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A COMPARATIVE STUDY OF THE LIFE CYCLE GLOBAL WARMING POTENTIAL OF CHARCOAL STOVE OPTIONS IN HAITI

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ABSTRACT

This study provides estimates and a comparative assertion on the life cycle global warming potential (GWP) impacts of three product systems: 1) traditional Haiti charcoal stove, 2) efficient charcoal stove manufactured in Haiti (Recho Mirak), and 3) imported efficient charcoal stove. Results indicate that efficient charcoal stoves, both local and imported, are better than traditional designs in terms of life cycle GWP impact. The traditional stove has the highest GWP per cooking-year of 5.6 tons CO_2*e on average; this is over 20% greater than the 4.3 tons* CO_2*e per cooking-year for both local and imported efficient stove products. Replacing a traditional stove, thus, results in reduction in emissions of about 1.3 tons* CO_2*e per year. Charcoal production and burning account for over 99% of the GWP impacts for the three product systems. Meanwhile, stove material and stove origin (i.e., local versus imported) contribute merely 0.1% of GWP impact for all three products. Imported efficient stoves would have less GWP than local efficient stoves if the former's charcoal use efficiency is at least equal to that of the latter. Furthermore, the parameters that have the greatest impact on the GWP of all product systems are frequency of cooking and cooking charcoal use intensity.*

Keywords: Life cycle analysis, charcoal stoves

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1. INTRODUCTION

As of 2006, only about 2% of Haiti's forest was left. Although this is due to many factors, one of the most significant is the heavy use of charcoal and wood as fuel for Haiti's energy demand. Haiti is estimated to consume at least 4 million tons of wood annually and that about 33% of this is transformed to charcoal [1]. In Port-Au-Prince, about 400, 000 tons of charcoal is consumed for cooking alone [1, 2]. As a step towards improved energy security, the Government of Haiti (GoH) is aggressively pursuing a program to lessen the country's dependence on very scarce and vital forest resource through the wider adoption of efficient cooking stoves (i.e.: stoves that use less charcoal). This national program is also expected to achieve gains in environmental protection and improve the financial well-being of Haiti's people. GoH targets 10% charcoal use by 2016 through increased production and use of efficient cooking stoves. However, due to insufficient supply of metal and human resources, Haiti is considering the option of importing efficient cooking stoves. Efficient cooking stoves consume less charcoal than the traditional type but 30% more metal is required for its production. It is interesting to determine which of the three product systems – traditional, local efficient, and imported efficient – has less environmental impact from a life cycle perspective as measured by global warming potential (GWP).

2. METHODS

2.1 Goal

This study aims to provide an initial estimate as well as perform a comparative assertion on the GWP life cycle impacts of three product systems: 1) a traditional Haiti charcoal stove, 2) a locally produced efficient charcoal stove, and 3) an imported efficient charcoal stove. Efficient charcoal stoves are estimated to consume 30% less charcoal than traditional ones [2]. Moreover, this study also aims to investigate the impact of importing efficient charcoal stoves and determine how it compares to the locally produced charcoal stoves. The results of this study may be useful to the government of Haiti in its efficient charcoal stove program. Since the government of Haiti is looking into the possibility of engaging in carbon credit schemes as a strategy to support its efficient charcoal program, this study may be useful in establishing initial estimates of carbon footprint information that the government may need. Moreover, the results of this study may also be of interest to individuals and organizations who are involved in charcoal stove research and design.

2.2 Scope

The scope of the analysis includes processes from production to use and disposal of the stove and charcoal. These processes are graphically illustrated in Figure 1 and are discussed in more detail in the next section.

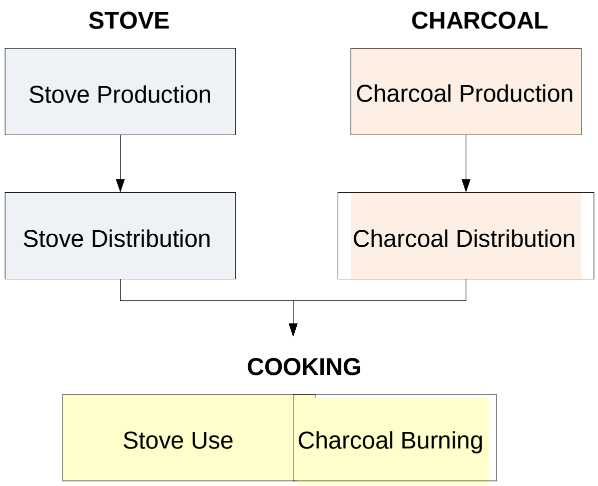

Figure 1. Unit Processes Included in System

The role of forests with respect to capture or emission of carbon is not included in this study. For one, forests are not planted for the sole purpose of charcoal production. They are deemed to be "products" by themselves that serve multifarious purposes to humanity. Thus, cutting them for the purpose of producing other products should be seen as an elimination of these services which need to be filled sooner than later. This would entail production of other product systems or ideally, the same tree system. How this should be included in this analysis is beyond the scope of this study. Thus, with respect to the GWP of charcoal production, only the emissions from the actual making of charcoal is considered here. A good discussion of inputs to earth mound charcoal production as well as the production process is provided by Food and Agriculture Organization of the United Nations [3].

2.3 Unit Process Description and Assumptions

In terms of geographic boundary, the first two systems – traditional stove and locally-produced efficient stove – are assumed to be made, distributed, used, and disposed in Haiti. As for the imported efficient stove, it is assumed that the same production process is adopted. Meanwhile, there are several efficient charcoal stove designs but for this study, the *Recho Mirak* model was chosen as a representative efficient stove model since it is the most popular type in Haiti. *Stove Production.* The Haiti charcoal stove production process, both for the traditional and more efficient stoves, is relatively simple. The process primarily involves metalworking processes such as forming, cutting, punching, and joining mostly with the use of a ball-peen hammer and chisels. Since there are no machines involved, the process requires certain level of artisanship. The only difference between the traditional and more efficient stove is the amount of material used and the stove design. The main material used is scrap metal (steel) which is usually obtained from junk yards. Painting, which is an additional finishing process, is undertaken for the efficient stove. The amount of metal needed to make one Recho *Mirak* was derived from the *Recho Mirak* stove specifications [4]. Given that the density of steel ranges from 7.75-8.05 g/cu cm [5], the mass of steel needed can be computed by multiplying this density by the volume of steel computed from the *Recho Mirak* product specifications. Meanwhile, the mass of steel needed for producing the traditional stove is computed as 70% of the *Recho Mirak* metal requirement [2]. As mentioned, scrap metal is the usual material used in stove production; thus, emissions from manufacturing of steel needed for production may be as low as zero since scrap metal may be obtained from junk yards or disposal areas. However, since metal resource is scarce, the possibility of using recycled metal is highly likely. In the initial calculations, average impact from manufactured metal was considered.

Charcoal Production. Production of charcoal may be done in many ways; for this study, only the earth mound method, is included since this type of charcoal production is ubiquitous in Haiti. To produce a kilogram of charcoal, about five kilograms of wood is needed [6].

Stove Distribution. Local artisans can be the sellers themselves or they may contract someone to sell their products. It was assumed in this study that distribution within the locality does not involve transportation through fossil-fuel powered vehicles. It was also assumed that no elaborate infrastructure is used for the purpose of selling the stoves and store hours occur only during the day; thus, no infrastructure or energy requirements are considered here. On the other hand, imported stoves were assumed to be transported from the place of manufacturing to Port-au-Prince, Haiti through an ocean freighter. Three scenarios were explored as to the exporter of the stoves – Kenya, Cuba, and U.S.A., Kenya was chosen because it has a thriving efficient charcoal stove market. U.S.A. was included as an exporter because some prominent universities in this country (e.g.: University of California, Massachusetts Institute of Technology) are active in charcoal stove research and these efforts may extend to aiding Haiti in its effort to meet its needed supply of charcoal stove. Lastly, Cuba was included to represent exporting countries that have close proximity to Haiti. To compute for the shipping distances from these three places the following ports were assumed to be the port of departure: Mombasa, Kenya; San Francisco, California; and Havana, Cuba. Port distances were obtained from Searates.com.

Charcoal Distribution. As for the distribution of charcoal, it is assumed that 40% of charcoal is supplied by Haiti while 60% is supplied by the Dominican Republic. It was reported that more than 60% of Haiti's charcoal needs is actually supplied by the Dominican Republic; however, only the lower bound is explored here. Thus, the results from the impact of charcoal distribution may be underestimated.

Stove Use/Charcoal Use. In the use phase, charcoal is burned to fuel the stove. Kindling devices such as matches, paper, or gas are used were not included in this study. Thus, for stove use, only the emission from charcoal burning is included in this study. Charcoal consumption was derived from unpublished reports [7] containing data on charcoal cooking intensity and frequency of cooking. It was assumed that on average, a household owns one charcoal stove. Yearly charcoal consumption per stove-year was computed by multiplying the average number of meals per year per household (i.e., average number of meals per day times 365 days/year) and the average amount of charcoal needed to cook a meal. These values are summarized in Table 1.

2.4 Functional Unit

The functional unit used in this study is one stove-cooking year in Haiti. This was deemed to be the best functional unit primarily because enabling cooking is the main function of the stove. Secondly, the traditional stove has a shorter lifetime of 3 to 12 months compared to the 2-3 year lifespan of the *Recho Mirak*. To be able to meaningfully compare the life cycle impacts of the two products, the comparison has to be made over the lifetime of either of the products. In this study, the comparison was made over the lifetime of the *Recho Mirak*.

2.5 Life Cycle Inventory

Data Sources. The data used in this study were obtained from a combination of primary and secondary sources. The table below summarizes the primary parameters used and their sources.

Table 1. Input Values and Data Sources

Unit Process	Parameter Considered	Quantity	Unit	Source
Stove Production	Mass of Scrap Metal Needed	Traditional: 6.3 Efficient: 4.9	kg/cooking-year	[2, 4]
	Density of Steel	7.75-8.05	g/cu cm	[5]
Stove Distribution	Distance from exporter to Port-Au-Prince	From Kenya: 8, 700	Nautical miles	[8]
Charcoal Production	Amount of Charcoal needed	Traditional: 1, 180 Efficient: 910	kg/cooking-year	[7]
	Amount of Wood needed	Traditional: 5, 900 Efficient: 4, 600	kg/cooking-year	[6]
	CO2 Emissions Factor for Charcoal Production	Average: 1, 510 Std. Dev.: 338	g/kg charcoal	[9, 10]
	CH4 Emissions Factor for Charcoal Production	Average: 37 Std. Dev.: 8.6	g/kg charcoal	[9, 10]
Charcoal Distribution	Distance from Dominican Republic to Port-Au-Prince	210	Miles	[11]
Stove/Charcoal Use	Useful Life	Traditional: 3- 12 Efficient-Body: 2 -3 Efficient-Basket: 6-12	Months Years Months	[2]
	Frequency of Cooking	1 to 3		[12]
	Cooking Charcoal Intensity	Traditional: 1.25 Efficient: 1.625	kg/meal kg/meal	[2, 7]
	CO2 Emissions Factor for Charcoal Burning	Average: 2, 430 Std. Dev.: 272	g/kg charcoal	[12, 13]
	CH4 Emissions Factor for Charcoal Burning	Average: 8.6 Std. Dev: 6.7	g/kg charcoal	[12, 13]

Data Quality. The Weidema method was used to evaluate data quality. The evaluation scores are shown in **Table 2**. This evaluation suggests that the quality of the data used is satisfactory.

Table 2. Data Quality Evaluation Using the Weidema Method

Phase	Parameter	Acquisition Method	Independence of Data Supplier	Data Age	Geographical Correlation	Technological Correlation
Stove Production	Mass of Scrap Metal Needed	2	1	1	1	1
	Density of Steel	4	1	1	2	1
Stove Distribution	Distance from exporter to Port-Au-Prince	3	1	1	1	1
Charcoal Production	Amount of Charcoal needed	3	1	2	1	1
	Amount of Wood needed	3	1	2	1	1
	CO2 Emissions Factor for Charcoal Production	1	1	3	3	1
	CH4 Emissions Factor for Charcoal Production	1	1	3	3	1
Charcoal Distribution	Distance from Dominican Republic to Port-Au-Prince	3	1	1	1	1
Stove/Charcoal Use	Useful Life	4	1	2	1	1
	Frequency of Cooking	1	1	2	1	1
	Cooking Charcoal Intensity	2	1	2	1	1
	CO2 Emissions Factor for Charcoal Burning	1	1	3	3	1
	CH4 Emissions Factor for Charcoal Burning	1	1	3	3	1

2.6 Life Cycle Impact Assessment

The GWP impact of the three product systems under study were derived by getting the sum of calculated emissions corresponding to the five phases discussed above. Emission corresponding to metal used in production was calculated using the data on Average of all Steel IDEMAT 2001 in SimaPro. Meanwhile, for stove distribution, the Ocean Freighter FAL (Franklin USA 98) database in SimaPro was used. As for Charcoal onroad transport from Dominican Republic and within Port-Au-prince, the Truck (single) diesel FAL (Franklin USA 98) database in SimaPro was used. The CO_2 emissions factors for Charcoal Production and Burning presented above were simply multiplied by the amount of charcoal used. The equivalent GWP corresponding to CH_4 emissions were obtained by multiplying the emissions factors presented above by 23; the product is then multiplied by the amount of charcoal used. The GWP impacts were computed and graphed in Microsoft Excel.

3. DISCUSSION OF RESULTS

Based on the results, the traditional stove has the highest GWP per cooking-year of 5.6 tons CO_2e, over 20% greater than the 4.3 tons CO_2e per cooking-year for both the efficient stove systems. Replacing a traditional stove then results in an emissions reduction of about 1.3 tons CO_2e per year. The estimated average life cycle GWP impacts for each product are shown in Figure 2.

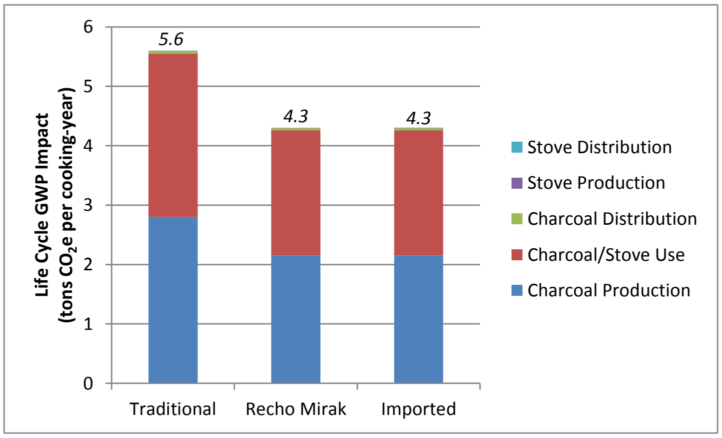

Figure 2. Life Cycle GWP Impact Results for Three Stoves

As can be seen, almost 100% of the GWP impacts of the three systems are attributable to charcoal production and burning (i.e.: red and blue bars). Impact from imported stove distribution is so marginal that in total, the imported and locally produced efficient stoves have about the same GWP. Stove material and stove origin (i.e., local versus imported) was also found to be far less of an issue than charcoal use intensity (i.e., charcoal) as indicated by the fact that stove production and distribution impact account for merely 0.1% of the total impact for all three stove types. Thus, decision on which type of stove to choose should be mainly based on the charcoal intensity of the stove.

3.2 Sensitivity Analysis

To test the robustness of the results of this study, the variations to the values of the key parameters were done. These variations are shown in Table 3.

Table 3. Sensitivity Analysis Inputs

Phase	Input	Traditional Stove	*Recho Mirak*	Imported Recho Copy
Stove Production	Mass of Scrap Metal (kg/ cooking-yr)	5.7	4.5	4.5
		6.3	4.9	4.9
		10.9	5	5
Stove Distribution	Distance Traveled (nautical miles)	NA	NA	650
				4, 030
				8, 700
	ton-nautical mile	NA	NA	3
				23
				50
Charcoal Production	Mass of Charcoal (tons/cooking-year)	0.5	370	370
		1.2	910	910
		2.3	1, 640	1, 640
	Mass of Wood (tons/cooking-yr)	2.3	1.8	1.8
		5.9	4.6	4.6
		11.5	8.2	8.2
Charcoal Distribution	Emissions from Combustion (ton CO2e/cooking-year)	1	1	1
		3	2	2
		7	5	5
40%	Distance: within Haiti (miles)	0	0	0
		5	5	5
		10	10	10
60%	Distance: Santo Domingo, Dominican Republic to Port-au-prince, Haiti (miles)	210	210	210
	ton-mile/cooking-year	60	50	50
		150	110	110
		300	210	210
Stove-Charcoal Use	Emissions from Combustion (tons CO2e/cooking-year)	1	1	1
		3	2	2
		8	5	5
Stove Disposal	Mass of Steel (kg/cooking-yr)	5.7	4.5	4.5
		6.3	4.9	4.9
		10.9	5	5

The corresponding GWP impact results from the above changes are summarized in Table 4. Based on the results, the range of GWP impact from the efficient stoves are still lower than that of the Traditional Stoves.

Table 4. Sensitivity Analysis on GWP Impact Results

Phase	Traditional Stove			*Recho Mirak*			Imported Recho Copy		
	Min	*Med*	*Max*	*Min*	*Med*	*Max*	*Min*	*Med*	*Max*
Stove Production (kg CO2e/cooking-year)	6	7	12	5 (4.8)	5 (5.2)	5 (5.3)	5 (4.8)	5 (5.2)	5 (5.3)
Stove Distribution (kg CO2e/cooking-year)	NA	NA	NA	NA	NA	NA	0.07	0.56	1.21
Charcoal Production (tons CO2e/cooking-year)	1	3	7	1	2	5	1	2	5
Charcoal Distribution (kg CO2e/cooking-year)	18.3	45.9	91.7	15.3	33.6	64.2	15.3	33.6	64.2
Stove-Charcoal Use (tons CO2e/cooking-year)	1	3	8	1	2	5	1	2	5
Total (tons CO2e/cooking-year)	1.9	5.6	11.9	1.5	4.3	8.5	1.5	4.3	8.5

Furthermore, it is interesting to determine which parameters are most significant in influencing the difference in GWPs of the three product systems. The tornado diagram (left) in Figure 3 indicates that the difference in the impact between traditional and efficient stoves is mostly influenced by charcoal use intensity and frequency of cooking. Based on the tornado diagrams generated using Precision Tree, as shown in

Figure 3, the most influential parameters are cooking charcoal use intensity and frequency of cooking.

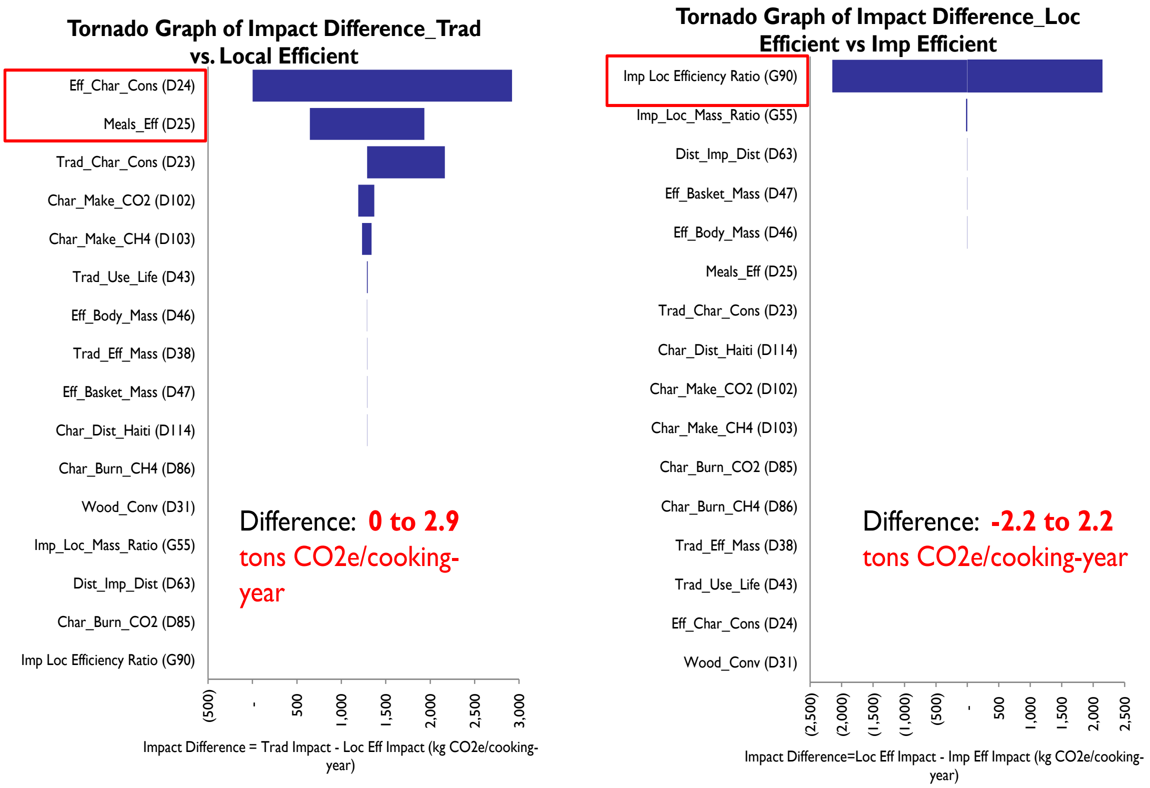

Figure 3. Tornado Diagrams corresponding to GWP difference between (left) Traditional and Haiti Efficient Stoves and (right) Haiti Efficient Stoves and Imported Efficient Stoves

4. CONCLUSIONS AND RECOMMENDATIONS

Results indicate that efficient charcoal stoves, both local and imported, are better than traditional ones in terms of life cycle GWP impact. From the results obtained above, it was found that replacing traditional stoves by efficient ones can result in over 20% decrease in life cycle GWP on average. The following are the estimated range of GWP of the three product systems analyzed:

Traditional: 1.9 to 11.9 tons CO2e/cooking-year (5.6 on average)
Recho Mirak: 1.5 to 8.5 CO2e/cooking-year (4.3 on average)
Imported Efficient Stove: 1.5 to 8.5 CO2e/cooking-year (4.3 on average)

The above values are believed to be conservative estimates for the reason that there are other processes or materials in the supply chains of the product systems that were not included in this study.

The most significant parameters are frequency of cooking and cooking charcoal use intensity. The former is influenced greatly by the level of disposable income of an average Haiti household. Thus, it may be interesting to see in further studies how the increase in disposable income brought about by less expenditure in charcoal would affect the frequency of cooking and ultimately, the new charcoal consumption level. Cooking charcoal intensity is affected by the type of stove used.

On the other hand, GWP due to Charcoal constitutes almost 100% of the life cycle impact of the stoves used. Distribution impact due to importing is maybe considered relatively trivial (<1%). It was also found from the sensitivity analysis conducted that the breakeven efficiency level of the imported stove versus the traditional type is at 23% (i.e.: imported stove has to use 23% less charcoal). Thus, based on GWP, it is acceptable to import efficient stoves as long as they have a charcoal intensity of at least 23% less than that of traditional charcoal stoves. Meanwhile, imported efficient stoves have to have at least the same level of charcoal use efficiency as the local efficient stoves in order to have the same or less life cycle GWP impact.

Since it was found that almost 100% of the GWP from the stoves are due to charcoal production and making, Haiti should pursue other types of stoves. For instance, a quick comparison using the LPG FAL (Franklin USA 98) in Sima Pro shows that LPG supplying the same amount of energy as charcoal (i.e.: 1 ton of charcoal supplies 30GJ [14] is equal to 1, 186 liters of LPG equivalent to about 243 kg CO2e) results in about 95% less CO2e.

Areas for further study

To come up with a more comprehensive comparison for public policy decision making, the life cycle costs and health effects of the efficient charcoal stove and other stove alternatives, including non-charcoal based ones, should also be considered.

In addition to widening the scope of the analysis in terms of stove type, as suggested above, the LCA method used in this study may be adopted in the context of the Philippines and other developing countries. In many developing countries, biomass is a primary source for cooking fuel and about 90% household energy consumption goes to cooking [15]. Furthermore, dependence on biomass is said to increase in the future. Thus, policy suggestions include promoting “more efficient and sustainable use of traditional biomass; and encouraging people to switch to modern cooking fuels and technologies." These policy options, at the outset, sound convincing. However, it is proposed that evidence-based LCA comparison of the costs and benefits – economic, environmental, and health – could yield a more comprehensive and robust understanding of different policy options.

It would also be interesting to understand how cost perceptions affect adoption of different cooking technology option. Preliminary calculations were made to compare the cost of using the *Recho Mirak* and the traditional stove in Haiti, assuming the following: stove costs [2]: Recho Mirak ($ 3.50), traditional stove ($ 2.5); charcoal cost ($ 300/ton) [16]; stove useful life, charcoal use, frequency of cooking, and cooking charcoal intensity as shown in Table 1. Without discounting, comparisons show that the *Recho Mirak* costs less than the traditional stove by about $ 15 - $ 75 per year. This suggests about 25% to 45% cost savings from using the *Recho Mirak* instead of a traditional stove. However, since the upfront cost of the more efficient stove (i.e., *Recho Mirak*) is higher, households are less likely to buy the efficient stoves. Understanding the mental model of consumers towards making decisions in cooking technology options may provide guidance on how to more effectively formulate and implement policy measures.

Another interesting area for further study would be to analyze a possible "rebound effect" in terms of increased frequency of cooking due to savings resulting from lower charcoal consumption with the use of efficient stoves. Lastly, the effect of introducing efficient imported stoves to the cooking technology market (e.g., analyzing price elasticity of the different cooking technologies) would be a very interesting future work.

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