# The Adoption and Impacts of Solar Ovens in Rural Senegal:

# A Randomized Controlled Trial

**Early Draft Not for Distribution**

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# Abstract

Over 2.5 billion of the world’s poorest people rely on wood and other biomass fuel for household energy. Indoor air pollution from burning biomass causes over 1 million deaths a year, primarily of children. Pneumonia and other lower respiratory infections, many of which are due to indoor air pollution, are the leading cause of death in Senegal.[[2]](#footnote-2) Burning biomass also leads to deforestation, loss of biodiversity, and the release of greenhouse gases. Finally, biomass fuel is a major time or financial cost for many poor households.

We performed a randomized evaluation of solar ovens in Senegal, comparing outcomes for treatment households randomly allocated the solar ovens early to a control group who received the solar ovens 6 months later. Usage of the solar ovens increased over time, as the local partner engaged in more training, but usage rates remained below 20% per day. The solar ovens cook a meal for only 6 or so people, so we focus on households in compounds with 12 members or less. For these households, solar ovens reduce daily fuel consumption about 7%. In addition, the average time the household spends collecting fuel declines by about 10 minutes a week, or 1%. There were no statistically significant reductions in exposure to carbon monoxide or improvements in self-reported health. Despite high demand for the solar ovens, their relatively small size makes the ovens a poor fit for the large extended families in the region we study.

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Over 3 billion of the world’s poorest people rely on wood and other biomass fuel for household energy ([Rehfuess et al., 2006](http://www.ehponline.org/docs/2006/8603/abstract.html))[[3]](#footnote-3). Indoor air pollution from burning biomass causes approximately 1.6 million deaths a year, primarily of children. For example, pneumonia and other lower respiratory infections, many of which are due to indoor air pollution, are the leading cause of death in Senegal.[[4]](#footnote-4) Burning biomass also leads to deforestation, loss of biodiversity, and the release of greenhouse gases. Finally, biomass fuel is a major time or financial cost for many poor households.

We performed a randomized evaluation of solar ovens in Senegal, comparing outcomes for treatment households randomly allocated the solar ovens early to a control group who received the solar ovens 6 months later. One goal of this study is to understand whether the solar oven used, the HotPot[[5]](#footnote-5), is the appropriate technology substitute for the traditional three stone fires used in rural Senegal.

After substantial training, many households made significant behavior change to cook with the solar oven. However, the solar oven, which feeds six, was too small to replace a fire because women lived in compounds with average size of 12. Because the solar oven proved to be too small the results for all outcome variables were modest. Households in the treatment group showed a small and significant decrease in daily wood use per person (7%) in the single difference at the six month follow-up when compared to the baseline.

# Literature Review

Improved biomass burning stoves and solar ovens in the developing world have the potential to reduce all the problems of traditional stoves. Studies in laboratories and in carefully controlled conditions have demonstrated many improved cookstoves have much lower fuel use and emissions than traditional stoves (cite xx). Solar ovens, such as we study, obviously have zero fuel use and emissions. Unfortunately, it is not obvious if the impressive results in the lab will into the experience of poor households.

A number of observations in the field also find poor health among those using traditional wood fires (cite xx). Unfortunately, it is unclear if other disadvantages might lead to both poor health and use of a traditional fire.

It is crucial to have rigorous evidence of how new technologies operate in the field to complement the important studies cited above. Unfortunatley, other than the path-breaking work of Kirk Smith and his colleagues (2007), there are few rigorous evaluations of the impacts on improved stoves.[[6]](#footnote-6)

Low-emissions stoves have not disseminated rapidly in most poor nations. The limits to adoption highlight the importance of designing both a stove and a distribution mechanism that is culturally appropriate and which facilitates the change from the traditional stove. Few programs dedicated to the distribution of improved stoves have included rigorous evaluation of the impacts.

Importantly, several mechanisms already exist and new ones, particularly the carbon credit market, are evolving for rich nations to subsidize the reduction of greenhouse gases. It is possible that these subsidies could accelerate the development and adoption of improved stoves. Rigorous evaluations are crucial to allocate carbon credits appropriately. The opportunity to pursue carbon credits should not be understated as many large donors have made significant resources available in order to scale up rigorously evaluated pilot projects.[[7]](#footnote-7)

Most poor households currently relying on biomass fuels are unlikely to switch to cleaner fuels in the near future due to lack of affordability. There is a critical need, therefore, for interventions that reduce exposures to high levels of indoor air pollution, including continued development of improved cook stoves that use less fuel and reduce emissions substantially.

## Effects of Burning Biomass Fuel

Fuel: Solid fuels account for [more than 95% of domestic energy use in twenty-five of the world's low-income countries](http://earthtrends.org/searchable_db/index.php?theme=6&variable_ID=1298&action=select_countries). Sub-Saharan Africa has the highest rate of biomass fuel use of any world region, with over 80% of the population using biomass fuels as the primary energy source of the household.[[8]](#footnote-8)

Demand for traditional fuel places significant pressure on local forests and woodlands, contributing to deforestation, soil erosion and desertification. Careful estimates suggest that under current trends, household energy use in Africa alone will produce 6.7 billion tons of carbon by 2050.[[9]](#footnote-9)

Costs of Collection of Biomass Fuel: The burden of time required to collect biomass fuels is great and often falls on women. Women are forced to tradeoff activities with potentially higher returns- including education and economic opportunities- in order to collect fuel for cooking. A study in rural Malawi found that women spent between 4 to 15 hours per week collecting fuel, depending on the distance from the woodland.[[10]](#footnote-10) In the same Malawi study, children from wood-scarce districts are 10 to 15 percent less likely to attend secondary school than children from less scarce districts. The time-consuming nature of fuel collection limits other opportunities for these women, such as education and income-generation. Thus, by reducing the time spent collecting wood, improved stoves can potentially give women and girls the opportunity to pursue other activities including education and employment outside the home. The effects on additional time for education and employment may positively affect intra-household bargaining and effectively increase women’s decision power in household decisions.

Costs of biomass fuel can also be a large percentage of household expenditure in developing countries. While cooking with gas is primarily an urban phenomenon in Senegal, 60% of our rural households report using gas once a day to reheat food. Thus, an improved cookstove that can reduce natural gas expenditures can also fight rural poverty.

Health:Because biomass fuels have very low combustion efficiency, they emit large quantities of health-damaging indoor air pollution (IAP). The WHO reports that indoor air pollution is responsible for 3.6% of the global burden of disease.[[11]](#footnote-11) The first randomized controlled trial to study how improved cookstoves affect IAP and health is Kirk Smith, et al., 2007. They found a statistically significant drop in the incidence of childhood pneumonia for households with improved stoves.[[12]](#footnote-12) More generally, a meta-review found unimproved cookstoves almost double children’s risk of pneumonia.[[13]](#footnote-13) “Reviews from many epidemiological studies of indoor air pollution from household solid fuel use in developing countries find significant health effects including child acute respiratory infections (ARI) and adult chronic obstructive pulmonary disease (COPD), with growing evidence of low birth weight, cataracts, lung cancer, otitis media, and tuberculosis.”[[14]](#footnote-14) [[15]](#footnote-15)

Women and children suffer disproportionately from indoor air pollution. Acute respiratory illness is one of the main causes of ill health in children. It includes a wide range of effects, including viral and bacterial infection of the lungs and respiratory tracts. It can also be caused or triggered by a large variety of risk factors, especially exposures to air pollution.[[16]](#footnote-16)

In Senegal, the leading cause of death, is Lower Respiratory Infection which claims 16% of total mortality – largely from children 4 and under.[[17]](#footnote-17) One of the leading causes of respiratory infections is exposure to inefficient cook stoves.

Pregnant women are at higher risk for adverse birth outcomes such as lower birth weight due to higher levels of exposure to CO and carbon particulate matter**.**[[18]](#footnote-18)For our sub-sample the women who wore the CO tube over the lunch meal, 17% carried a child on their back while cooking. From the six month CO survey, women cooks are on average age 26 (median of 24) and are of prime childbearing age. Thus, high levels of CO are particularly deleterious for the health of the women population which cooks and their children.

# Project Design

## Solar Energy

Proponents claim solar energy for cooking has the following advantages (cite xx):

1. Many poverty-stricken families worldwide spend 25% or more of their income on cooking fuel. Fuel for solar is free and abundant.
2. Further, money saved can be used for other pressing development needs including food, education, health care, etc.
3. Solar cooking is also convenient and saves time. The food does not need to be stirred and won’t burn. Food can be placed in a solar cooker and left to cook, unattended for an hour at a time while other activities are pursued. By eliminating the costs of fuel by solar, women and girls who bear the burden for cooking and gathering fuel, have more income and time to spend on more lucrative enterprises including education.
4. Further, pots used for solar cooking are easy to clean, which can be especially valuable for women who must walk many kilometers to collect water.
5. This solar cooker is easily portable, allowing for solar cooking at work sites such as nearby farms.
6. Solar cookers help preserve nutrients in food and thus improve health.

The government of Senegal had expressed strong interest in solar power (cite xx) and Tostan had plans to roll out solar ovens nationally. If a rigorous evaluation showed the solar ovens were effective, we hoped it would facilitate greenhouse gas credits for a broader roll-out. If the evaluation showed the solar ovens were ineffective, we hoped it would redirect resources towards higher value interventions.

## The intervention

The HotPot solar oven was designed and engineered by Solar Household Energy (SHE). SHEm an NGO founded in 1998, has significant experience in the distribution and marketing of solar ovens. SHE has distributed over 5000 of its HotPots in Africa and Latin America.

 Under a tropical sun the HotPot can cook rice in under an hour, a chicken in about two hours, and beans in four hours. On a sunny day in Senegal the oven can be put out as early as 8 or 9 am and can cook as long as 4 to 5pm. Appendix xx describes the HotPot in more detail.

The choice of the Hotpot was based on a needs assessment conducted by SHE in Mekhe, Senegal. They worked with 20 households and reported that the ovens fit the communities’ needs and had very high uptake.

In order to spur adoption, for this pilot study, Tostan heavily subsidized the solar oven so its cost to villagers was about $5. This price represents between a 90-95% subsidy, as import costs of the Hotpot proved to be very high.

On average our sample reported a combined family income of the equivalent of US $18.50/week, while women reported earning on average $6.50/week. Thus the $5 cost of the solar oven represents 19% of women’s monthly income or 7% of the household monthly income.

In order to assess the effects of solar ovens on rural households average fuel consumption, health, and time spent collecting biomass fuel[[19]](#footnote-19) the Center for Evaluation of Global Action (CEGA) worked with SHE and Tostan Senegal[[20]](#footnote-20) to design a randomized controlled trial which took place from April to October 2008. The study design is that of a phased intervention which measures the impacts of a treatment group that received the solar oven at the baseline survey and a control group that did not receive the solar oven until the 6-month follow-up survey. The phased roll-out fit well with the existing constraints of the intervention. Due to shipping constraints of the HotPot from Mexico (where they were produced) to Senegal, only half the population could receive the ovens at one time.

The study design outlined a total of 1000 households in 20 rural villages in the Thies region in Senegal. All 20 villages in our sample are rural, and of varying size and distance to the city. In each village a total of 50 households were allowed to enroll in the program. Of these 50 households at baseline, 25 households were randomly selected to receive the solar oven immediately, while 25 households were selected to receive the ovens after the 6 months evaluation. All households were asked to participate in three survey waves:

* Baseline: (April 2008)- Treatment households receive oven
* One-month follow-up: (May 2008) One month after Treatment receive oven.
* Six month follow-up: (October 2008) 6 months after Treatment receive their oven and at the end of the village visit the Control Households receive their ovens.

# Data

We collect data at baseline and six month follow-up surveys on household weekly fuel use, time by entire household spent collecting fuel, cooking practices, self reported respiratory and other health related symptoms for women and their children to cooking, as well as statistics on wealth, education, marital status, and family size. In addition to the baseline and six month follow-up surveys a subset of our sample was selected on both day 1 and day 3 to measure the carbon monoxide exposure for women cooking for the lunch meal and an accompanying CO survey about the type of cooking structure and time spent cooking lunch and types of fuel actually being used. Further, at the six month follow-up, a survey was enumerated on the village focal point women to understand a wide variety of village level fixed effects including- the distance from the closest hospital, elementary, middle, and high school, and to local forest and well, as well as information on money lending in the village, etc.

Further, our surveys at the six month follow-up benefitted from our knowledge gained in the baseline and 1 month follow-up survey.

In particular, one such refinement included the discovery that a significant portion of our participant households are part of multi-household compounds, typically due to polygamy, although sometimes containing multiple brothers or other relatives. Despite, having requested for only one woman per compound to participate in the solar oven program, this policy was not followed. Thus, 28% of our sample (209 households) were part of a compound with another treatment or control. The result is that 38% of treatment households and 25% of control households have another treatment or control household in the compound. Given this phenomena we test whether our results change when we account for compounds with more than one study participant.

Stove Utilization:Stove usage is measured with an ibutton, a computer chip enclosed in a 16mm thick stainless steel can.[[21]](#footnote-21) We use the term Stove Usage Monitor (SUM)[[22]](#footnote-22) We programmed the SUM’s to take temperature readings every 30 minutes. Thus, they provide a reliable estimate of daily stove usage per household. We installed SUMs the first month treatment homes had the solar ovens and in month six. There are two months which are measured- the first month- April-May and the sixth month- October-November. This objective data is contrasted by self-reported usage rates and observed usage rates on six month follow-up village household level visits, to examine how reliable self-reporting may be. We asked women for self-reported stove usage over the last week prior to both the one month follow-up and six month follow-up survey.

Wood use: Households were asked on all three surveys to report the amount of each type of fuel- charcoal, gas, animal dung, farm waste, and wood- they used last week. In addition to this qualitative self-report, on all three surveys, all households were asked to draw from a pile of wood the estimated amount of wood they used to cook lunch with yesterday as well as the number of people they cooked for. On the six month follow-up survey households were asked to draw from their own wood pile and to estimate not only the amount of wood they used to cook lunch yesterday but the amount of wood they used to cook all the day’s meals yesterday. The wood measurements were adapted to include a daily measure of wood because at the one month follow-up survey we found that the majority of households were using their solar oven to prepare dinner and thus the lunch measure would not be sufficient to capture any reduction in wood use for households.

### Fuel Costs

Respondents reported how much time they and their families spent last week collecting fuel. We also asked the financial cost of wood, charcoal and gas fuel over the last xx.

The baseline survey asked women to list how many times they collect wood per week, and each time they collect how much time they spend in hours collecting fuel. These questions were repeated for other household members. A significant portion of our households (25%) collected wood in bulk for a long period of usage. Thus, the in six-month follow-up we updated our survey to capture this phenomenon by xx.

### Exposure to carbon monoxide

To measure exposure to carbon monoxide (CO) while cooking lunch, on a subset of our population, enumerators distributed Drager Color Diffusion Tubes (from here forward referred to as CO tubes) in the morning (between 8:30-10:00am) and collected them about 5 hours later (2:00-3:30 p.m.) after lunch. These tubes are attached to the cook’s attire and households were selected randomly to receive the tube. The only criteria (other than the household’s permission) is that the household was cooking with wood, thus any households found cooking with gas were skipped. Using the principles of gas diffusion and colorimetric reaction, the Diffusion Tubes allow the reader to reliably measure the Time Weighted Average (TWA) concentrations of CO resulting in CO ppm/hour measure of the lunch meal.

The team measured CO tubes on all three surveys in the village on a subset of households. However, because of the structure of the visit, the six month follow-up measurement provides the most precise measure. This is attributed to the fact our enumerators went house to house instead of holding a central village meeting as in the first two days. Going house to house allowed the team to deliver the CO tube much earlier and catch 80% of households before they had started the fire and thus provide a much more accurate level of readings. For baseline and one month follow-up surveys only 20% of households tested received the CO tube before their fire for lunch was started. Given the late distribution for the baseline and the one month follow-up of the CO tubes we concentrate on the data reported at the six month follow-up in this report.

Because of high humidity levels in the region of study we have followed recommendations from the CO tube manufacturer to adjust our sample uniformly for humidity levels.

### Health

Respondents reported seven symptoms of respiratory illness over the last 2 weeks: 1) Fever; 2). Sore throat; 3. Runny/stuffy nose; 4). Cough; 5). Wheezing or trouble breathing; 6). Woke up with chest heaviness at night; and 7). Coughed up mucus. At the six-month follow-up, respondents also reported on these symptoms for their husbands (to serve as a partial control, as husbands have low exposure to smoke from cookfires).

In addition to respiratory illness symptoms, we followed Smith et al. (2007) and also asked about four common problems during cooking: eye discomfort, headache, irritated throat, and back pain.

# Methods

Because the treatment group has been randomly selected, individuals assigned to the treatment and control groups differ in expectation of core results only through their exposure to the treatment. In the Summary Statistics section we test whether our sample has been successfully randomized and find that it has.

Analysis of our core study outcomes begins with examining the single and double difference of means between our two groups.

$\hat{D}=\left[\hat{E}\left[Y\_{1}^{T}|T\right]-\hat{E}\left[Y\_{0}^{T}|T\right]\right]$ Single Difference (1)

$\hat{DD}=\left[\hat{E}\left[Y\_{1}^{T}|T\right]-\hat{E}\left[Y\_{0}^{T}|T\right]\right]- \left[\hat{E}\left[Y\_{1}^{C}|C\right]-\hat{E}\left[Y\_{0}^{C}|C\right]\right]$ Double difference (2)

To measure percent changes we standardize by the mean baseline level of the treatment group. Thus, in the example of kilograms of wood used over the lunch meal for the treatment:

$Single Difference=\frac{\left[Wood Lunch\_{T}^{6 mo.}-Wood Lunch\_{C}^{Baseline}\right] }{Wood Lunch\_{T}^{Baseline}}$ (3)

We also analyze the core impacts of the solar oven- fuel use, wood collection time, carbon monoxide exposure, and self-reported health symptoms using OLS regressions controlling for baseline characteristics and outcomes.

The basic regression to test our outcome variables, labeled $Y\_{i}$ - wood use, time spent collecting fuel, carbon monoxide exposure, and the mean of 7 respiratory symptoms- can be written:

$Y\_{i}= α+ βT+ ϵ\_{i}$ (4)

Here T is a dummy for assignment to the treatment group. Equation (4) can be estimated with ordinary least squares, and it can easily be shown that:

$\hat{B}\_{OLS}= \hat{E}\left(T\right)- \hat{E}(Y\_{i}|C)$ (5)

This result tells us that when a randomized evaluation is correctly designed and implemented, it provides an unbiased estimate of the impact of the program for the sample being study.[[23]](#footnote-23) As is common practice we begin with the most basic regression model (4) and build from there. Using the example of wood use over the lunch meal, our regression analysis includes the regression equation (6) below which tests whether the treatment group had a significant change in wood kilograms consumed in the lunch meal at the six month follow-up. [[24]](#footnote-24)

(6). $WoodKg\\_lunch\_{6month}= α+ βT+ ϵ\_{6 month}$

The regression specifications we present in this paper are first for households which cook for 12 persons or less and are written below in equation (7) and (8). Here *Wood use6* is either lunch or daily wood use and the time periods 0 is shorthand for baseline survey data while 6 is shorthand for the six month follow-up.

*Wood use6 = b1 cooked for0  + b2 cooked for02 + b3 #cooked for6 + b4#cooked for62.+b5 Lunch wood use0 + b6 Treatment*  (7)

*Wood use6 = b1 cooked for0  + b2 cooked for02+ b3 #cooked for6 + b4#cooked for62.+b5Lunch wood use0 + b6Treatment + b7Treatment with more than 1 Treatment in compound* (8)

Further we run a regression which does not restrict to those who cook for 12 persons or less which is written below in equation (9).

*Wood use6 = b1 cooked for6persons or less6  + b2 cooked for 7 to 12 persons6 + b3 cooked for 13 persons or more for6 + b4cooked for 6 persons or less \* treatment6.+b5 cooked for 7 to 12 persons \* treatmen6 + b6cooked for 13 persons or more \* treatment (9)*

Equation (9) regresses the wood used by households at the six month follow-up separately for both daily kilograms used and daily kilograms/person on dummy variables indicating household size of six and under, household size of 7 to 12, household size of 13 and above, and treatment dummy variables interacted with each of dummy variables for different household size.

Our continuous measures such as wood kilograms, carbon monoxide, and so forth had large outliers. To avoid undue influence from a few observations, we compressed outliers to the 5th and 95th percentiles. We only compressed CO exposure from above as there were not small outliers.

## Rationale for Using Only Households with 12 members or less

The lunch meal in Senegal is the biggest meal of the day and is eaten in rural areas between 2-3pm. As the HotPot is solar powered, we hypothesized that the lunch meal would be the best meal of the day to use the HotPot and to replace the traditional stove. Thus, the study had been originally designed with the expectation that if the stove is adopted by households, the households would replace the traditional stove with the HotPot for the lunch meal.[[25]](#footnote-25) In fact the HotPot could not replace the traditional stove completely for the lunch meal as an average household had approximately 12 members (28% of the time with more than one wife), and the solar oven can cook for approximately 6 people. Thus, in order to see any effect of the HotPot on our outcome indicators we limit our sample to households who report cooking for 12 persons or less in our analysis. A compound represents a polygamous household where multiple wives live together, often in a circle of huts, fenced off from the rest of the village. It is common for multiple wives to share cooking responsibilities. Thus, we limit the size of households and compounds to 12 and under in order to see any effect of the solar oven.

# Summary Statistics

## Sample Size

In total our sample has 1113 households in our dataset (see Table 1). This includes the 25 households which withdrew from the program at the one month follow-up, the 15 which withdrew from the program at the six month follow-up, as well as a small sub-sample of what we call the comparison group (113 households). Households that withdrew from the program are households that were originally inscribed at the time of the baseline survey and subsequently withdrew from the program on either the 1 month or 6 month follow-up studies. In total 80% of the households which withdrew were from the treatment group while 20% were from the control group. For the 32 women which withdrew from the treatment group at either one of the follow-up studies, their ovens were repossessed and redistributed.

The comparison group is composed of women who expressed interest in the program and came to the village level meeting to learn more about the solar oven, but were not enrolled officially in the program. Women in the control group were most often not enrolled due to a limited number of ovens in the pilot phase. Because of the inherent limitations of the small sample size of the comparison group we use this group only for our carbon monoxide results.

At baseline there are 960 households of the envisioned 1000 intention to treat in both the control and treatment group, 792 took Survey 1, though only 736 of those households weighed wood. On Survey 3, at the 6 months follow-up, 906 households from the intention to treatment group took the survey, of which 810 also weighed wood.

We permitted other women from the village (usually from the same compound) to take the survey on behalf of the women inscribed in the program if the inscribed woman was not present. 47% of respondents at the six month follow-up were substitutes. Treatment households were slightly more represented at the six month follow-up with 50% of households (N=224) being represented while 43% of control households being represented (N=206). We had higher recorded substitutes at the six month follow-up in part because the survey occurred during fish smelting season, a high-commerce period, so many people were gone from their village. In addition, treatment respondents that had already received their solar oven had less incentive to be present in the village to take the six month follow-up survey than the control group, which was waiting for their HotPot. We record a higher number of respondents being represented at the six month follow-up than noted at the baseline survey (88% higher). This is also likely in response to a formal question being added on the six month follow-up to help identify households who were represented.

|  |
| --- |
| Table 1: Sample Size and General Attendance on Survey Day |
|  | Randomized treatment | Randomized control | Total Intention to Treat | Treatment with at least one other Treatment in Compound | Control with at least one other Treatment in Compound | Only One Control in Compound  |
|
| Number Receiving Lottery Ticket | 488 | 472 | 960 | 184 | 117 | 355 |
| Baseline Survey | Absent, but returned at follow-up | 4 | 104 | 108 | 2 | 22 | 82 |
| Original respondent | 430 | 305 | 735 | 168 | 89 | 257 |
| Original respondent absent, but another woman in compound responded for her | 35 | 22 | 57 | 14 | 6 | 16 |
| Total who Completed Survey | 465 | 327 | 792 | 182 | 95 | 273 |
| Baseline Wood Weighing | Yes | 438 | 298 | 736 | 170 | 78 | 220 |
| No, cook with gas | 19 | 17 | 36 | 1 | 3 | 14 |
| No, took survey but left before wood weighing | 27 | 29 | 56 | 12 | 17 | 53 |
| Six Month Follow-up Survey | Withdrew from Study at either 1 month follow-up or six month follow-up | 32 | 8 | 40 |  0 | 0  |  0 |
| Absent at Six month follow-up | 8 | 11 | 19 | 0 | 10 | 1 |
| Original respondent | 246 | 230 | 476 | 72 | 50 | 135 |
| Original respondent absent but another woman in compound responded for her | 224 | 206 | 430 | 95 | 53 | 153 |
| Total who Completed Survey | 470 | 436 | 906 | 167 | 103 | 288 |
| Six month follow-up Wood Weighing | Yes | 419 | 391 | 810 | 167 | 103 | 288 |
| No, cook with gas | 47 | 47 | 94 | 8 | 8 | 39 |
| Six month follow-up  | Sub-sample carbon monoxide tube | 221 | 136 (+90\*)= 226 | 452 | 86 | 32 | 104 |
| \*= Comparison group |

For the baseline we had less recorded wood weighing because the wood weighing was a second station separate from the household survey. Thus a portion of households took the survey but did not continue on to the wood weighing station despite the best efforts in the field to encourage women to complete the wood weighing station.

We do not include data from the one-month follow-up in our core results because only 9% use the solar ovens (according to the stove usage monitor) during the first month. This rate is too low to detect any changes in wood use and thus we focus our analysis on the difference between the baseline and the six month follow-up where usage is up to 19% of the time.

## Household size

There are several measures we undertake to estimate household size and the number of people the respondent cooks for. In the baseline survey we ask the respondents to list everyone who is in their household. A household is defined in such a way to account mainly for people the woman may potentially cook for. Enumerators read aloud the following definition to each woman before asking her to list every member of her household who adhered to the following criteria.

1. The people living in the household/compound are there all the time.
2. The guests in the household who have passed more than two weeks in the household.
3. When given polygamy, if the houses/rooms of women are close to one another it is considered one household/compound.
4. If you have children that do not live with you, Please do not give their names.

This criteria was designed specifically to encourage women to list only members of the household who were present on a daily basis; that is, not to include co-wives living in another village or children who live apart. It turned out that it is not obvious that the woman cooks all meals for all members of her household. At baseline, 68% of women report sharing cooking responsibilities intra-household.

To determine how many people women in our sample cook for, they were asked at the same time they weighed wood, how many people they cooked for yesterday. Thus, the self reported number of people women cook for yesterday is how we determine size of household for whom she cooks. At both the baseline survey and the six month follow-up women report how many people they cooked for (see Table 1 below). Thus, when we define wood kilograms/person per household; we use the number of kilograms of wood that women participants report divided by the number of members of their household that they cook for. If women in our sample are part of a compound- or part of a multi-household family- we still determine kg/person the same way, or the number of kilograms she uses to cook divided by the number of people she cooks for. When we analyze wood used for the lunch meal and daily wood used we use only the subset of households which have 12 persons or less.

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| Table 2: Household Size and Number of People for whom Women Cook |
|    | Treatment | Control |
| Baseline  |   | n | mean  | Med.  | Std. Dev | n | mean | Med. | Std. Dev |
| Household Size  | 465 | 12 | 12 | 8.1 | 327 | 11.4 | 11 | 7.3 |
| No. People Cooks Lunch For | 459 | 13.82 | 13 | 6.7 | 313 | 12.77 | 12 | 6.1 |
| 6 month follow-up | No. People Cooks Lunch For | 434 | 11.69 | 10 | 6.5 | 409 | 11.03 | 10 |  6.1 |

From Table 2, it can be noted that treatment households report cooking for slightly more people (median 13) than controls (median 12) on the baseline survey, and slightly more than they report in their household (median for treatments 12). At the six month review both treatment and control households report cooking for slightly fewer (median 10) persons than in the baseline. It could be that there is simply a high level of variance for who women cook for from day to day. Another potential reason for the level change for number of people women cook for could be due to the higher level of representation of women at the six month follow-up, and thus more estimates at the six month follow-up. Or as we do not ask women to list all their household members at the six month follow-up, perhaps there is more room for estimation and error when asked how many she cooks for daily.

The sum of all household members for the intention to treat households recorded on Baseline number 11,529 persons. The average household size for our sample is 12 persons. Of that sample 53% are female. As is consistent with poor, underdeveloped countries, the largest percentage of the sample population are young; 60% are 24 and under while 76% of the sample is aged 34 and under.

### Indicators of poverty

Education levels are low, with 94% of those over age 50 and 48% of youth 13-18 reporting zero or missing education[[26]](#footnote-26). Further, other health symptoms associated with cooking including- irritated throat, headache, sore eyes, and back pain while cooking range between 79-91% of the sample at baseline (see Table 2b). Given the extremely low level of formal education and the high burden of disease associate with cooking, a new stove appropriate for the communities has the potential to cause substantial health and education changes for women.

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| Table 2b: Baseline Percent of Total1 Surveyed Reporting Symptoms either Sometimes or Always while Cooking |
|  | Treatment  | Control |
| Irritated throat while cooking (%) | 83%  | 83% |
| Headache while cooking (%) | 84% | 80% |
| Sore eyes while cooking (%) | 88% | 91% |
| Back pain while cooking (%)  | 81% | 79% |

1. Total is the intention to treat group.

Further, households cook in four different types of kitchens or cooking structures (see Figure 2). From the six month carbon monoxide tube survey, our enumerators most frequently observed households cooking in a semi-enclosed cooking structure with at least one window (44% of the time) and 23% cook completely enclosed.

## Wood Use and Seasonal Trends

Households use a variety of fuel sources on a daily basis and thus have multiple stoves. In addition to our households being primarily wood users on average, 60% of households report they use gas to reheat meals at the baseline survey and 25% report they cook breakfast with gas. We find large seasonal differences in wood use between our data from the baseline Survey conducted in April/Early May (in the end of the dry season) and the 6 month follow-up conducted in October (directly after the rainy season)[[27]](#footnote-27).

From Figure 3 we see that there is a drop off in wood purchased across the entire sample 7% and 13% drop in charcoal use and a 1% increase in gas use. One hypothesis for this seasonal change is perhaps wood becomes more scarce at the end of the dry season right before the rainy season and thus families substitute more purchasing fuel for collecting. This hypothesis is supported by Figure 4 below which shows a 82% decrease in spending on wood from the baseline survey and a corresponding 59% decrease in spending on charcoal.

The main observed seasonal differences of economic activities is a sub-sample of our villages had women who were involved in selling mangos during the season of April/May. Thus, it is possible that women have increased demands on their time during this period and perhaps households substitute purchasing fuel for collecting. In contract, many women tend to harvest their local farms in October after the rainy season.

## Wood Collection Practices

Households report a wide variation between households on fuel gathering techniques. At baseline, 45% of women report they collect wood while 51% of women report others in their household collect wood. 15% of households report both the respondent and other family members collect wood. This said, 34% report they primarily buy wood, and 30% both collect and buy wood. From the medians- 50% of women report that the wood they collect lasts 4 days. While at the 75th percent level the wood they collect lasts 30 days. And at the 25th percent level wood they collect lasts 2 days. Thus, we understand that on average our sample collects wood on a weekly basis though a smaller subset of the population (25%) stockpiles on a monthly basis. Finally, Table 4 (below) synthesizes the results and shows on average women spend 6-7 hours/day cooking all three meals daily. When we add the time women collect fuel this is another hour/day. Women spend between 2.5-4.5 hours/day next to the cooking fire each day. In summary, women spend 7-8 hours a day cooking and collecting firewood- equivalent to a full day of work.

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| Table 4: Sample Average Time Spent Cooking (Baseline Survey) |
|   | **n** | **Median** |
| Time Spent Cooking Breakfast  | 875 | 1 hour or less |
| Time Spent Cooking Lunch  | 652 | 2- 3 hours |
| Time Spent Cooking Dinner | 834 | 2-3 hours |
| Total Time Spent Cooking Daily |  | 6-7 hours |
|   |
| Time Spent Sitting Next to Fire at Breakfast | 876 | 30 minutes |
| Time Spent Sitting Next to Fire at Lunch | 650 | 1-2 hours |
| Time Spent Sitting Next to Fire at Dinner | 834 | 1-2 hours |
| Total Time Spent Next to the Fire. |  | 2.5-4.5 hours |

## Carbon Monoxide Exposure

We analyze carbon monoxide exposure measured over the lunch cooking period at the six-month follow-up. For the CO levels there is no disaggregation for households 12 or less, due to the smaller sample size receiving the CO tubes.

74% of the households that received CO tubes had not already lit their fire.

At the six month follow-up the field team also incorporated a separate CO survey and our enumerators noted that 27% of women had irritated or red eyes from the cooking fire upon their visit. Further, 16% of women had children on their back while cooking. Public health specialists note that pregnant women are at higher risk for adverse birth outcomes such as lower birth weight due to higher levels of exposure to carbon monoxide and carbon particulate matter**.**[[28]](#footnote-28)Because it is culturally inappropriate to ask if a woman is pregnant the question was not included in our survey. However, the average age of cooks in our CO sample is 26 years of age (median of 24 years). Thus, given women in our baseline survey who have a mean age of 23 and on average reported having 3 children, we can induce that women who cook are of prime childbearing age and thus high levels of carbon monoxide are particularly deleterious for their health. Most women in our sample have or will lose a child, and thus cutting indoor air pollution would benefit the health of children as well as mothers.

The average carbon monoxide PPM/hour exposure is 7.5 over all households sampled (Table 14). The World Health Organization cites 25 ppm as the average limit for any 8 hours exposure.[[29]](#footnote-29) Given on average over our entire sample women report a total cook time of 6-7 hours daily this results in over 45 ppm CO daily. Thus, our sample of cooks had daily exposure to carbon monoxide roughly twice what the WHO deems safe.

## Self Reported Health

Women in our sample have on average 5 children each, and only 2% of women in our sample report no having no children. From the six month follow-up we find the mortality rate of children under five of 115 per 1000 live births.[[30]](#footnote-30) Of the total children born to women in the sample, 49% of children died between 0-4 years of age; 35% of children were “born dead”[[31]](#footnote-31), and 15% of children died between 5-25 years of age. This indicates an overall high burden of disease on children under five in our communities.

When women reported on their husbands, the men had only 2/3 as many respiratory symptoms (2.63, not 3.96; control women, 6-month follow-up). While some of the women’s disadvantage may be due to measurement error, the difference is also consistent with problems related to exposure to cookfires (or to female disadvantages more generally).

## Is the Sample Balanced?

The averages characteristics of the treatment and control groups are very similar at the baseline survey. Of the small reported differences the treatment group reports being slightly more employed (76%) versus the control group (64%). However, the control group reports slightly more self-employment- 5% higher than the treatment. Further, the woman in the treatment group report earning slightly more per week than the control. However, this is balanced by women in the control group who report receiving slightly more income per week from their husbands than those in the treatment group. When we put together the amount women reported earning per week and the amount women report receiving from their husbands, overall women in the control group report earning a little less than a dollar more a week than women in the treatment group.

Further, in terms of wealth approximation by household structure both the treatment and control households have on average the same type of household dwellings. Both report 82%/83% of households have roofs made of tin and 76%/71% have cement floor with carpet in their houses. Households also report similar levels of consumption of rice and flour per week. Control households report consuming slightly less of both than treatments (8% less rice and 4% less flour), however these are relatively small differences.

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| Table 5: Summary Statistics on Age, Gender, Education, Income and Employment |
|   | Total Sample | Treatment  | Control  |
| n | Average | n | average | n | average |
| Age | 13,080 | 18 \* | 6799 | 18\* | 4392 | 18\* |
| Gender Female (Male) | 7231 (6343) | 53% (47%) | 3751 (3276) | 54% (46%) | 2367 (2135) | 53% (47%) |
| Portion of Sample with No Education | 8819 | 65% | 4562 | 65% | 2853 | 63% |
| Portion of Women Inscibed in Program with No Education | 835 | 78% | 415 | 76% | 285 | 78% |
| Employed? | 953 | yes (69%) | 477 | yes (76%) | 336 | yes (64%) |
| Occupation if employed | 302 | housework (84%) | 127 | housework (83%) | 117 | housework (85%) |
| Woman's Weekly Salary (CFA)  | 484 | 5429 | 279 | 6139 | 156 | 4841 |
| Self Employed? | 797 | yes (89%) | 413 | yes (87%) | 275 | yes (92%) |
| Type of payment woman receives for work | 265 | unpaid (51%) | 137 | unpaid (45%) | 94 | unpaid (53%) |
| If married, does your husband work?  | 892 | yes (83%) | 448 | yes (82%) | 311 | yes (86%) |
| The main occupation of husband?  | 678 | driver (both taxi and horse) (28%) | 332 | driver (both taxi and horse) (29%) | 240 | driver (both taxi and horse) (27%) |
| If married, is husband self-employed?  | 760 | yes (68%) | 384 | yes (68%) | 265 | yes (67%) |
| Type of payment husband Receives for work | 371 | monthly salary (57%) | 192 | monthly salary (59%) | 132 | monthly salary (57%) |
| How much money did your husband give you last week?  | 740 | 10,051 | 375 | 9504 | 260 | 11091 |
| Average kg/week of rice your family consumes | 945 | 3.13 | 472 | 3.21 | 334 | 2.97 |
| Average kg/week of rice your family consumes | 577 | 3.08 | 294 | 3.07 | 200 | 2.94 |
| Key Household decision maker | 935 | husband (57%) | 466 | husband (56%) | 329 | husband (61%) |
| Material of your home's roof?  | 948 | tin roof (82%) | 474 | tin roof (82%) | 277 | tin roof (83%) |
| Does your home have a floor other than dirt?  | 948 | yes (95%) | 474 | yes (96%) | 334 | yes (95%) |
| Type of floor in your home?  | 854 | cement with carpet (74%) | 428 | cement with carpet (78%) | 310 | cement with carpet (71%) |
| Baseline Wood Kg per Person over the lunch meal |
|  | Total Sample | Treatment  | Control  |
|  | n | average | n | average | n | average |
| Baseline Lunch Kg of Wood per person  | 838 | .585 | 438 | .566 | 296 | .542 |
| \* indicates the median; All data for this table is from the baseline survey, collected April 2008. |

To further test if our sample is balanced, we run t tests on household size and number of people women report cooking for at the baseline survey. We find no significant difference for reported household size between the two groups. Though a significant difference between controls and treatments in the number of people they cook for at baseline is found at the 99% level. Control households report cooking for 12.7 persons while treatments report 13.8 persons (mean). However, when we run a t-test on the number of persons women report cooking for at the six month follow-up we find that the difference is not significant between the treatment and control groups.[[32]](#footnote-32) Thus, while this difference is unexpected, it could be due to the fact that there are a lower number of control households present at the baseline survey and thus biasing the number of people reported cooking for downwards.

To test whether there are significant differences between the control and treatment groups we run a test on the reported kilograms of wood consumed at the lunch meal. We find no significant difference in the reported lunch kilograms of wood consumed at the baseline survey between the two groups

For time spent collecting wood, a t-test shows there are no significant differences between the control and treatment groups at baseline in either the time respondents or their family members spend collecting wood. In addition, there is no significant difference between the two groups in the time the wood lasts which they collect- as both treatment and controls report the wood they collect lasts 4 days on average. Thus, we can conclude that at baseline the two groups were successfully randomized[[33]](#footnote-33)

Overall, there are no large differences found between the treatment and the control groups for self reported employment, and income proxies. There are no notable differences in type of housing between the two groups. The majority of both the Control and Treatment Groups report that their husband makes decisions about major household purchases. On average married women in both groups reported the employment status of their husband as employed (68% Treatment and 67% Control). And both groups report the main employment of their husband to be a driver of both a taxi and/or horse (29% Treatment and 27% Control). Further, t-tests on the baseline indicators for household size, wood consumed, time spent collecting fuel, and how long the fuel lasts show no significant difference between the treatment and control group. After examining the baseline wood collection and consumption as well as the income and employment characteristics we find no significant differences between the control and treatment group at baseline and thus we are confident the results of the randomization was successful.

# Solar Oven Usage

## Rates of Solar Oven Usage & SUMS

On average in the first month of having the solar oven, 9% of women in the treatment group use the stove on any given day. In the sixth month. 19% of women (on average) use the oven on any given day.

The more than doubling of usage from the first to the sixth month is partially a result of intensive ongoing village training during the first six months by stove specialists employed by the local NGO partner Tostan. Stove specialists visit each village on average twice between the 2nd and 6th month and for villages which the team found very low usage and or weak[[34]](#footnote-34) lead village level facilitators stove specialists stayed between 2-4 days in the village to individually visit women at home to provide additional training on how to cook with the solar oven.

This intensive training model proved successful at bolstering usage in previously low usage zones, except for the two villages located on the sea. These two villages[[35]](#footnote-35) proved to be the wrong environment for the solar ovens as the regular wind from the sea compromised the solar oven’s mechanics and cooking was impaired. Despite the limitations for cooking in this zone, demand was relatively high as both villages were at 40% over-subscribed with requests to buy the oven. One potential reason for this high demand is that this zone is a center for fish smelting and, thus, these villages suffer a tremendous burden of flies. Thus, woman may have liked the oven because its casserole dish sealed and you could store food in it away from the flies. If we drop these two villages, solar oven usage increased to over 20% of days in the remaining 18 villages. Nevertheless, even after doubling to near 20%, oven usage remained fairly low.

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| Table 3: Stove Usage Monitors  |
| First Month Usage of Solar Ovens  |
|   | 110 degrees F and below | N |
| Average Time Period Measured- No. of Days (median) | 24 | 457 |
| Average # of Uses (mean) | 2.24 | 457 |
| Daily Usage Rate | 9.3% | 457 |
| Average # of uses without Beach Villages(mean) | 2.2 | 418 |
| Daily Usage Rate without 2 Beach Villages | 9.2% | 418 |
| 6 Month Usage of Stoves |
| Average Time Period Measured- No. of Days (median) | 25 | 438 |
| Average # of Uses | 4.76 | 438 |
| Daily Usage Rate | 19.0% | 438 |
| Average # of uses without Beach Villages(mean) | 5.1 | 396 |
| Daily Usage Rate without 2 Beach Villages | 20.4% | 396 |

The SUM’s were important in measuring objective measures of solar oven usage as at the six month follow-up respondents report on average woman use the solar oven 38% of the time– or double the SUM usage rate of 19%. On the day of our 6 month village visit, for the 17 of the 20 villages where the weather was sunny, we found 61% of women using their solar ovens– or more than three times the actual usage rate.

## Feedback for Solar Oven

A series of questions at the six month follow-up for women in the treatment group on feedback and usage of the solar oven are detailed below. In summary:

* For women in the treatment group only 3% of their husbands ever complained about the solar oven over the six months period.
* 18% of households reported sharing their solar oven with friends and families
* On average each household reported attending two trainings on how to use the solar oven over the 6 months of the pilot study.

The top three complaints after six months of usage are:

1). (49% of total responses) “To make the stove bigger”;

2). (35% of total responses) “To shorten the time of cooking”;

3). (13% of total responses) “To make reflector more durable”.

The top three favorite aspects[[36]](#footnote-36) of the solar oven are:

1). (31% of total responses) “It saves time”;

2). (25% of total responses) “It saves fuel”;

3). (24% of total responses) “I breathe less smoke.”

## How Participants Used the Solar Oven

As mentioned, we had originally designed the study with the expectation that if the oven is adopted by households, the households would replace the traditional stove with the HotPot for the lunch meal.[[37]](#footnote-37) If the HotPot replaced completely households’ primary fuel consumption of wood during the lunch meal than the HotPot had the potential to offset the largest biomass fuel use and carbon monoxide exposure of all three daily meals.[[38]](#footnote-38)

However, given the mismatch of the size of the HotPot (feeds 6 people) and the average family size (12 persons) the solar oven could not replace the traditional stove for the lunch meal. Due to the size constraints, in our final survey, only 8% of our sample used the HotPot to prepare part, or all, of the lunch meal. In fact, the main complaint of households about the solar oven was the size was too small (49%). Despite the constraints of the HotPot, our households proved innovative and as reported in Figure 1, instead of using the oven to cook lunch, used the oven to prepare the relatively smaller dinner meal (40%), snack (28%), and meals for children or diabetics apart (13%).[[39]](#footnote-39) From self-reported data on the six month follow-up women report on their cooking practices and time spent preparing meals daily.[[40]](#footnote-40) Of the women interviewed, 85%, 62 and 79% of the women interviewed report cooking breakfast, lunch and dinner daily.

When households were asked to describe which food they prepare most often with their solar oven, only 2% of households report preparing ceebu jen, the national favorite lunch dish, eaten most frequently for lunch in our sample. The food most frequently prepared with the solar oven by our households are vegetables and boiling water (22%), porridge (23%)-which is primarily a dinner meal-, eggs (15%) of the time which can be for snack and/or lunch or dinner, and sauce for the dinner meal (21%).[[41]](#footnote-41) In summary, the majority of woman used the solar oven to prepare the relatively smaller dinner meal.

# Impacts

## Wood Usage

We focus our analysis on wood usage the day prior to the six-month follow-up. Recall that women selected an appropriate bundle of wood from a large pile at their home to represent the daily wood used to cook all the meals yesterday and the wood used to cook lunch yesterday. Then, enumerators weighed each woman’s bundle. Because the solar oven cooks for only 6 or so people, we focus our analysis on respondents who cook for 12 persons or fewer.

Among households cooking for 12 or fewer at the six month follow-up, treatments use a mean of 9.9 (median of 9) kg of wood daily, while controls used a mean of 10.28 (median of 9.52). This equates to 4% lower mean (5% lower median) wood use of treatments (See Table A7 in Appendix 8 for full results).

Dividing by the number of people women report cooking for at the six month follow-up, treatments use a mean of 1.04 (median of 0.84) kg of wood per person, while controls use 1.12 (median of 0.90) kg of wood per person daily. This equates to a 7% (7% lower median) overall drop in wood use per person daily. This 7% drop in fuel used per person daily is significant at the 95% level.[[42]](#footnote-42)

As 28% (209) of our households are part of multi-household compounds, we can further segment our sample by compounds with more than one study participant per compound. In Table 6 we present the means for both the treatment and control groups in our sample of average wood used.[[43]](#footnote-43) Then we take the single and double difference of the change in the means in our sample groups over time.

### Wood Used over the Lunch Meal

The double difference of kg of wood consumed for the lunch meal for compounds of 12 or fewer shows a 6% drop for average treatment households versus controls (significant at the 95% level). While statistically significant, this drop is small and shows us again that the solar oven HotPot is too small for these extended families.

The results are not due to pre-existing differences given at the baseline measure treatment households used 6.81 kg of wood while control households used 6.68 kg of wood to cook lunch. Thus, the households show no significant difference in wood consumption at the baseline survey.

This relative decline is larger when we divide by the number of people in the household women cook for and the double difference result of kilograms per persons over the lunch meal shows a 14% drop in fuel used, significant at the 95% level. (We address the pontetial endogeneity of the number of people cooked for in the regression analyses, below.)

Dividing the treatment group into treatment households with at least one other treatment household in the compound for households cooking for 12 or fewer the mean wood kg per person is 0.54 (median 0.45) while control households report 0.62 kg (median of 0.50) of wood used per person at the lunch meal. This is a 10% drop in wood use for the lunch meal/person over the double difference and is significant at the 99% level.

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| Table 6: Single differences over the Lunch Meal Kilograms of Wood Used[[44]](#footnote-44) |
| (The six month follow-up-Baseline) / Baseline  | Wood Kg Used at the lunch meal in households and compounds with 12 persons and under (Std. error) | Wood Kg/pp Used at the lunch meal in households and compounds with 12 persons and under |
|  Average- Over All Groups (N= 841, Std error 1.6) | -18% | 1% |
|  Treatment (N=439, Std error 1.6) | -20%  | 0%  |
|  Control (N=298, Std error 1.6) | -14% | 14% |
|  Treatment with at least 1 other treatment study participant in compound (N=170, Std. error 1.6) | -19% | 5% |
|  Treatment with only 1 study participant in compound (N=269, Std. error 1.6) | -20% | -2% |
| Control with at least one other treatment study participant in compound (N=78, Std. error 1.5) | -12% | 8% |
|  Control with only 1 study participant in compound (N=220, Std. error 1.6) | -14% | 0% |
| Double Difference Results |
| Treatment – Control | -6% (\*) | -14%(\*) |
| At least 2 Treatment Study Participants in 1 Compound-Control | -5% | -10%(\*\*) |
| At least 2 Treatment Study Participants in 1 Compound-Control with only 1 study participant in compound | -5%(\*) | 5%(\*\*) |
| Control with at least 1 treatment household in compound – Control | 2% | -6% |
| \*\* (\*) = statistically significant difference in one-sided t-test at the 1% (5%) level;Note: All data has been top and bottom coded at the 5% level. |

### Daily Wood Consumption

In Table 7 are the results for the six month follow-up measure of total wood used to cook daily. This measure should most accurately record any drop in wood use due to the multiple meals cooked with the solar ovens. Treatment households use 6% less wood at the six month follow-up than control households. This effect is larger (14%) examining wood use per capita. As expected, this effect on wood use per capita is larger when looking at compounds with 2 solar ovens (10% drop in wood consumption versus the control group).

Further dividing the treatment group into treatment households with at least one other treatment study participant in the compound for households cooking for 12 or fewer the mean wood kg daily per person is 0.97 (median 0.80) while control households with only 1 study participant in compound report 1.18 kg (median of 0.94) of wood used per person daily. This is an 18% drop in daily wood used and is significant at the 99% level.

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| Table 7: Single Difference Daily Wood Usage Six month follow-up |
| (The six month follow-up-Baseline) / Baseline | Wood Kg Used daily for households and compounds with 12 persons and less | Wood Kg/pp Used daily for households and compounds with 12 persons and less |
| Treatment (N=418) – Control (N=391) | -4% | -7% (\*) |
| At least 2 Treatment Study Participants in 1 Compound (N=167)-Control (N=391) | -2% | -13%(\*\*) |
| At least 2 Treatment Study Participants in 1 Compound (N=167)-Control with only 1 study participant in compound (N=103) | -2% | -18%(\*\*) |
| Control with at least 1 treatment household in compound(N=103) – Control(N=391) | 5% | -13%(\*\*) |
| \*\* (\*) = statistically significant difference in one-sided t-test at the 1% (5%) level; Note: All data has been top and bottom coded at the 5% level. |

### Regression Results

Our baseline regression analyzes kilograms of wood used yesterday among a sample of compounds with 12 or fewer residents. In specification 1 we include only the treatment dummy and village fixed effects. The treatment effect is small and not statistically significant. <<Next draft will explore why the cross-tab loses significance. xx>>

In column 2 we add the number cooked for and its square, both at baseline and at the 6-month follow-up. Again, the estimated treatment effect is small and not significant. Column 3 adds a dummy for treatment households in compounds with one or more other treatments. Both it and the overall treatment effect are small and not significant. Column 4 adds baseline wood use at lunch and a number of household characteristics including the respondent’s salary last week, the amount of money the husband gave the wife last week, rice per person, flour per person, baseline wood kilograms used, and respondents shared cooking with others in the compound. The treatment dummy remains small and not significant.

The number of people a woman cooks for may rise if she has a solar oven. Thus, in col. 5 we instrument for the number she cooks for (and it square) at the 6-month follow-up, using the number she cooks for (and its square) from baseline as instrumental variables. The tests for the first stage show the instruments are strong xx. The treatment effect remains not significant. <<We will explore why its point estimate rises so much; possibly a coding error. Xx>>

In col. 6 we drop the restriction that households and compounds have fewer than 12 members and include several dummy variables interacting treatment with categories cooking for. Women cooking for 7-12 at follow-up use 0.09 kg. less wood than controls of that size (P < .05), but women cooking for 0-6 use 0.18 *more* wood than controls of that size (n.s.). Thus, the results overall suggest not treatment effect. Finally, in col. 7 we analyze wood use at lunch yesterday (instead of all day). Unsurprisingly, the treatment effect remains small and not statistically significant.

In results not shown we analyzed wood use over lunch using all of these specifications. In most cases we find a negative effect of treatment on wood use, but the coefficient is usually not statistically significant.

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| Table 8: Wood Consumption |
| Coefficient (standard error) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dependent variable = wood used yesterday… | All day | All day | All day | All day | All day | All day | **At Lunch**  |
|  | OLS | OLS | OLS | OLS | **IV[[45]](#footnote-45)** | OLS | OLS |
| Sample restricted to households size 12 or less | Yes | Yes | Yes | Yes | Yes | **No** | Yes |
| Treatment | .291 (.448) | -.056 (.484) | -.501 (.589) | -.710 (.615) | 2.95 (13.91) |  | -.010 (.251) |
| Treatment and cook for < 6 at follow-up |  |  |  |  |  | .179 (.132) |  |
| Treatment and cook for 7-12 at follow-up |  |  |  |  |  | -.091\* (.047) |  |
| Treatment and cook for >12 at follow-up |  |  |  |  |  | -.004 (.026) |  |
| #cooked for, baseline |  | .008 (.081) | -.003 (.082) | .063 (.095) |  | .007 (.038) | -.020 (.043) |
| #cooked for, baseline, centered2  |  | .005 (.004) | .006 (.004) | .002 (.004) |  | .003 (.002) | .003 (.003) |
| #cooked for, 6-month follow-up |  | .169\*\* (.045) | .172\*\* (.045) | .197\*\* (.045) | -1.91 (10.97) | .148 (.107) | .140\*\* (.023) |
| #cooked for, 6-month follow-up, centered2  |  | .000 (.002) | -.000 (.002) | -.003 (.002) | .332 (1.45) | -.000 (.002) | -.002 (.001) |
| More than one treatment household in the compound |  |  | .886 (.673) | .911 (.676) |  |  |  |
| Dummy Woman’s reports no salary (Salary=0) |  |  |  | -.170 (.619) |  |  |  |
| Dummy Woman reports high salary or USD $ 6/week equivalent  |  |  |  | .687 (.762) |  |  |  |
| Dummy Husband reports no salary (Salary=0  |  |  |  | .309 (.783) |  |  |  |
| Dummy Husband salary is middle of the spectrum or USD $21-$1/week equivalent  |  |  |  | -.104 (.580) |  |  |  |
| Kg. of rice consumed per capita |  |  |  | 5.26\* (2.43) |  |  |  |
| Kg of flour consumed per capita … |  |  |  | 2.51 (2.41) |  |  |  |
| Dummy for woman shares cooking hut |  |  |  | .411 (1.12) |  |  |  |
| Lunch Kilos of Wood at Baseline |  |  |  | .288\* (.122) |  |  |  |
| Village Fixed effects  | Yes | Yes | Yes | Yes | Yes  | Yes | Yes |
| R2 | .208 | .289 | .292 | .263 | … | 0.319 | .323 |
| N | 400 | 400 | 400 | 400 | 400 | 809 | 396 |

Notes: \*\* (\*) = statistically significant at the 1% (5%) level; †= statistically significant at the 10% level. Dependent variables are compressed to the 5th and 95% percentiles.

## Time Spent Collecting Fuel and Cooking Practices

We measure how much time women spent collecting wood per week, how much time other household members spent collecting wood per week, and how long the wood lasts the household which they collect each week. On our six month follow-up survey we included additional questions on how households collected wood, to capture cases with bulk wood collection lasting multiple weeks.

At the six month follow-up survey treatment households spent ten minutes less a week than control households collecting wood. This result is statistically significant at the 95% level according to the t-test[[46]](#footnote-46). The result however represents only a 1% drop in time spent gathering wood per wood as on average our households spend 2 hours a day collecting fuel.

|  |
| --- |
| Table 9: Number of hours per week woman and their families spend collecting wood each week |
| Estimated Time Woman Spends Collecting Wood Each Week | **n** | **mean** | **median** | **25%** | **75%** |
| 397 | 7.8 | 7.0 | 4.5 | 10.5 |
| Estimated Time Family Spends Collecting Wood Each Week | 315 | 8.1 | 7.0 | 4.0 | 10.0 |
| Estimated Time Both Woman and Family Spend Collecting Wood Each Week | 269 | 15.6 | 14.0 | 9.0 | 20.0 |
| Data from the six month follow-up. |

<<Missing observations on own time are presumably zero if they reported others’ time, and conversely. Thus, N should be near 450, not 269. Why N << 800? Are the rest zeros because they buy wood? ITT estimate includes all those zeros xx>>

|  |
| --- |
| Table 10: Time Spent Collecting Wood |
|  |  |  | Mean  | Median | Std. Dev | N | Difference in means |
|  | Total Intention to Treat Sample |  | minutes |  |  | (treat (a) – Control (a)) |
|  | Woman | 159.46 | 150 | 48.53 | 405 |  |
|  | Rest of Hhld | 160.36 | 150 | 52.6 | 321 |  |
| Treat (a) | Treatment | Woman | 158.91 | 150 | 45.07 | 188 | 0.1 |
| Rest of Hhld | 157.07 | 150 | 49.71 | 148 | -9.81(\*) |
| Control (a) | Control | Woman | 158.81 | 150 | 49.99 | 171 |  |
| Rest of Hhld | 166.88 | 150 | 56.03 | 135 | (Treat (b)- Control (c) |
| Treat (b) | Treatment households which are part of compounds with at least 2 treatment study participants | Woman | 155.9 | 150 | 47.91 | 76 | -0.28 |
| Rest of Hhld | 155.14 | 150 | 48.6 | 64 | -11.99 |
| Control (c) | Control households which have only 1 study participant in the compound | Woman | 156.18 | 150 | 50.13 | 126 |  |
| Rest of Hhld | 167.13 | 150 | 59.71 | 150 |  |
| \*\* (\*) = statistically significant difference in one-sided t-test at the 1% (5%) levelAll data is from the six month follow-up study which took place in October 2008. |

### Robustness tests

We ran regressions predicting time spent collecting wood similar to those for wood usage. Specifically, we begin with a specification to include the dependent variable and the dummy for treatment households, then we add village dummies, then we add the household characteristics and a dummy variable indicating households which report having more than one treatment in the compound.

The dependent variable is either time women spend collecting wood each week per amount of time; amount of time other household members spend collecting wood each week; and amount of time total household spends collecting wood each week per number of days fuel collected weekly lasts.

For all measures of time collecting wood and for all specifications the treatment effect was small and not statistically significant.

## Carbon Monoxide Exposure

At the six month follow-up survey there is no significant difference in carbon monoxide exposure over the lunch meal between our treatment and control group (see Table 13). Results show controls consuming on average 14% less carbon monoxide ppm/hour than treatments. These results are reversed for treatment households with more than one treatment participant in the compound versus the Control group with only one study participant in the compound- there is a 16% drop for treatments with more than one treatment participant versus controls with only 1 study participant. These results are seen in Table 12 below.

In the six month follow-up survey there are 221 treatment households, 135 control households, and 90 comparison group households who receive the CO tube. Because there is no reason that the comparison group households should be significantly different than the control group households for how they cook, it is possible to look at the results when both sub-groups are combined. The result of the control group plus the comparison group gives us 225 households, while the treatment has 221 households.

The mean for the treatment group is 7.92 CO ppm/hour and for the control plus comparison group is 7.11 (Table 11). The 0.80 CO ppm/hour lower exposure of the control group (or 11% difference) is not statistically significant (84% level).

|  |
| --- |
| Table 11: T-test for Carbon Monoxide PPM  |
| Two-sample t-test with equal variance  |  |  |  |  |
|  | Obs | Mean | Std. Err. | Std. Dev. | 95% Conf. Interval |
| Control | 135 | 6.953 | 0.772 | 8.973 | 5.426 | 8.481 |
| Treatment | 221 | 7.923 | 0.609 | 9.049 | 6.723 | 9.123 |
| Control - Treatment |  | -0.969 | 0.986 |  | -2.907 | 0.969 |
| t=-0.984 (P = 0.163) |  |  |
| Data from six month follow-up CO measures which have been top coded at the top 5%.  |

When we divide our treatment group into households which have at least more than 1 treatment study participant in the compound the mean is CO/ppm of 6.35, much lower than the entire treatment group of 7.92 and the wider control and comparison group average of 7.108. Importantly because control households had a high portion of treatment study participants in the compound, the mean for the control households with no other study participants in the compound is 7.58, higher than the total control household average of 6.95. Thus, as we compare particularly treatment households with more than one treatment participant in the household versus control households with only one study participant in the compound, we see the difference between the means of CO/ppm exposure per hour drop by 16%. However, again here the CO ppm/hour results are not significant. Thus we can conclude that the means are not statistically significant between the two groups.

|  |
| --- |
| Table 12 carbon monoxide PPM/hour (top coded) |
|   |   | Mean | Median | Std. Dev | N | Difference in means |
|   | Overall | 7.512 | 4.075 | 8.854 | 446 |  (treat (a) – Control (a)) |
| Treat (a) | Treatment  | 7.923 | 4.478 | 9.049 | 221 | 0.969 (+14%) |
| Control (a) | Control  | 6.954 | 3.75 | 8.973 | 135 | (treat (a)- Control + Compare Group (b)) |
| Control (b) | Control + Compare Group | 7.108 | 4 | 8.658 | 225 | 0.815 (+11%) |
| Treat (b) | Treatment households which are part of compounds with at least 2 treatment study participants | 6.352 | 3.846 | 7.082 | 85 |  (Treat (b)- Control (d) |
| Control (c) | Control households which are part of compounds with at least 1 treatment study participant | 7.374 | 4.298 | 8.344 | 52 | -1.226 (-16%) |
| Control (d) | Control households which have only 1 study participant in the compound | 7.578 | 4.037 | 9.794 | 103 | (Treat (b)- Control + Compare (e)) |
| Control (e) | Control + Compare households which have only 1 study participant in the compound | 7.186 | 4.027 | 8.524 | 169 | -0.834 (-12%) |

\*\* (\*) = statistically significant difference in one-sided t-test at the 1% (5%) level

In short there is no consistent treatment effect on exposure to carbon monoxide.

## Self-Reported Health

The single difference of prevalence of eye discomfort, throat irritation, back pain and/or headache while cooking show no significant differences between the treatment and control groups in the odds of having any of the reported symptoms at the 6 mo. follow-up (see Table 13). There is a slight drop in symptoms for treatment households, but this drop is mirrored in the control households. We cannot conclude that the drop in symptoms across time periods can be attributed to the solar ovens. Finally, we try to divide by Control households without another household in the compound, but still no significant difference.

|  |
| --- |
| Table 13: Single Difference Symptoms While Cooking |
|  | Treatment | Control |
| Sometimes  | Always | Yes= S+A | Sometimes  | Always | Yes= S+A |
| Irritated Throat while cooking (%) | 14% | -18% | -4% | 7% | -15% | -8% |
| Headache while cooking (%) | 14% | -15% | -1% | 12% | -12% | 0% |
| Sore eyes while cooking (%) | 14% | -14% | -1% | 9% | -13% | -4% |
| Back pain while cooking (%)  | 9% | -19% | -10% | 11% | -21% | -10% |

*Note*: Respiratory symptoms were reported over last 2 weeks and included fever, cough,…xx

At the six-month follow-up, the treatment group has slightly fewer respiratory symptoms on average than the control (3.85 vs. 3.96, difference n.s.). While not statistically significant, this result is consistent with small health benefits from the solar ovens.

In contrast, at baseline the treatment group has slightly more respiratory symptoms on average than the control (3.33 vs. 3.02, Figure 6). The double difference shows xx.

We ran a number of regressions predicting the number of respiratory symptoms and problems cooking a woman reports at the six month follow-up (results not shown). The first specifications follow those in table <<wood regressions xx>>. We then added the respondent’s symptoms at baseline and then her report of her husband’s symptoms. (Her husband’s symptoms are endogenous if some men catch an infection from their wives, which will bias coefficients towards finding no treatment effect.)

The indicator for treatment group is not significant in these regressions; however the coefficient is consistently negative when predicting the seven respiratory symptoms and positive when predicting problems while cooking. In short, there is no evidence that the solar oven improved health. This result is consistent with the lack of detectable reduction in exposure to carbon monoxide.

# Conclusions

## Summary

The stove usage monitor measured solar oven usage of about 9% per day in the first month treatment households had them. In the sixth month average use the oven rose to 19% of days. This more than doubling of stove usage between the 1st and 6th months reflects the important role of training in facilitating behavior change.

The stove usage monitor’s were critical in measuring oven usage. Solar oven users at the six month follow-up report using their solar oven 38% of days – double the SUM rate. When we observed solar oven usage at the six month follow-up (so respondents knew we ere in the villages), over half were using their solar ovens. Thus, we see clearly a role for SUM’s in future studies.

Treatment households use about 6% less wood at the six month follow-up than control households. As expected, this effect on wood use per capita is larger when looking at compounds with 2 solar ovens (10% drop in wood consumption).

At the six month follow-up treatment households spend ten minutes less a week than control households collecting wood (P<.05). The result however represents only a 1% drop in time spent gathering wood per week as households (on average) spend 2 hours a day collecting fuel.

Cooks in rural Senegal are exposed to roughly twice WHO guidelines for safe carbon monoxide exposure. There is no significant difference in carbon monoxide exposure over the lunch meal between our treatment and control group. Consistent with the lack of effect on exposure to CO, there were not robust reduction in health problems for treatment homes.

These results all point to the solar oven does reduce wood used and time spent collecting wood, though the impacts are small due to the inappropriate size of the solar oven for the household size.

## Implications

This evaluation stopped Tostan from pouring resources into a national roll-out of solar ovens. Thus, the evaluation was a success.

At the same time, a better needs assessment would have shown the solar oven was too small for these extended families prior to the roll-out for these first 20 villages. For example, our team detected this problem early in collecting the baseline. We continued the evaluation in part because it is important not to select completion of randomized controlled trials based on results during the study. <<explain xx>>

We are undertaking a similar randomized trial of improved wood-burning cookstoves in rural Ghana. We hope a suite of these studies will identify cost-effective stoves that can save lives and slow global climate change. Ideally, those findings will spur carbon credits to subsidize improved stoves with these important co-benefits.

## Appendix 2: HotPot Product Description

The HotPot is manufactured by Energia Portatil S.A. de C.V. in Monterrey, Mexico and is of the panel solar cooker variety. The HotPot was developed by Solar Household Energy and consists of the parts A-E pictured below.

 

The HotPot cooks on solar energy properties and is fueled by direct and indirect solar energy captured by the oven’s reflector. The sun’s rays penetrate the tempered glass “greenhouse” bowl, strike the 5-liter black enameled steel pot and convert to heat. The heat is retained around the pot by the greenhouse bow, achieving cooking temperatures. The HotPot is most efficient under a cloudless sky, in the shelter of cold winds and between the hours of 10 am and 4 pm. Ambient temperature has only slight impact on cooking performance. More important is the elevation of the sun in the sky. The higher the sun in the sky the better and thus the oven is most efficient in summer, spring, and fall.

To best use your HotPot select a site that will not be shaded by trees or buildings during the course of the day. Deploy your reflector on an elevated surface or the ground and orient the low side of the reflector to the sun. The performance of the oven depends on the reflector’s orientation to the sun as it arcs across the sky. For maximum efficiency an adjustment should be made each hour or so, see picture below.

#

## Appendix 4: Average Gas Usage

## Appendix 8: Main Wood Results

|  |
| --- |
| Table A7 : Main Wood Results \* |
|   | Wood Kg Used at the lunch meal in households and compounds with 12 persons or less | Wood Kg/pp Used at the lunch meal in households and compounds with 12 persons or less |
|
|   | Mean | Median | Std Dev. | No. Observ-ations | Mean | Median | Std Dev. | No. Obser-vations |
| Baseline Lunch Wood Use  |
|  Average- Over All Groups | 6.75 | 6.42 | 2.53 | 841 | 0.585 | 0.523 | 0.31 | 838 |
|  Treatment | 6.81 | 6.49 | 2.45 | 439 | 0.566 | 0.507 | 0.28 | 438 |
|  Control | 6.68 | 6.42 | 2.61 | 298 | 0.542 | 0.609 | 0.34 | 296 |
|  Treatment with at least 1 other treatment study participant in compound | 7.06 | 6.65 | 2.35 | 170 | 0.512 | 0.453 | 0.27 | 170 |
|  Treatment with only 1 study participant in compound | 6.65 | 6.22 | 2.50 | 269 | 0.600 | 0.549 | 0.29 | 268 |
| Control with at least one other treatment study participant in compound | 7.04 | 6.79 | 2.56 | 78 | 0.516 | 0.427 | 0.38 | 78 |
|  Control with only 1 study participant in compound | 6.55 | 6.30 | 2.62 | 220 | 0.642 | 0.574 | 0.31 | 218 |
|  Average-Over All Groups | 5.54 | 5.00 | 2.47 | 913 | 0.590 | 0.482 | 0.38 | 891 |
|  Treatment | 5.47 | 5.00 | 2.45 | 419 | 0.568 | 0.476 | 0.37 | 407 |
|  Control | 5.77 | 5.00 | 2.53 | 388 | 0.620 | 0.500 | 0.39 | 379 |
|  Treatment with at least 1 other treatment study participant in compound | 5.71 | 5.26 | 2.50 | 167 | 0.536 | 0.450 | 0.31 | 164 |
|  Treatment with only 1 study participant in compound | 5.31 | 4.75 | 2.40 | 252 | 0.590 | 0.500 | 0.41 | 243 |
| Control with at least one other treatment study participant in compound | 6.20 | 5.76 | 2.61 | 102 | 0.558 | 0.458 | 0.34 | 100 |
|  Control with only 1 study participant in compound | 5.61 | 5.00 | 2.49 | 286 | 0.642 | 0.500 | 0.40 | 279 |
| Six Month Follow-up Daily Wood Usage |
|   |  Wood Kg used Daily in households with 12 persons or less |  Wood Kg/pp Used Daily in households with 12 persons or less |
|   | Mean | Median | Std Dev. | No. Observations | Mean | Median | Std Dev. | No. Observations |
| Average-Over All Groups | 9.93 | 9.00 | 4.69 | 915 | 1.07 | 0.87 | 0.74 | 893 |
|  Treatment | 9.90 | 9.00 | 4.72 | 418 | 1.04 | 0.84 | 0.77 | 405 |
|  Control | 10.28 | 9.52 | 4.67 | 391 | 1.12 | 0.90 | 0.74 | 383 |
|  Treatment with at least 1 other treatment study participant in compound | 10.04 | 8.60 | 4.91 | 167 | 0.97 | 0.80 | 0.73 | 164 |
|  Treatment with only 1 study participant in compound | 9.69 | 9.00 | 4.60 | 251 | 1.08 | 0.90 | 0.79 | 241 |
| Control with at least one other treatment study participant in compound | 10.83 | 9.07 | 4.94 | 103 | 0.97 | 0.80 | 0.62 | 101 |
|  Control with only 1 study participant in compound | 10.08 | 9.52 | 4.56 | 288 | 1.18 | 0.94 | 0.77 | 282 |
| Note : All Data Presented has been top and bottom coded at the 5% level as is common practice to control for outliers. |

**T tests for Wood**

NOTE: All data is for wood kilograms that have been top and bottom coded and for households with 12 persons or less in the household. T tests are run for both equal and unequal variance assumptions, though t tests with unequal variance are only shown if they change significance of the outcomes.

Part 1: Ttests for Lunch Wood Use between Treatment and Control sub samples

To test whether the mean differences are significant between treatment and control households consumption of wood kilograms for the lunch meal at the six month follow-up the following ttests are run.

sample group 0=control 1= treatment

ttest Lunch kilos at the six month follow-up 0=control; 1=treatment with equal variance assumption

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 388 5.768166 .1285082 2.531317 5.515504 6.020827

 1treat | 419 5.468924 .1195749 2.447638 5.233881 5.703967

---------+--------------------------------------------------------------------

combined | 807 5.612798 .0876933 2.49117 5.440663 5.784932

---------+--------------------------------------------------------------------

 diff | .2992416 .1753082 -.0448736 .6433568

------------------------------------------------------------------------------

 diff = mean(0control) - mean(1treat) t = 1.7069

Ho: diff = 0 degrees of freedom = 805

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9559 Pr(|T| > |t|) = 0.0882 Pr(T > t) = 0.0441

Results the Treatments should have a lower mean than the controls and this is significant at the 95% level of significance.

To test whether the mean differences are significant between treatment and control households consumption of wood kilograms per person for the lunch meal at the six month follow-up the following ttests are run.

Sample group 0=control 1= treatment

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 379 .6197849 .0198905 .387226 .580675 .6588947

 1treat | 407 .5680339 .0184352 .3719154 .5317936 .6042742

---------+--------------------------------------------------------------------

combined | 786 .5929876 .0135547 .3800147 .5663799 .6195953

---------+--------------------------------------------------------------------

 diff | .051751 .0270809 -.0014086 .1049106

------------------------------------------------------------------------------

 diff = mean(0control) - mean(1treat) t = 1.9110

Ho: diff = 0 degrees of freedom = 784

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9718 Pr(|T| > |t|) = 0.0564 Pr(T > t) = 0.0282

Results: For the lunch kilogram per person at the six month follow-up treatment households should have a mean lower than controls and this result is significant at the 97% level.

To test whether there is a significant difference in wood consumed for the lunch meal between control households with only 1 study participant and treatment households with at least 2 treatment study participants in compound we run the following ttests.

0= control households with only 1 study participant in compound;

1=treatment households with at least 2 treatment study participants in compound.

Two-sample t test with equal variances

------------------------------------------------------------------------------

Variable | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

control\_ | 286 5.612405 .1471227 2.48807 5.322821 5.90199

 2treat | 186 6.013385 .1846232 2.517925 5.649147 6.377623

---------+--------------------------------------------------------------------

combined | 472 5.770419 .1152974 2.5049 5.543858 5.99698

---------+--------------------------------------------------------------------

 diff | -.4009797 .2354767 -.863697 .0617377

------------------------------------------------------------------------------

 diff = mean(control\_) - mean(2treat) t = -1.7028

Ho: diff = 0 degrees of freedom = 470

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.0446 Pr(|T| > |t|) = 0.0893 Pr(T > t) = 0.9554

The result is on average for the lunch meal kilograms of wood consumed the treatment households with at least 2 treatment study participants in compound.have a statistically significant lower mean at the 95% level when compared to the control households with only 1 study participant in compound;

We run the same ttest for lunch kilograms per person over the lunch meal.

0= control households with only 1 study participant in compound;

1=treatment households with at least 2 treatment study participants in compound

Two-sample t test with unequal variances

------------------------------------------------------------------------------

Variable | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

control\_ | 279 .6417965 .0239264 .3996505 .5946965 .6888966

 2treat | 184 .5305857 .0216453 .2936114 .4878793 .5732922

---------+--------------------------------------------------------------------

combined | 463 .5976004 .0169629 .364999 .5642664 .6309345

---------+--------------------------------------------------------------------

 diff | .1112108 .0322645 .0478052 .1746164

------------------------------------------------------------------------------

 diff = mean(control\_) - mean(2treat) t = 3.4469

Ho: diff = 0 Satterthwaite's degrees of freedom = 455.632

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9997 Pr(|T| > |t|) = 0.0006 Pr(T > t) = 0.0003

The result is on average for the lunch meal kilograms of wood consumed the treatment households with at least 2 treatment study participants in compound.have a statistically significant lower mean at the 95% level when compared to the control households with only 1 study participant in compound;

To test whether the average mean difference of lunch kilos consumed at the six month follow-up is significantly different between the control group and treatment households with at least 2 treatment study participants in compound we run the following ttests where:

0= control group

1=treatment households with at least 2 treatment study participants in compound

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 388 5.768166 .1285082 2.531317 5.515504 6.020827

2treatme | 167 5.707454 .1933852 2.499088 5.325643 6.089266

---------+--------------------------------------------------------------------

combined | 555 5.749898 .1069495 2.519563 5.539822 5.959974

---------+--------------------------------------------------------------------

 diff | .0607114 .2333799 -.3977081 .5191309

------------------------------------------------------------------------------

 diff = mean(0control) - mean(2treatme) t = 0.2601

Ho: diff = 0 degrees of freedom = 553

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.6026 Pr(|T| > |t|) = 0.7949 Pr(T > t) = 0.3974

The result is the difference between the mean kilograms of wood consumed between the control group and the group of treatments with at least 2 treatment participants in compounds is insignificant.

To test whether the average mean difference of lunch kilos per person consumed at the six month follow-up is significantly different between the control group and treatment households with at least 2 treatment study participants in compound we run the following ttests where:

0= control group

1=treatment households with at least 2 treatment study participants in compound

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 379 .6197849 .0198905 .387226 .580675 .6588947

2treatme | 164 .5359684 .0244603 .3132441 .4876685 .5842682

---------+--------------------------------------------------------------------

combined | 543 .5944701 .0158007 .3681931 .563432 .6255082

---------+--------------------------------------------------------------------

 diff | .0838165 .0342567 .0165241 .1511089

------------------------------------------------------------------------------

 diff = mean(0control) - mean(2treatme) t = 2.4467

Ho: diff = 0 degrees of freedom = 541

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9926 Pr(|T| > |t|) = 0.0147 Pr(T > t) = 0.0074

The result is that the average mean difference of lunch kilos per person consumed at the six month follow-up is lower for the treatment households with at least 2 treatment study participants in compound than the control group and is statistically significant at the 99% level.

Part 2: Ttests for Day kilogram use

To test whether the mean differences are significant between treatment and control households’ consumption of wood kilograms daily at the six month follow-up the following ttests are run.

sample group 0=control 1= treatment

ttest Wood kilos daily used at the six month follow-up 0=control; 1=treatment with equal variance assumption

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 391 10.27888 .2361793 4.670143 9.814535 10.74322

 1treat | 418 9.829424 .2309392 4.721563 9.375474 10.28337

---------+--------------------------------------------------------------------

combined | 809 10.04665 .1652169 4.699253 9.722346 10.37096

---------+--------------------------------------------------------------------

 diff | .4494552 .3304443 -.1991765 1.098087

------------------------------------------------------------------------------

 diff = mean(0control) - mean(1treat) t = 1.3602

Ho: diff = 0 degrees of freedom = 807

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9129 Pr(|T| > |t|) = 0.1742 Pr(T > t) = 0.0871

The result is the mean daily wood consumption is lower than that of the control group and is signficant at the 91% level. However, because it is below 95% we do not include it.

To test whether there is a significant difference in wood consumed daily between control households with only 1 study participant and treatment households with at least 2 treatment study participants in compound we run the following ttests.

0= control households with only 1 study participant in compound;

1=treatment households with at least 2 treatment study participants in compound.

Two-sample t test with equal variances

------------------------------------------------------------------------------

Variable | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

control\_ | 288 10.08329 .2689221 4.563759 9.553976 10.6126

 2treat | 187 10.53244 .3571601 4.88409 9.82783 11.23704

---------+--------------------------------------------------------------------

combined | 475 10.26011 .2153079 4.692526 9.837033 10.68319

---------+--------------------------------------------------------------------

 diff | -.4491496 .4406753 -1.315073 .4167738

------------------------------------------------------------------------------

 diff = mean(control\_) - mean(2treat) t = -1.0192

Ho: diff = 0 degrees of freedom = 473

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.1543 Pr(|T| > |t|) = 0.3086 Pr(T > t) = 0.8457

The results are insignificant.

To test whether the mean differences are significant between treatment and control households’ consumption of wood kilograms daily per person at the six month follow-up the following ttests are run.

sample group 0=control 1= treatment

ttest daily kilos per person at the six month follow-up 0=control; 1=treatment with equal variance assumption

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 383 1.121702 .0376204 .7362458 1.047733 1.195671

 1treat | 405 1.037847 .0380247 .7652315 .9630961 1.112598

---------+--------------------------------------------------------------------

combined | 788 1.078604 .0267881 .7519769 1.026019 1.131188

---------+--------------------------------------------------------------------

 diff | .0838548 .0535476 -.0212585 .1889681

------------------------------------------------------------------------------

 diff = mean(0control) - mean(1treat) t = 1.5660

Ho: diff = 0 degrees of freedom = 786

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9411 Pr(|T| > |t|) = 0.1178 Pr(T > t) = 0.0589

Two-sample t test with unequal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 383 1.121702 .0376204 .7362458 1.047733 1.195671

 1treat | 405 1.037847 .0380247 .7652315 .9630961 1.112598

---------+--------------------------------------------------------------------

combined | 788 1.078604 .0267881 .7519769 1.026019 1.131188

---------+--------------------------------------------------------------------

 diff | .0838548 .0534899 -.0211452 .1888548

------------------------------------------------------------------------------

 diff = mean(0control) - mean(1treat) t = 1.5677

Ho: diff = 0 Satterthwaite's degrees of freedom = 785.765

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9413 Pr(|T| > |t|) = 0.1174 Pr(T > t) = 0.0587

The result is for daily kilograms per person consumed at the six month review on average the treatment group has a significant (at the 95% level) lower mean than the control group.

To test whether there is a significant difference in wood consumed daily per person between control households with only 1 study participant and treatment households with at least 2 treatment study participants in compound we run the following ttests.

0= control households with only 1 study participant in compound;

1=treatment households with at least 2 treatment study participants in compound.

Two-sample t test with equal variances

------------------------------------------------------------------------------

Variable | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

control\_ | 282 1.177727 .0457408 .768119 1.087688 1.267765

 2treat | 185 .950084 .049803 .6773934 .8518257 1.048342

---------+--------------------------------------------------------------------

combined | 467 1.087547 .0342988 .7412024 1.020148 1.154946

---------+--------------------------------------------------------------------

 diff | .2276426 .069404 .0912582 .364027

------------------------------------------------------------------------------

 diff = mean(control\_) - mean(2treat) t = 3.2800

Ho: diff = 0 degrees of freedom = 465

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9994 Pr(|T| > |t|) = 0.0011 Pr(T > t) = 0.0006

The results are treatment households with at least 2 treatment study participants in compound have significantly lower mean consumption (99%) of kilograms daily wood used per person than control households with only 1 study participant.

To test whether the average mean difference of daily kilos per person consumed at the six month follow-up is significantly different between the control group and treatment households with at least 2 treatment study participants in compound we run the following ttests where:

0= control group

1=treatment households with at least 2 treatment study participants in compound

Two-sample t test with equal variances

------------------------------------------------------------------------------

 Group | Obs Mean Std. Err. Std. Dev. [95% Conf. Interval]

---------+--------------------------------------------------------------------

0control | 383 1.121702 .0376204 .7362458 1.047733 1.195671

2treatme | 164 .9721969 .0569061 .7287531 .8598288 1.084565

---------+--------------------------------------------------------------------

combined | 547 1.076878 .0314921 .7365385 1.015017 1.138738

---------+--------------------------------------------------------------------

 diff | .1495049 .0684977 .014953 .2840567

------------------------------------------------------------------------------

 diff = mean(0control) - mean(2treatme) t = 2.1826

Ho: diff = 0 degrees of freedom = 545

 Ha: diff < 0 Ha: diff != 0 Ha: diff > 0

 Pr(T < t) = 0.9853 Pr(|T| > |t|) = 0.0295 Pr(T > t) = 0.0147

|  |
| --- |
| Table 4: Summary Statistics from Carbon Monoxide Tube Sub-Sample |
| cm9 | What type of fuel do you prepare lunch with today? |  No. |  % |
| Wood | 335 | 73 |
| Animal Dung | 2 | 0 |
| Straw and/or other farm waste | 120 | 26 |
| Total | 457 | 100 |
| cm10 | What type of structure do you cook in? |   |   |
| Enclosed no windows | 102 | 23 |
| Semi-enclosed with at least one window | 200 | 44 |
| Hut Open Air Thatch Roof | 102 | 23 |
| Open Air | 49 | 11 |
| Total | 453 | 100 |
| cm11 | Do you have an improved stove? |   |   |
| Yes | 119 | 26 |
| No | 335 | 74 |
| Total | 454 | 100 |
| cm12 | Is the fire already lite for lunch today |   |   |
| Yes | 118 | 26 |
| No | 337 | 74 |
| Total | 455 | 100 |
| cm13 | Did you cook breakfast today? |   |   |
| Yes | 337 | 75 |
| No | 112 | 25 |
| Total | 449 | 100 |
| cm14 | Are her eyes irritated? (observation) |   |   |
| Yes | 124 | 27 |
| No | 330 | 72 |
| Not clear | 2 | 0 |
| Total | 456 | 100 |
| cm15 | Does she have a child on her back? (observation) |   |   |
| Yes | 75 | 16 |
| No | 380 | 84 |
| Total | 455 | 100 |
| Data comes from the Six month follow-up Carbon Monoxide Survey.  |

1. The project was managed by Solar Household Energy, Tostan Senegal and Tostan International and this evaluation would not have been possible without their cooperation. Dame Gueye, Kine Seck, and Magueye Ndiaye of TOSTAN were especially involved in the evaluation component. We also appreciate research assistance from (CEGA), Lamine Ndiaye, Henry Silverman, Richard Tam, Kenneth Tsang and Cheikh Sidaty Ndiaye and especially our field supervisor Vanissa Reed. [↑](#footnote-ref-1)
2. Lower respiratory infections are responsible for 16% of all-ages mortality. [WHO Mortality Country Fact Sheet](http://www.who.int/whosis/mort/profiles/mort_afro_gha_ghana.pdf), 2006 and Senegal: WHO, 2007 http://www.who.int/whosis/mort/profiles/mort\_afro\_sen\_senegal.pdf [↑](#footnote-ref-2)
3. “Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals” by

Eva Rehfuess, Sumi Mehta, and Annette Prüss-Üstün, *Environmental Health Perspectives* Volume 114, Number 3, March 2006**,** http://www.ehponline.org/docs/2006/8603/abstract.html [↑](#footnote-ref-3)
4. Lower respiratory infections are responsible for 16% of all-ages mortality. [WHO Mortality Country Fact Sheet](http://www.who.int/whosis/mort/profiles/mort_afro_gha_ghana.pdf), 2006 and Senegal: WHO, 2007 http://www.who.int/whosis/mort/profiles/mort\_afro\_sen\_senegal.pdf [↑](#footnote-ref-4)
5. For description of HotPot and image see Appendix 2 [↑](#footnote-ref-5)
6. Indoor air pollution in developing countries and acute lower respiratory infections in children,” Smith KR, Samet JM, Romieu I, Bruce N, Environmental Health Sciences, University of California, Berkeley 94720-7360, USA. http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed&uid=10817802&cmd=showdetailview&indexed=google [↑](#footnote-ref-6)
7. The World Bank Group currently manages about one billion dollars to purchase credits for greenhouse gas emissions reductions. [↑](#footnote-ref-7)
8. WHO *Global Health Atlas*, 2007, http://www.who.int/globalatlas/ [↑](#footnote-ref-8)
9. Robert Bailis, Majid Ezzati, Daniel M. Kammen, “Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa,” *Science* Vol. 308. no. 5718, April 2005: 98 – 103. [↑](#footnote-ref-9)
10. [Rehfuess et al., 2006](http://www.ehponline.org/docs/2006/8603/abstract.html). [↑](#footnote-ref-10)
11. http://www.who.int/indoorair/en/ [↑](#footnote-ref-11)
12. XXX k. smith etc. [↑](#footnote-ref-12)
13. Mukesh Dherani, Daniel Pope, Maya Mascarenhas, Kirk R Smith, Martin Weber & Nigel Bruce, «Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis Bulletin of the World Health Organization 2008;86:390–398. [↑](#footnote-ref-13)
14. Michael Clark, Paulsen, M., Smith, K., Canuz, E. and Simpson, C. “Urinary Methoxyphenol Biomarkers and Woodsmoke Exposure: Comparisons in Rural Guatemala with Personal CO and Kitchen CO, Levoglucosan and PM2.5” Environmental Science Technology 2007, 41. 3481-3487. [↑](#footnote-ref-14)
15. Recent research includes work by Esther Duflo and Michael Greenstone from MIT, Mushfiq Mobarak, Professor, Department of Economics, Yale University and Darby Jack, Professor, School of Public Health, Columbia University cite xx [↑](#footnote-ref-15)
16. http://www.who.int/ceh/indicators/ARImortality0\_4.pdf [↑](#footnote-ref-16)
17. [WHO Mortality Country Fact Sheet](http://www.who.int/whosis/mort/profiles/mort_afro_gha_ghana.pdf), 2006 and Senegal: WHO, 2007 http://www.who.int/whosis/mort/profiles/mort\_afro\_sen\_senegal.pdf This represents all ages mortality. [↑](#footnote-ref-17)
18. . (Ritz & Yu, Environ. Health Perspectives, 1999) & http://www.ehponline.org/members/2005/7751/7751.html [↑](#footnote-ref-18)
19. Biomass fuel measured includes wood, animal dung and farm waste. [↑](#footnote-ref-19)
20. Tostan Senegal has been working with rural communities in Senegal since the 1970s. Tostan implemented its three-year community empowerment program in over 2,000 villages from 1991-2008. [↑](#footnote-ref-20)
21. The ibutton is a product sold by Maxim. [↑](#footnote-ref-21)
22. The use of ibuttons to measure stove usage was first piloted by Kirk Smith and his team in their RESPIRE study in Guatemala. We have greatly benefited from this team’s pioneering work and advise on the SUM’s for this study.

http://www.hedon.info/BP55:Low-costTemperatureLoggersAsStoveUseMonitors [↑](#footnote-ref-22)
23. See Appendix 1 [↑](#footnote-ref-23)
24. Given time constraints we do not include the following results. These will be in our final report. We will then test whether household size is significant, baseline fuel consumption, and whether our interaction variables of treatment with household [↑](#footnote-ref-24)
25. A small initial pilot study conducted by our NGO partner SHE, in a small sample in rural Senegal, showed preliminary evidence that the HotPot was a good match with the size of households and the needs of communities in Senegal. Using this information we designed our study accordingly. [↑](#footnote-ref-25)
26. See Appendix 3 [↑](#footnote-ref-26)
27. Rainy Season is officially June-September. [↑](#footnote-ref-27)
28. . (Ritz & Yu, Environ. Health Perspectives, 1999) & http://www.ehponline.org/members/2005/7751/7751.html [↑](#footnote-ref-28)
29. http://www.coheadquarters.com/ZerotoMillion1.htm [↑](#footnote-ref-29)
30. This is consistent with other agencies findings for Senegal- UNDP in 2007 cites 114/1000 and the WHO (2006) cites 137/1000 for live births. [↑](#footnote-ref-30)
31. Because our enumerators were not trained professionals this definition is not consistent with the UN definition of live birth which classifies a child as live if it “shows any evidence of life” outside the womb including “beating of the heart, pulsation of the umbilical cord or definite movement of voluntary muscles”. [↑](#footnote-ref-31)
32. See Appendix 6 [↑](#footnote-ref-32)
33. See Appendix 7 [↑](#footnote-ref-33)
34. Relatively low levels of usage were found in the following villages during Month 1: Baliga, Malicounda Bambara, Darou Salam Joal II, and Khelcom Joal. [↑](#footnote-ref-34)
35. The seaside villages are Darou Salam Joal II and Khelcom Joal [↑](#footnote-ref-35)
36. See Appendix 4, Table A4 and A5. [↑](#footnote-ref-36)
37. A small initial pilot study conducted by our NGO partner SHE, in a small sample in rural Senegal, showed preliminary evidence that the HotPot was a good match with the size of households and the needs of communities in Senegal. Using this information we designed our study accordingly. [↑](#footnote-ref-37)
38. At the six month follow-up, the lunch meal consumed 58% of total daily wood consumption and hence quantifies that lunch is the biggest meal of the day in rural Senegal. [↑](#footnote-ref-38)
39. Data from Survey 3 enumerated at the six month follow-up on self-reported usage of solar oven. Total responses were 901 while there were 527 women with solar ovens in the treatment group which responded to the question. [↑](#footnote-ref-39)
40. For a full breakdown of our sample’s time spent cooking and time spent next to the cooking fire see Tables in Appendix 7 [↑](#footnote-ref-40)
41. See Appendix 5 for full breakdown of meals cooked in the solar oven [↑](#footnote-ref-41)
42. See Appendix 8 for all t tests for wood consumed both over the lunch meal and daily. [↑](#footnote-ref-42)
43. For a full breakdown of wood kilograms used both daily and for the lunch meal see Appendix 8. [↑](#footnote-ref-43)
44. Note that the single differences are taken such that the denominator of the single difference equation changes along with the sub-group. I.E. take for example the sub-group of mixed compounds with at least two treatment households. Here the denominator will be Baseline Wood Weighed for the sub-group with two treatments. I choose to vary the denominator along with the sub-group instead of fixing the wider baseline control group to avoid results being biased by differences in baseline wood weighing between the sub-group and the wider control group. [↑](#footnote-ref-44)
45. F test for first stage instruments shows xx. [↑](#footnote-ref-45)
46. See Appendix 7 [↑](#footnote-ref-46)