ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

- Team Project Report -

Selecting Cooking Stove and Fuel Technology using Pairwise Comparison Method

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Instructor	:	Dr. Dundar Kocaoglu
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Author(s)	:	Karina Hershberg, John Elliot

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Executive Summary

The focus of this project was to apply the Pair-Wise Comparison Method to the topic of cooking stove and fuel technologies in developing world communities. The issue of cooking stoves is a significant one since the most commonly used stove and fuel type has serious health, environmental and economic downsides. As a result, there is increasing attention and resources being given to the idea of providing communities and households with stove and fuel types that are more efficient, produce less pollution, and are more easily maintained.

There were 24 technologies stove and fuel combinations considered in the project. These technologies were evaluated against four criteria – efficiency, emissions, cost, and job creation. The source of information was ratings by experts specifically chosen based on their area of expertise. Although the surveys were sent to 15 experts, only five returned them in time for inclusion in the results of this paper. Due to the low number of returned surveys, each technology was only rated by one expert, instead of multiple expert rating per technology as was originally intended in the design of the model.

The survey results were evaluated using the Pairwise Comparison Software, version 1.4. Due to the large number of combinations for evaluation, the pairwise comparison sets were broken down into smaller portions. In order to still compare all the combinations to each other, they all were normalized against a common stove type that was included in all the surveys. The results of the project showed that the gasifier stove with uncarbonized briquettes was the highest rated technology. This is not surprising since these technologies were rated the highest on the categories that were two of the three most important - emissions and efficiency.

Although the survey response rate was low, the hope is that the results of this project will still serve as a strong starting point for dialogue between the experts in stove and fuel research and ultimately lead to a cooking stove and fuel that improves the lives of those who use it.

Background and Research

Much of the developing world depends on wood and charcoal based stoves to meet their daily cooking needs. Often called a "three stone stove", it is the most basic form of burning wood-based biofuels. Although this is a standard and simple solution for creating a heating source for food and water, it is far from an ideal solution. The World Health Organization estimates that smoke from the inefficient burning of biomass accounts for 1.6 million deaths annually worldwide.[1] In countries where indoor cooking fires are used extensively, diseases caused by indoor air pollution are the fourth highest cause of death and illness[2].

In addition to the health-related problems with the three stone wood stove, there are serious environmental considerations as well. The UN estimates that inefficient stoves account for almost 25% of black carbon emissions, a significant factor in global warming[3]. Furthermore, the never-ending demand for wood and wood-based products is leading to widespread deforestation. The impacts of this are twofold. Since the forest serves as a natural filter for removing certain greenhouse gases from the surrounding atmosphere, this important process is lost. The loss of forest also impacts the stability of the soil, making it more susceptible to runoff, loss of the nutrient rich top soil, flooding and large scale mudslides. The impacts on the surrounding communities can be devastating.

Unfortunately the story doesn't even end with health and environmental impacts. Although wood is a natural resource, since its use in stoves is so widespread its can become harder and harder to obtain. As a classic case of supply and demand, the increasingly limited supply can drive cost up to the point where it consumes a family's entire daily income. Collection of wood by women and children can take a significant amount of time, preventing children from attending school and women from participating in income generating activities. There is an additional risk in areas with safety problems.

As women and children have to search father away from their communities, they are at higher risk for attacks and abductions.

Given that 2.4 billion people use these high emission biofuels and stoves, this is a problem of significant size[4]. There are numerous government, non-government and non-profit groups around the world trying to find better stove and fuel options. The US State Department recently awarded $50 million in funding for the Global Alliance for Clean Cookstoves, a program that has the goal of creating and distributing 100 million improved cookstoves by 2020[5]. Another $12 million is expected from the US Department of Energy for research on improved stove and fuel technologies. The Aprovecho Research Center, a stove research facility located in Eugene, Oregon, has been getting increased attention and usage as the question of stoves and fuel sources gains more attention worldwide[6].

Research on stoves and fuel types is not a new topic. There are multiple factors to consider when making a decision on design strategies. As is often the case in decision making, there isn't always a completely perfect option. Decision choices require trying to find the option that best meets the most important needs. But which needs are most important? And which technologies provide the most benefit? These can be very difficult questions to answer, especially considering that much of the research for stove and fuels happens in developing communities where there is limited access to formal testing equipment. As a result, much of the data on stoves and fuel comes from the knowledge and experience of experts working in the field. Decision making theory provides methodologies that can help answer these questions using the knowledge of the experts.

The goal of this project is to evaluate 24 stove and fuel combination on the basis of emissions, efficiency, cost and job creation. The project was developed with the assistance of an expert in stove and fuel technologies who has worked both in the US and in Uganda on stove and fuel improvement projects[7].

Potential Candidates

Selecting the stove and fuel types for evaluation in the project took careful consideration. Since there are many groups working in parallel on the issue of better stoves and better fuel, there are numerous technologies being tested and used in the field. The issue is further complicated by the fact that different stoves use different fuel types. Therefore each stove has to be evaluated with the fuel types that can be used with it.

This posed a challenge in the creation of the pair-wise comparison surveys for three reasons. First, it was not possible to compare Stove X with Stove Y for Fuel Type A because it was possible that Stove X or Stove Y couldn't both use Fuel Type A. Therefore each candidate had to be specific about not only the stove type, but also the fuel type. The second issue was the candidate list became large enough that it was impractical to include all the candidates in a single pair-wise comparison survey. The final issue was that stove and fuel experts are experts on the stove and fuel types they work with most. Given the wide range of stove technologies, fuel types and fuel manufacturing processes there was no one who was an expert in all areas. Therefore the survey had to be divided into sections both because of the size and because of the areas of expertise among the survey participants.

Technologies

There were six types of stoves evaluated in the project. There were multiple fuel types associated with these six stoves. The fuel types get complicated because each type is defined not only by material, but also manufacturing process. The six types are stoves in the study were as follows:

- Three stone
- Gasifier
- Improved stove
- Rocket Stove
- Rok Stove
- Metal Traditional Stove

The three stone stove is the most basic and most widely used, so it was the common stove for all the surveys (use of a common item for comparison is discussed in further detail in the Model section of the paper). The three stone stove is essentially what it sounds like- three stones with a wood or charcoal fire in the center. The stones serve as both heatsinks for the heat generated by the fire, as well as a resting location for a cooking pot. Although simple and extremely cost effective, the many downsides associated with this stove were discussed in the initial portion of this paper. The health, environmental and economic issues are significant. The main fuel types used with this form of stove are usually wood and charcoal, although biomass briquettes can also be used.

The other stoves in the project are considered improved stoves because they address one or more of the negative drawbacks of the three stone stove. For example, the rocket stove can cut fuel usage by 50% and reduces the emission of soot and other health threatening particles.[8] It is important to clarify that although they are all considered improved stoves, there is also a specific type of improved stove that is called an "improved stove". The improved stoves category included the gasifier, improved stove, rocket stove, Rok stove and the metal traditional stove.

In general, the improved stoves all focus on more efficient use of fuel and more efficient heat transfer. These concepts can be seen in various design aspects in each of the stoves. The stove types included in the project are shown below with images and brief descriptions of the technology:

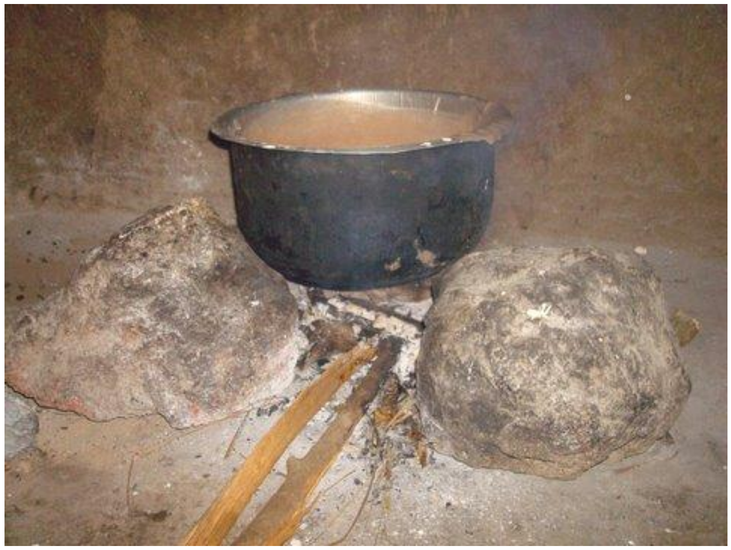

Figure 1 Traditional Three Stone Wood or Charcoal Stove

The traditional and most commonly used stove is the three stone stove with a wood or charcoal fuel source. Although easy and affordable, it has serious health drawbacks due to its high level of particle emissions and inefficient use of fuel.

Figure 2 Rocket Stove for wood or briquettes

The rocket stove utilizes improved airflow and insulation to maintain higher temperatures and more controlled burning of the fuel source so that more complete combustion and better transfer of heat is achieved. It is one of the most widely used improved stoves and can use either wood or briquette fuel types. Another feature is that the fuel chamber is on the side of the stove. This is a key difference since the fuel for most stoves is loaded from the top prior to placement of the cooking pot. An advantage of the side-load fuel chamber, in addition to the airflow benefits, is that the cooking pot doesn’t have to be physically removed from the stove for more fuel to be added.

Figure 3 Rok Stove with agri-waste uncarbonized briquette with hole

The Rok Stove (also known as the Holey Roket Stove) follows on the rocket stove's concept of better airflow through the insulated stove chamber. The key difference is that the Rok Stove uses the holey briquette, which as the name implies, is a briquette with a hole in the center[9]. The briquette hole helps with better airflow through the fuel into the chamber.

Figure 4 Improved Charcoal Stove

The improved stove has insulated walls which help maintain heat energy and give more efficient heat transfer to the cooking pot. [10]

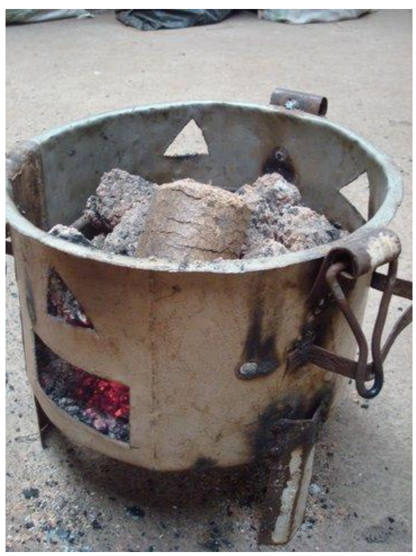

Figure 5 Traditional Metal Stove

The traditional metal stove also utilizes the common idea of improved airflow, but is a purely metal frame and does not have insulation in the walls.

Figure 2 Gasifier Stove

The basic concept behind a gasifier stove is the transformation of a solid biofuel into a combustible gas.[11] It relies on proper airflow through the chamber and results in a very clean burning of the fuel with minimal negative emissions.

As previously mentioned, the fuel types are more complicated because both materials and manufacturing processes are variables. The fuel materials considered in this project were:

- Agri-Waste
- Wood
- Wood Based Charcoal
- Wood Based Charcoal Fines

These materials are then either used as is or transformed by various processing techniques into different products. The processing options include carbonization, formation into a briquette and formation into a briquette with a center hole. The survey documents sent to the experts contained Table 1, which is a definitions table created by the main expert on the project to help clarify these different fuel types.

Improved Stove	Any stove that performs better in emissions or efficiency that does not fall under another category in the study. E.g. clay lined stoves, jikos, other other insulated stoves.
Metal Traditional Stove	A stove made of metal with no insulating component.
Wood Based Charcoal Fines	Charcoal dust that can be found in charcoal seller stands/markets. The particles are too small to sell as charcoal. This category is defined as "wood-based" because the charcoal fines do not come from agri-wastes which have been carbonized.
Agri-Waste	Any agricultural waste not including animal waste, such as corn stalks, rice hulls, and straw. Waste paper and sawdust are included in this category.
Wood	Gathered wood of any size, or wood chips, but not pellets or briquettes.
Uncarbonized briquettes	Raw biomass that has been formed into a briquette after being chopped, or not chopped if the pieces are already small enough, e.g. sawdust or rice hulls.
Carbonized briquettes	Biomass has been converted to charcoal in either a brick retort, a 55 gallon metal drum/barrel, or through traditional burial or mound methods.
Hole	Has a center hole in a round or square briquette of any size.
No Hole	Does not have a center hole in a round or square briquette of any size. Sometimes called a puck.
Simple Press	A press using minimal materials such as two cans, an impact press, or small Lee Hite press. Does not include Peterson Press or Mini-bryant which both create briquettes with holes and are larger.
Hand Formed	Briquette is formed by squeezing water out with your hands. Round or oblong shaped.
Extruder	Meat press or other machine that uses a hand crank to form oblong sausage shaped briquettes.

Table 1: Definitions of Key Terminology

Figure 3 Briquettes with Hole- Regional Material Difference[12]

Decision Criteria

Although the need for an improved alternative is obvious, there are multiple factors that need to be considered when evaluating a new technology. For the project, there were four main categories that were identified. They are efficiency, cost, emissions and job creation. These topics will be described in further detail in this section.

It is easy to understand why cost is a significant issue. In general, users of the standard three-stone stove have extremely limited financial resources so purchase of an expensive product, regardless of how beneficial it might be, would not be an option. The same cost constraints are true for fuel sources as well. Although funding resources such as the Global Alliance for Clean Cookstoves can help some communities, widespread adoption of new technologies and materials requires them to be financial available to all the current users of the three stone system.

As mentioned previously, two of the biggest problems with the three stone stoves with wood fuel are the health and environmental impacts. Therefore two of the factors selected for consideration are emissions and efficiency. The emissions factor is important because of its impact on both human health and the environment. The health problems associated with cooking stoves are tied to the soot, particulate and CO2 emissions from the fuel source. Therefore an important factor when looking at improving the technology and materials is how much the emissions are reduced because this will indicate how much improvement will be seen in the overall air quality- both in the home and the global environment.

The other health and environment related consideration is efficiency. Inefficient fuel sources and burning methods are problematic for a number of reasons. For starters, inefficient burning of the fuel means that potential heat energy is being lost. This can mean that more fuel (and therefore more cost and effort) is needed to achieve the necessary temperatures for heating food or boiling water.

Higher smoke and soot emissions are also seen when the fuel is not burning cleaning. Factors that can impact the amount of smoke include moisture levels in the fuel, airflow through the stove, airflow through the fuel, fuel material type and temperature of the briquettes immediately prior to burning (i.e. pre-heat)[13]

The final factor considered in the project was job creation. Although job creation isn't directly tied to the study of stoves and fuel, it is an ever present question in humanitarian aid projects. Technologies that can not only solve the problem focus but can also be self sustained by the people using them, as well as provide means for further improving their overall quality of life, are obviously the ultimate goal for any aid effort.

Survey Experts

The experts for the survey were chosen based on their experience and areas of knowledge. Since the subject matter has such broad reaching relevance in international aid projects, it is not surprising that there is a worldwide community of individuals who are very passionate and dedicated to the topic. The main expert for the project is quite involved with this community and was able to advise on who in the community would be best suited to provide information for the survey. In many cases, the experts were the inventors of either stoves or briquette manufacturing tools.

Even though stoves and fuel are intertwined technologies, the research is often split to focus mostly on just one of the technologies. Yet since they are so interdependent, most experts end up with experience in both areas just by default. The experts that were chosen for the survey mainly had expertise in either stove or fuel, but in general they all had at least a basic knowledge in both areas.

It is important to note that one weakness in the project was the lack of focus on a specific region. The issue of fuel materials can vary depending on the geographic region of the project. For example, materials available in central Africa might not be available in Southeast Asia. Therefore a stove that works well with the materials in central Africa still might not be a good fit for the communities in Asia. The variable of location is an important one but unfortunately it was also one that was difficult to make into a constant. This was due to wide variation in experience among the experts. Although stove and fuel projects are gaining more attention and funding, it is still on a fairly small scale so there aren't necessarily multiple experts on a topic in the same region. In order to get enough experts to cover all the stove and fuel types included in the survey, the variable of region had to be ignored. The experts selected for the survey mainly have experience in central Africa, Asia and Central America.

Since there were so many options being compared in the project, each survey only contained some of the stove and fuel technologies. This was also important in selecting experts because in general, no expert was truly on expert on all the technologies. Each expert had specific technologies that they were most knowledgeable on. Therefore each survey was customized to the knowledge base of the individual receiving that survey. The hope with the project was that multiple experts would respond on each option so biases and variations from individuals would be better normalized. Unfortunately a low number of respondents returned the surveys so duplicate coverage was not included in the final analysis.

Pairwise Comparison Method Model

The Pairwise Comparison Method (PCM) is ideal for this application because it allows us to gather undocumented knowledge from a diverse field of experts and provide objective values that can be used to rank the various stove/fuel combinations.

As previously described, there are 24 different types of stove/fuel combinations that need to be compared. If we were to use standard pairwise comparison for all of these stoves, each expert would have to complete over 1000 comparisons. This would be undesirable because it would be challenging for any expert to focus and provide thoughtful information over that many comparisons. So instead of sending every stove type to every expert, we broke the stoves down into groups depending on the background and expertise of the expert. We selected one type of stove that was familiar to all experts to include in each group. This common stove provides a reference point to align all of the results. The common stove selected is the 3-stone wood burning stove.

We sent the surveys to 15 experts. In the end, we received completed surveys from five of the experts. We entered the results of these surveys into the Pairwise Comparison software, version 1.4. The output of the software provided us with weighted results based on each expert's comparison. An example of these results from one expert is shown it the table below.

Stove Type	**Fuel Source**	**Processing**	**Carbonization Technique**	**Shape**	**Briquette Pressing Technique**	**Efficiency**	**Cost**	**Emissions**	**Job Creation**
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	extruder	0.36	0.05	0.32	0.29
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	simple press	0.28	0.08	0.32	0.32
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	hand formed	0.25	0.11	0.32	0.36
3-Stone	Wood					0.11	0.76	0.04	0.04

Table 2: Example of PCM Output

The next step was to normalize the results to the common 3-Stone, Wood stove. To do this, each value in a column was divided by the value of the 3-Stone stove. Performing this calculation on the above table, we get the following results:

Stove Type	Fuel Source	Processing	Carbonization Technique	Shape	Briquette Pressing Technique	Efficiency	Cost	Emissions	Job Creation
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	extruder	3.27273	0.06579	8	7.25
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	simple press	2.54545	0.10526	8	8
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	hand formed	2.27273	0.14474	8	9
3-Stone	Wood					1	1	1	1

Table 3: Example of PCM Output Normalized to 3-Stone Wood Stove

Once this calculation had been performed on the results from every expert, the various stoves could be compared directly to one another. The final calculation scaled the values for each stove such that the sum of all the values totaled 1.

We now had four categories in which the sum of the values in each category totaled 1. To provide the final ranking of the stoves, each category was multiplied by a weight and then summed together. This weighting was provided through pairwise comparison of the categories by our key expert. The comparison of the categories yielded the following weighting:

Efficiency	0.37
Cost	0.32
Emissions	0.28
Job Creation	0.03

Table 4: Category Weighting

Results

Using the model described in the previous section, the following results were generated:

Stove Type	Fuel Source	Processing	Carb. Tech.	Shape	Briquette Pressing Technique	Efficiency	Cost	Emissions	Job Creation	Weighted Total
Gasifier	Agri-Waste	uncarbonized briquettes		no hole	simple press	0.1745	0.031	0.10644	0.01324	0.10473
Gasifier	Agri-Waste	uncarbonized briquettes		no hole	hand formed	0.18177	0.031	0.092557	0.01324	0.10353
Gasifier	Agri-Waste	uncarbonized briquettes		hole		0.15996	0.019	0.10644	0.01324	0.09536
3-Stone	Wood					0.00727	0.156	0.009256	0.00361	0.05522
Improved Stove	Agri-Waste	carbonized briquettes	metal drum	no hole	simple press	0.04484	0.067	0.038565	0.02383	0.04946
3-Stone	Agri-Waste	uncarbonized briquettes		no hole	simple press	0.02181	0.118	0.004628	0.00361	0.04735
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	simple press	0.02908	0.071	0.038565	0.01589	0.04482
Rocket	Agri-Waste	uncarbonized briquettes		no hole	hand formed	0.04362	0.056	0.032395	0.01204	0.04351
Improved Stove	Agri-Waste	carbonized briquettes	traditional burial	no hole	simple press	0.02545	0.071	0.038565	0.01661	0.04349
RokStove	Agri-Waste	uncarbonized briquettes		hole		0.04362	0.062	0.023139	0.01806	0.04309
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes		no hole	hand formed	0.01333	0.08	0.030852	0.01228	0.03957
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	hole		0.02908	0.075	0.013884	0.01806	0.03911
Improved Stove	Argi-Waste	carbonized briquettes	brick retort	no hole	simple press	0.03635	0.044	0.037023	0.01324	0.03817
Rocket	Agri-Waste	uncarbonized briquettes		no hole	simple press	0.04362	0.037	0.032395	0.01324	0.03757
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	hand formed	0.01652	0.023	0.074046	0.0325	0.03503
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	simple press	0.01851	0.016	0.074046	0.02889	0.03369
Improved Stove	Wood Based Charcoal Fines	carbonized briquettes	traditional burial	no hole	extruder	0.0238	0.01	0.074046	0.02618	0.0336
Gasifier	Wood					0.00727	0.002	0.076359	0.18056	0.03
Gasifier	Wood					0.02472	0.004	0.024682	0.09028	0.01994
Rocket	Wood					0.01342	0.002	0.028924	0.18056	0.01899
Gasifier	Agri-Waste					0.01381	0.004	0.023139	0.09028	0.01547
Improved Stove	Wood Based Charcoal		traditional burial			0.01672	0.011	0.008484	0.09028	0.01479
Metal Traditional Stove	Wood Based Charcoal		traditional burial			0.01091	0.011	0.01157	0.09028	0.0135

Table 5: Final Results

In each category, the top stove is highlighted green, the second stove is highlighted yellow, and the third stove is highlighted red. The results show that the same stoves that were top in both Efficiency and Emissions, were the top three overall stoves. We can also see that the stoves that ranked highest in job creation, ranked lowest overall. This shows how little impact the Job Creation category has on the final result. The other interesting thing to note is that the common 3-Stone, wood stove ranked 4th overall even though it is the oldest and most primitive of the stoves. In most cases the experts were very consistent in their rankings. The top three stoves are summarized in Table 6 below.

Stove Type	Fuel Source	Processing	Carb. Tech.	Shape	Briquette Pressing Technique
Gasifier	Agri-Waste	uncarbonized briquettes		no hole	simple press
Gasifier	Agri-Waste	uncarbonized briquettes		no hole	hand formed
Gasifier	Agri-Waste	uncarbonized briquettes		hole	

Table 6: Top Three Stoves

Conclusions

Overall the results achieved with the surveys and our model were consistent and logical. It makes sense that the stoves with the highest scores in the most heavily weighted categories would be ranked highest overall. It was interesting to see that the stoves with the highest job creation potential all ranked at the bottom of the overall list. What this tells us is that the stoves with high job creation potential are lacking in the more important categories of emissions and efficiency.

We reviewed the results with our key expert. She agreed that the results were as expected. Even though the Gasifiers were more expensive, they perform very well from an Emissions and Efficiency standpoint to come out on top. As a future step, she would like to see how local culture can be incorporated into a study; the fact that different cultures incorporate different stove types more easily.

We did have challenges receiving responses to our surveys. One reason for this is because many of the experts are spread around the world in remote locations and have trouble accessing the internet. In some cases the experts had concerns about the validity of the survey and were hesitant to give their opinions. Interestingly, the experts who expressed strongest concerns about the survey also had a financial stake in the outcome because they worked in Stove manufacturing.

Due to the limited responses, each stove was only reviewed by one expert. This is a severe limitation for our results. There is only limited accuracy because of the single review. Additionally, the 3-Stone, Wood stove may not have been the best for comparison. While all experts were familiar with this stove type, this stove ranked very poorly in all categories except for cost and it ranked very highly in the cost category. Since it fell at these extremes it made the distinctions between the other stoves more difficult to judge. The results could have been more accurate if we could have selected a common stove that was closer to the middle of the pack.

In the end, the project provided a good starting point for capturing knowledge from stove and fuel experts. Although there is plenty of information available about stove and fuel technologies, there are a limited number of resources comparing the technologies to each other. As more funding becomes available and stove and fuel technologies are being deployed on a larger scale, these types of comparative studies will become more important. Hopefully the work from this project will help start those comparative dialogues and ultimately lead to technologies that will help improve the lives of those directly impacted by these issues.

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