fuelwood budget, and 50kg would be offset from the purchased fuelwood budget. The same 50kg would be offset regardless of the ratio of purchased to collected fuelwood. Maximum potential financial benefits are always pegged at total monthly expenditure.

4.3 Survey methodology

The objective of the survey was to create a baseline understanding of household energy use patterns within the rural and semi-rural communities that are served by Xelateco to guide them in developing their business and marketing strategies for the Doña Dora cookstove and other products. In order to accomplish this, the survey was designed to characterize household energy portfolios in general with a specific focus on cooking fuels. In our effort to generate information about the potential market demand for improved cookstoves we collected data about the factors that affect ability and desire to purchase an ICS. Data types collected were categorical, ordinal and continuous.

Quetzaltenango urban residents are consuming an average of 0.9 m^3 per person per year of fuelwood, while rural residents are consuming nearly four times that amount at 3.5 m^3 per person per year (Instituto de Agricultura, Recursos Naturales y Ambiente, 2009). This is because a large proportion of urban Guatemalan residents (65%) primarily use LPG for their cooking fuel (Instituto Nacional de Estadisticas, 2002). Because of this we focused our survey exclusively on rural residents because they are more likely to be dependent on fuelwood for cooking. The target population is defined generally as individuals whose homes are located in rural areas within the reach of Xelateco in Quetzaltenango (14° 50’ 45” N, 91° 31’ 08” W). The service area of Xelateco is defined as homes that are within the boundaries of Quetzaltenango Department. Quetzaltenango is divided into 24 municipalities, with a total population of

737,593, an average density of 378 people/km^2 with 55% being urban and 45% being rural (Instituto Nacional de Estadisticas, 2008).

4.3.1 Survey design

For this survey I used a stratified random block survey design with municipality (e.g. county) population densities used to define each stratum. This is the same methodology used by the US Census Bureau. Strata boundaries for defining rural, semi-rural and urban municipalities were defined using population density thresholds that were observed in the data (0-600, 600-1000, 1000+ pp/km^2) (Figure A2). The municipalities of Ostuncalco, Quetzaltenango, Salcaja and Cantel, all with population densities above 1000 ppl/km^2, were designated as urban and excluded from the sampling (see Figure A2).

In order to generate a random selection of sample blocks, I overlaid all rural and semi-rural municipalities into Google Earth and divided them into 18 minute by 18 minute quads that were numbered consecutively for each stratum (>5000 quads per stratum). In Figure 12 the 18 minute quads are the smaller quads inside of the larger quads. Eight blocks were selected randomly from within each stratum (see Figure 13).[16] Many quads were skipped when no houses were visible after reviewing satellite image (Figure 12). In general, satellite images had sufficient resolution to allow me to identify typical characteristics of villages and houses, particularly roads and corrugated metal roofs. If too few houses were observed then the quad was increased in size until it encompassed a sufficient number of houses (Figure 12). Sixty-four complete surveys

[16] Using a random number generator function in Microsoft Excel

were conducted over a two week period in July of 2010 (Figure 14). The map below (Figure 13) has the exact locations of the 16 sample sites that were visited and surveyed. There was a balanced distribution between stratum with eight rural and eight semi-rural quads sampled and 4.1 and 3.9 surveys per block completed on average respectively (Table 1). It is interesting to observe that the samples do not appear to be very well distributed geographically, with two clusters in the northern and northeastern regions of the department (see Figure 13).

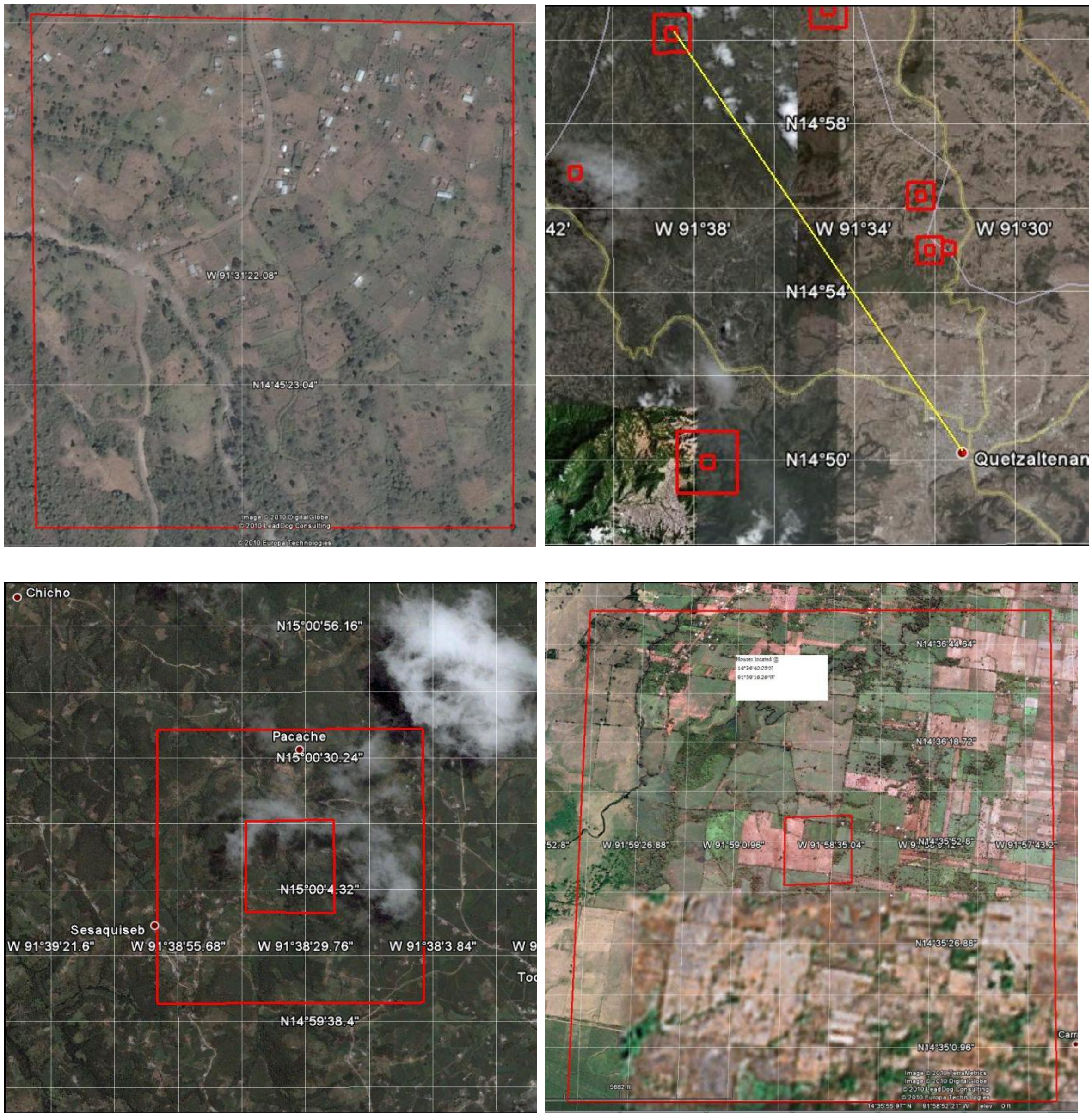

Figure 12: Maps of sample blocks identified in Google Earth.

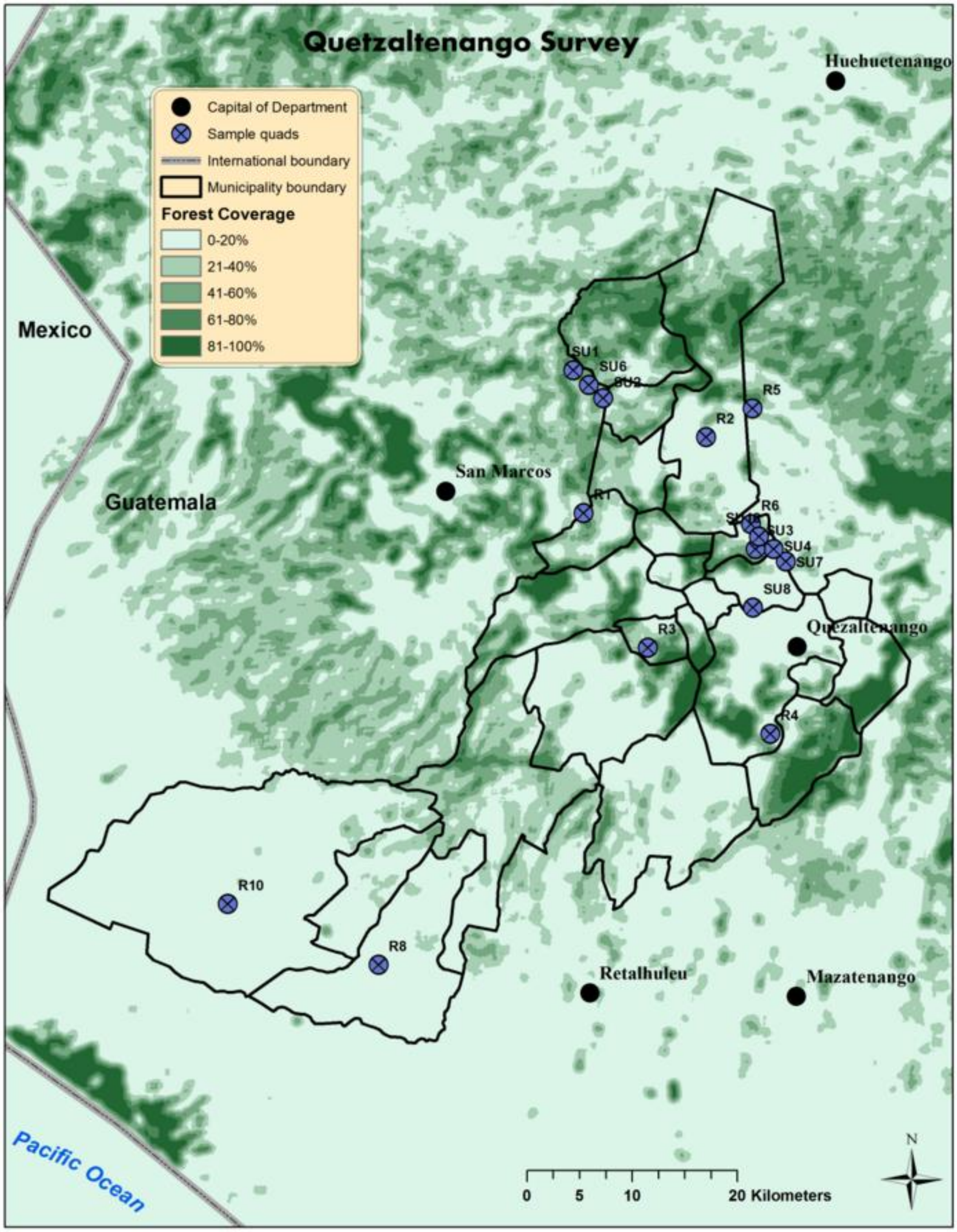

Figure 13: Map of the Quetzaltenango Department with department capital cities, survey quad locations and density of forest coverage. *Map source: Tirian Mink, 2011*

Table 1: Sample quads and total number of surveys in each quad.

Quad code	# Surveys
R2	2
SU4	5
R8	4
SU7	4
SU10	3
R10	6
R5	3
R1	5
SU2	3
SU1	4
R6	6
R3	2
SU6	6

Figure 14: Survey enumerator and Kiche language translator (right) conducting an interview with the female head of household in San Francisco la Union Municipality.

4.3.2 Inferential power of the sample

Extra time and resources were invested to ensure that the survey data would have as much inferential power as possible. Inferential power comes from having a properly designed and implemented random sampling component within your study (Ramsey & Schafer, 2002). This ensures that all subpopulations are represented in the sample in roughly the same mix as the overall population (Ramsey & Schafer, 2002). The random sampling component made for long days of driving while searching for locations that were often unfamiliar to my local partners. Homemade maps and GPSs helped deliver us to each of the 16 quads and conduct 64 (complete) surveys over a 2 week period. In this case, the population to which inferences can be made is "all rural and semi-rural municipalities within the state," - approximately 490,662 people or 85,000 households (Instituto Nacional de Estadisticas, 2010).[17]

Unfortunately there are several factors that combine to undermine and constrain this inferential power. First, 64 surveys represent a relatively small proportion of the total population (0.08%), causing inferences to the entire population to come with a considerable degree of uncertainty. For example, our survey results indicate 55 out of 64 households (85%) own a traditional plancha stove, suggesting that approximately 72,000 households in the population have traditional planchas. However, with a sample size of 64 and using a one-proportion statistical model, an 85% positive response comes with a

[17] This figure is based on Guatemalan census (2010) estimates of household densities (5.8 people per household) in a population of approximately 490,662 people is 84,600 households.

95% confidence interval between 74% and 92%, a range of approximately 63,000 to 78,000 households (Table 2). In other words, if we repeatedly pulled samples of 64 from the population using the same methods, we expect that 95% of the time the estimate would be within that range. This is considered a measure of the certainty for the estimated parameter. Furthermore, the assumption of normal distribution of the sample must be abandoned at very low and very high proportions (e.g. near 0 and 1), especially with smaller sample sizes. The rule of thumb is that the product of sample size (n) and the proportion (p), as well as the product of n and $1-p$ must be equal to or greater than 5 (Kirk, 2010). For a sample size of 64 this threshold is reached at 5/64 (7.8%) and 89/64 (92%). In other words, if proportional estimates from our sample are below 7.8% or above 92% they cannot be considered representative of the population. These two statistical concepts place important constraints on the inferential power associated with a parameter estimate based on our sample of the population.

Table 2: Estimate of total households within the population that have a traditional plancha (center column) along with lower and upper values of 95% confidence intervals (CI) for population based on a 85% positive response from a sample of 64.

	Lower limit of 95% CI	Estimate	Upper limit 95% CI
Percentage of population	74%	85%	94%
Individuals	363,000	417,000	461,000
Households	63,000	72,000	78,000

In addition, within each block non-responses were common occurrences. This is a very important factor that affects our estimates in ways that we are unable to quantify or characterize very well. That is to say, it is difficult to infer how non-responses may have skewed our results. I estimate that non-responses occurred at a rate of about three non-responses to one response. Reasons for non-response were diverse and were not recorded systematically by survey enumerators. However, based on my personal experience and verbal feedback from other enumerators, I can say that quite often there was no one home at the time of visit. Also, it was common for the woman of the house to state that she was too busy to participate, often the case during meal preparation times. In the end we arrived at 64 surveys, but because time and resource limitations did not allow for follow-up on the non-responsive samples, characterizing the bias is difficult. However, we can infer that our sampling method selected against households where people are either too occupied with chores or for some other reason were outside of the house at the time of our visit. Unfortunately we are left to only speculate about the affect this may have had on the results.

All of these factors combine to both constrain the inferential power and skew the results of our survey, the latter in unpredictable ways. Thus, while it is tempting to make inferences from the survey results to the entire population of rural Quetzaltenango, those inferences must be accompanied with all of the above caveats. Therefore, throughout this report I will be explicit in identifying these limitations when making inferences to the population that are derived from the sample.

4.3.3 Language barrier

Surveys were usually conducted in Spanish. However, two indigenous language groups are represented in the population: Kiche and Mam. Kiche and Mam translators were hired to assist with translation in cases where Spanish was not the most appropriate language. Therefore, language should not be considered as a factor affecting the non-response bias.

4.4 Market demand analysis case study

The objective of the market demand analysis is to estimate the total households in rural Quetzaltenango that could theoretically benefit financially from the purchase of the Doña Dora ICS. In order to do this I have defined a baseline scenario which represents the most likely outcome. For the baseline scenario, household input parameters are set to average values of the population, and stove performance input parameters are set at conservative levels. Household parameters are all derived from survey data. Input parameters for stove performance relative to existing stove technology (e.g. fuel savings) are based on educated guesses made by the client, AIDG. As mentioned above, in order to fully understand the benefits component of the cost to benefit analysis, the Doña Dora would need to go through a regime of at least 40 KPTs for each existing stove type (Bailis, et al. 2007). In the absence of real data, the baseline scenario includes conservative assumptions regarding fuel savings (see Section 4.4.6 for a discussion of this parameter). Because of the uncertainty that comes along with making educated guesses about critical input parameters, sensitivity analysis becomes very important. The effect of incremental changes in critical input parameters on key economic metrics is presented in Section 6.1.

Here I will define the baseline scenario inputs that are used in the financial feasibility analysis. As previously mentioned, there are two distinct baseline groups, separated by fuelwood sourcing method. Households that purchase all of their fuelwood represent approximately 37% (31,000) of rural Quetzaltenango households and spend an average of $27.5 a month on fuelwood (Table 3). Households that purchase *and* collect their fuelwood represent approximately 27% (23,000) of rural Quetzaltenango households and spend an average of $23.6 a month on fuelwood (Table 3). These two groups will be treated separately in the analysis; the main difference being with respect to mean monthly fuel expenditures and projected fuel savings.

Table 3. Baseline parameters and values used in market demand analysis.

ICS Input Parameter	Value	Source
Capital Cost ($)	$189	Doña Dora cookstove, 2010 (Quetzaltenango, Guatemala)(Crowe, 2010)
O&M Cost 1 ($ /yr)	$1.86	Doña Dora cookstove, 2010 (Quetzaltenango, Guatemala)(Crowe, 2010)
O&M Cost 2 ($ /2-yr)	$8.07	Doña Dora cookstove, 2010 (Quetzaltenango, Guatemala)(Crowe, 2010)
Lifetime (yr)	5	Doña Dora cookstove, 2010 (Quetzaltenango, Guatemala)(Crowe, 2010)
Fuel Cost "buy only" ($ /household/m)	$27.5	Household survey, 2010 (Quetzaltenango, Guatemala)
Fuel Cost "buy & collect" ($ /household/m)	$23.6	Household survey, 2010 (Quetzaltenango, Guatemala)
Fuel Escalation Rate (%)	4.6%	(Banco Nacional de Guatemala, 2009)
Fuel Savings (%)	35%	(Masera, et al. 2005) (Álvarez, et al 2004)
Fuel Savings Multiplier (%)	75%	See Section 4.2.5
Real Discount Rate (%)	17%	(Crowe 1010) (Banco Nacional de Guatemala 2011)

4.4.1 Capital cost

The capital cost for the Doña Dora is $189. This includes delivery, installation, and at least one follow up visit for repair and maintenance. The stove comes with a one-year warranty against factory defects (Crowe, 2010) (Table 3).

4.4.2 Operation and maintenance

There are some components of the stove that are expected to need regular replacement including the fuelwood support and the chimney elbow. The fuelwood support will need to be replaced once per year and will cost $1.86. Replacing this component does not require skilled labor and can easily be done by the homeowner.

AIDG estimates that the chimney elbow will need to be replaced every two years at a cost of $6.21. This price includes installation by a trained stove technician. In summary, the maintenance cost is estimated to be $1.86 every year and an additional $6.21 every other year (Crowe, 2010)(Table 3).

4.4.3 Lifetime

The baseline value for stove lifetime is set to five years. It is unknown what the actual life time will be because this is a new product. Prototypes have been around for several years but have not been used daily and are therefore not representative of actual product resilience in the field. According to Crowe (2010), five years is a minimum to expect with proper maintenance (Table 3).

4.4.4 Fuel expenditure

This analysis will be completed separately for two subgroups of the sample that are categorized by how they source their fuelwood. Households that purchase all fuelwood represent 37% of the sample and spend an average $27.5 per month. Households that purchase and collect fuelwood represent 27% of the sample and spend an average of $23.6 per month on fuelwood. These are the baseline fuel expenditure values that will be used in the financial feasibility analysis (Table 3).

4.4.5 Fuel escalation rate

The fuel escalation rate is an estimate of the yearly rate at which the cost of a given unit of fuel will increase in price above the present year after accounting for inflation. However, predicting future prices for any commodity that is traded freely in the market is difficult and therefore this metric usually is accompanied with a significant amount of uncertainty. This is particularly true for the informal fuelwood market in Guatemala where no recent national study exists with reliable data (Morales, et al. 2002, 148). This is largely due to the fact that fuelwood is “practically invisible” in national economic indicators and therefore is not accounted for in national economic reports (Morales, et al. 2002, 137). Studies cited in Morales, et al. (2002) have collected information on fuelwood prices in various regions of Guatemala but the data are incomplete and therefore cannot be used to calculate a fuel escalation rate. Because of this, it is necessary to find an economic indicator that will serve as a reasonable proxy to fuelwood prices. A national study that tracks total value and quantity of standing forest stock in Guatemala reported that between 1980 and 2005 the estimated value of a cubic meter of Guatemala’s existing forest stock increased 219% (corrected for inflation) (Banco Nacional de Guatemala, 2009). This represents an average escalation rate of 4.6% per year over this 25 year period (see Appendix B. Guatemalan wood inventory). Due to ongoing depletion of existing forest stock of 1% a year and population growth, it seems likely that this trend will continue for the foreseeable future. I use 4.6% as a baseline fuel escalation rate for this analysis (Table 3). Further studies focused on the behavior of fuelwood markets will be necessary in order to verify that this is a good proxy for fuelwood escalation rates in rural Quetzaltenango. In Section 6.1, I will explore the sensitivity of financial feasibility metrics to incremental changes in fuel escalation.

4.4.6 Fuel savings

Very few stove programs have the resources or capacity to successfully quantify fuel savings. However, there are reliable results from the Interdisciplinary Group of Rural Appropriate Technology (GIRA) in Patzcuaro Mexico for the Patsari Cookstove. The Patsari gets 67% fuel savings compared to a traditional “U” fire[18] and 59% savings compared to the open fire (Masera, et al. 2005). Álvarez et al. (2004, p. xvi) conducted an extensive evaluation of improved cookstove programs in Guatemala. One of their main findings was that ICS beneficiaries reported fuel savings of 50-67% over their traditional cooking methods. Actual fuel savings will be determined by both stove performance with respect to the existing stove as well as household use patterns. For the purposes of the economic analysis, we have defined the baseline fuel reduction conservatively at 35% (Table 3). Sensitivity of financial feasibility metrics to incremental changes in fuel savings is presented in Section 6.1.

4.4.7 Fuel savings multiplier

The fuel savings multiplier is the fraction of fuelwood savings that will lead to avoided expenditures. For households that purchase all of their fuelwood, I assume a multiplier of one between fuel savings and avoided expenditures (Table 3). In other words, 100% of the fuelwood savings will offset expenditures on fuelwood. For households that purchase and collect fuelwood we assumed a multiplier of 0.75 because it is expected that fuelwood savings will offset a portion of fuel collection activities as well

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[18] The “U” Fire is similar to the Three Stone Fire made of bricks or mud built into the shape of a U with a metal plancha, grill, or comal propped on top.

as fuel purchasing. The actual fuel savings multiplier will be different for each household and situation. By using 0.75 for households that purchase and collect fuelwood, I assume that households in our sample that purchase and collect fuelwood prefer to save money over time by a ratio of three to one. Future surveys would benefit from including a question that would attempt to quantify this parameter for each household. Sensitivity of financial metrics to incremental changes in the fuel savings multiplier is presented in Section 6.1.

4.4.8 Discount rate

In this analysis I am using a real discount rate of 17%. The real discount rate is the actual rate at which a future sum of costs and benefits is discounted by the potential investor, and includes the effect of inflation on future purchasing power. In this case I define the nominal discount rate as the cost of borrowing money. This is because in a village economy, the cost of borrowing money is a good measure of the cost of capital to the individual household. Micro-financing packages that are available to the communities in rural Quetzaltenango, designed specifically for an investment in the Doña Dora ICS, are charging 25% APR according to Crowe (2010). The ten-year average increase in consumer price index for Guatemala is 7.0% (see Appendix C. Consumer Price Index 2000-2010). The Fisher equation relates real discount rate, nominal discount rate and inflation rates:

Equation 4

$$R_r = \frac{\mathrm{R_n} + 1}{\mathrm{R_i} + 1} - 1$$

where

R_r = Real discount rate

R_n = Nominal discount rate

R_i = Inflation rate

Therefore the real discount rate is 17%. Actual discount rates may be much higher (or lower) depending on individual circumstances. Sensitivity of financial metrics to large changes in discount rate is presented in Section 6.1.

4.4.9 Carbon offset value

I did not include carbon offsets in the baseline analysis. Nevertheless, research has demonstrated that a successful cookstove intervention program in Michoacán, Mexico is generating carbon offsets of around 3.9 MT of CO_2e per stove per year (Johnson, et al. 2010). Sensitivity of carbon offset value ($/MT), assuming offsets of 2.0 MT of CO_2e per stove per year, is presented in Section 6.1.

5 LIFE IN RURAL QUETZALTENANGO: HOUSEHOLD SURVEY RESULTS

In this chapter I combine results from our household survey with a review of recent literature to illuminate some of the conditions of household life in rural Quetzaltenango (Figure 15). I characterize demographics, household energy use, energy use in the kitchen, and household expenditures related to energy use. I present primary data describing the houses people live in, the materials used in construction, and the ownership rates of cropland and farm animals. I also present results that shed light on individual perspectives on the relationships between fuel consumption, environment, family health and energy use. Lastly I present my findings on gender and purchasing power and compare my findings to the conclusions of Miraftab (1996) and Katz (1995) (as discussed in Section 3.5).

Figure 15: Grandfather taking care of great grandson and neighbor boys (back) while granddaughter makes tortillas over an open fire. *Photo: Tirian Mink 2010*

The department of Quetzaltenango, where this study took place, is located in the western highlands of Guatemala and covers 1951 square kilometers of land (CIA, 2010). The national census estimates the total state population to be approximately 738,000, with 40% of the economically active population engaged in agriculture (Instituto

Nacional de Estadisticas, 2008).[19] The municipality of Quetzaltenango is the head municipality of the department and is usually referred to by its indigenous name, *Xelaju*.' It is the second most populous city in Guatemala with an estimated 143,000 people (Instituto Nacional de Estadisticas, 2008).

5.1 Households

The average household in our sample has 5.8 members, with slightly more women per household (3.0) than men (2.8). The average age of all family members is 25.6 years (Figure 16). Interviewees, who were almost exclusively the female head of the household, reported having an average level of education of third or fourth grade (3.6 years). Fifty-two percent of households report speaking Spanish only in the household with forty-five percent speaking Kiche or Mam in addition to Spanish (Figure 17). Poverty is widespread in Quetzaltenango with an estimated 44% living in poverty and 10% living in extreme poverty (Instituto Nacional de Estadisticas, 2008). Indigenous groups, which represent 44% of the population, have higher rates of poverty (55%) and extreme poverty (14%) than the population as a whole (Instituto Nacional de Estadisticas, 2008).

[19] Our survey found 54% (+/- 10%) of "rural" household respondents reporting agriculture as the primary income generating activity.

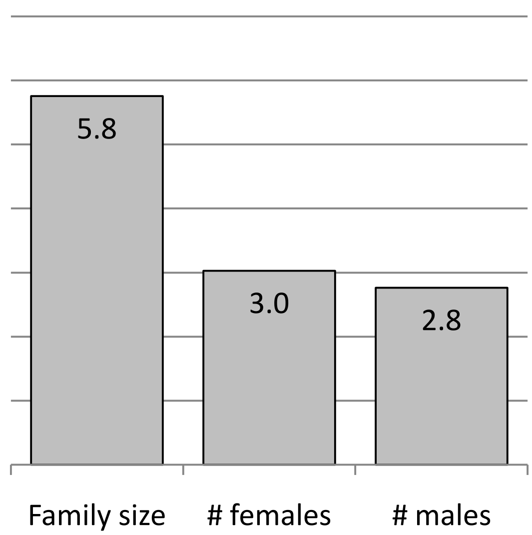

Figure 16: Mean number of household members as well as mean number of females and males.

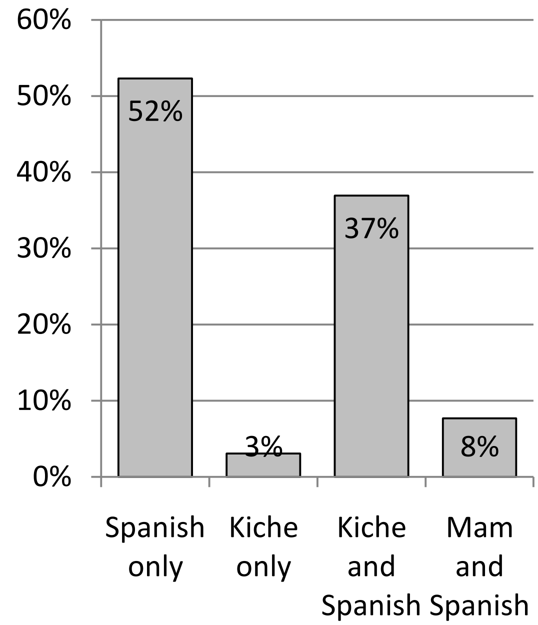

Figure 17: Three languages groups are represented in the sample including Spanish and two indigenous languages Mam and Kiche, with the large majority reporting some level of Spanish proficiency.

Eighty-nine percent of survey respondents said they own their own property.[20] Most homes in our sample are simple concrete block structures (65%) with poured concrete (63%) or earth (29%) floors (Figure 18).[21] The sample population reported an average of 3.6 rooms (including the kitchen) with an average property size of slightly less

[20] The Guatemala National Census estimates that property ownership is going up across the country with a rise from 64.7% in 1981 to 80.6% in 2002. The property ownership rate in rural areas across the nation was higher at 86.9%, very similar to our findings(Instituto Nacional de Estadisticas, 2002).

[21] This compares to Guatemalan National Census estimates of 50%, 24% and 16% of households in the country have concrete block, adobe and wood respectively, for wall material (Instituto de Agricultura, Recursos Naturales y Ambiente, 2009).

than one hectare (0.98 Ha) (Figure 18). The majority of the sample is engaged in subsistence agriculture and animal husbandry, but these activities are usually done on land that is rented from a local property owner, paying around $50 per Ha per year in land rental fees. In fact, 69% of the households reported cultivating corn (primarily for the purpose of household consumption) with an average crop of two hectares.

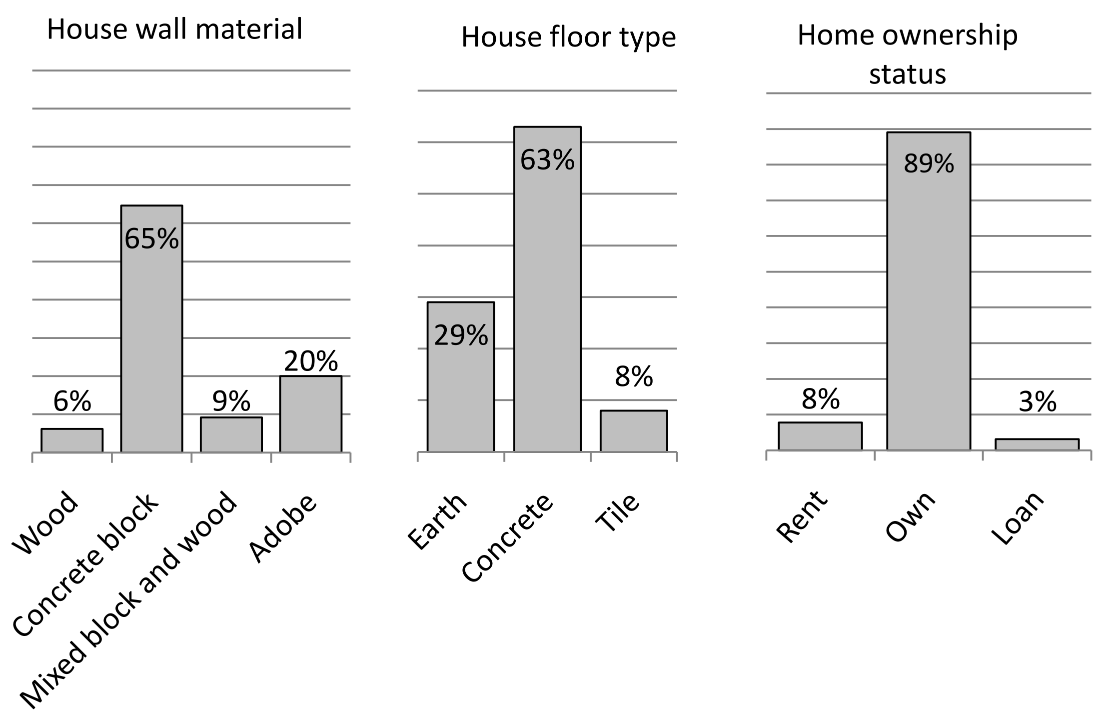

Figure 18: House wall and flooring type, and home ownership status of households in sample

The most common animals owned by households in our sample are pigs (54%), poultry (51%) and cows (32%) (Figure 19). Residents reported that these animals are used either for household consumption or for income generation depending on the state of household finances and market prices.

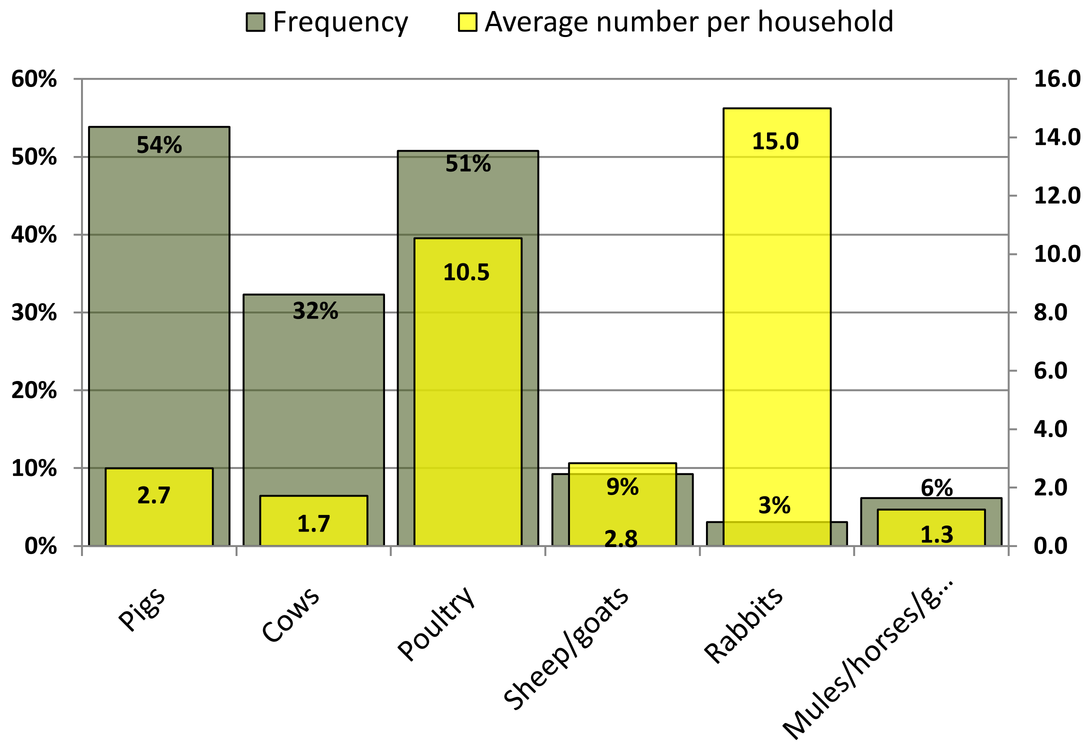

Figure 19: Percentage of households in sample that own pigs, cows, poultry, sheep/goats, rabbits, mules/horses/bulls overlaid with mean number owned per household for of each animal type.

5.2 Household energy use

Only 1 of 64 households that we surveyed did not have grid electric service. This ratio falls outside the bounds of the low and high proportion rule that I discussed in Section 4.3.2. Therefore we cannot say that 98% of rural Quetzaltenango households have access to grid electricity based on our survey data. However, 88% of survey respondents reported the use of incandescent and/or compact florescent lighting daily and for this group there is a mean monthly electricity bill of $12.[22] Use of electric lighting is a better measure of "access" when discussing electric service (see section 3.3 for a discussion of factors that determine access) because it indicates that a household has both the ability *and* means to derive benefit from the service. These numbers do not contradict the 91.2% electrification rate for the whole Quetzaltenango Department, as reported by *Union Fenosa* in 2002, the primary electric utility provider in western Guatemala (cited in Economic Consulting Associates LTD, 2002). *Union Fenosa* also reports a 42.2% increase in electrification rate in Quetzaltenango between 1991 and 2000 (Economic Consulting Associates LTD, 2002, p. 15), a dramatic expansion of coverage for a nine year period.

5.3 Energy use in the kitchen

Twelve percent of survey respondents report the use of open fires for cooking, while a large majority (85%) reported owning a "traditional *plancha*," a partially improved biomass cookstove. Thirty-two percent of respondents reported using propane gas in addition to their wood stove. For these households the mean monthly expenditure is $11.40 per month ($2.50 per person). This is lower than the mean monthly fuelwood expenditures for all 64 households ($14.8 per month) and much lower than the average expenditures for those who purchase all their fuelwood ($27.5 per month) and those who purchase and collect their fuelwood ($23.4 per month) (see Section 5.4). This makes

[22] This estimate has a 95% confidence interval of 77% - 94%.

sense because most gas users reported using gas less than an hour a day for small tasks such as warming up previously cooked food, or heating water for hot drinks.

Traditional *planchas* (see Figure 20) are an improvement over an open fire for two reasons. First, they elevate the stove off the ground so that the user is not required to kneel in the dirt while making her tortillas or stirring her beans. Second, they usually improve indoor air quality by directing the emissions out of the kitchen via a chimney. This second benefit can often be reduced by poor installation and/or deferred maintenance, resulting in emissions leaking into the kitchen. Our survey found this to be the case; while 81% of surveyed households have chimneys, only 50% reported having a smoke free kitchen. The 50% of the sample that cooks in smoky kitchens overwhelmingly cited eye irritation as the primary negative impact leading one to conclude that there is considerable room for improvement in indoor air quality within households in rural Quetzaltenango.

Figure 20: Traditional *Plancha* in Quetzaltenango, Guatemala. *Photo source: Tirian Mink 2010*

While the traditional *plancha* can be considered an improvement over the open fire with respect to ease of use and indoor air quality, it is not necessarily associated with higher fuel efficiency (Granderson, et al. 2005). In fact, a recent study in neighboring San Marcos Department used Kitchen Performance Tests to compare fuel efficiency improvements in a group of households that had received traditional *planchas*. They found no significant improvement (Granderson, et al. 2005).

5.4 Fuel Sourcing and Expenditures

Grouping the population by *fuel sourcing method* allows us to see patterns within the population that are linked how people procure their fuelwood. The population falls into three distinct groups based on how they source their fuelwood. Households that purchase all of their fuelwood, and do not collect, represent 37% of the sample; while households that both purchase and collect fuelwood represent 27%. Households that collect all of their fuelwood represent the remaining 37% of the sample.

Households that collect all of their fuelwood spend an average of 20 hours each month dedicated to collecting wood and reported consuming an average of 650 kg of woodfuel each month (137 kg per person). Households that purchase and collect fuelwood spend an average of 16 hours each month dedicated to collecting fuel; they have a mean monthly fuelwood expenditure of $23 and reported consuming an average of 648 kg per month (455 kg collected, 193 kg purchased) (93 kg per person). Households that purchase all of their fuelwood report the highest mean monthly expenditure on wood fuel at $27.5. This group reported consuming the least amount of wood both per household per month (285 kg) and per person per month (58 kg) (Figure 21, Figure 22). The average monthly expenditure for the whole sample (including those with zero monthly fuel expenses) is $14.8.[23]

[23] A recent study in the neighboring and demographically similar Department of San Marcos found that the average household (with 5 members) purchases one *tarea* of fuelwood per month for an average monthly expenditure of between 14.1 and 18.1 USD (Gutierrez, 2010, p. 88).

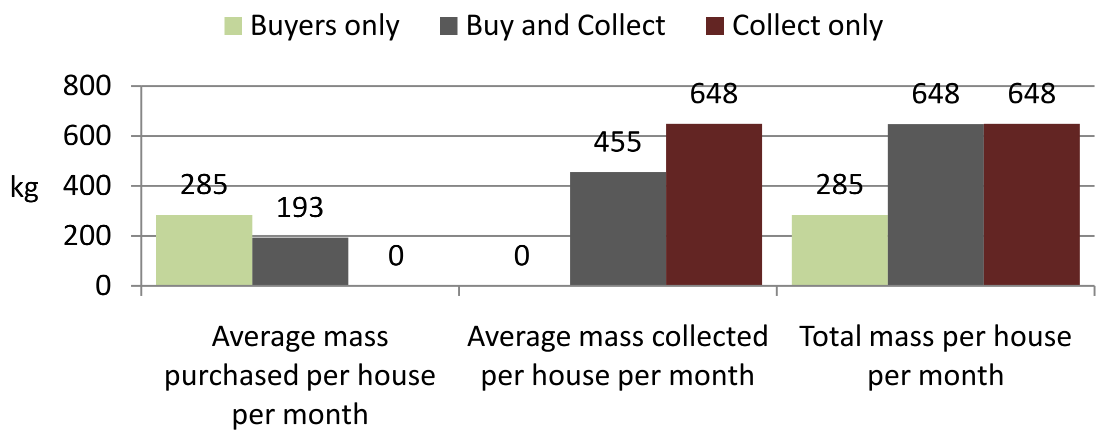

Figure 21. Total household fuelwood purchased and collected per month by sourcing method.

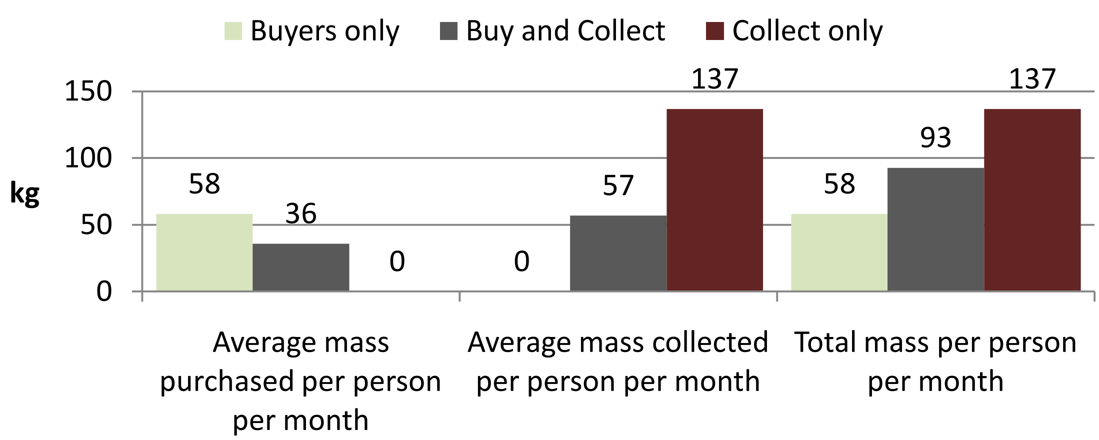

Figure 22. Per capita fuelwood purchased and collected per month by sourcing method.

5.5 Household perspectives

Households were asked to share their perspective on concepts related to saving money, conservation of forests, the effect of biomass stoves, and poor indoor air quality on health. When asked if they could name a domestic activity that could save their household money, 74% of respondents said yes and named an activity while 26% said could not name one. The majority of households cited “efficient use of household energy” (58%) as the primary way they could save their household money, while some cited investing more in “crops and livestock” (6%) or “finding more work” (4%) as the best way to save more money (Figure 23).

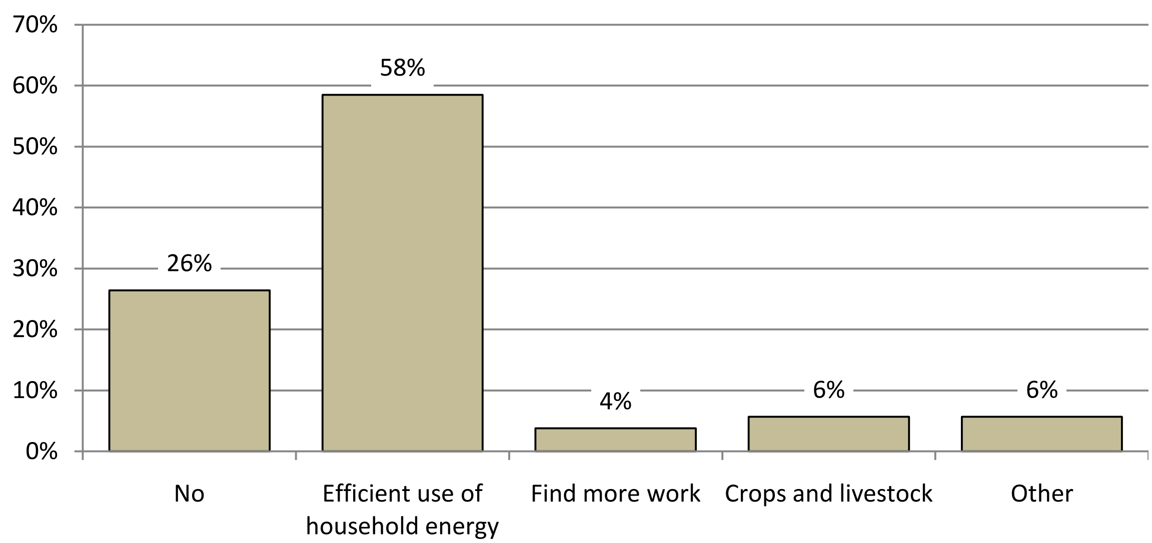

Figure 23: Responses to the question, "Do you believe there are domestic activities that can help your family save money? If so, what?"

Results from our survey sample suggests that rural Quetzaltenango residents value and understand the relationship between the forests and their own quality of life. This makes sense as the Guatemalan National Statistics Institute (INE) estimates that three quarters of the country is directly dependent on forest resources for a wide range of services that extends beyond fuelwood (Instituto Nacional de Estadisticas, 2002). When asked to rate the importance of healthy forests on their family's quality of life, on a scale of one to five, the average response was a 3.8. When asked if they could think of a domestic activity that can contribute to the conservation of forests, people named tree planting (41%), not cutting trees (22%) and saving on fuelwood (13%) (Figure 24).

Figure 24: Responses to the question, "Can you think of a domestic activity that can contribute to the conservation of the forests?"

Residents cited “clean water” (31%), “clean air” (27%), “general environment” (13%), and “fuelwood for cooking” (11%) as their primary reasons for valuing the forests (Figure 25). A majority of households (54%) associated poor indoor air quality with burning solid fuels indoor.

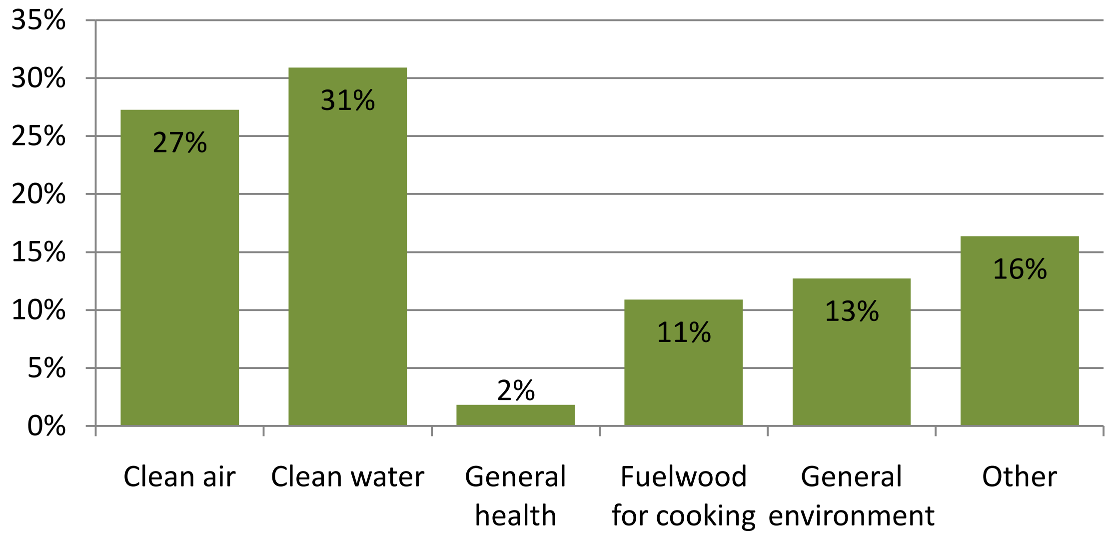

Figure 25: Responses to the question, "*How is the conservation of the forests important to your family's quality of life*?"

When asked to specify how this air pollution bothered them, most named "eye irritation" (28%) as being the primary consequence from the smoke. Many elected not to cite a specific problem that was caused by the IAP from their stove (14%), while some merely stated that it bothered them because it is bad for general health (6%). A small percentage of the population reported that there is IAP from their stove but that it does not bother them in any way (5%) (Figure 26).

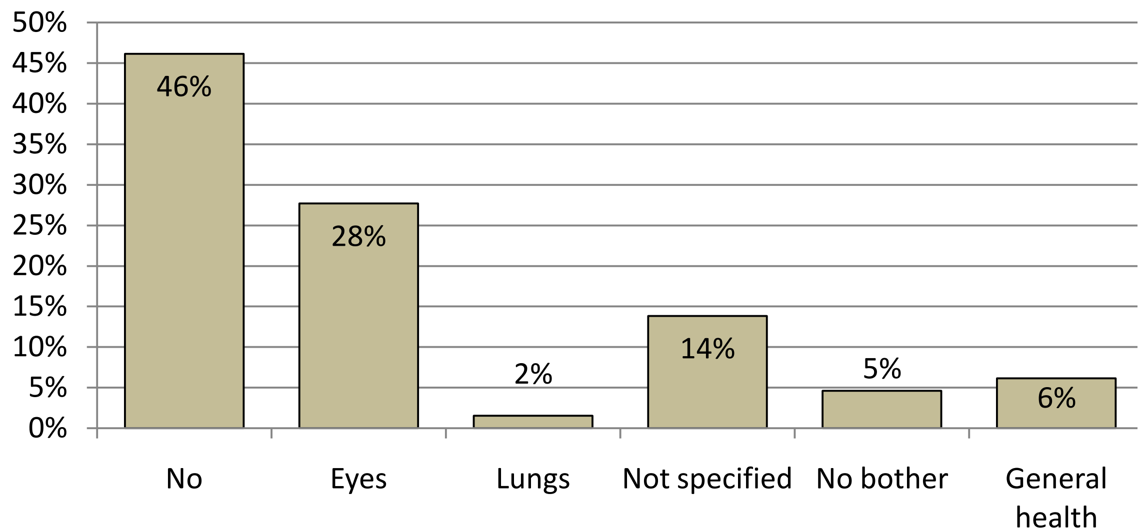

Figure 26: Responses when asked the question, "*Does smoke from your stove bother you and if so how?*"

In fact most of the respondents do not think there is a linkage between stove usage and health (62%).[24] The most commonly cited linkage between health and stove use was the negative effect on eyes (25%) (Figure 27).

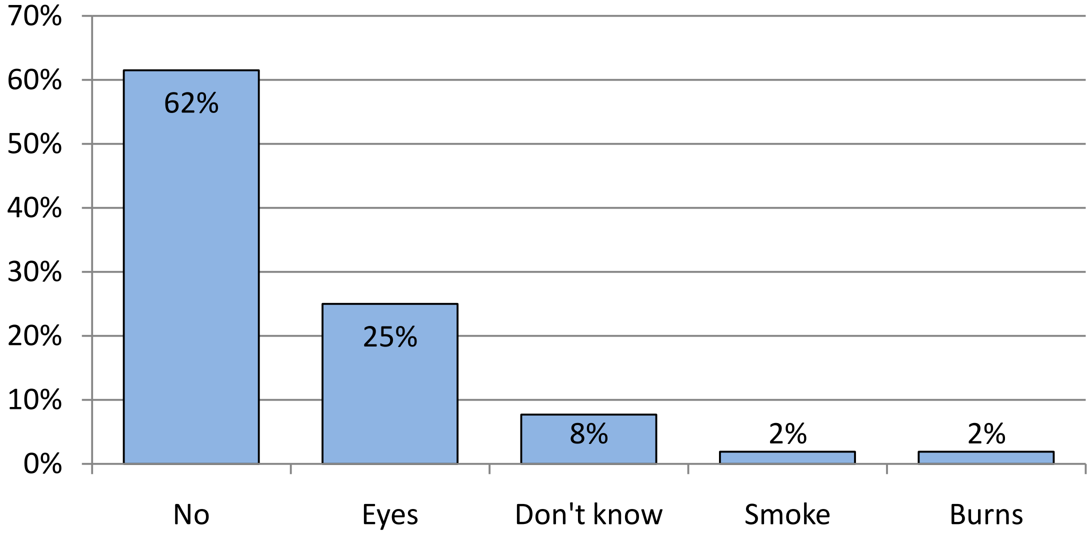

Figure 27: Responses to the question, *"Do you believe your stove has an effect on the health of your family? If so how?"*

[24] Nearly all of the surveys were conducted with the female head of household occasionally in the presence of the male head of household.

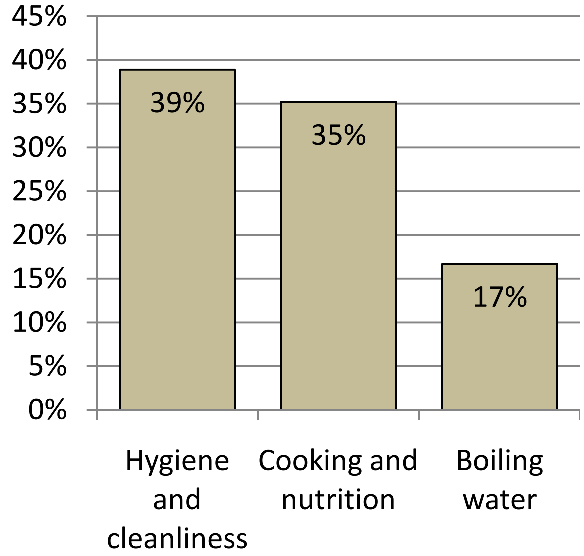

Figure 28: Responses to the question, *"What domestic activities can be done to improve the health of your family?"*

Finally, with respect to family health, most household respondents (90%) said that there are domestic activities that can contribute to good family health. This was an open question; the responses fall neatly into categories including: cooking and nutrition (35%), hygiene and cleanliness (39%), and boiling water (17%) (Figure 28).

Earlier I discussed the concept of gender dynamics within the household and how these dynamics affect the power balance between the genders in decision making processes around large household purchases. Results of our survey contrast somewhat with the findings of Doss (1996) who concludes that women in the western highlands of Guatemalan do not possess equal influence to men over non-food purchasing decisions. For example, when asked about income sources, we found that 66% of households report that the man of the house is the primary income provider and 11% report it is the female head of household (Figure 29).

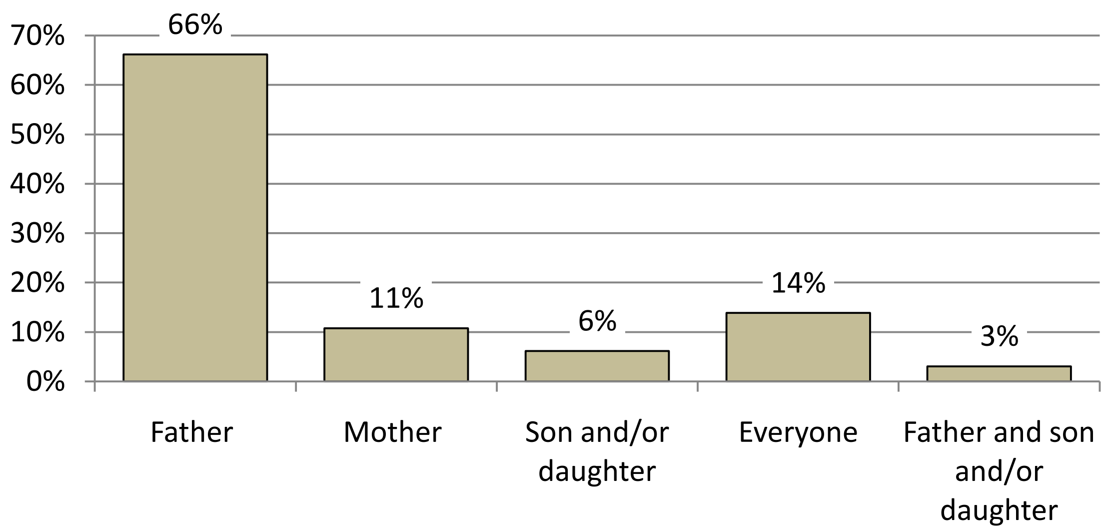

Figure 29: Survey responses when asked *who the primary income provider is for the household*.

This result suggests that the man plays a dominant role in income generation for most households. On the other hand, when asked about decision making roles with respect to large household purchases, 40% reported that these decisions are shared by the mother and father equally (Figure 30). Nineteen per-cent reported that the father is responsible for these decisions exclusively, while 14% reported this was true for the mother. Twenty-two per-cent of households reported that all family members participate in the process equally.

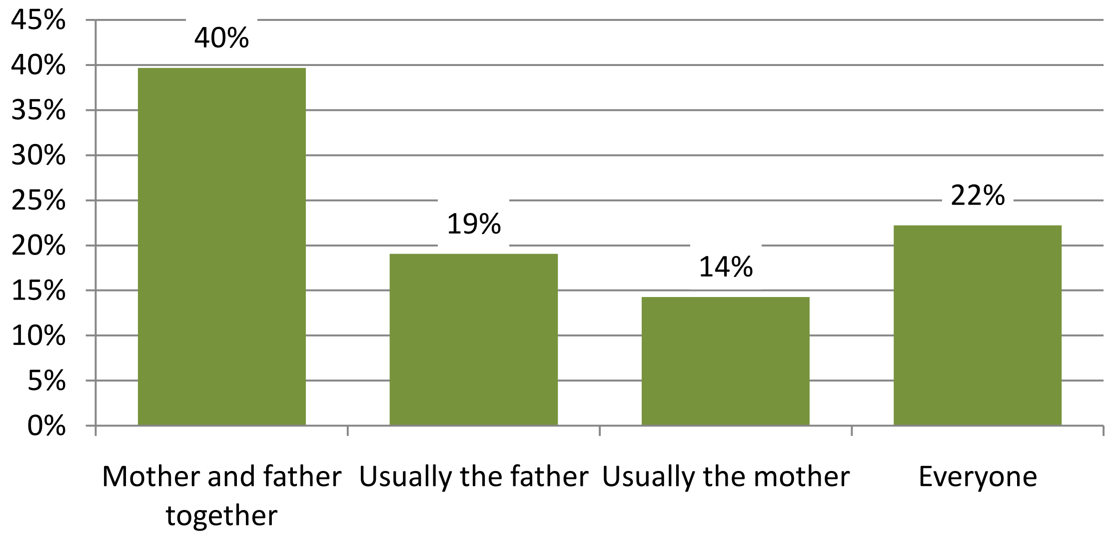

Figure 30: Survey responses when asked *who is responsible for large household purchases*.

One might conclude from this result that rural Quetzaltenango women may buck the trend and wield significant influence over the decision making process in regards to large household purchases. There are other possible explanations for why our survey results contradict other studies in the same region. One possible explanation is that the responses to our survey do not represent what would actually take place if the opportunity were presented. After all our survey was a snapshot in time of the perceptions of the interviewee to the questions we asked; there was no follow up, observation, or measurement process to verify the responses. Another possible factor contributing to this was the role that gender dynamics played in the interview process itself. While an effort was made to interview only the female heads of house, this was not exclusively what happened. In many cases the man of the house was actively participating in the interview, perhaps influencing the responses provided by the women, and in some cases answering the questions directly; in a small number of cases the man answered all of the questions because the woman was not available. Furthermore, survey enumerators were both male and female, and whenever possible the interviews were carried out by teams of two, including a male and female, but in many cases resources did not allow for this. It is not clear what effect this may have had on the outcome of the survey. Our survey represents the responses of the interviewees to the interview questions and this is not necessarily representative of the actual dynamics that would come into play in decision making processes within the house. Given the conflicting results between our study and the previously mentioned study in the same area, it remains unclear what effect household gender dynamics have on decision making processes for relatively large purchases.

All of these conditions, household life, perspectives on health and environment, and gender dynamics, are relevant when interpreting the result of the market demand analysis.

6 MARKET DEMAND ANALYSIS RESULTS

In this chapter I present the results of the market demand analysis. Using the input parameters from Section 4.4 and the Cookstove Calculator, I estimate financial feasibility metrics separately for two subgroups in our sample: households that purchase all fuelwood, and households that purchase and collect fuelwood. Based on these results I make inferences to the wider population and estimate the total number of households in rural Quetzaltenango for which the investment in the Doña Dora ICS is net positive. I present distribution plots, confidence intervals and box plots of the results for each subgroup, and briefly discuss the significance of the distribution pattern across the subgroups. Finally, I present the Cookstove Calculator's automatically generated sensitivity plots for eight input parameters in order to demonstrate the sensitivity of financial metrics to incremental changes in input parameter values.

For the group that purchases all of their fuelwood (37% of sample), the financial analysis indicates that the Doña Dora ICS is a favorable investment (Table 4). Using the group mean for monthly fuel expenditure ($27.5, 95% CI [$21.3, $30.7]) and baseline values (see Section 4.4) for all other input parameters yields a NPV of $210, time to payback of 1.6 years, discounted time to payback of 2.0 years, benefit to cost ratio of 2.0, an IRR of 58%, and a monthly benefit of $9.6 (Table 3). When the economic metrics are calculated separately for each household in the group (n=22) (see Table 4), results are similar with mean values for NPV of $218 (95% CI [124, 312]), benefit to cost ratio of

2.1 (95% CI [1.6, 2.6]), IRR of 57% (95% CI [40%, 74%]), and monthly estimated benefit is $9.6 (95% CI [$7.4, $11.8]) (Table 7).

The results in Table 4 show that for 20 of 22 households in this sample subgroup, an investment in a Doña Dora is estimated to have a NPV of greater than zero. If we assume that the sample is representative of all rural households that collect fuelwood, we can infer from this result that the same is true for 91% (95% CI [71%, 99%]) of the 31,000 households in the populations. In other words, investing in a Doña Dora ICS is estimated to be a net positive investment for approximately 28,000 (95% CI [22,000, 31,000]) households in rural Quetzaltenango who purchase all their fuelwood.

Table 4: Economic cost-benefit results assuming mean baseline input parameter values for households that buy all fuelwood.

Economic Metric	Value
Total number of houses	31,000
NPV of stove over 5 years	$210
Time to Payback (years)	1.6
Discounted Time to Payback (years)	2.0
Benefit/Cost Ratio	2.0
IRR	58%
Monthly benefit	$9.6

Table 5: Monthly fuel expenditure and economic cost-benefit results for individual households that buy all fuelwood.

#	Monthly Fuel Expenditure ($)	NPV ($)	Time to Payback (years)	Discounted Time to Payback (years)	Benefit/Cost Ratio	IRR	Monthly Benefit ($)
1	5	-124	>5	>5	0.4	-17%	2
2	10	-48	4.3	>5	0.8	6%	4
3	15	29	2.9	4.2	1.1	23%	5
4	16	37	2.8	4.0	1.2	25%	5
5	16	37	2.8	4.0	1.2	25%	5
6	19	85	2.3	3.1	1.4	35%	7
7	19	85	2.3	3.1	1.4	35%	7
8	21	117	2.1	2.8	1.6	41%	7
9	24	161	1.8	2.4	1.8	49%	8
10	25	180	1.7	2.2	1.9	52%	9
11	25	180	1.7	2.2	1.9	52%	9
12	25	180	1.7	2.2	1.9	52%	9
13	29	237	1.5	1.9	2.1	62%	10
14	31	275	1.4	1.7	2.3	69%	11
15	31	275	1.4	1.7	2.3	69%	11
16	31	275	1.4	1.7	2.3	69%	11
17	31	275	1.4	1.7	2.3	69%	11
18	38	370	1.2	1.4	2.8	85%	13
19	38	370	1.2	1.4	2.8	85%	13
20	38	370	1.2	1.4	2.8	85%	13
21	59	693	0.7	0.9	4.3	137%	21
22	63	749	0.7	0.8	4.6	146%	22

For the group that purchases and collects their fuelwood (27% of sample), the financial analysis indicates that the Doña Dora ICS is a favorable investment but not to the same degree as for the group that buys all fuelwood (Table 4). Using the group mean for monthly fuel expenditure ($23.6, 95% CI [$15.4, $31.8]) and baseline values for all other input parameters yields a NPV of $61, time to payback of 2.5 years, discounted time to payback of 3.5 years, benefit to cost ratio of 1.3, IRR of 30% and a monthly benefit of $6.2 (Table 6). When the economic metrics are calculated separately for each household in the group (n=17) (see Table 6), results are similar with mean values for NPV of $69 (95% CI [$-25, $163]), benefit to cost ratio of 1.3 (95% CI [0.8, 1.8]), IRR of 26% (95% CI [6%, 46%], and monthly estimated benefit is $6.2 (95% CI [$4.0, $8.4]) (Table 7).

The results in Table 6 show that for 10 of 17 households in this sample subgroup, an investment in a Doña Dora is estimated to have a NPV of greater than zero. Using the same logic as above, we can infer from this result that the same is true for 59% (95% CI [33%, 82%]) of the 23,000 households in the populations. In other words, investing in a Doña Dora ICS is estimated to be a net positive investment for approximately 14,000 (95% CI [7,600, 19,000]) households in rural Quetzaltenango who purchase and collect their fuelwood.

Table 6. Economic cost-benefit results assuming baseline input parameter values for households that buy and collect fuelwood.

Economic Metric	Value
Total number of houses	23,000
NPV of stove over 5 years	$61
Time to payback (years)	2.5
Discounted time to payback (years)	3.5
Benefit to cost ratio	1.3
IRR	30%
Monthly benefit	$6.2

Table 7: Monthly fuel expenditure and economic cost-benefit results for individual households that buy and collect fuelwood.

#	Monthly Fuel Expenditure ($)	NPV ($)	Time to Payback (years)	Discounted Time to Payback (years)	Benefit/Cost Ratio	IRR	Monthly Benefit ($)
1	3.1	-164.6	>5	>5	0.2	-36%	0.8
2	4.7	-146.8	>5	>5	0.3	-26%	1.2
3	6.3	-128.9	>5	>5	0.4	-19%	1.6
4	7.8	-111.1	>5	>5	0.5	-12%	2.1
5	9.4	-93.3	>5	>5	0.6	-7%	2.5
6	10.3	-82.7	>5	>5	0.6	-3%	2.7
7	12.5	-57.7	4.6	>5	0.7	3%	3.3
8	25.0	84.7	2.3	3.1	1.4	35%	6.6
9	25.0	84.7	2.3	3.1	1.4	35%	6.6
10	31.3	156.0	1.9	2.4	1.7	48%	8.2
11	31.3	156.0	1.9	2.4	1.7	48%	8.2
12	31.3	156.0	1.9	2.4	1.7	48%	8.2
13	32.5	170.2	1.8	2.3	1.8	51%	8.5
14	33.8	184.4	1.7	2.2	1.9	53%	8.9
15	37.5	227.2	1.5	1.9	2.1	61%	9.8
16	37.5	227.2	1.5	1.9	2.1	61%	9.8
17	62.5	512.1	0.9	1.1	3.5	108%	16.4

Table 8: Estimates of sample mean values for NPV, benefit to cost ratio, IRR and monthly benefit for households that buy all fuelwood (B) and households that buy and collect (BC).

	Monthly Fuel Expenditure ($)		NPV ($)		Benefit/Cost Ratio		IRR (%)		Monthly Benefit ($)	
	B	BC	B	BC	B	BC	B	BC	B	BC
Mean	27.5	23.6	218	69	2.1	1.3	57%	26%	9.6	6.2
StDev	13.9	16.0	211	182	1.0	0.9	38%	39%	4.9	4.2
SE	3.0	3.9	45	44	0.2	0.2	8%	10%	1.0	1.0
+/- 95% CI	6.2	8.2	94	94	0.5	0.5	17%	20%	2.2	2.2

These results indicate that an investment in the Doña Dora ICS is a net positive investment for the average household in each group, albeit more positive for households that purchase all fuelwood than for those that purchase and collect fuelwood. Furthermore, for 30 out of 64 households in our sample (47%, 95% CI [34%, 60%]), the investment in the Doña Dora is estimated to be net positive (Table 4 and Table 6). If we assume that our sample is representative of the entire population of rural households in Quetzaltenango (84,600 households, see Section 4.3.1), we can infer that the Doña Dora ICS is a net positive investment for 40,000 households (95% CI [29,000, 51,000]).

However, while these statistics are useful for characterizing the sample as a whole, they do not have much predictive power for an individual household within the sample or population. The magnitude of an individual household's monthly fuel expenditure's deviation from the group mean will determine the magnitude that the estimates of financial metrics will deviate from the mean. This is because financial benefits are dependent on the ICS generating savings in the form of avoided expenditures on fuelwood.

In order to better understand the relevance of these results to individual households within the group and population it is helpful to consider how the results were distributed across the sample. Figure 31 to 40 include frequency distribution plots (top) and box plots of minimum, first quartile, median, third quartile and maximum (middle) for monthly fuel expenditure and each estimated economic metric for both groups. Also included are graphical representations of the 95% confidence intervals for the mean and median (bottom). Overall the plots of financial feasibility metrics (NPV, benefit to cost ratio, IRR, time to payback and monthly benefit) are distributed in a way that follows the pattern that was set by the distribution of monthly fuel expenditures for each subgroup in the sample.

It makes sense then to explore the distribution of monthly fuel expenditure for each subgroup in order to illuminate the significance that this particular distribution pattern has on results of the overall analysis. The mean monthly fuel expenditure for households that buy all fuelwood is $27.5 (n=22, sd 13.9, 95% CI [$21.4, $33.7]) and is a figure that comes from the household survey. We can see from Figure 31 and Figure 32 that monthly fuel expenditure is not distributed normally for either subgroup. For households that purchase all their fuelwood, the plot is clearly right-skewed and contains apparent outliers on the right that are contributing to this. This suggests that for this subgroup the median monthly fuel expenditure for households ($25.0) is a better predictor of individual household monthly fuel expenditure than the mean is ($27.5) (Figure 31). Because of this, it would be more appropriate to use $25.0 (I used $27.5) as the baseline for this subgroup's financial analysis.[25] This lower value would result in overall lower estimates of the financial benefits for households that purchase all fuelwood. Specifically NPV would decrease to $180 (from $210), time to payback would increase to 1.7 years (from 1.6), benefit to cost ratio would decrease to 1.9 (from 2.0), IRR would increase to 52% (from 58%) and monthly benefit would decrease to $8.8 (from $9.6).

Within the same subgroup, two households reported monthly fuel expenditures of $59 and $63 (Table 4) representing 4.2 and 4.5 standard deviations above the mean value ($27.5). The estimates of financial feasibility metrics based on these data are similarly divergent from the group means leading to estimated NPVs of $965 and $1040, representing 3.5 and 3.7 standard deviations above the mean value ($340) respectively (Table 4). Also the benefit to cost ratios and estimates of monthly benefit for these two outliers are 4.2 and 4.5 standard deviations above the mean. These high deviations may suggest that these two households are not a representative selection from population. However, due to the relatively small sample size (n = 22) it is difficult to determine, and therefore they are included in the analysis.

[25] The sensitivity of financial metrics to incremental changes in monthly fuel expenditure is presented in Section 6.1.

The distribution of the results for the subgroup of households that purchase and collect fuelwood has a right-skewness characteristic as well (Figure 32). This is because one household reported a monthly fuel expenditure of $63, representing 3.9 standard deviations above the mean value ($23) (Table 6). This yields an estimated NPV of $727, representing 3.0 standard deviations above the mean estimate for the subgroup ($151). Similarly, the benefit to cost ratio and estimate of monthly benefit for this household are both 3.9 standard deviations above the mean estimates for this subgroup. Furthermore there is a gap between $12.5 per month and $25.0 per month in which no households are represented (Table 6). This could be indicative of a real phenomenon within this subgroup that leads to a bifurcation in household monthly fuel expenditure; something that could be demonstrated by repeating the sampling methodology with a higher sample size. However, a more likely explanation is that the small sample size (n=17) is insufficient to properly capture the true shape of the distribution, which would include households that have monthly fuel expenditures between $12.5 and $25.0 per month. This would lead to a distribution similar to that of the subgroup that buys all fuelwood. In the absence of compelling evidence suggesting otherwise, I opted to leave the outlier in and analyze the subsample without modifications.

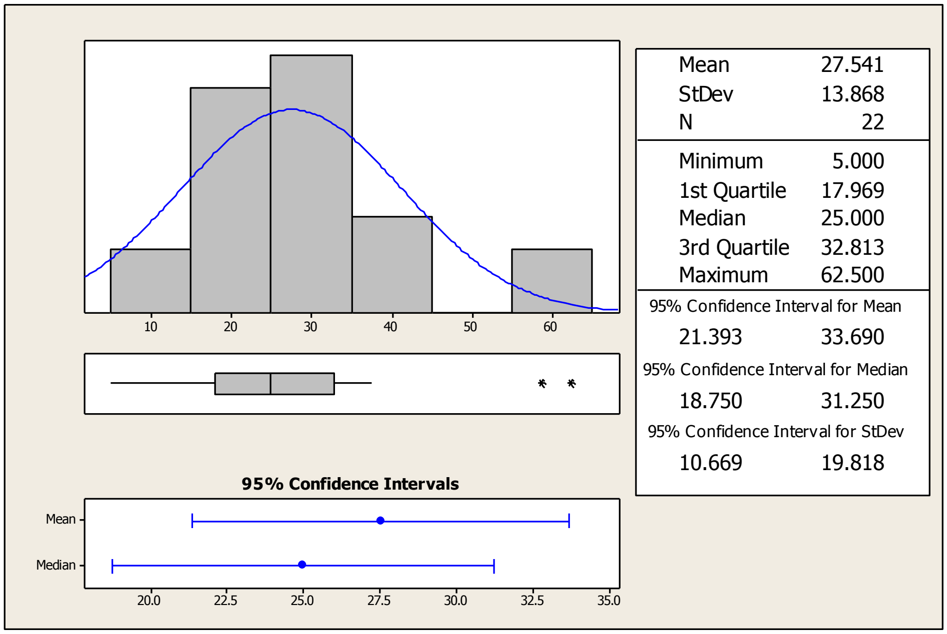

Figure 31: Summary statistics for monthly fuel expenditure in dollars for households that purchase all their fuelwood.

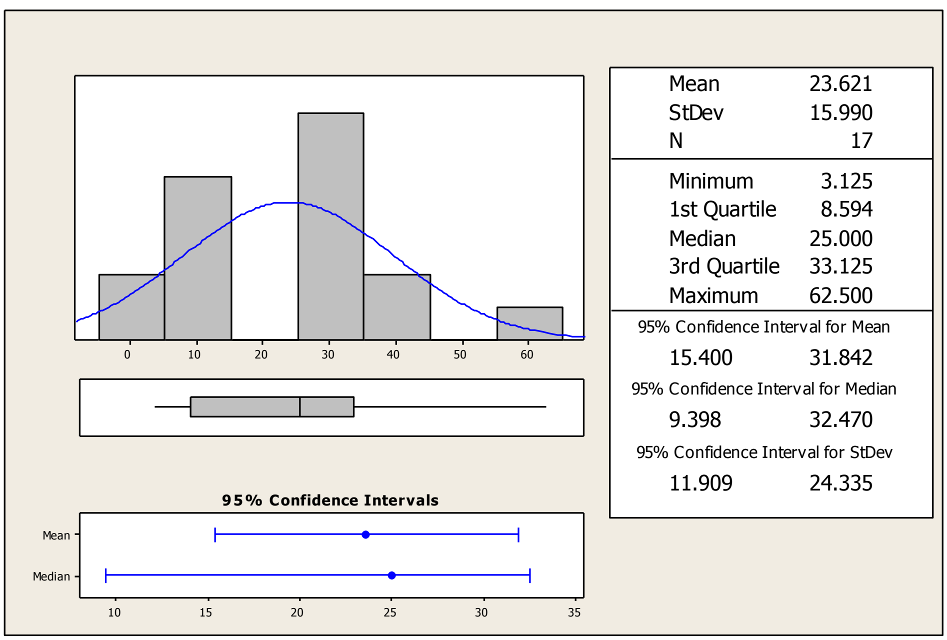

Figure 32: Summary statistics for monthly fuel expenditure in dollars for households that purchase and collect their fuelwood.

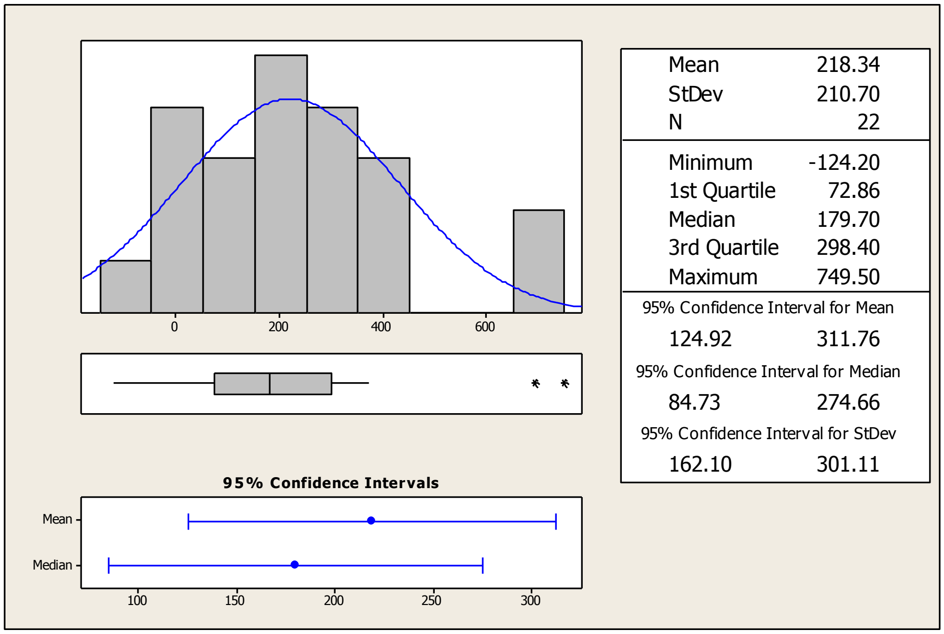

Figure 33: Summary statistics of NPV of stove over 5 year lifetime in dollars for households that purchase all their fuelwood.

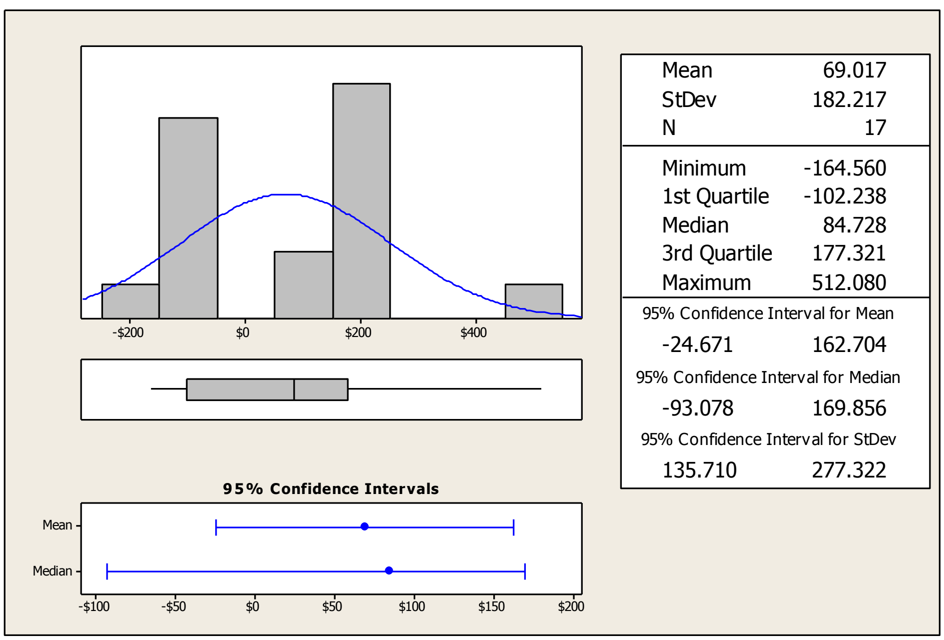

Figure 34: Summary statistics of NPV of stove over 5 year lifetime in dollars for households that purchase and collect their fuelwood.

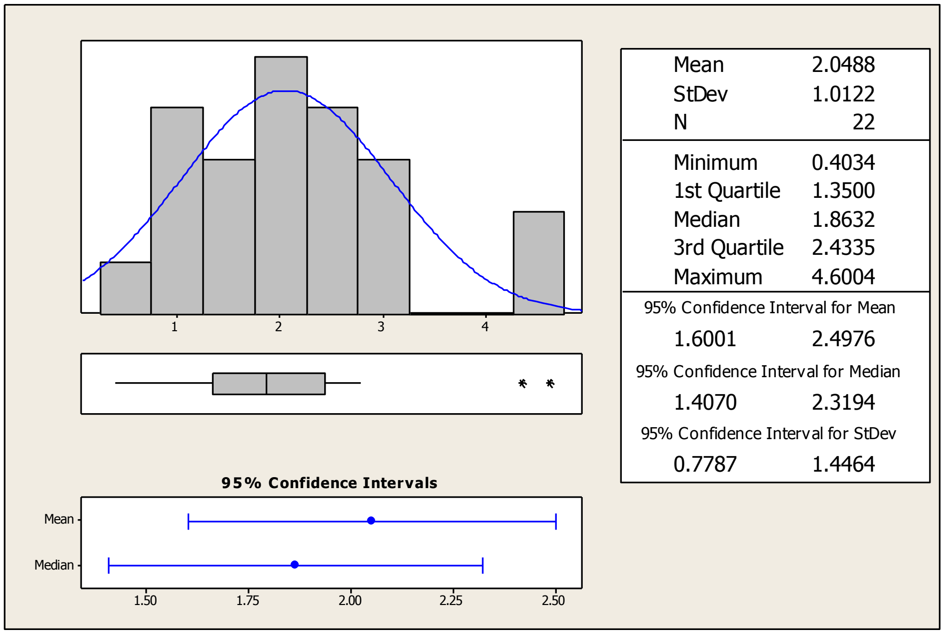

Figure 35: Summary statistics of benefit to cost ratio of stove for households that purchase all their fuelwood.

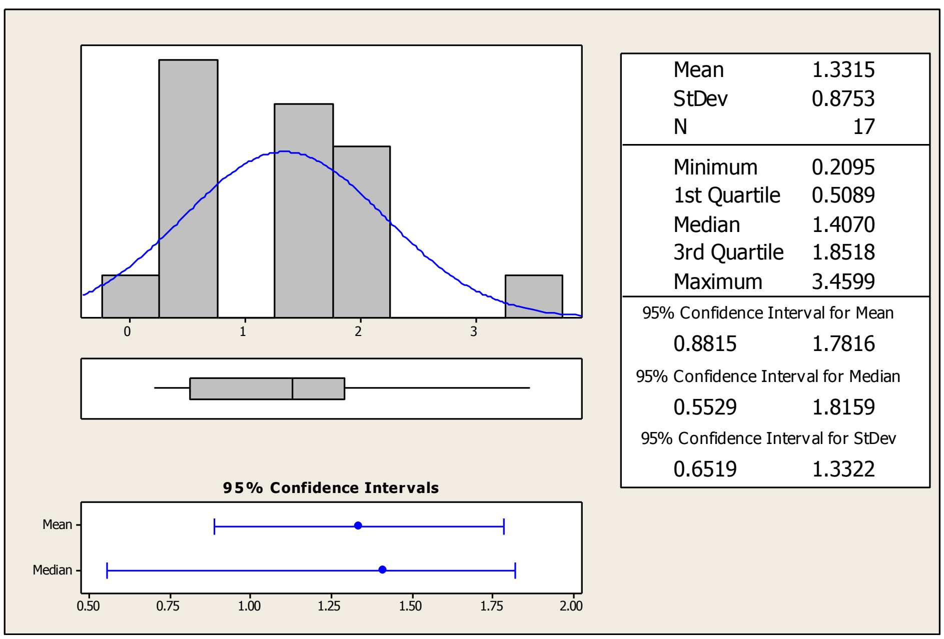

Figure 36: Summary statistics of benefit to cost ratio of stove for households that purchase and collect their fuelwood.

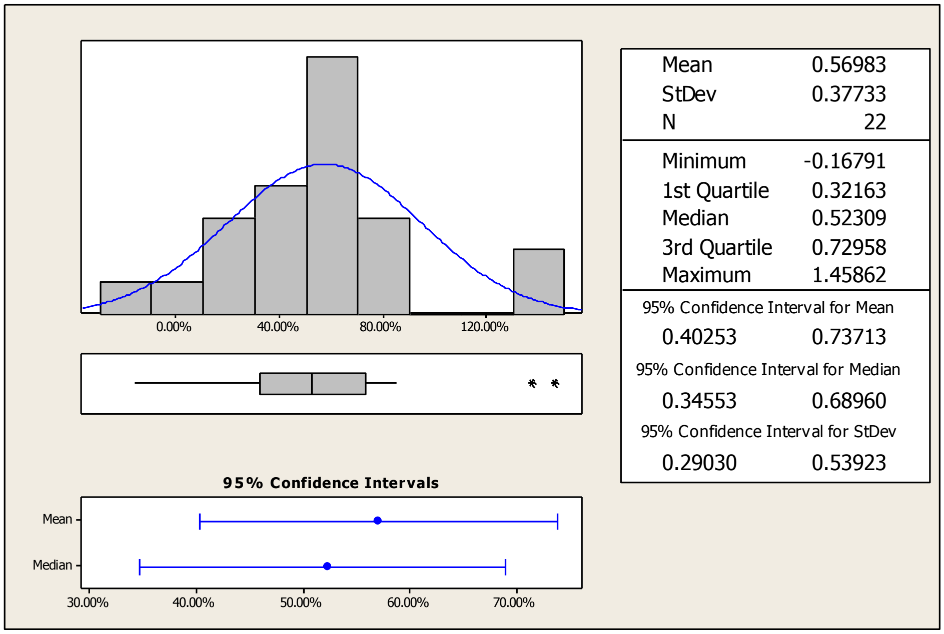

Figure 37: Summary statistics of internal rate of return of stove purchase for households that purchase all their fuelwood.

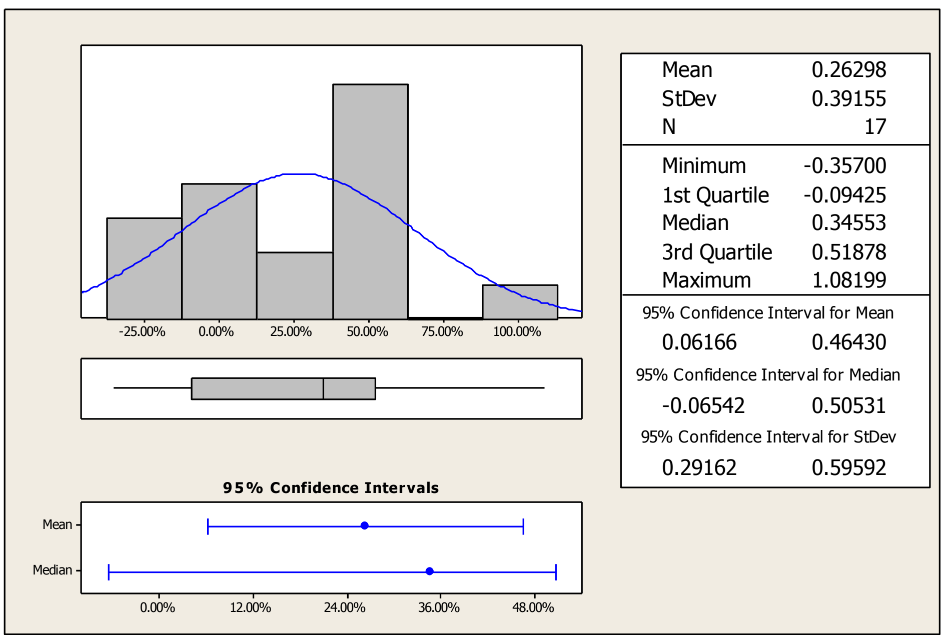

Figure 38: Summary statistics of internal rate of return of stove purchase for households that purchase and collect their fuelwood.

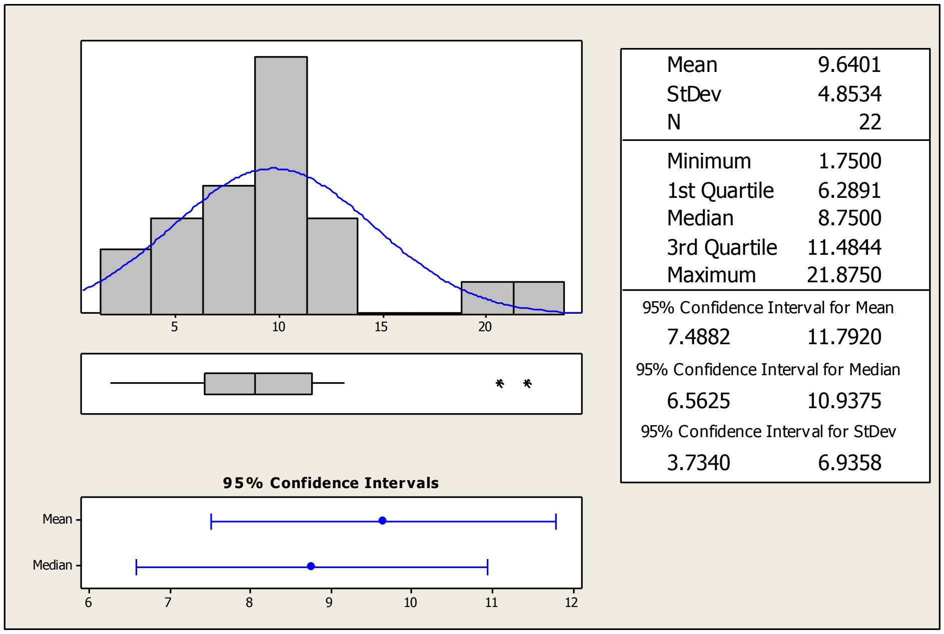

Figure 39: Summary statistics of monthly financial benefit from investment in stove for households that purchase all their fuelwood.

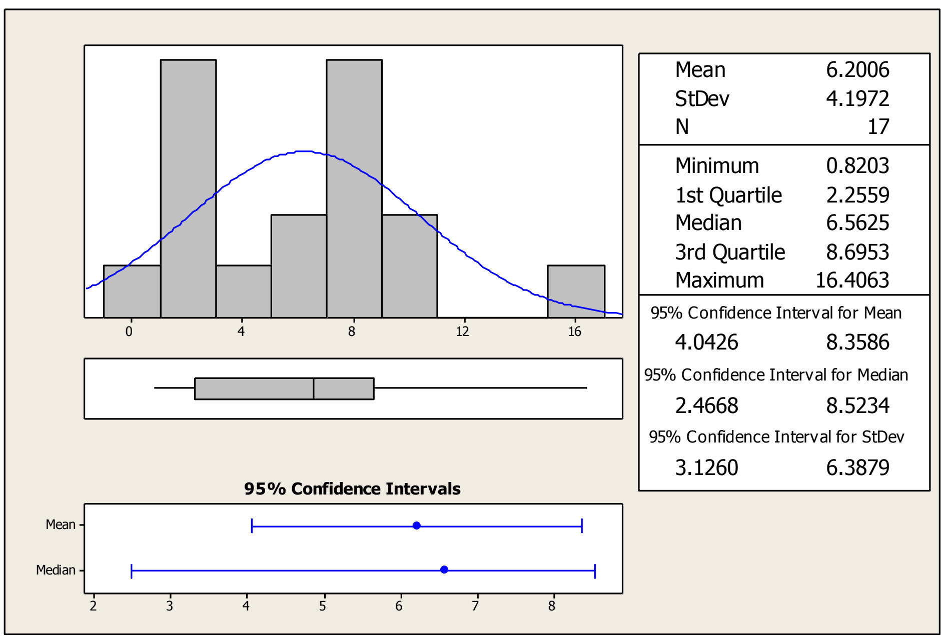

Figure 40: Summary statistics of monthly financial benefit from investment in stove for households that purchase and collect their fuelwood.

6.1 Market demand analysis: sensitivity of parameters

In this section I will present a detailed sensitivity analysis. The intention of this section is to demonstrate the sensitivity of the results to incremental changes in input parameters. Reasonable changes in all key input parameters (monthly fuel expenditure, fuel savings, etc.) are plotted with each economic metric to demonstrate their relationship visually. I present these plots only for households that purchase all fuelwood because the relative sensitivity of output metrics to changes in input metrics is very similar for both groups. As expected, incremental improvements in ICS performance or cost related parameters (fuel savings, stove lifetime, stove capital cost), result in improved economic metrics. Incremental increases in parameters related to fuelwood supply and consumption (monthly fuel expenditure, fuel escalation rate) generally also result in improved economic metrics. Higher real discount rates negatively affect economic metrics. In the next chapter I will discuss the significance of these results and how they can provide critical information for the key stakeholders.

6.1.1 Fuel savings

A 10% increase in fuel saving from the baseline of 35% to 45%, results in a $119 (57%) increase in NPV (Figure 41), a 21% real (36% relative) increase in IRR (Figure 42), a 0.4 (22%) year decrease in time to payback (Figure 43), and a 0.57 (29%) increase in benefit cost ratio (Figure 44).

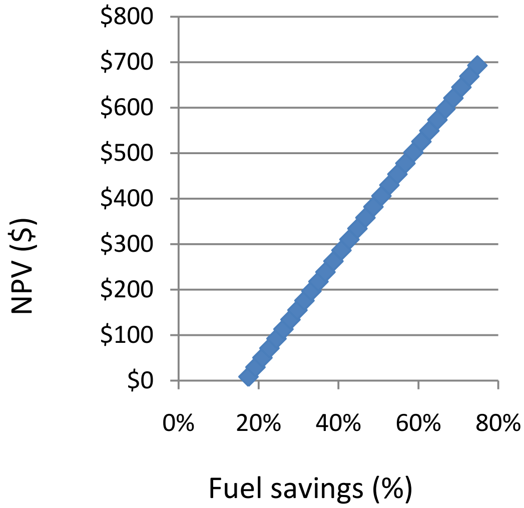

Figure 41: Sensitivity plot of net present value versus fuel savings percentage.

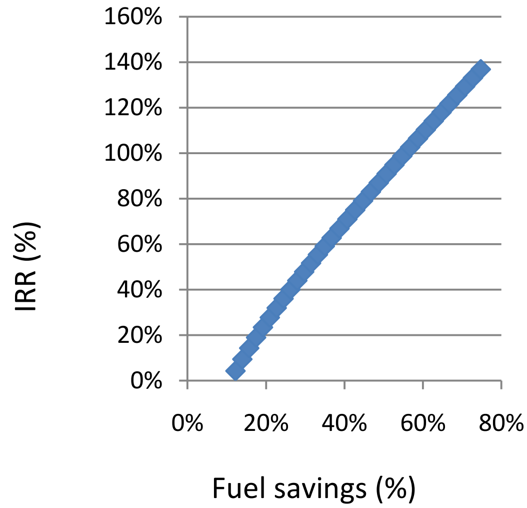

Figure 42: Sensitivity plot of internal rate of return percentage versus fuel savings percentage.

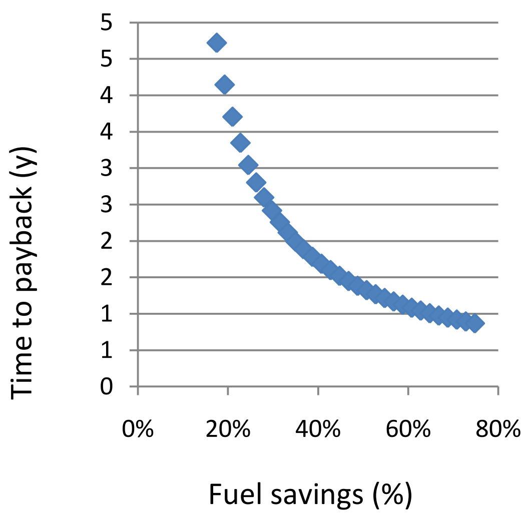

Figure 43: Sensitivity plot of time to payback in years versus fuel savings percentage.

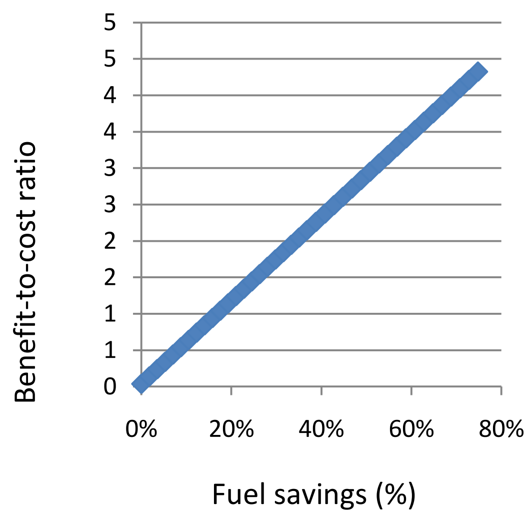

Figure 44: Sensitivity plot of benefit-to-cost ratio versus fuel savings in percent.

6.1.2 Monthly fuel expenditure

Increasing monthly fuel expenditure by one standard deviation ($16) from the baseline of $27.5 to $43.5 results in a $243 (116%) increase in NPV (Figure 45), a 41% real (71% relative) increase in IRR (Figure 46), a 0.6 (37%) year decrease in time to payback (Figure 47), and a 1.2 (58%) increase in benefit cost ratio (Figure 48). On the other hand, decreasing the monthly fuel expenditure by one standard deviation below the baseline to $11 results in a $243 (116%) decrease in NPV (Figure 45), a 48% real (84% relative) decrease in IRR (Figure 46), a 2.3 (143%) year increase in time to payback (Figure 47), and a 1.2 (58%) decrease in benefit cost ratio (Figure 48). While NPV and benefit cost ratio move symmetrically at one standard deviation below and above the average, IRR and time to payback do not.

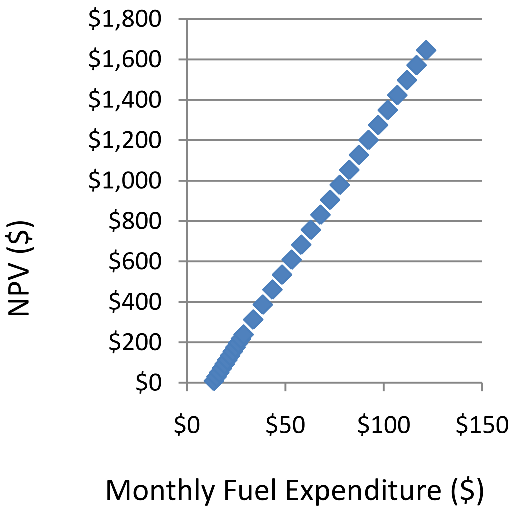

Figure 45: Sensitivity plot of net present value in dollars versus monthly fuel expenditure in dollars.

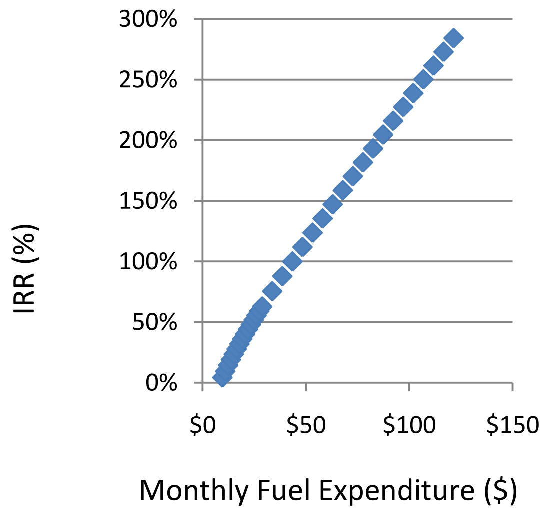

Figure 46: Sensitivity plot of internal rate of return in percentage versus monthly fuel expenditure in dollars.

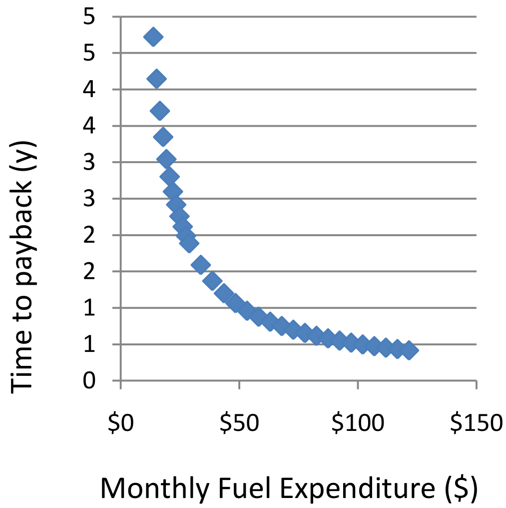

Figure 47: Sensitivity plot of time to payback in years versus monthly fuel expenditure in dollars.

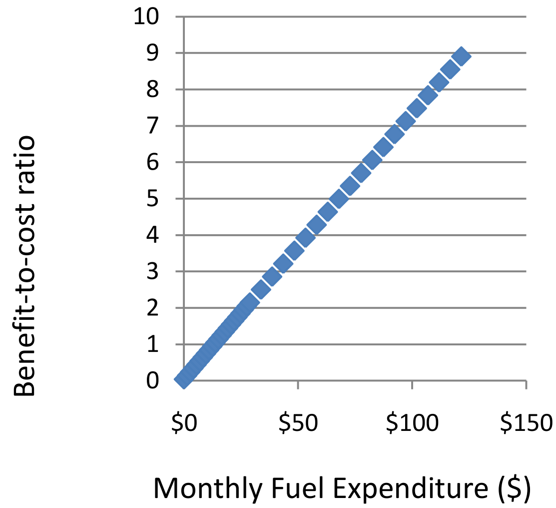

Figure 48: Sensitivity plot of benefit-to-cost ratio versus monthly fuel expenditure in dollars.

6.1.3 Stove lifetime

Increasing the stove lifetime by 2 years, results in a $107 (51%) increase in NPV (Figure 49), a 5% real (9% relative) increase in IRR (Figure 50) and a 0.5 (24%) increase in benefit cost ratio (Figure 52). Time to payback is not affected by an increase in stove lifetime since the baseline payback of 1.8 years is reached much earlier.

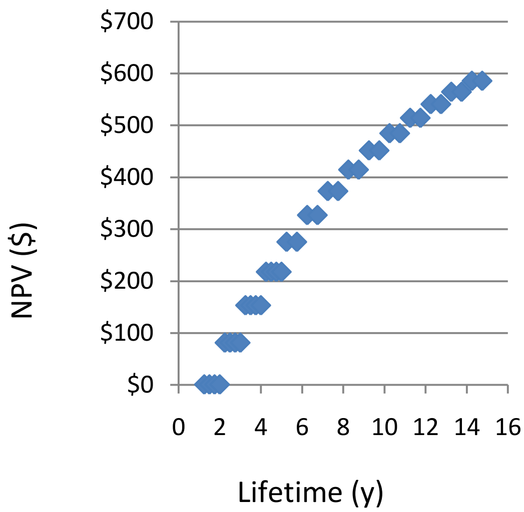

Figure 49: Sensitivity plot of net present value in dollars versus stove lifetime in years

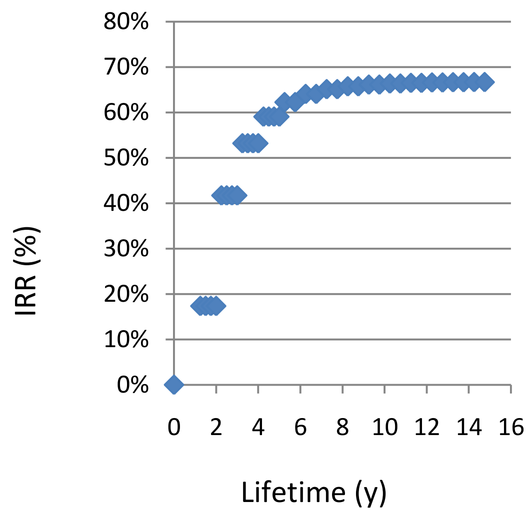

Figure 50: Sensitivity plot of internal rate of return in percent versus stove lifetime in dollars.

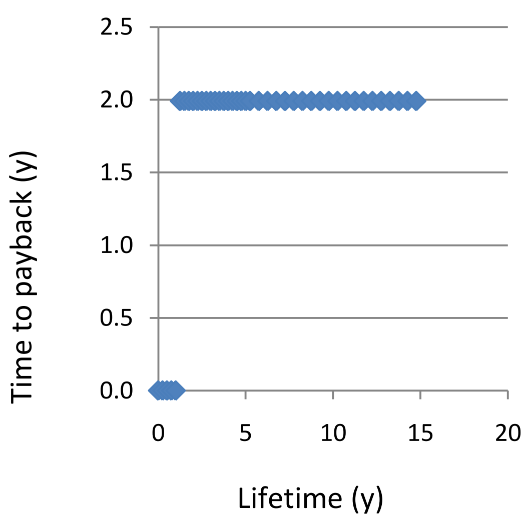

Figure 51: Sensitivity plot of time to payback in years versus monthly fuel expenditure in dollars.

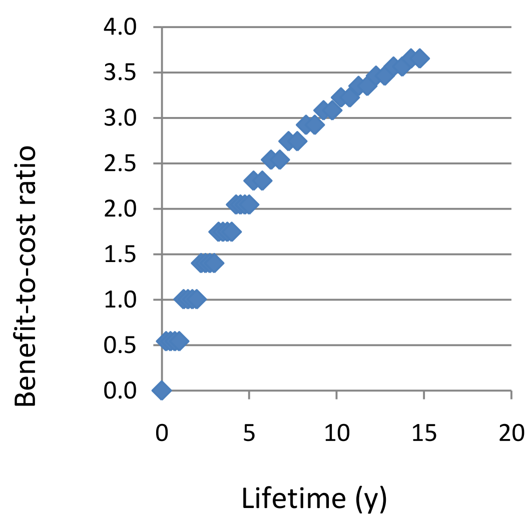

Figure 52: Sensitivity plot of benefit to cost ratio versus stove lifetime in years.

6.1.4 Discount rate

Increasing the real discount rate from the baseline of 17% to 100% results in a \$275 (131%) decrease in NPV (Figure 53) and a 1.3 (67%) decrease in benefit cost ratio (Figure 54). IRR (Figure 55) and time to payback (Figure 56) are not affected by changes in discount rate. Decreasing the real discount rate to 0%, results in a NPV of \$607. This is a \$397 (189%) increase above the baseline estimate. This discount rate leads to a benefit to cost ratio of 3.7, representing a 1.7 (84%) increase from the baseline estimate.

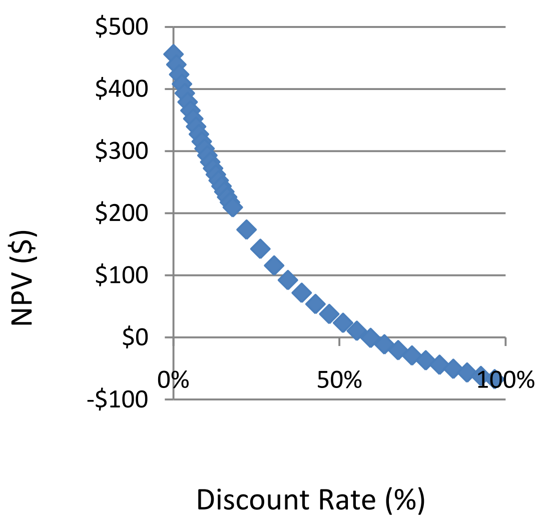

Figure 53: Sensitivity plot of net present value in dollars versus discount rate in percent.

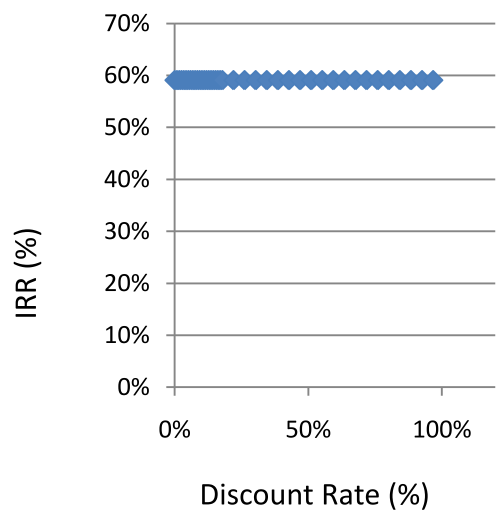

Figure 54: Sensitivity plot of internal rate of return in percent versus discount rate in percent.

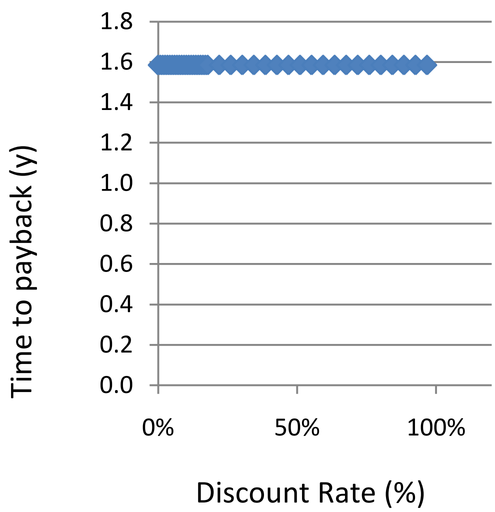

Figure 55: Sensitivity plot of time to payback in years versus discount rate in percent.

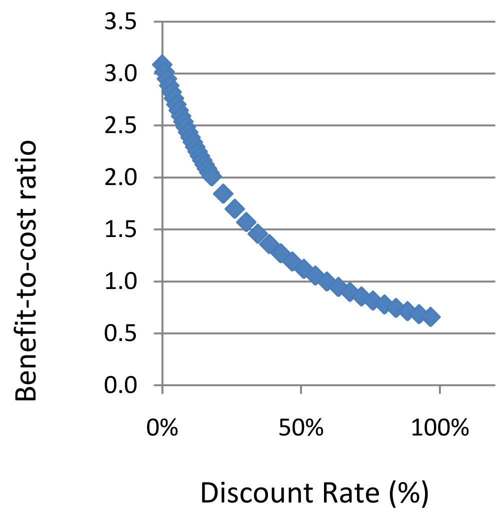

Figure 56: Sensitivity plot of benefit to cost ratio versus discount rate in percent.

6.1.5 Capital cost

Decreasing the stove capital cost by 25% from \$189 to \$142 results in a \$47 (23%) increase in NPV (Figure 57), 23% real (40% relative) increase in IRR (Figure 58), a 0.4 (24%) year decrease in time to payback (Figure 59), and a 0.6 (29%) increase in benefit cost ratio (Figure 60).

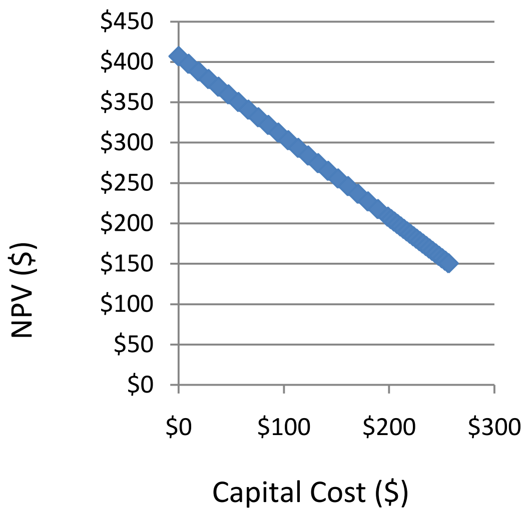

Figure 57: Sensitivity plot of net present value in dollars versus capital cost in dollars.

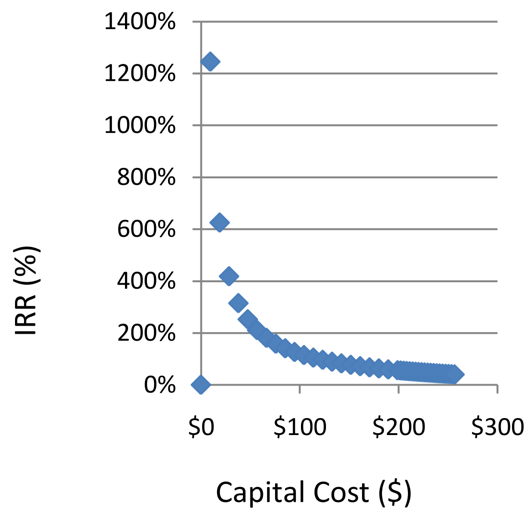

Figure 58: Sensitivity plot of internal rate of return in percent versus capital cost in dollars.

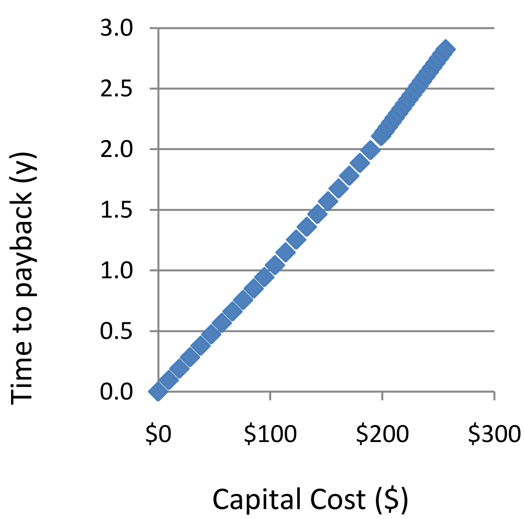

Figure 59: Sensitivity plot of time to payback in years versus capital cost in dollars.

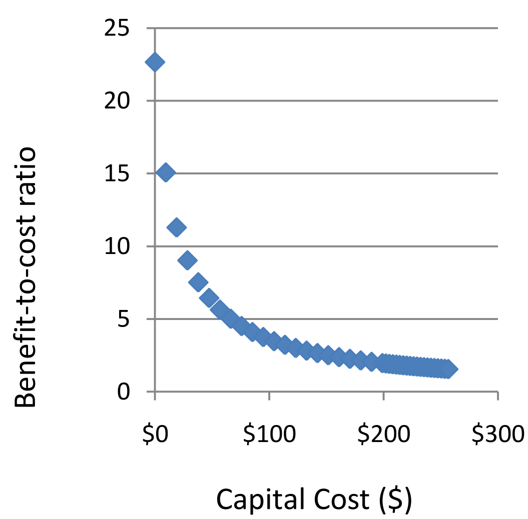

Figure 60: Sensitivity plot of benefit to cost ratio versus capital cost in dollars.

6.1.6 Fuel escalation rate

It is possible that fuel escalation rates will increase in years to come as forest resources continue to be depleted. An increase in fuel escalation rate from 4.6% to 8%, results in a $43 (13%) increase in NPV (Figure 61), a 4% real (7% relative) increase in IRR (Figure 62), a 0.21 (8%) year decrease in time to payback (Figure 63) and a 0.21 increase (8%) in benefit cost ratio (Figure 64).

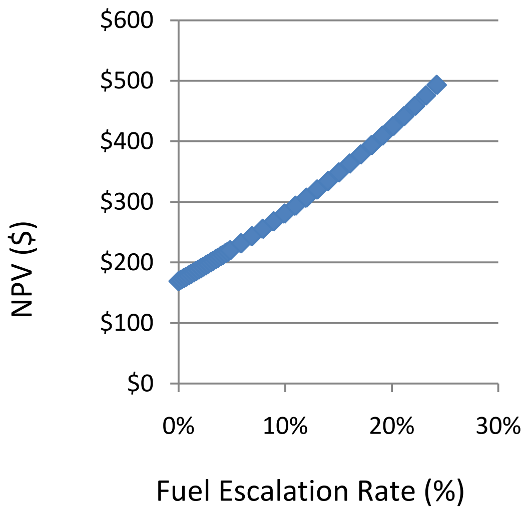

Figure 61: Sensitivity plot of net present value in dollars versus fuel escalation rate in percent.

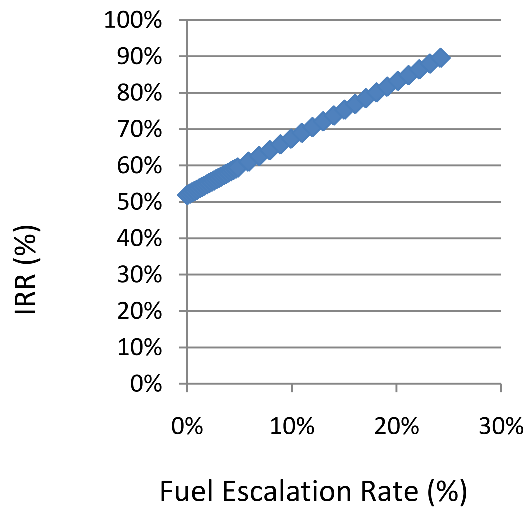

Figure 62: Sensitivity plot of internal rate of return in percent versus fuel escalation rate in percent.

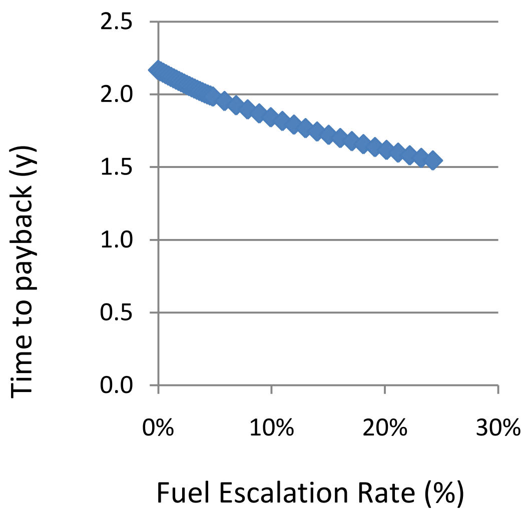

Figure 63: Sensitivity plot of time to payback in years versus fuel escalation rate.

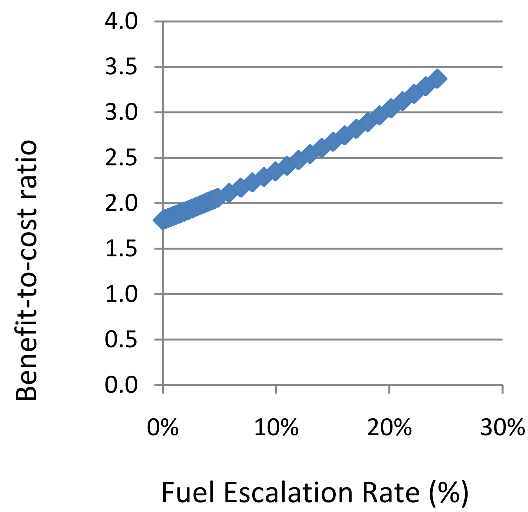

Figure 64: Sensitivity plot of benefit to cost ratio versus fuel escalation rate in percent.

6.1.7 Carbon offset value

This sensitivity analysis of carbon offset value assumes a conservative abatement rate of 2.0 MT of CO_2e per stove per year, about half the value of current estimates from successful cookstove interventions in neighboring Mexico (Johnson, et al. 2010) and assumes that all benefits generated from cookstoves are returned to the household. Including a carbon offset value of $10 per year in the analysis while all other baseline parameters remain unchanged, results in an $20 (5.9%) increase in NPV (Figure 65), a 2.8% real (4.7% relative) increase in IRR (Figure 66), a 0.06 (4.0%) year decrease in time to payback (Figure 67) and a 0.09 (3.6%) increase in benefit to cost ratio (Figure 68) when compared to the baseline analysis. Increasing the value of the carbon offset from $10 to $20 results in similar additional benefits with a $20 (5.6%) increase in NPV (Figure 65), a 2.8% real (4.5% relative) increase in IRR (Figure 66), a 0.06 (3.8%) year decrease in time to payback (Figure 67) and a 0.09 (3.5%) increase in benefit to cost ratio (Figure 68).

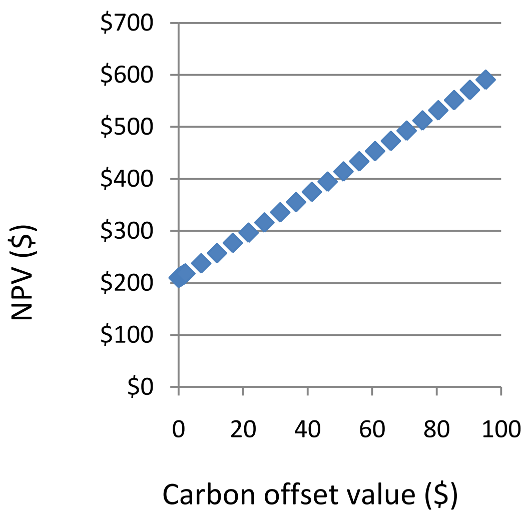

Figure 65: Sensitivity plot of net present value in dollars versus carbon offset value in dollars.

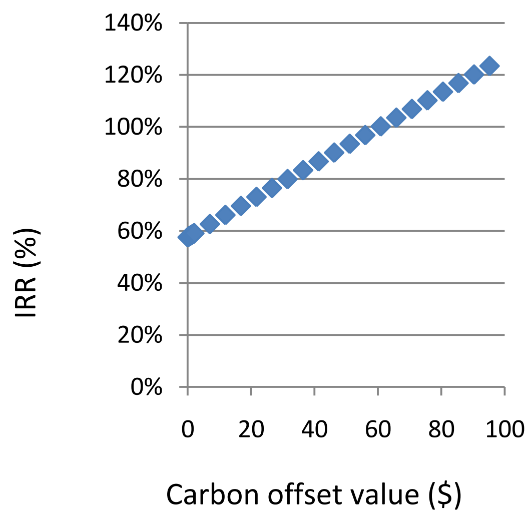

Figure 66: Sensitivity plot of internal rate of return in percent versus carbon offset value in dollars.

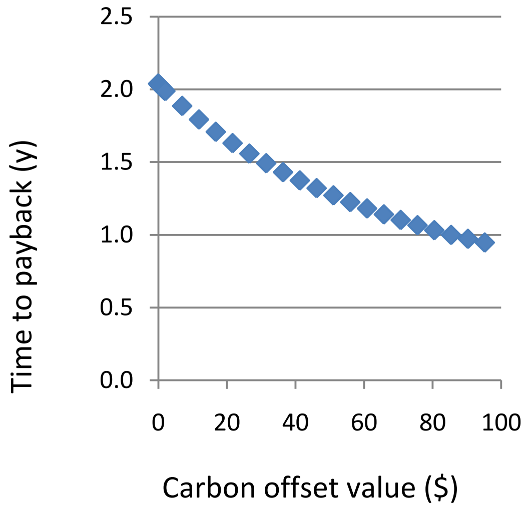

Figure 67: Sensitivity plot of time to payback in years versus carbon offset value in dollars.

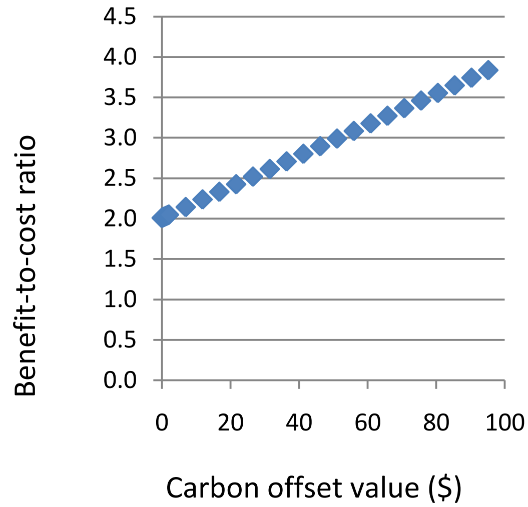

Figure 68: Sensitivity plot of benefit to cost ratio versus carbon offset value in dollars.

6.1.8 Fuel savings multiplier

The fraction of fuelwood savings that displaces purchased fuelwood rather than collected, is the parameter referred to as the fuel savings multiplier. Increasing this parameter value from the baseline value of 75% to 100% results in a $118 (83%) increase in NPV (Figure 69), a 17% real (56% relative) increase in IRR (Figure 70), a 0.7 year decrease in time to payback (Figure 71), and a 0.6 (33%) increase in benefit cost ratio (Figure 72).

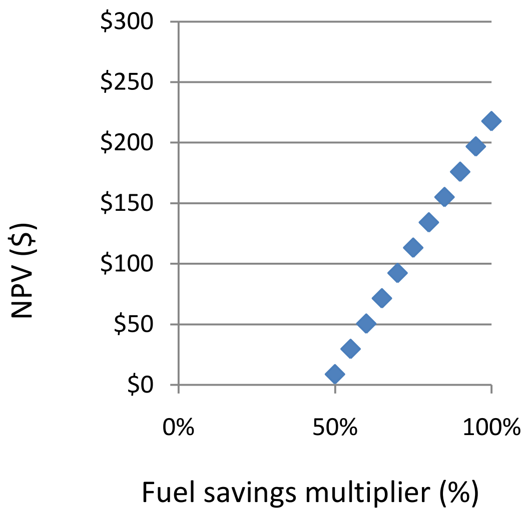

Figure 69: Sensitivity plot of net present value in dollars versus fuel savings multiplier in percent.

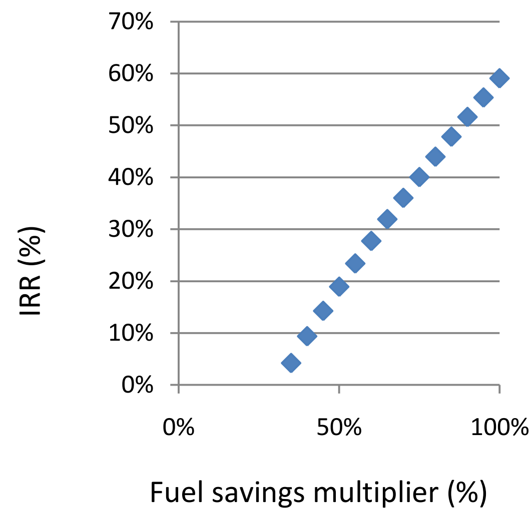

Figure 70: Sensitivity plot of internal rate of return in percent versus fuel savings multiplier in percent.

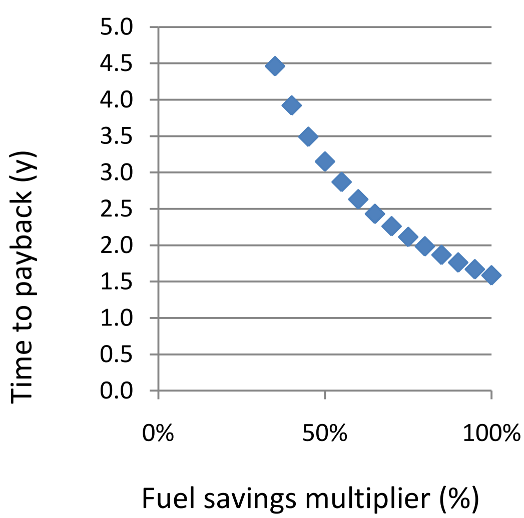

Figure 71: Sensitivity plot of time to payback in years versus fuel savings multiplier in percent.

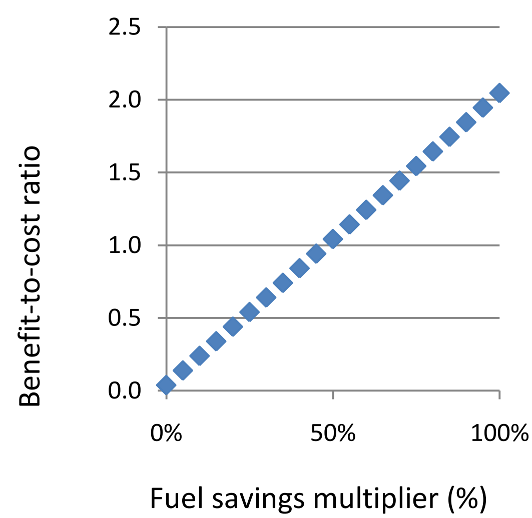

Figure 72: Sensitivity plot of benefit to cost ratio versus fuel savings multiplier in percent.

7 DISCUSSION

The results of these market demand and financial feasibility analyses and associated sensitivity analyses provide market intelligence that can inform key stakeholders in the cookstove market sector including individual households, micro-financing institutions, marketing programs, and manufacturers. In this section I discuss these lessons and their relevance to each stakeholder group. Through this discussion I hope to demonstrate the power of this methodology towards filling in critical gaps in market intelligence, and how by filling those gaps certain market failures are alleviated.

7.1 Critical parameters

Organizations that are interested in estimating total market demand in their region of operation need to conduct a random household survey similar to the one I demonstrated in this thesis. Information needs to be collected around all of the input parameters that are used in the Cookstove Calculator. However, some variables exert more influence on the results than others and therefore carry more weight in the analysis. The calculator has the functionality to allow organizations to conduct sensitivity analyses on all input parameters with the click of a button (see Section 6.1, Market demand analysis: sensitivity of parameters). While each analysis will be distinct for the particular cookstove product and population, some parameters are more critical than others for accurately estimating financial feasibility and market demand. Organizations who implement these methods should take care to acquire accurate estimates for the parameters that are the most influential, particularly monthly fuel expenditure and fuel savings.

Monthly fuel expenditure determines the total monthly costs that can be offset by an ICS. It is also one of the parameters that have the highest variability within our Quetzaltenango survey (see Section 4.4.4). In the absence of reliable estimates of this parameter, financial feasibility and market demand cannot be accurately estimated. Fuel savings is another parameter that strongly influences the outcome of the analysis. In the Quetzaltenango case study we made an educated guess that the Doña Dora would generate a fuel savings of 35%. We can see from the sensitivity plots of fuel savings versus NPV that reasonable changes in fuel savings leads to large changes in NPV. This demonstrates that small changes in the performance of a given ICS will lead to large differences in results and conclusions. Therefore, when conducting this analysis, it is crucial not to overestimate the fuel savings for the ICS product. Accuracy of financial feasibility and market demand analyses is highly dependent on having accurate estimates of monthly fuel expenditure and fuel savings.

7.2 Lessons for households

If we assume that our sample is representative of the entire population of rural households in Quetzaltenango, we can infer that the Doña Dora ICS is a net positive investment for roughly 40,000 households (95% CI [29,000, 51,000]). Nevertheless, these estimates do not have much predictive power to an individual household within the population. Individual households are each unique; in order to understand the financial feasibility of the potential investment in an ICS, or any other renewable energy or energy efficiency projects for that matter, it is necessary to complete an individual household analysis for each situation.

Within the observed range of monthly fuel expenditures there is considerable variability in estimates of financial feasibility. The standard deviation of monthly fuel expenditure in Group 1 is $16. Decreasing monthly fuel expenditure by one standard deviation below the mean, and leaving all other parameters unchanged, leads to a significantly different scenario including a $243 (116%) decrease in NPV (Figure 45), a 48% real (84% relative) decrease in IRR (Figure 46), a 2.3 year (143%) increase in time to payback (Figure 47), and a 1.2 (58%) decrease in benefit cost ratio (Figure 48). Similarly, increasing monthly fuel expenditure by one standard deviation above the mean yields a $243 (116%) increase in NPV (Figure 45), a 41% real (71% relative) increase in IRR (Figure 46), a 0.6 year (37%) decrease in time to payback (Figure 47), and a 1.2 (58%) increase in benefit cost ratio (Figure 48). In other words, estimates of NPV, IRR, time to payback, and benefit cost ratio for rural Quetzaltenango residents who purchase all of their fuelwood, exhibit considerable variance across reasonable changes in monthly fuel expenditure. This bolsters the argument that individual household analyses are essential.

The tools and methodology that I have presented in this thesis are designed to facilitate rapid financial feasibility analyses for individual households. The procedure includes a 10 minute household survey followed by a 5 minute analysis using the

Cookstove Calculator. These tools can be incorporated into a marketing program as an initial step to identify potential customers. From the perspective of the average rural household, these tools and methods are largely inaccessible because it requires the use of technology (spreadsheets and computers) that is most likely unfamiliar and unavailable to the average consumer at the base of the pyramid. The methodology and analyses must be executed by trained representatives from micro-financing institutions or direct marketing programs.

In the absence of an individualized household analysis, there is no adequate information about household financial benefits. As I discussed previously, this may cause market failure because individuals either forgo making a purchase that would have benefited their household, or proceed to make a purchase that will result in sub-optimal outcomes for their household. Financial feasibility analysis results can be presented to individual households in language that is understandable. If this is done, a key barrier to a well-functioning competitive market is eliminated. Specifically, information will be available regarding benefits that consumers will realize from the procurement of a good or service.

7.3 Lessons for micro-financing institutions

Replacement of traditional cooking stoves with a Doña Dora ICS can result in substantial economic benefits for the average rural household. However, with the majority of households reporting total household monthly incomes of less than $125, the up-front cost is a significant barrier. Xelateco is addressing this barrier by investigating micro-financing mechanisms which can spread up-front cost over time. A favorable micro-financing scheme is imperative to making the Doña Dora accessible to the average household. For the 27% of the population that reportedly collects all fuelwood, the economics do not make sense unless these households can substitute remunerated activities for the time they save on collecting fuelwood.

The methodology and tools presented in this thesis can benefit micro-financing institutions (MFIs) that are considering financing services for ICSs. The application of these methods and market intelligence that they generate is not limited to Quetzaltenango or even Guatemala. They are designed to facilitate MFIs to conduct rapid financial feasibility analyses for individual households and market demand analyses in any region of the world for any ICS product.

As is the case for any lending institution charged with providing financing services for any investment project of any scale, MFIs need to be able to generate this information at the level of the individual family and household. These analyses provide MFIs with critical information that is unique to each household's individual situation with respect to their potential investment in an ICS.

For example, information about monthly benefits that will be generated from the investment is important in order to understand the household's ability to pay down the loan. This information can be used by the MFI to design financing packages and customize loan parameters to service unique situations. The primary loan parameter that can be customized to adjust monthly payments is the financing term - the number of months over which the loan is amortized.

The Cookstove Calculator allows the MFI to adjust loan parameters such as down payment, interest rate, and financing term in order to match estimated monthly benefit to monthly payments. In the case that the MFI is unable to match monthly benefit to monthly payment, because of institutional policies or financial limitations on loan terms, the Cookstove Calculator can be used to estimate subsidy level that will be needed to fill in the gap.

Figure 73 and Figure 74 are screen shots of the Cookstove Calculator, each representing a baseline for households that purchase all fuelwood with the Financing Option on. In the two scenarios all input parameters are held constant while the loan term is adjusted from 12 months to 24 months. By setting the loan term at 12 months (Figure 73), monthly payments are approximately $14.48 while the monthly benefits are estimated to be $9.63. In other words, this financing scheme would require the household to come up with an additional $4.85 each month beyond the estimated monthly benefits. This may be difficult or impossible for the average consumer. By setting the loan term at 24 months (Figure 74), monthly payments are approximately $8.10 while the monthly benefits remain unchanged at $9.63. This demonstrates that for average household in this subgroup, financing packages that are amortized over 24 months are perhaps more accessible than those amortized over 12 months. In fact, the threshold for months of amortization of a loan, at which the estimated monthly benefit and monthly payment are equal, is approximately 20 months. For households that purchase all fuelwood, amortizing a loan over fewer than 20 months results in monthly payments exceeding the estimate of monthly benefit.

Input Parameter	Value
Cookstove Purchase Year	2011
Cookstove Lifetime (years)	7
Cookstove Capital Cost (GTQ/stove)	1,525
Discount Rate (%)	7.00%
Fuel Source Method	b
Monthly Fuel Expenditure (GTQ/mo)	220
Fuel Savings (%)	35%
Fuel Savings Multiplier (%)	75%
Fuel Escalation Rate (%)	5.30%
Currency Exchange (GTQ/US$)	8
O&M Cost 1 (GTQ/yr)	15
O&M Cost 2 (GTQ/2-yr)	65

Financing Option	
Financing Option (yes/no)	yes
Financing Term (months)	12
Annual Interest Rate (%)	24.00%
Down Payment (GTQ)	300
Payments Due	0

Results		
Output Metric	**Value**	**$US**
Fuel Source Method	buy	buy
NPV (ROI in GTQ)	4,240	$530
Time to Payback (years)	1.8	1.8
Discounted Time to Payback	1.9	1.9
Benefit/Cost Ratio	3.3	3.3
IRR	97.7%	97.7%
Monthly Payment (GTQ)	115.84	$14.48
Monthly Benefit	77	$9.63

Figure 73: Cookstove Calculator screen shots of Input Parameters, Financing Option and Results. Financing term is set at 12 months, resulting in monthly payments of $14.48.

Input Parameter	Value
Cookstove Purchase Year	2011
Cookstove Lifetime (years)	7
Cookstove Capital Cost (GTQ/stove)	1,525
Discount Rate (%)	7.00%
Fuel Source Method	b
Monthly Fuel Expenditure (GTQ/mo)	220
Fuel Savings (%)	35%
Fuel Savings Multiplier (%)	75%
Fuel Escalation Rate (%)	5.30%
Currency Exchange (GTQ/US$)	8
O&M Cost 1 (GTQ/yr)	15
O&M Cost 2 (GTQ/2-yr)	65

Financing Option	
Financing Option (yes/no)	yes
Financing Term (months)	24
Annual Interest Rate (%)	24.00%
Down Payment (GTQ)	300
Payments Due	0

	Results	
Output Metric	Value	$US
Fuel Source Method	buy	buy
NPV (ROI in GTQ)	4,134	$517
Time to Payback (years)	1.7	1.7
Discounted Time to Payback	1.9	1.9
Benefit/Cost Ratio	3.1	3.1
IRR	120.1%	120.1%
Monthly Payment (GTQ)	64.77	$8.10
Monthly Benefit	77	$9.63

Figure 74: Cookstove Calculator screen shots of Input Parameters, Financing Option and Results. Financing term is set at 24 months, resulting in monthly payments of $8.10.

These methods allow MFIs to estimate total market demand in their region of activity. Estimates of the number of loan packages that are needed in a specific region are useful for MFIs when making decisions regarding allocation of loan resources. In the case of the Doña Dora in rural Quetzaltenango, the economic metrics suggest that for approximately 40,000 households, the investment provides a positive return.

MFIs may have different thresholds for economic metric criteria for determining what is economically viable. For example an MFI may wish to quantify the total number of households that have a time to payback of less than one year in order that the loan terms can be met within 12 months without additional financial burden on households. This information can be generated using the same methodology presented in this thesis, by simply changing the definition of financially viable to include a time to payback of less than one year.

We can see from the case study that there are several pathways to achieve a time to payback of less than one year for the average households in our survey. Lowering the upfront capital cost of the stove is one way. For example, decreasing the upfront capital cost of the stove by $76 (40%) from the baseline value for the subgroup that buys all fuelwood and $111 (58%) from the baseline for the subgroup that buys and collects fuelwood, yields times to payback of 12 months for each group (Figure 59). Another pathway for achieving the same threshold for time to payback is through increased fuel savings above the baseline value. For example, if the Doña Dora can provide fuel savings of 53% for the subgroup that buys all fuelwood and 82% for the subgroup that buys and collects fuelwood, times to payback are estimated to be 12 months (Figure 43). Fuel savings of 53% are a reasonable benchmark that has been achieved by other ICS programs; however 82% might be beyond reach (Masera, et al. 2005). For the subgroup of households that buy and collect fuelwood to realize times to payback of 12 months it may be necessary to provide gap financing to reduce the upfront cost.

7.4 Lessons for stove manufacturers

Manufacturers of ICSs can benefit from having access to the information that is generated in this methodology. Specifically, it will help guide them when prioritizing investments in product design and modification. I will use a theoretical example to demonstrate how this methodology can be implemented. Imagine that Xelateco is considering whether to improve their design with lower gauge (e.g. thicker) steel cladding. They estimate that the modification will add 20% to the upfront cost while increasing the lifetime by 2 years. By changing the baseline parameters to reflect these new input parameters we can easily compare the relative financial feasibility of the two options. Figure 75 represents a baseline analysis for the subgroup that buys all fuelwood with a NPV of $339, time to payback of 1.6 years, benefit to cost ratio of 2.6 and IRR of 58.9%. Figure 76 represents the proposed modified stove with higher quality steel cladding, a 20% increase in upfront cost and a 7 year lifetime. The analysis suggests that modification will result in a $162 (48%) increase in NPV and a 0.34 (13%) increase in benefit to cost ratio. However, it will also lead to a 0.32 year (20%) increase in time to payback and 6% real decrease (11% relative) in IRR. This information can be used by the manufacturer to decide whether this modification makes sense within the context of their decision making criteria.

Input Parameter	Value
Cookstove Purchase Year	2011
Cookstove Lifetime (years)	5
Cookstove Capital Cost (GTQ/stove)	1,525
Discount Rate (%)	7.00%
Fuel Source Method	b
Monthly Fuel Expenditure (GTQ/mo)	220
Fuel Savings (%)	35%
Fuel Savings Multiplier (%)	75%
Fuel Escalation Rate (%)	5.30%
Currency Exchange (GTQ/US$)	8
O&M Cost 1 (GTQ/yr)	15
O&M Cost 2 (GTQ/2-yr)	65

Results		
Output Metric	**Value**	**$US**
Fuel Source Method	buy	buy
NPV (ROI in GTQ)	2,712	$339
Time to Payback (years)	1.6	1.6
Discounted Time to Payback	1.8	1.8
Benefit/Cost Ratio	2.6	2.6
IRR	58.9%	58.9%
Monthly Payment (GTQ)	0.00	$0.00
Monthly Benefit	77	$9.63

Figure 75: Cookstove Calculator screen shots of Input Parameters and Results (financing option off). All input parameters are set a baseline values for Group 1 yielding NPV of $339, time to payback of 1.6 years, benefit to cost ratio of 2.6 and IRR of 58.9%.

Input Parameter	Value
Cookstove Purchase Year	2011
Cookstove Lifetime (years)	7
Cookstove Capital Cost (GTQ/stove)	1,830
Discount Rate (%)	7.00%
Fuel Source Method	b
Monthly Fuel Expenditure (GTQ/mo)	220
Fuel Savings (%)	35%
Fuel Savings Multiplier (%)	75%
Fuel Escalation Rate (%)	5.30%
Currency Exchange (GTQ/US$)	8
O&M Cost 1 (GTQ/yr)	15
O&M Cost 2 (GTQ/2-yr)	65

	Results	
Output Metric	Value	$US
Fuel Source Method	buy	buy
NPV (ROI in GTQ)	4,009	$501
Time to Payback (years)	1.9	1.9
Discounted Time to Payback	2.1	2.1
Benefit/Cost Ratio	2.9	2.9
IRR	52.7%	52.7%
Monthly Payment (GTQ)	0.00	$0.00
Monthly Benefit	77	$9.63

Figure 76: Cookstove Calculator screen shots of Input Parameters and Results (financing option off). Input baseline value for lifetime is increased to seven years while capital cost is increased by 20% yielding an NPV of $501, time to payback of 1.9 years, benefit to cost ratio of 2.1 and IRR of 52.7%.

7.5 Lessons for stove marketing programs

Stove marketing programs can benefit from employing these methods in two distinct ways. Through the lens of the case study of the Doña Dora ICS in rural Quetzaltenango, I demonstrated both of the methods. The first method is to conduct a random household survey in the region of interest that allows the marketing program to estimate the financial feasibility of the investment for a representative sample of the population. If the analysis and survey are conducted properly, this will result in an estimated total number of households that can theoretically benefit financially from the purchase of an ICS. In the case of the Doña Dora in Quetzaltenango, this resulted in an estimate of roughly 40,000 households for which the investment in the product is estimated to be net positive. In addition, the individual household analysis can be integrated into any marketing program to estimate the financial benefits that will be generated at the household level. This information can be generated fairly rapidly with a brief household survey; the estimates are generated automatically after the parameter values are entered into the Cookstove Calculator. Using similar methods as discussed above, these methods and tools can be used to design unique financing and purchasing packages for each household that is in line with their distinct economic reality. Marketing programs can also use these tools to estimate the quantity and magnitude of subsidies that are needed to meet target levels of market penetration.

7.6 Co-benefits

There are many co-benefits to ICSs that are not easily quantified monetarily including improvements to health and quality of life, and savings in time previously spent collecting fuelwood. These benefits were not included in this analysis. Other studies have addressed including these benefits in their analyses by assigning a nominal monetary value for health impacts and time saved (Garcia-Frapolli, et al., 2010). By including these benefits in the analysis the economic metrics will certainly improve for all groups. Nevertheless there is doubt as to what extent these co-benefits can be translated into real income (Hackett, 2006). Carbon offsets were also excluded from the baseline analyses for the same reason. While cookstove interventions have demonstrated that a significant amount of carbon can be abated with successful programs, the mechanism for distributing the associated financial benefits to individual households is not well established. In my opinion, conservative assumptions are necessary to avoid overestimating the monetary value of co-benefits.

8 CONCLUSION

In this thesis I demonstrated a methodology that is useful for generating market intelligence for improved cookstove products. Through the case study I show how to use these methods to conduct traditional financial feasibility and market demand analyses for cookstove products and how to interpret the results for individual households, micro-financing institutions, marketing programs and manufacturers.

For the average household in our subgroup that represents roughly 31,000 rural Quetzaltenango households that purchase all of their fuelwood, economic results indicate that the Doña Dora ICS is a favorable investment with an average return of $210, time to payback of 1.6 years, benefit to cost ratio of 2.0, an IRR of 58% and a monthly benefit of $9.6. For the average household in our subgroup that represents roughly 23,000 rural Quetzaltenango households that buy and collect their fuelwood, economic results are also positive, with an average return of $61 over a five year lifetime, time to payback of 2.5 years, benefit to cost ratio of 1.3, IRR of 30% and monthly benefit of $6.2. Individual household analyses for the sample indicate that an investment in the Doña Dora is net positive for roughly 47% of the households. If we assume that our sample is representative of the population, then this corresponds to an estimate of total market demand for this demographic of roughly 40,000 households.

Nevertheless, these results do not carry predictive power to the level of the individual household because of the high level of variability in household energy use patterns within the population. This bolsters the need for individual household analyses for each potential consumer. While this process may add new complications, it is necessary in order to accurately predict the real benefits that will be realized by a given household. Fuel savings, capital cost and stove lifetime are the critical stove parameters for affecting financial feasibility. Within the household, monthly fuel expenditure and the fuel savings multiplier are the critical parameters that affect financial feasibility. In the absence of reliable estimates for these parameters, financial feasibility is difficult to predict with certainty. Micro-financing institutions can utilize these tools and methods to conduct rapid financial feasibility assessments that can accurately characterize households' monthly benefit and associated ability to pay back small loans for cookstoves. Cookstove manufacturers can use these methods to guide their engineering and design process in order to build stoves that will maximize benefits within their target populations.

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APPENDIX A. SURVEY DOCUMENTATION

AIDG
Appropriate Infrastructure Development Group

Forma de Consentimiento de Encuesta

Nosotros colaboramos con la Organización No Gubernamental "Grupo de Desarrollo para Infraestructura Apropiada" ubicado en Xela, Quetzaltenango. Esta organización lleva más de 5 años trabajando en el Altiplano Guatemalteco con el objetivo principal de facilitar a la población acceso a los servicios básicos y energía limpia. Actualmente estamos realizando entrevistas en diversas poblaciones del departamento de Quetzaltenango. Todas las preguntas de la encuesta son en relación al tema de la energía en el hogar así como las costumbres de las familias para realizar algunas tareas domésticas.

Su participación en esta entrevista es voluntaria. La entrevista durará aproximadamente una hora de su tiempo. La entrevista no lleva ningún riesgo para Ud. Y su familia. Usted es libre de terminar la entrevista en el momento que lo desee sin ninguna consecuencia. Su nombre y otros datos específicos suyos son completamente confidenciales y no se compartirán con otras personas ni organizaciones.

Considerамos importante hacer de su conocimiento que no contamos con recursos para ofrecerle ningún tipo de compensación por su tiempo. Esperamos que la información que obtengamos con este estudio aumente la base de conocimiento acerca de las necesidades de la gente que vive en el Altiplano Guatemalteco. La información que estamos recabando también será utilizada como parte de un estudio en una tesis de maestría o un artículo publicado en una revista profesional.

Su firma abajo representa su consentimiento para participar en esta encuesta. Muchas gracias!

Firma de entrevistador(a) ____________________________ fecha________________

Firma del entrevistado(a): ____________________________ fecha________________

Figure A1: Survey consent form

...obre el estudio o nuestro trabajo por favor contáctanos en la oficina ...tzaltenango. Tel. 77-683-453.

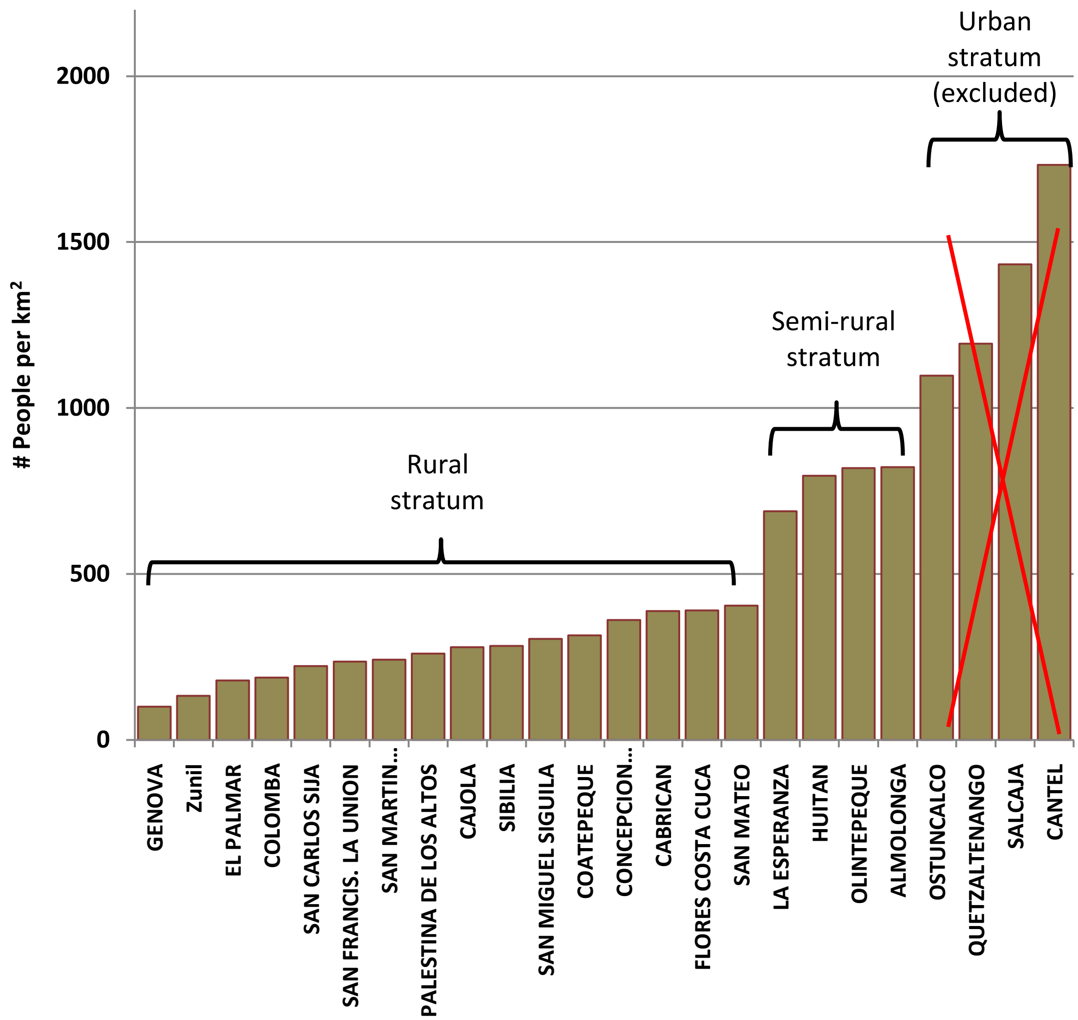

Figure A2: County level population density stata for Quetzaltenango

APPENDIX B. GUATEMALAN WOOD INVENTORY.

Table B1: Total volume, inflation corrected total value, inflation corrected price per unit, and rate of growth in real price per unit from 1980 to 2005.

Year	Total volume of wood (m^3)	Total value (1980 GTQ)	GTQ/m^3	Rate of growth in value per unit from 1980
1980	948,453,433	2,271,003,704	2.4	-
1981	942,020,534	2,104,576,247	2.2	-6.9%
1982	935,581,456	2,066,253,487	2.2	-4.0%
1983	929,165,665	2,015,268,444	2.2	-3.3%
1984	920,328,638	2,262,303,485	2.5	0.7%
1985	911,600,685	2,672,654,078	2.9	4.0%
1986	902,872,957	2,092,488,973	2.3	-0.5%
1987	894,161,653	2,226,277,325	2.5	0.6%
1988	885,435,122	2,276,694,652	2.6	0.9%
1989	876,716,365	2,945,582,602	3.4	3.8%
1990	866,763,038	2,859,896,578	3.3	3.2%
1991	858,195,012	2,983,840,364	3.5	3.4%
1992	845,703,848	3,131,253,345	3.7	3.6%
1993	832,835,957	3,268,443,969	3.9	3.8%
1994	819,994,845	3,405,621,951	4.2	3.9%
1995	807,035,868	3,572,669,933	4.4	4.1%
1996	794139483	3686751943	4.6	4.1%
1997	783,000,686	3,859,851,825	4.9	4.2%
1998	771,564,255	4,053,965,181	5.3	4.4%
1999	760,432,539	4,121,236,168	5.4	4.3%
2000	749,281,145	4,210,027,922	5.6	4.3%
2001	738,369,652	4,324,503,812	5.9	4.3%
2002	727,895,128	4,429,914,359	6.1	4.2%
2003	717,952,351	4,531,079,916	6.3	4.2%
2004	708,324,238	4,884,956,086	6.9	4.4%
2005	698,434,711	5,330,204,767	7.6	4.6%

Source: Instituto de Agricultura, Recursos Naturales y Ambiente (2009)

APPENDIX C. GUATEMALA CONSUMER PRICE INDEX 2000-2010

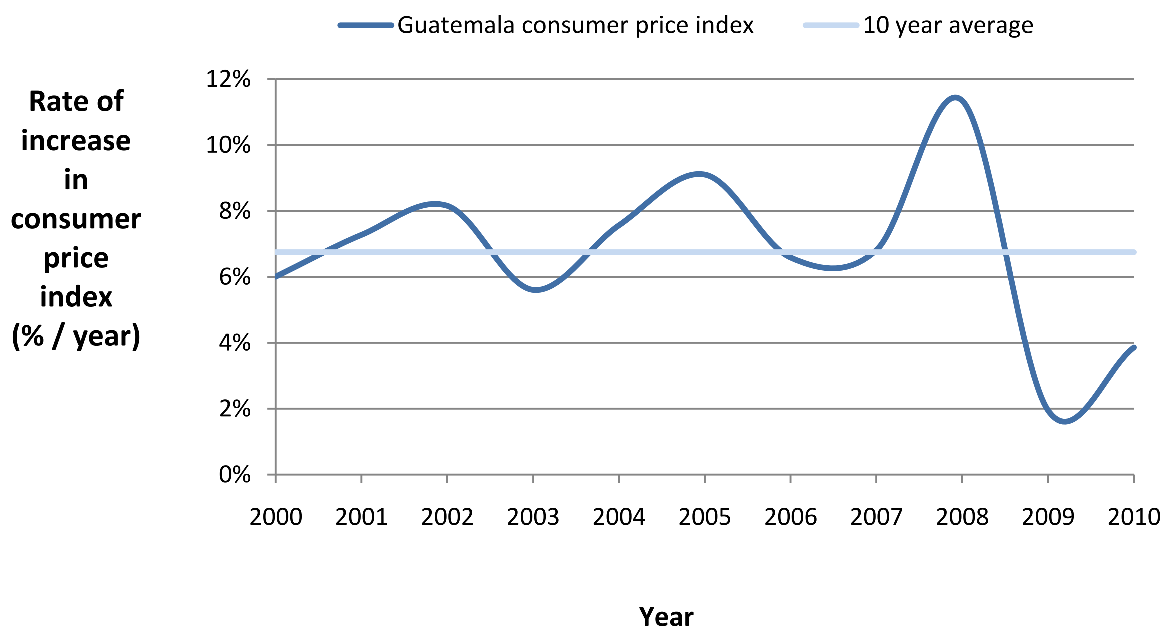

Figure C1: Guatemala consumer price index for 2000-2010. *Source: Banco Nacional de Guatemala 2011.*

APPENDIX D. ZINACANTAN CASE STUDY

The case of the Ecological Stove Project in Zinacantan, Chiapas offers important lessons for stove dissemination projects with respect to process of adoption and the barriers that can inhibit a stove project from realizing its objectives. San Lorenzo Zinacantan is a municipality in the southern part of central Chiapas highlands in southern Mexico. The population of approximately 30,000 is 98% Totzil speaking Maya, an indigenous language and ethnic group with cultural ties to other Maya peoples throughout southern Mexico and northern Guatemala. The Department of Chiapas is one of the least developed areas in Mexico. The Mexican National Census (INEGI, 2000, p. 152) reported for example that in Chiapas only 23.2% of residences have roofs made from solid materials[26] compared to 63.8% countrywide(INEGI, 2000, p. 152). 37.9% of residences have dirt floors compared to 13.2% at the national level (INEGI, 2000, p. 148). With respect to fuel use in the kitchen 53.4% of the population in Chiapas reports using woodfuel or charcoal compared to 17.2% at the national level (INEGI, 2000, p. 155). Although the national census does not characterize stove type, the traditional method of cooking over an open fire inside the home predominates throughout the region, particularly in rural areas.

The Ecological Stove Project

In June of 2008 the office of the Secretary of Social Development (SEDESOL), under the supervision of HELPS International, installed 102 ONIL Stoves[27] in Zinacantán (Figure D1) The "Ecological Stove Project" was highlighted in the national media and culminated in a ceremony which included a speech by Mexican President Felipe Calderón. SEDESOL representatives from 10 regions of southern Mexico participated in what amounted to an ICS capacity building and training program for government employees. According to the final project report (HELPS, 2008) there were three follow up visits to the homes of the beneficiaries to "verify the operation of the technology and the level of adoption." In the first follow-up they found that 82.5 % of the visited

[26] Refers to roofs constructed of materials such as concrete, brick or wood tiles.
[27] ONIL Stoves are highly efficient factory built ICSs that have been distributed widely throughout Guatemala.

families were using the stove (47% everyday; 30% 3-4 times per week; 5% < 3 times per week). In the third follow-up visit they found nearly the same level of overall use with 79% of the visited families reported using the stove, but with lower frequency (41% everyday; 20% 3-4 times per week; 18% < 3 times per week).

Figure D1. Abandoned ONIL Stove outside a home in Zinacantan, Chiapas.

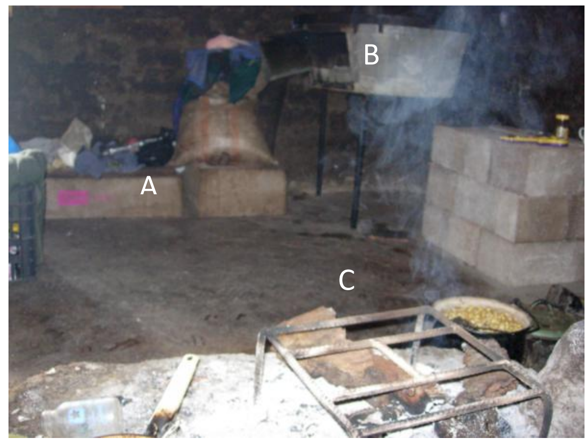

Figure D2. Several stove technologies in a single home. (a) Dismantled ONIL, (b) Unknown stove, (c) Open fire

Adoption rate two years later

On August 24th 2010 I conducted a random survey of beneficiaries of the Ecological Stove Project. The objective of the survey was to quantify the adoption rate 26 months after installation and seek user feedback in order to understand the barriers that beneficiaries were experiencing with stove adoption. I was accompanied by Alberto Saadi Cebellos of HELPS International. I surveyed 10 stove recipients (9.8% of the total) who were selected at random from a list of project beneficiaries. I found a dramatically different story than the one reported by SEDESOL. With respect to the general condition of the ONIL stove, I observed that merely 10% of the stoves were in normal working condition, 30% were either destroyed or in bad condition and the remaining 60% were unused (Figure D3). In fact 80% of the stove beneficiaries were still using an open fire for their daily cooking needs (Figure D4).

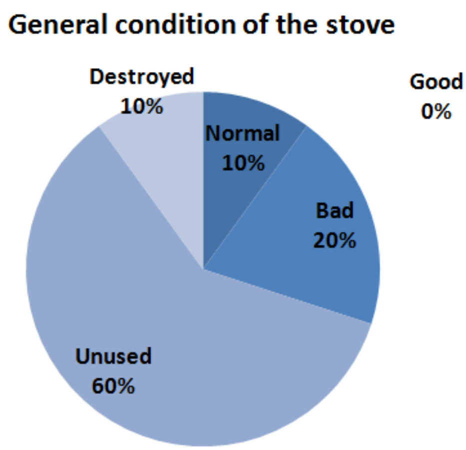

Figure D3. Observed condition of ONIL Stove at time of survey

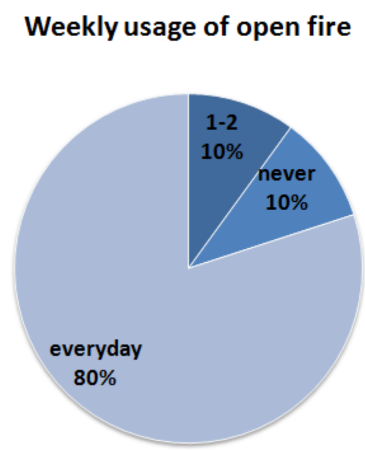

Figure D4. Reported weekly usage of open fire in homes with ONIL Stove

Notably 60% reported never using the ONIL Stove for cooking (Figure D5). According to the users, the primary reasons for this were that the cooking surface of the ONIL Stove is too small to accommodate large pots and tortillas (40%), and the combustion chamber is too small to accommodate the dimensions of the commonly acquired fuelwood (40%) (Figure D6).

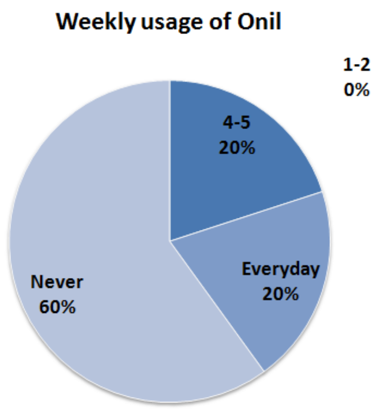

Figure D5. Reported weekly usage of ONIL Stove.

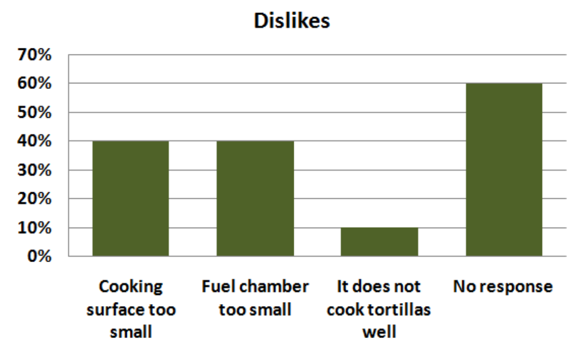

Figure D6. Reported dislikes with respect to ONIL Stove in Zinacantán.

Lessons learned

While the ONIL Stove may be highly efficient in laboratory setting, this does not translate into benefits to the recipients in the Ecological Stove Project who have abandoned the ONIL. Indoor air quality and decreases in fuel consumption are relative to the adoption level by the beneficiary. In the case of the ONIL Stove in Zinacantán, stove users are not satisfied with the smaller dimensions of the stove and the limits this puts on their fuel use and cooking. The conclusions of this small survey substantiate a common story that was communicated to me by various key players in the stove dissemination community throughout southern Mexico and Guatemala regarding ICSs in general and the ONIL Stove in particular. The ONIL Stove has been widely disseminated throughout the region especially in Guatemala where it was originally developed and deployed. Ironically the characteristic that leads to its increased efficiency, its small rocket box style combustion chamber, is also the characteristic that leads to it being rejected by the user. Forty percent of the users surveyed in Zinacantán cited the small dimensions of the combustion chamber as a barrier. Common fuelwood dimensions (Figure D7) (10-20 cm diameter) are too large to fit into the combustion chamber (7.5 x 10.5 cm) and therefore require additional labor before it can be used in the ONIL Stove.

In July 2010 I visited various homes San Marcos Guatemala that had received donated ONIL Stoves from the federal government following Hurricane Agatha. Most of the stoves were still being used but had been modified by users in such as way that the stove could no longer be considered improved (Figure D8). Without exception the combustion chambers had been dismantled in order to allow the users to use their standard fuelwood sizes.

Figure D7. Fuelwood outside a home in San Marcos Guatemala.

Figure D8. Modified ONIL Stove with the combustion chamber dismantled in a home in San Marcos Guatemala.

Stove dissemination programs that include a mechanism for incorporating user feedback into the design process will be able to react and modify stove designs in order that they increase the adoption rate among beneficiaries. In some cases it may be necessary to sacrifice fuel efficiency in order to accommodate user preferences and increase the adoption rate.