Ethanol as a Household Fuel in Madagascar:

Health Benefits, Economic Assessment and Review of African Lessons for Scaling up

Component A

FINAL REPORT

Analysis of Household Air Pollution Interventions in Madagascar

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Executive Summary

Overview

This study sought to evaluate the effectiveness of three household energy interventions and an awareness-raising campaign in comparison to a control group in one highland location (Ambositra) and one coastal location (Vatomandry). The primary intervention in both locations was an imported ethanol cook stove, which was found to reduce women's exposure to CO significantly by between 75% (highland households) and 54% (costal location) and child exposure by 60% (highland) and a non-significant reduction of 14% in the costal community from the open fire and traditional charcoal stove baselines. Reductions in kitchen concentrations of CO and $PM_{2.5}$ were also significant. Modelling of impacts on child pneumonia show that widespread adoption of ethanol stoves in Madagascar, steadily increasing over a 10-year period at a rate that would see universal access by 2030, would avert around 9,000 deaths from this cause by 2020. This 'ideal scenario', however, assumes full use of ethanol, and given the results found in this study, about one-third of this impact can be expected. A Malagasy improved wood stove with chimney, also tested in this study, showed some promise in reducing pollution exposures (a significant reduction of exposure to CO in children of 31%), a finding that is relevant to the large numbers of households in rural areas who rely on wood fuel and are likely to continue to do so far into the future.

Introduction

This Final Report provides a comprehensive review of activities undertaken and results generated within Component A of the Madagascar: Ethanol as a Household Fuel Project. It includes full reporting on the activities undertaken in the third and final phase of the project from July through December 2010, as well a review of the results obtained in the first and second phases.

Component A concerns the analysis of Household Air Pollution (HAP) interventions in two Malagasy locations – Ambositra in the central highlands and Vatomandry on the coast – and has four primary tasks:

- sample selection
- air quality and personal exposure monitoring
- household survey including fuel and stove use
- monitoring of health status
- modelling of impacts of ethanol use on child pneumonia

Using a 'before, after, after' study design, Component A sought to evaluate the effectiveness of three household energy interventions and an awareness-raising campaign while comparing to a control group that received no intervention or exposure to the awareness raising campaign. The primary intervention in both locations was an ethanol cook stove, which was compared to the open fire baseline stove, as well as to an improved charcoal stove in both locations and also to an improved wood stove in Vatomandry. The total baseline sample size was 180 households in Vatomandry and 144 for Ambositra.

The intervention phases began with an awareness raising campaign followed by the distribution of 'improved' fuel wood, charcoal and ethanol cook stoves. The baseline and follow-up fieldwork were originally planned to fit in with these intervention phases conducted by implementing partners and to span the climatic seasons: wet (baseline), dry (after 1), wet (after 2). However as a result of insufficient preliminary assessment of stove options prior to the commissioning of the evaluation work, the implementation partners struggled to identify and procure a reliable and safe ethanol stove, which led to a significant 12-month delay between the baseline round and the first after round.

The objectives of each phase of activities are summarised below:

Phase 1 Objectives:

1. Create a sample of eligible households in each town
2. Collect baseline information across a spectrum of qualitative and quantitative indicators related to demographic and socio-economic characteristics, household fuel use, and health

Phase 2 Objectives:

1. Assist with the identification of a safe and effective ethanol stove
2. Plan for the random allocation of the interventions, including awareness-raising to the households
3. Prepare and implement the second round of data collection at the two study sites
4. Process the collected data and provide preliminary analysis and reporting

Phase 3 Objectives:

1. Prepare and implement the third round of data collection at the two study sites
2. Process the collected data and provide in-depth analysis and reporting of indoor air and health results
3. Present the results for discussion to the project leadership and stakeholders

The fieldwork was led by two consortium staff, assisted by two Malagasy health professionals and four local surveyors, recruited and trained at each site. The same team performed all three rounds of monitoring.

Selection of interventions

The selection of interventions and the design of the awareness raising campaign were the responsibility of the implementing partners, although the Component A team provided technical assistance.

The interventions used in Ambositra were:

- awareness-raising of the benefits of cleaner stoves
- a charcoal stove similar to the Kenyan Ceramic Jiko, commonly available in Madagascar
- an imported CleanCook Ethanol stove, not currently on the market in Madagascar

The interventions used in Vatomandry were:

- awareness-raising of the benefits of cleaner stoves
- a charcoal stove similar to the Kenyan Ceramic Jiko, commonly available in Madagascar
- the CleanCook Ethanol stove, not currently on the market in Madagascar

- a large ceramic biomass stove called Fatana Pipa, which included a metal chimney that was placed through a hole in the roof of the house to allow the smoke to vent to the outside

The selection process for the ethanol stove was essential but also lengthy and complex, which created several challenges for the Component A team, summarized below. Concerns were raised from the outset about the safety and effectiveness of the Proimpex ethanol stove, originally selected for the intervention. After a six month delay, representatives of the consortium conducted a series of stove performance and usability tests in June-July 2009 to address these concerns. Complimentary laboratory tests were also conducted at the Aprovecho Research Center in Oregon, USA. Testing results revealed that both the Proimpex stove and a modified version of the ISPM stove, also under consideration, presented significant performance and safety risks. This eventually led to the choice of a new intervention stove — the CleanCook (with which there was several years experience in other African countries) — which arrived in the country in January 2010.

Methods

In line with the initial project requirements and to meet the tight resource constraints, the consortium decided that only charcoal homes would be recruited for the baseline study in Ambositra. In Vatomandry, the team targeted a baseline that was 60% wood users and 40% charcoal. The following criteria were used to identify households within the target study group:

1. Have a child under 4 years
2. Use charcoal or wood as main fuel currently
3. Purchase at least half of their fuel
4. Have an enclosed kitchen
5. Have Mother as main cook
6. Have an interest in having an improved stove

A structured questionnaire, administered at interview by trained field staff, was used to collect information from participants on their household energy use, health status, and economic status as well as baseline information required to evaluate the health status of participant and child. These included some health and safety outcomes that could be followed up post-intervention and for which intervention impacts could be assessed in the context of this relatively small, short-duration study.

Baseline household kitchen concentrations of fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) were measured in every study household. The air samplers and real-time monitors were placed in the kitchen area over a 24-hour sampling period. Personal exposure to CO was also measured for the mother (primary cook) and a child under 4 over a 24-hour period as a proxy for PM exposure. Carbon monoxide was used for this purpose as monitoring $PM_{2.5}$ is cumbersome and inconvenient for adults, and impractical for young children, and the use of CO as a proxy has been shown to be effective in other studies. This same set of kitchen and personal monitoring was performed in the two post-intervention phases.

Questions related to the participants' health were used to provide an indication of the prevalence of chronic respiratory symptoms at baseline. Information on another common symptom, headaches, was also collected to investigate the relationship between reported frequency/severity of headaches and CO levels/ women's exposure. Rates of eye irritation in women and burns (women and children) were also reported before and after intervention. For children, as it was not feasible within the time-frame, sample size and resources available to measure ALRI incidence directly, this study proposed using changes in exposure of children to estimate impacts on local ALRI rates using available evidence on the relationship between exposure levels and risk of ALRI.

A structured questionnaire was used to collect information from participants on their patterns of household energy use, cooking habits and the households that had received a project stove were asked about their initial experiences and perceptions of the stove. The results provided in this report are drawn from all three rounds of sampling: baseline, first 'after' round (referred to as Round 2) and second 'after' round (referred to as Round 3). This full study data set allows reporting here on the final results of the impacts of the various interventions on stove use and adoption, house pollution, personal exposure and health. A thorough assessment of (and adjustment for) confounding factors has also been carried out.

HAP data was analyzed using both a paired "difference in difference" tests as well as through statistical modelling using generalized estimating equations (GEE). The team first compared the R2 and R3 (and R2 and R3 combined) intervention groups to the baseline. Following Round 3, there was no evidence suggesting that HAP levels changed significantly relative to baseline. Absolute HAP differences and percent differences were also determined, and tests of significance were performed for each comparison within each intervention groups (ethanol, improved charcoal, improved biomass, and awareness).

Generalized Estimating Equations (GEE) with robust standard errors and an exchangeable correlation structure ("xtgee") were used to assess the population level effect of each intervention on 24-hr average CO and PM2.5 concentration. Each study site, Ambositra and Vatomandry, was analyzed separately due to the large differences in air pollution concentrations. The model accounted for differing starting fuels within each intervention group and adjusted for the location of the kitchen, which was found to be a significant covariate (see section on "Factors Affecting HAP"). All analysis was performed in Stata 11 (StataCorp LP, College Station, TX, USA).

As $PM_{2.5}$ was not directly measured on women and children, regression analysis was used to predict values for each person, at each round, based on their measured CO values. The regression equations used to carry out this prediction were obtained from information on CO and $PM_{2.5}$ measured at the same location in the kitchens of a sub-sample of homes, in each round of the study. The choice of equation was determined by the main fuel that the household stated they were using, even if this was at odds with the intervention group they were allocated to.

However on review of the data it was felt that the lack of precision in the equation and the small range of CO would make prediction of $PM_{2.5}$ for the charcoal in Vatomandry very unreliable. Similarly, as only post-intervention data were available for studying these relationships with ethanol, the site-specific equations were judged too imprecise to consider using them separately for each site. Accordingly, as with the charcoal group, while $PM_{2.5}$ could be predicted for ethanol use in Ambositra using the equation based on all of the data, prediction on $PM_{2.5}$ for the ethanol group in Vatomandry was not carried out. Therefore regression equations were used to predict the mother's or child's $PM_{2.5}$, based on the personal CO measurements obtained at each round, for all of the groups in Ambositra, and for the wood stove intervention group only in Vatomandry.

In order to summarise the effects of the interventions on personal exposure, to make use of all of the available data, and to allow for the possible effect of confounding and changing circumstances over the course of the study, a multiple regression approach was used. Generalised estimating equations (GEE) with robust variability estimation were calculated for longitudinal modelling of personal exposure data for adults and children, using xtgee in Stata, version 9.

This summary analysis of effects on exposure was applied to both the measured COppm and – for Ambositra only - the predicted $PM_{2.5}$ data. The analyses were carried out with untransformed and log(n) transformed distributions, due to the predominantly (but not exclusively) positively skewed distributions of exposure data. The results are presented as the difference between each individual intervention group, and the control group. Comparisons between interventions have been made including the Baseline data, which provides summary estimates of intervention effects, allowing for any differences between groups at Baseline.

Challenges experienced

In implementing the study, the field team encountered four primary challenges:

- There was significant loss of households in Ambositra between the baseline and intervention period. Due to the time it took to identify a safe and effective ethanol stove, a full year elapsed between the Baseline and Round 2 surveys. In that time people had moved away, and there had been major political and economic unrest in the country that further exacerbated the problem.
- In Ambositra, the implementing partner initially carried out an incorrect intervention allocation plan.
- The various delays with the stoves and the ethanol supply, along with efforts to adjust the household allocation to mitigate the effect of lost households, resulted in uneven and insufficient time for households to adjust to the intervention stoves.
- Again, linked to the implementation delays, the round 2 surveys were completed at the end of the wet season rather than at its peak in January-February.

The Component A team addressed these challenges as quickly and methodically as possible within limitations presented by factors beyond their control. In response to the allocation confusion, the implementing partner was asked to assess the misallocations and correct them as far as possible. The consultant team then made some additional reallocations. Measures were also carried out to address the loss of follow-up with targeted reallocations of households, especially for the ethanol group. Ten new households in Ambositra and seven in Vatomandry were then identified using strict selection criteria and added to the control group.

Household allocation and follow-up

The interventions (including control group status) were assigned to each household using random allocations within two kitchen configuration strata at baseline (separate from house and joined to/within house). The procedure used to randomly allocate the intervention was slightly different at each study site to take into account the two main baseline cooking fuels used in Vatomandry. Households were allocated as close to a random schedule as possible, given the constraints imposed by homes having to use a fuel suitable to the intervention (i.e. wood users needing a biomass stove). Despite the challenges, each group, including the control groups at both sites, had almost 80% of their households from baseline, who were still available at Round 3, correctly allocated.

The allocation was well balanced in Ambositra with regard to key variables, although less so in Vatomandry. In Vatomandry the wood stove users and the awareness group participants appear to be several years older than the other groups. A higher proportion of ethanol and charcoal stove users reached secondary or higher education (p=0.016) than in the other groups. There appears to have been a dramatic move towards having a kitchen attached to the house in the ethanol study group in the time since the baseline survey. These differences in study groups in Vatomandry were accounted for in the Round 3 analysis.

Overall there was 13.2% (n=20) loss to follow-up in Ambositra and 14.4% (n=27) in Vatomandry between the Baseline and the first "after' sampling. The reason for most of these losses was that the participant had moved away. Neither the extent of losses (13-14%), nor their characteristics, suggests very substantial bias. The higher rate of loss to follow-up among users of traditional charcoal stoves compared to wood stove users in Vatomandry should be kept in mind when interpreting results. Analysis showed no significant differences in key characteristics between the 17 new control group households and those lost to follow-up.

Loss to follow-up was much less significant between the two rounds of 'after' sampling, as these occurred within four months of each other. A further 3 households from Ambositra and 7 from Vatomandry, lost between the Round 2 data collection and the final round (Round 3), gave an overall loss to follow up of 14.9% (n=23) in Ambositra and 18.1% (n=34) in Vatomandry. The % loss to follow-up allowed for in the sample size calculations was 20%. The stoves were given for free but the households were expected to purchase the fuel they required for the duration of the post-intervention study period.

Results

Project stove use and perceptions

All participants in the stove groups were asked about their perceptions of the stove at Round 2 within a period of 3-6 weeks of receiving the stove. The immediate reaction was positive and described in more detail below. The participant's perceptions of the study stoves were explored again 5 months after receiving the stove. This data confirmed the positive responses and widespread adoption of the project stoves.

Despite the fact that there had been a limited time to adjust to the interventions before the Round 2 data was collected, at least 80% in each study group used the project stove as their main stove. The usage was slightly lower in the ethanol group (81.2 % (n=26) in Ambositra and 90.6% (n=29) in Vatomandry), but these levels still reflect a high rate of initial adoption. As it takes time to adjust to a new stove and, for some, a very different fuel, the Round 3 data may be a more representative measure of acceptability and adoption. After 5 months of use at Round 3, 97% of the ethanol stove households in Ambositra reported that they use their ethanol stove as the main stove; this was lower in Vatomandry at 77%. The charcoal stove was used as the main stove at consistently high rates: 100% were using it as the main stove at both study sites by Round 3. The biomass stove was also being used as the main stove by 93% of the intervention group in Vatomandry.

However, at Round 2 many households appear to still need a secondary stove. Use of a secondary stove was significantly different between study groups in both

Ambositra (p=<0.005 at Round 2 and (p<0.005) at Round 3) and Vatomandry (p=0.002 at Round 2 and (p<0.005) at Round 3), with the ethanol stove households reporting a higher use of a secondary stove than the other groups in both study sites: (84.4% Round 2 and 80.6% by Round 3 in Ambositra and 75% at Round 2 increasing to 83.9% at Round 3 in Vatomandry). This may reflect the transitions in kitchen management needed to integrate a very different type of stove and fuel. At Round 2 households reported that the ethanol stove was not able to cook all of the food types they wanted (43.7% (n=14) in Ambositra and 31.2% (n=10) in Vatomandry) but by Round 3 this decreased to 29.0% in Ambositra and 22.6% in Vatomandry. Cost may be another contributing factor, however, as at Round 3 a lack of access to fuel due to insufficient funds (n=5 (8.1%) and not able to get to the store (n=3 (4.8%) in total) had stopped a small number of participants using their stove. There were significantly fewer problems reported by the biomass and charcoal users at both sites (charcoal Ambositra 6.5% (n=2); charcoal Vatomandry 9.4% (n=3); biomass Vatomandry 9% (n=3)).

The majority of households that received a project stove (92.1% in Ambositra and 87.6% in Vatomandry) believed the new stove to be a bit or much better than their previous stove. The results were more favourable for the ethanol stoves. 6.5% (n=2) of the charcoal stove users in Ambositra and 21.9% (n=9) in Vatomandry reported that the liner within the stove broke within the short time since installation. There was no one particular problem experienced with the biomass stove, but 18.2% (n=6) felt it was dangerous due to the chimney getting hot and potentially causing a house fire.

These issues were raised again at Round 3 when the participants were asked if they would make any changes to the stove. The table below shows the number of participants who would make changes and examples of the changes they would make, with the comments being similar from both sites.

	N (%)	**Suggested changes**
Ethanol stove	17 (27.4)	2 burner stove and increase the size
Wood Stove	5 (15.1)	Increase number of pot stands. Reduce the overall size of the stove
Charcoal stove	18 (29.0)	Stove is too small. Needs a stronger liner. Needs a two pot capacity.

The wood stove caused some concern to the households using it: 18.2% (n=6) felt it was dangerous due to the chimney getting hot and potentially causing a house fire. This persisted at Round 3 with 12.1 % still fearful of house fire started by the stove. At Round 3, 7 (11.3%) households over both sites believed the ethanol stove to be ‘a bit dangerous’. They feared that the pot might fall off the stove and that, on occasions, flames would continue to burn when the stove was turned off were two examples of why the households thought the ethanol stove was more dangerous than their previous stove. The small number of households (7.9% (n=5) from both study sites) who thought the charcoal stove was dangerous, cited general fire/ cooking safety reasons that were not particular to the study stove.

Air Pollution Monitoring

The ethanol stove reduced kitchen PM2.5 and CO levels in both locations by a significant level from the baseline.

Estimated change from baseline in 24-hr average kitchen concentrations for CO (ppm) and $PM_{2.5}$ (ug/m^3) for ethanol treatment group in Ambositra and Vatomandry (p-values)

	Ambositra		Vatomandry	
	Ethanol (Wood Baseline)	Ethanol (Char Baseline)	Ethanol (Wood Baseline)	Ethanol (Char Baseline)
CO (ppm)	**NA**	**-79% (<0.01)**	**-93% (0.01)**	**-93% (0.02)**
$PM_{2.5}$ (ug/m3)	**NA**	**-57% (<0.01)**	**-85% (<0.01)**	**-72% (<0.01)**

A comparison of the 24-hr kitchen CO averages shows that the ethanol stove can significantly reduce kitchen CO levels below the 8-hr WHO guideline level of 8.7 ppm. Although the ethanol stove significantly reduced $PM_{2.5}$ concentrations in the kitchen, the Round 2 and 3 levels in Vatomandry were still about two to three times the annual WHO Interim Target 1 for $PM_{2.5}$ of 35 µg/m^3, while in Ambositra they were approximately four times the annual Target 1. An increase between Round 2 and 3 in reported supplemental fuel mixing or primary fuel substitution was observed in the ethanol group and may explain the slight increase in CO and $PM_{2.5}$, to varying degrees, across both locations.

The improved wood stove also showed an ability to reduce kitchen CO by approximately 63% and $PM_{2.5}$ by an estimated 66% at significant or near significant levels (only relevant to Vatomandry). The reductions were not as dramatic as with the ethanol stove, and the average $PM_{2.5}$ concentration was not close to the WHO Interim Target 1 in either round. The ethanol stove and improved wood stove decreased the overall variability in IAP between users in Round 2 and Round 3 relative to the Baseline.

The improved charcoal stove was not effective at reducing average kitchen CO or $PM_{2.5}$ concentrations in either Ambositra or Vatomandry, as the stove was not found to have a significant effect for either pollutant in the GEE model. Awareness-raising had no effect on Round 2 and Round 3 kitchen $PM_{2.5}$ (p-value = 0.348) or kitchen CO (p-value = 0.987) in Ambositra compared to the baseline. In Vatomandry, where awareness-raising was conducted in both wood and charcoal-using households, a significant reduction in $PM_{2.5}$ of -1232 ug/m^3 (p-value < 0.01) was measured among wood users, but no effect was detected for charcoal users (p-value = 0.179). No effect of awareness-raising on 24-hr average kitchen CO concentrations was measured in Vatomandry, regardless of fuel type.

Neither of the control groups at either location showed a significant change in kitchen concentrations for either pollutant between Rounds 1, 2, and 3, suggesting conditions remained generally constant over time and that there was little to no contamination of the control groups by any of the interventions.

Exposure Monitoring

In both study sites, compliance with use of the CO diffusion tubes used for measurement was overall good, with around 90% or more of women and 91% of children found to be wearing the monitor when the fieldworker arrived at the home on Day 2, and these levels were maintained across both post-intervention rounds.

Observed and reported compliance was variable, however, with the lowest rate in the charcoal group.

The overall impacts of the Ethanol intervention on personal exposure to CO and $PM_{2.5}$ (predicted) are derived from the multiple regression analyses and allow for any baseline differences between groups, and for confounding factors. It should be noted that in both Ambositra and Vatomandry, at least 80% of the households in the Ethanol intervention group also used a charcoal or wood stove for some of their cooking, so it can reasonably be assumed that exposure reductions would have been even greater if all households had been able to use ethanol exclusively. There were insufficient numbers of 'pure' ethanol using homes to study exposures in this group.

In Ambositra the very clear finding was that only the ethanol intervention reduced the exposure levels in the women and children. In this group there was a quite substantial reduction of 75% for the exposure to CO and 45% for the predicted $PM_{2.5}$. The median post intervention level of predicted $PM_{2.5}$ was approx 50µg/m^3 (the WHO indoor air quality guidance for 24hr mean levels of $PM_{2.5}$ is 25µg/m^3 and the per annual average is 10µg/m^3 [1]).

Pollutant	Ambositra		Vatomandry	
	Mother	Child	Mother	Child
CO	**-74%**	**-64%**	**-54%**	**-14%**
Predicted $PM_{2.5}$	**-45%**	**-40%**	**N/A**	**N/A**

The impacts of the interventions on the exposure levels in the children in Ambositra reflected the adults very closely with again only the ethanol intervention resulting in substantial reductions. These were a 60% reduction in CO and 40% in predicted $PM_{2.5.}$ A post intervention level of exposure to predicted $PM_{2.5.}$ of around 50µg/m^3 was seen.

For Vatomandry the exposure levels of CO were much lower. For women, the reductions in CO were 45.3% and 53.9% for wood and ethanol stoves respectively. For predicted $PM_{2.5}$, which was only calculated for the wood stove intervention group in this location, there was a reduction from 80µg/m^3 at baseline to 50µg/m^3 at follow up (P value from paired test comparing Baseline and Round 2: p=0.02 and Baseline and Round 3: p=0.452).

In Vatomandry the child exposure results were characterised by unexplained increases in measured levels of CO exposure in all groups over the course of study. In the summary comparative analysis relative to the control group (which showed increased levels of exposure) the wood stove group significantly and the ethanol stove group somewhat less (non-significantly) had reduced exposures. The reasons for this absolute increase over time are however unclear, although there are a number of possible explanations, including a small increase in the compliance in wearing the CO monitors and/or seasonal weather conditions. Nonetheless, we can

[1] WHO (World Health Organisation). 2006. WHO Air Quality Guidelines: Global Update for 2005. Copenhagen: World Health Organisation Regional Office for Europe.

With the type and amount of data collected for this study (e.g. 2 post intervention measurements), it is reasonable to compare with either the annual or the 24-hr WHO indoor Air Quality Guidelines. The annual measurement is the 'annual mean', which the average value presented in this study provides a good estimate of given that it was measured in two seasons on 30+ homes. The 24 hr mean level is the 99% level, so gives an idea of what individual homes should not exceed, more than occasionally (3 occasion/year).

conclude that overall the impact on child exposure levels in Vatomandry was at best small, possibly due to children being outdoors at lot more. However the methodological uncertainties discussed here suggest that these findings should be interpreted with caution.

Health-related issues

The follow-up phase of the study examined the frequency of headaches, eye irritation and burns in women and frequency and severity of burns in children. Mothers were also asked about their level of anxiety regarding the risk of children being burnt in the kitchen.

When comparing with the control group in the summary analysis, we found that the ethanol stove led to substantial and highly significant reductions in headaches, eye irritation and burns amongst women in Ambositra. There was also a non-significant reduction of burns in children. Of the other groups in Ambositra only the improved charcoal group showed benefits, which were seen for headache, eye irritation and burns in adults. However the reductions in risks were generally less than those seen for the ethanol groups. Non- significant reductions in burns were seen in the ethanol stove group for children but no strong evidence of reduced risk in the other groups.

In Vatomandry the same analysis showed large and highly significant reductions in the women's reported headache and eye irritation for the charcoal, wood and ethanol intervention groups. The ethanol group reported substantially less burns in women and wood stove group showed marginally significant reductions. Only the wood stove group showed significant reductions in burns in children.

Perceptions of risk of burn

The mothers levels of concern about risk of burn were very consistent not only with the relatively high frequency of burns at baseline but also the reduction in risk that were seen with the ethanol stove and some of the other interventions at follow up.

Ingestion of fuel

The issue of ingestion of fuel is highlighted as it presents a potential serious risk of lung injury particularly with kerosene. The risk of ingestion of ethanol is less well documented although anecdotally we understand children are less likely to drink it. The fact that both of these liquid fuels are purchased and stored in soft drink bottles requires attention.

Perceptions of health

At end of the follow up period the women respondents were asked about their impression on the overall impact of the intervention (in case of control group the time in study) and whether it had beneficial, neutral or negative effects on the health of the family. In Ambositra the most positive assessments in improvements were seen in the ethanol group, with some evidence of benefits in the charcoal intervention group.

In Vatomandry again the ethanol group showed the clearest evidence of perceived benefits to family health. With at least as positive benefits reported by the intervention wood stove users. The other three groups showed very little evidence of change.

Modelled health impacts from exposure reduction

The expected impact of clean stoves on major health outcomes was modelled over 10 years (2010-2019) in two ways. First, an 'ideal scenario' (Scenario 1) aiming to meet the universal modern energy access by 2030 target of the UN Secretary General's Advisory Group of Energy and Climate Change (AGECC) was adopted. The second was based on a 'market growth scenario' (Scenario 2) drawing on the projection made for ethanol adoption at 35 cents/litre[2] over a 20 year programme. The modelling includes three health outcomes for which reliable estimates of risk reduction were available, namely childhood pneumonia, chronic obstructive pulmonary disease (COPD) and ischaemic heart disease (IHD), and applies the methods of the comparative risk assessment (CRA) component of the Global Burden of Disease project.

This modelling found that the more ambitious Scenario 1 (AGECC target) would, in the year 2019, lead to the prevention of around 17%, 16% and 5% respectively of total national deaths and DALY's for child ALRI, adult COPD and IHD. Scenario 2, based on market growth with an ethanol price of 35 cents/litre, would in the year 2019, result in prevention of around 3%, 2.5% and 1% respectively of total national deaths and DALY's for child ALRI, adult COPD and IHD. We could of course use other summary measures of the impact, e.g. not the 2019, but the whole 10-year period. However we believe, that the 2019 provides a clearer idea of how much benefit per year is gained after 10 years. The Scenario 2 estimates assume that all homes in this market projection are using solid fuels at the start of the period.

For both scenarios, it was also assumed that exposure would be reduced by more than 90%, as information required for estimating the impact of intermediate reductions is currently being prepared for publication and is not available at the time of preparation of this report. Based on the exposure reductions actually measured in the study, however, and using published preliminary evidence, it is estimated that the resulting impacts on health benefits would be about one-third of those reported here. With more consistent and widespread use of clean fuels, it is expected that exposure reductions will over time, and in practice, fall further towards this best-case assumption.

Conclusion and Next Steps

Conclusions

This study clearly demonstrated that the ethanol is an attractive alternative to solid household fuels in Madagascar. The Cleancook ethanol stove performed well, substantially reducing household concentrations of the health-damaging fine particles ($PM_{2.5}$) and carbon monoxide (CO). In Ambositra, personal (predicted) $PM_{2.5}$ exposure was reduced to around 50 µg/m^3, still above the World Health Organization guideline levels (10 µg/m^3 for annual $PM_{2.5}$), but encouraging nonetheless (the data did not permit reliable prediction of $PM_{2.5}$ exposure in Vatomandry). The ethanol stove was used consistently by the test households, which resulted in reductions in levels of exposures at both study sites with largest reductions in the highland community and among women.

Some specific health impacts have been modeled for the Malagasy context showing that widespread adoption of clean cookstoves (including ethanol) would have a

[2] This is a conservative estimate of predicted price of ethanol based on several variables including the cost of feedstock's and co-products and taking into consideration the fact that there is currently no large-scale micro-distillery operation in Madagascar. For further information on the calculation of this figure please refer to: Madagascar: Ethanol as a Household Fuel: Approach for Market, Financial and Economic Analysis – March 2011

substantial impact on mortality and illness from conditions such as childhood pneumonia and chronic obstructive pulmonary disease (COPD). The study also directly measured impacts on common symptoms of eye irritation and headaches in mothers, and also burns in both mother and children. In comparison with the control group, the ethanol stoves were found to substantially reduce risk of all of these outcomes for the mothers, although effects on child burns were non-significant.

Another key lesson from this study is that the design of the ethanol stove matters, as do factors associated with obtaining the fuel – access and price. Initially, the complexity of choosing an appropriate and safe stove was underestimated by the implementing partners. Fortunately, the team was able to recover from this oversight, but a repeat of this mistake in the program design and scale-up phase would have more dire consequences. Furthermore survey findings indicating that some households curtailed their use of the ethanol stove because the fuel was hard to obtain and/or too expensive suggest that the fuel supply chain issue also requires careful planning and monitoring.

This study also suggests that the locally produced Fantana Pipa wood stove, used only in the Vatomandry site, is also a promising stove, although it cannot compare with the performance of the liquid fuel ethanol stove, primarily because it relies on venting smoke outside the home rather than reducing emissions. Despite its limitations, most households that received it felt that it was better than their existing options and improvements in common health symptoms were documented. Thus this improved woodstove with a chimney could provide an interim household energy improvement to families who can't access cleaner fuels in the near term.

The charcoal stove tested in this study performed poorly in respect of kitchen air pollution and personal exposure measures, and cannot be relied upon to deliver any health benefits to the Malagasy population. It is recommended that this stove is not considered for any further investment. In this study, the group of homes that received only the awareness-raising intervention did not show any consistent improved outcomes over the control group. However, the authors recommend that this finding be interpreted in the context of the modest resources invested in the awareness-raising campaign for this project. Further the participant perceptions gathered through this study could be used to inform valuable future awareness-raising efforts to support introduction of improved stoves and fuels.

Scientific and Technical Next Steps

To our knowledge, these results represent the most comprehensive household level assessment of the impacts of ethanol on indoor air quality and personal exposure, as well as the first time the impacts of such personal exposure reductions on childhood pneumonia and other health outcomes (COPD, IHD) have been modeled for an African context. As a result, the authors recommend that the key results be submitted for publication in a peer-reviewed journal.

Further from a scientific perspective, this study's success in measuring a significant and sustained effect from an improved cookstove intervention on personal exposure justifies a more detailed evaluation of the pathway from which health benefits could be derived. This should include more detailed assessment of exposure, including personal particulates and biomarkers. Once larger scale sustained use of ethanol stoves is established, impacts on priority health outcomes, including child pneumonia, adverse pregnancy outcomes and the development of adult respiratory disease could also be studied.

Programmatic Next Steps

One of the clear and consistent findings of the qualitative surveys done for this study was the prevalence of a secondary fuel and/or stove in many homes. This finding is not surprising, as similar patterns of fuel mixing have been documented in other parts of Africa. This secondary fuel use must have an impact on indoor air quality and personal exposure, and it may explain certain trends in the data, but currently the authors can only speculate on the details of these effects. Therefore one recommendation for next steps is to undertake a further study of total household energy usage using temperature sensors that can provide an objective record of daily stove use.

The primary goal of this study was to inform investment decisions for program stakeholders with regards to improved cookstoves both in terms of potential impacts on health (Component A) and the feasibility of the ethanol supply chain (Component B). Consequently the results presented here must be interpreted as demonstrating the efficacy of a potential intervention, which cannot substitute for an assessment of true effectiveness once the program has been implemented. It is recommended that these subsequent assessments focus on access to, and adoption of, ethanol stoves including effectiveness of supply chains, financing, behavior change support, etc.

The Fatana Pipa wood stove performed well but to be effective as an intervention, the design and installation challenges of this stove and its chimney would need to be addressed. It is also recommended that it be subject to rigorous laboratory testing to understand the mechanisms behind its high performance and perhaps optimize those advantages. A broader testing of other wood stoves available in Madagascar as well as the suitability and affordability of alternative, cleaner burning biomass stoves technologies be assessed in the context of Madagascar.

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Abbreviations and Acronyms

Abbreviation or acronym	Meaning
Ar	Ariary: Currency in Madagascar (Also MGA)
ALRI	Acute lower respiratory infection
AME	Adult male equivalent
CBO	Community based organisation
CCT	Controlled cooking test
CO	Carbon monoxide
COHb	Carboxyhemoglobin
COPD	Chronic obstructive pulmonary disease
DALY's	Disability adjusted life year
GEE	Generalized estimating equations
IAP	Indoor air pollution
IHD	Ischemic heart disease
IQR	Inter-quartile range
LPG	Liquefied petroleum gas
MD	Mere Dilligentes
NGO	Non-governmental organisation
$PM_{2.5}$	Particulate matter less than 2.5 micrometers in aerodynamic diameter
ppm	Parts per million
QC/QA	Quality control/ quality assurance
SD	Standard deviation
ToR	Terms of reference
WBT	Water boiling test
WHO	World Health Organisation

Exchange rate (approximate at time of report)

1 USD = 2,190.00 MGA

1. Introduction

Component A of the Madagascar: Ethanol as a Household Fuel Project concerns Analysis of Household Air Pollution interventions in Madagascar and has four primary tasks: sample selection, air quality monitoring, household survey and monitoring of health status.

1.1. Overview of study aims/ objectives

1.1.1. Aim of Component A

To evaluate the health and socio-economic impacts of ethanol as a household cooking fuel and alternative interventions in the context of Madagascar.

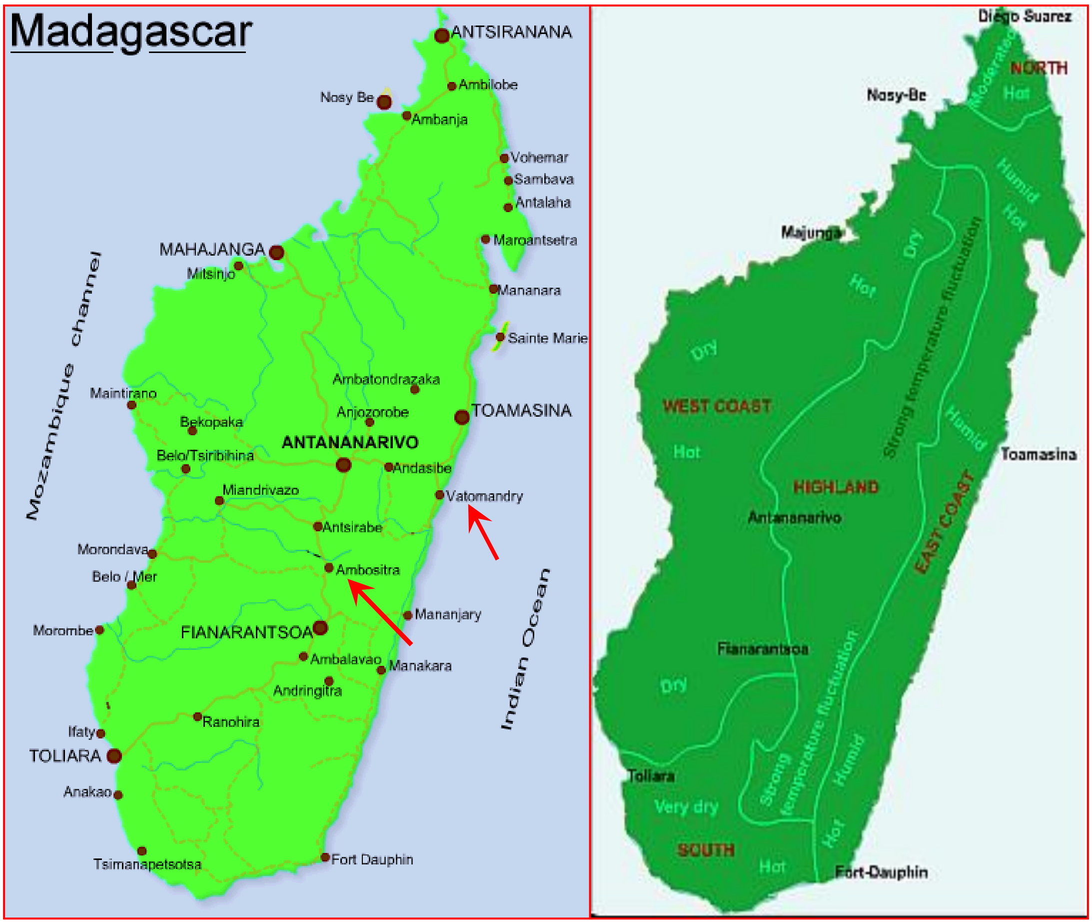
1.1.2. Specific objectives

- To measure indoor concentrations of fine particles ($PM_{2.5}$) and carbon monoxide (CO) and to assess and compare the effectiveness of interventions to reduce those concentrations.
- To obtain indirect estimates of the impact of the interventions on key child and adult health outcomes by combining data on measured exposure reduction, relative risks obtained from existing epidemiological studies, and local rates of disease incidence.
- To assess the impact of the interventions on additional indicators of health and well-being, including eye irritation, headache, burns to children and cooks (and perceived risk of burns).
- To assess the impact of the interventions on social and economic factors of importance to households and relating to the use of energy, including how time is spent and expenditure.
- To determine how well the interventions meet the needs of households, maintenance requirements, and any unexpected advantages and disadvantages.
- To contribute data required for the economic evaluation of the interventions.
- To conduct three coordinated rounds of monitoring during which high-quality data is collected to meet the analysis needs of Components A and B with minimal disturbance to residents and at minimal cost.

1.2. Study sites

Building on local interest and previous projects on ethanol, the project locations selected by the World Bank were the Vatomandry and Ambositra towns, representative of both coastal and inland plateau conditions (Figure 1.1).

Figure 1-1: Map of Madagascar showing study sites



1.2.1. Ambositra

With a population of 44,726 (August 2008 estimate), the city or 'commune urbaine' of Ambositra is located in the central highland of Madagascar, approximately 260km south of the capital city Antananarivo. At an altitude of 1295m, it experiences a lower rainfall and cooler temperatures compared to coastal Vatomandry but still has distinct wet (Nov-Mar) and dry seasons (April-Oct).

Ambositra is a well-developed regional centre, housing both local and regional government buildings and offering commercial, financial, and medical services (

Figure 1-2). The major occupation of the adult males is described as 'artisan', producing products for local markets such as wood carvings and brick making. The main crop grown is rice, which again is for local supply with very little exported.

Figure 1-2: View of Ambositra from the countryside

Most of the homes in Ambositra are made of brick and wood and typically of two stories (Figure 1-3 and Figure 1-4). They do not have indoor toilets; these are usually separate from the main house. The people who live in the town centre do not keep livestock, but in the rural areas, many people have pigs and chickens.

Figure 1-3: Typical house in Ambositra

The kitchens in Ambositra are typically located inside of the homes, either in a separate room or in the place where people sleep. The walls of these kitchens are made of mud brick and the roofs of wooden planks, allowing for only moderate ventilation (Figure 1-4). The traditional charcoal stove is usually located in the corner of the room.

Figure 1-4: Smoke filled kitchen in Ambositra

1.2.2. Vatomandry

The town of Vatomandry is located on the central east coast of Madagascar, in the province of Fianarantsoa. With a higher rainfall than Ambositra, Vatomandry still has two distinct seasons: wet (Dec-Mar) and dry (April-Nov). The weather throughout the year is hot, and proper ventilation is needed especially during the dry season.

Figure 1-5: Vatomandry Neighbourhood

The town has recently experienced a wave of investment due to a find of highest quality ruby deposits, including a resurgence of tourism and the opening of a new road, which provides a fast link to the capital Antananarivo. National chain stores have recently opened branches, while investors from Antananarivo and Toamasina have established other businesses - hotels and restaurants in particular - providing employment opportunities. Vatomandry is a popular vacation destination for many people from the capital because it is easily accessible from Antananarivo. Consequently, many of its residents are not native to the region.

Figure 1-6: Vatomandry Neighbourhood (2)

The housing stock in Vatomandry is primarily single-story wooden homes. Palm groves supply most of the construction materials, and residents use palm branch to build the walls and roofs of their homes. The homes throughout the 12 study neighbourhoods were located close together and had external toilets.

The kitchens in Vatomandry are usually located in a separate building from the main house. The kitchen is usually small in size and located in the back of the main house.

2. Methods

2.1. Study design

An evaluation of the effects of household ethanol use in comparison to the two most commonly used domestic fuels, charcoal and fuel wood, within the study communities is being carried out using a ‘before and twice after study’ within multiple control and intervention groups. The approach is quasi-experimental; a controlled intervention design with the random allocation of interventions to households being moderated by what was most appropriate to the family (e.g. a family that used a lot of gathered wood could not be allocated an ethanol stove for which bought fuel would be needed).

2.2. Sample Composition

2.2.1. Sample size

The main sample size calculation was based on the reduction required in kitchen air pollution level. The minimum to be detected in a two-group comparison (e.g. between an improved stove group and the control group) is a 40% reduction in a concentration estimated at 500 mcg/m3 in $PM_{2.5}$ (based on prior studies in similar circumstances), with a power of 80% and significance level of 5%. This yields a sample size of 24.7, rounded up to 30. This is the minimum number required at the last follow-up round, and allowing a 20% loss due to dropouts and lost data, the initial baseline group size is taken at 36. Therefore total baseline sample size is 180 for Vatomandry and 144 for Ambositra as detailed in the table below:

Table 2.1: Household Sample Sizes and Composition

Intervention	Vatomandry	Ambositra
No intervention (control group)	36	36
Awareness Raising only	36	36
Awareness Raising + improved biomass stove	36	0
Awareness Raising + improved charcoal stove	36	36
Awareness Raising + ethanol stove	36	36
Totals	**180**	**144**

The 40% reduction was chosen as this is the absolute minimum reduction in kitchen air pollution that is needed to achieve a useful reduction in personal exposures of women and children. Our experience has shown repeatedly, that in intervention studies, personal exposures are generally reduced proportionately less than kitchen air pollution levels.

This sample size will also allow detection of large reductions in common symptoms such as sore eyes during cooking, for example from 60% to 30%, which is expected in switching from use of wood fuel to a clean fuel such as ethanol.

The study does not have the power to detect useful reductions in respiratory symptoms between the intervention and control arms, and for this reason, these symptoms are not included at follow up (they are included at baseline to help in estimating prevalence of chronic respiratory illness in these populations).

2.2.2. Household selection and recruitment

In order to meet the projects tight implementation timeline and budget, the consortium agreed early on that the selection and recruitment of study households would ideally be managed by local partners in advance of the field team's arrival. The consortium partners therefore designed a rapid appraisal tool that could be implemented by local community groups to collect basic information on household fuel use and find households that matched the study criteria.

Criteria

The following criteria were used to identify households within the target study group.

- Have a child under 4 years
- Use charcoal or wood as main fuel currently
- Purchase at least half of their fuel
- Have enclosed kitchen
- Have Mother as main cook
- Be interested in having an improved stove

In line with the ToR sample specified and to meet the tight budget requirements, the consortium decided that only charcoal homes would be recruited for the baseline study in Ambositra. In Vatomandry, the team targeted a baseline that was 60% wood users and 40% charcoal.

A copy of the Rapid Appraisal Census Form is included in Annex 1

Selection Process

The implementing partner, Tany Meva, used partner local community-based organisations (CBOs) to support the household selection process and provided them with the census form. In Ambositra, the partner Mere Dilligentes recruited and trained five guides two weeks before the survey team arrived. The guides were then deployed in the Ambositra urban area where they visited and prequalified homes for the study. In Vatomandry, the local guides were organized by the community organization AJDV. Six guides completed the census forms in their respective neighbourhoods several days before the team arrived.

While the community organisation partners were dedicated and conscientious, the consortium's original household selection procedure faced some challenges that had to be addressed once the field team was on the ground. Primarily, the process suffered from a gap in the expectation of accuracy between the local community organisations and the study team. While the study required 100% compliance with the selection criteria, the local guides would often find and prequalify households that almost fit the criteria but were missing one or two qualifying factors.

Compliance with the criteria concerning baseline fuel type proved particularly difficult. In keeping with the criteria, the Ambositra guides looked for both wood and charcoal-using households. However, in the poorer neighbourhoods at the town's periphery most households collected wood because they could not afford buying wood or charcoal. The survey teams went to four different sections in Ambositra. The teams did not have challenge in finding homes in two sections in and around the city centre that cooked with charcoal. However, in the other two sections it was more of a challenge because many people collected wood and could not afford to either buy wood or charcoal. After reflection and discussion within with the World Bank team, a decision was taken to maintain the approach specified in the ToR and survey only charcoal-using homes in Ambositra, while assessing both wood and charcoal baseline fuels in Vatomandry. This however resulted in an insufficient number of charcoal-using homes being prequalified for the study. In Vatomandry, the guides found both wood and charcoal homes, but the wood homes often gathered most of their fuel, whereas primarily wood-purchasing homes were needed for the study. The fact that some households use a mix of charcoal, collected wood and purchased wood to meet their cooking needs further complicated this issue.

Therefore, when the field team first arrived in Ambositra to begin the baseline sampling, they realised that they could not rely on the prequalified household pool to meet the study criteria. For example, one day the guides took them to 16 study households, of which 10 did not fit all the criteria.

As a result, a secondary household selection process was instituted to overcome these challenges. At towards the end of each sampling day, the team would go with the guide to the next group of households to verify that they met the criteria, before placing air pollution instruments and administering the survey on the following day. In Ambositra, the team also altered the study area somewhat to focus more on urban neighbourhoods where charcoal use is more prevalent.

Consent Procedure

The consent form was presented to each participant at the beginning of the survey and reviewed orally by a local surveyor in local language. If the mothers agreed to all the conditions of the study they then signed the form.

The consent form provides;

1. An explanation of the study's purpose and activities, including details on the type of data that each piece of equipment collects during the 24hr sampling period.
2. Information on the different phases of the project and when the participants should expect to receive an improved stove.
3. Details on how each participant is expected to respond to the study's kitchen and personal monitoring instruments. It states that the personal monitors should be worn for a 24hr period by both the mother and the child.

The surveyors also demonstrated to the participant how the carbon monoxide and particulate matter monitors would be placed in their kitchens and requested that the instruments not be disturbed by anyone in the household during the 24hr sampling period.

The consent form is presented as Annex 2

2.3. Household Questionnaire

A structured questionnaire was used to collect information from participants on their household energy use, health status, and economic status. This questionnaire was developed to achieve the following objectives.

- To obtain indirect estimates of the impact of the interventions on key child (pneumonia) and adult health (COPD) by estimating local rates of disease incidence and prevalence.
- To assess the impact of the interventions on additional indicators of health and wellbeing, including eye irritation, headache, burns to children and cooks (and perceived risk of burns.
- To collect information on the participants' household energy use and procurement. This baseline information will allow an assessment of stove types used as the main and secondary stove, how fuel was procured (whether bought or gathered), the amount of time taken to obtain fuel, and the amount spent on fuel.
- To determine how well the interventions meet the needs of households, maintenance requirements, and any unexpected advantages and disadvantages.
- To contribute data required for the economic evaluation of the interventions.
- To contribute to a review of the approach, impact, scale and sustainability of household energy programs in Africa.

Measuring the inter-related effects of household energy on such issues as health, women's lives, IAQ and income generation is a complex and challenging task influenced by very locally specific features such as culture, climate and environment. The questionnaire was therefore designed and modified in close collaboration with local representatives and all project partners.

For discussion on the testing of the validity and reliability of the questionnaire please see section 2.12.1 on Quality Assurance. See Annex. 3 for topics covered by the questionnaires and Annex 5, 6,17,19 for samples of the final documents for each round of data collection.

2.4. Methods to Evaluate the Household, Socio-Economic and other Health-Related Factors

Information on household characteristics such as kitchen configuration, socio-economic factors including parent's educational levels and household possessions, and socio demographic features of the study population for example age and marital status was collected using the structured questionnaire.

2.5. Methods to Assess Acceptability and Usability of the Intervention Stoves

The questionnaire was used to explore the nature and extent of the intervention stoves use and adoption. How the stove met the daily cooking requirements of each household; how it performed in comparison to the previous stove in relation to speed of cooking; ease of use; fuel economy was assessed using qualitative and quantitative data.

2.6. IAP Monitoring Methods

Household kitchen concentrations of fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) were measured in every study household. The air samplers and real-time monitors were placed on a wall in the kitchen area. All equipment was collocated 1.0 meter from the stove and 1.5 meters above the floor (Figure 2-1.)

Figure 2-1: Collocated Monitors in Home

Monitoring periods lasted 24 hours. Sampling data sheets were used to record the details of air sampling. Sampling teams also measured kitchen, window and door dimensions during the visit when monitors were installed. Finally the teams took photographs of equipment with the household ID number to ensure that all data was correctly tracked. The Indoor Air Pollution House Data Form is attached in Annex 8

2.6.1. Particulate matter

$PM_{2.5}$ was measured in every study household using the UCB Particle Monitor, which uses a light-scattering detector (Litton et al., 2004; Edwards et al., 2006; Chowdhury et al., 2007). For consistency, the UCB monitor (e.g. same serial number) used in a given household in Baseline was again used in the same household in Round 2. Additional $PM_{2.5}$ measurements were taken with a TSI DustTrak 8520 Aerosol Analyzer (TSI Inc., USA) in 25% of houses to validate the results from the primary data collection method (UCB Particle Monitor). The DustTrak also uses a light-scattering detector. These two instruments recorded real-time, minute-by-minute kitchen concentrations throughout the sampling period.

To field-calibrate the real-time, light-scattering measurements, gravimetric $PM_{2.5}$ samples were also collected in 25% of households (the same households where the DustTraks were employed). The gravimetric sampling used aluminium cyclones equipped with 37 mm diameter Teflon filters. Casella Apex (Casella Measurement, UK) constant flow pumps were operated at a flow rate of 1.5 litres/minute, achieving a median particulate matter cut point of 2.5 μm. The pumps were calibrated using a DryCal DC-Lite primary flow meter (Bios International, USA) to within ±5% of the target flow rate.

Regular measurements of ambient particulate matter ($PM_{2.5}$) were also taken at both study sites throughout the project using a MiniVol™ TAS (Airmetrics, USA). The

MiniVol sampled ambient $PM_{2.5}$ onto 47 mm filters at 5 litres/minute. These measurements were taken throughout the two study areas. The MiniVol samples were collected in the same areas and on the same days as when the household monitoring occurred.

Gravimetric analyses of the household and ambient filter samples were conducted in a temperature and humidity controlled lab at the University of California Berkeley using a Mettler-Toledo balance. The balance is calibrated annually by a certified Mettler-Toledo representative.

2.6.2. Carbon Monoxide Monitoring Methods: Kitchen

Carbon monoxide (CO) was primarily measured using the GasBadge Pro Single Gas Monitor (Industrial Scientific). As with the particle measurements, minute-by-minute kitchen concentrations were recorded. The GasBadge Pro measured CO in the 0-1,500 ppm range in 1ppm increments. All GasBadge monitors were calibrated prior to each round in Berkeley, California, using 50ppm span gas.

In addition, Drager Carbon Monoxide Diffusion Tubes 50/a-D (50-600 ppm*h), were co-located with the GasBadge monitors in a sub-set of kitchens in each round in order to establish a relationship between the CO readings from the GasBadge Pro and the Drager tubes.

2.7. Methods to Evaluate Women's Health and Well Being

2.7.1. Personal Exposure Monitoring Methods

The impact of the interventions on women's exposure was measured in order to provide the best possible indication of the likely change in risk of Chronic Obstructive Pulmonary Disease (COPD)[3]. The mother's 24-hour exposure to CO was measured in all study households as a proxy for personal exposure to PM. The portable GasBadge Pro (Industrial Scientific) was placed on a cell-phone necklace, and participants were asked to wear it around their necks as continually as possible and to keep it close by when they were sleeping or bathing. They were instructed not to touch the bottom of the monitor and not to allow anyone else to touch it. In the day 2 questionnaire, women were asked to describe how well they were able to follow the instructions and what, if any, changes they made in their daily activities due to the monitor.

2.7.2. Interpretation of CO values and comparisons

Although carbon monoxide (CO) is toxic to humans, the primary reason for measuring this gas in the present exposure study is as a proxy for $PM_{2.5}$, which is

[3] As the study was not able to provide robust estimates of changes in chronic respiratory disease symptoms due to the small sample size in each intervention/comparison group, data on respiratory symptoms was not collected during Round 2 monitoring.

generally accepted as being the single best measure of combustion-related health damaging pollutants. 24-hr measurements of CO have therefore been made in order to estimate personal (woman and child) $PM_{2.5}$ exposures. Direct measurement of 24-hr personal $PM_{2.5}$ requires much more cumbersome equipment, is more expensive, and is not practical for infants and young children.

As a product of combustion, the relationship between $PM_{2.5}$ and CO varies between different fuel/stove combinations. For any given level of $PM_{2.5}$ emissions, wood fuel emits less CO than charcoal or ethanol fuels. That is, each fuel type has a different CO/ $PM_{2.5}$ ratio, and the ratio is lower for wood than for charcoal and ethanol. Hence, direct comparison of CO levels obtained from different fuel groups should not be undertaken in order to draw conclusions about the equivalent $PM_{2.5}$ concentrations for those same groups.

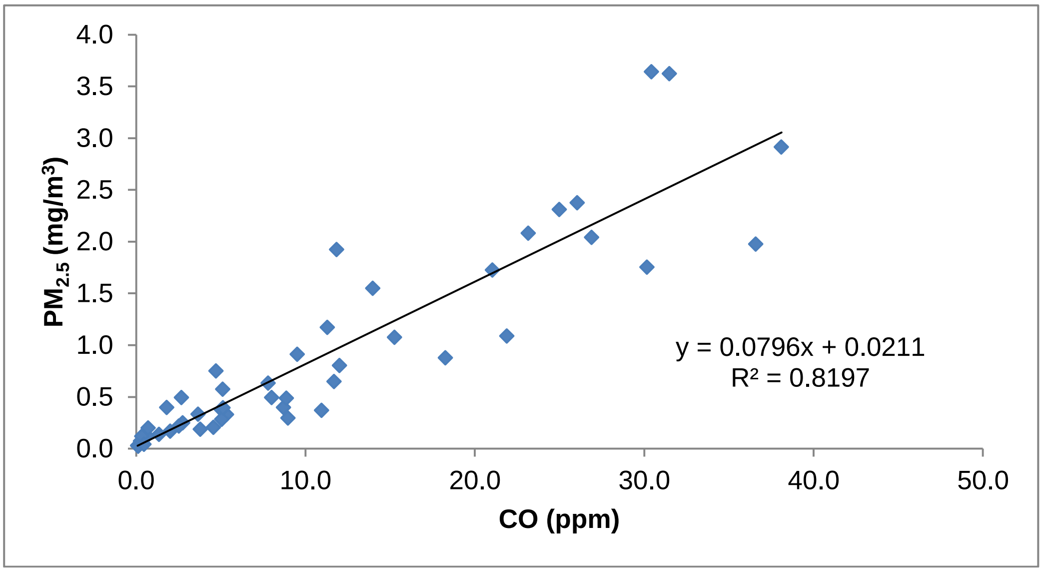
In order to deal with this issue, comparisons have being made between kitchen concentrations of CO and $PM_{2.5}$ for each fuel type using co-located samplers at each round of data collection. This information has been used to describe the relationship between CO and $PM_{2.5}$ for each fuel, and the resulting regression equations will allow 'prediction' of the $PM_{2.5}$ value for any given value of CO.

2.7.2.1. Method for obtaining predicted PM2.5 exposure concentrations

Shown below are the relationships between CO and $PM_{2.5}$, using all available measurement across the three rounds, for wood, charcoal and ethanol. Clearly, data for ethanol was only available from Rounds 2 and 3. Only subjects for whom the main fuel was the one stated are included in these analysis, so for example, households in the Ethanol intervention group who were not using ethanol as their main fuel, were excluded.

Wood: Figure 2.2 shows a consistent relationship for wood fuel based on data from Vatomandry only, with a regression equation of $PM_{2.5}$ = 0.0796 (CO) + 0.0211. The R^2 value (a measure of the amount of variation in $PM_{2.5}$ explained by the CO values) of 0.82 indicates that the level of CO predicts the observed $PM_{2.5}$ level quite closely.

Figure 2-2: Wood users - scatter plot and regression line (with equation and R2 value) for relationship between CO (x-axis, in ppm) and PM2.5 (y-axis, in mg/m3)



Charcoal: For the prediction of levels of exposure to $PM_{2.5}$ in people that used charcoal as their main fuel the intercept was forced through 30 µg/m3 (which was representative of background levels). This was done because of a number of homes had relatively low CO and high $PM_{2.5}$, likely to be due to some wood use. Without this adjustment to the intercept, the value of $PM_{2.5}$ with CO at zero would be around 170 µg/m^3, an unrealistic result.

Figure 2-3(a): Charcoal users - scatter plot and regression line (with equation and R2 value) for relationship between CO (x-axis, in ppm) and PM2.5 (y-axis, in mg/m3)

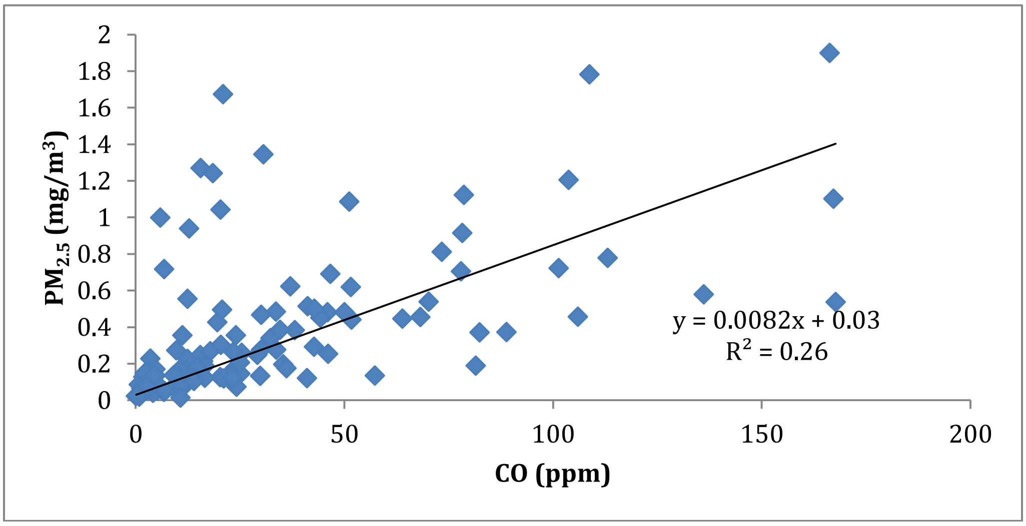


Figure 2.3(a) shows that the relationship for charcoal is less consistent, with an R^2 of only 0.26 indicating that the level of CO does not predict the observed $PM_{2.5}$ level particularly closely. This should be interpreted as meaning that although individual subject's $PM_{2.5}$ will not be predicted with any accuracy, the overall group average (e.g. for all charcoal users in a particular round) can still be usefully estimated. The regression equation is $PM_{2.5}$ = 0.0082 (CO) + 0.03. An examination of the relationships between CO and PM2.5 for charcoal in the two study sites, however, showed quite marked differences, shown in Figures 2.3(b) and (c)

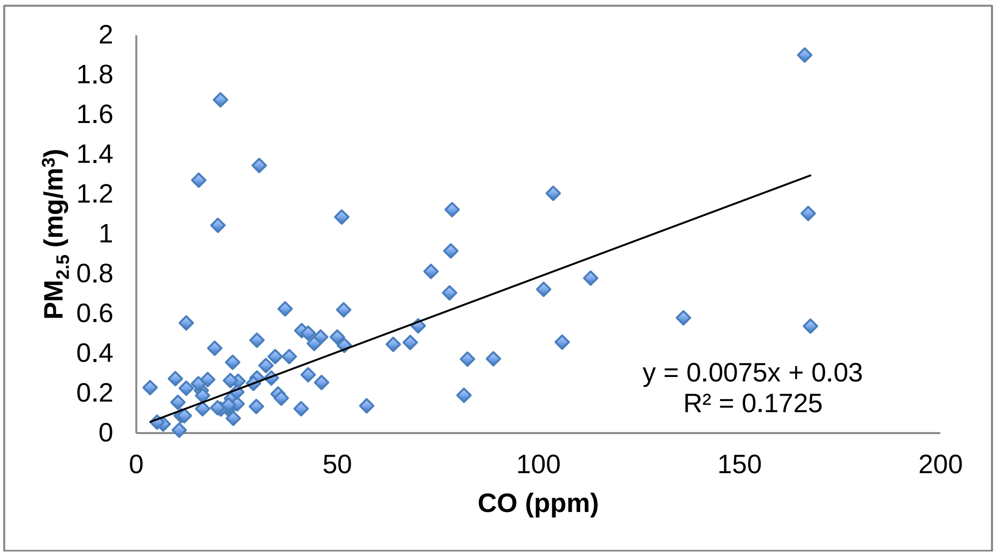


Figure 2.3(b): scatter plot and regression line for the relationship between $PM_{2.5}$ and CO, Ambositra (intercept forced through 30 µg/m3)

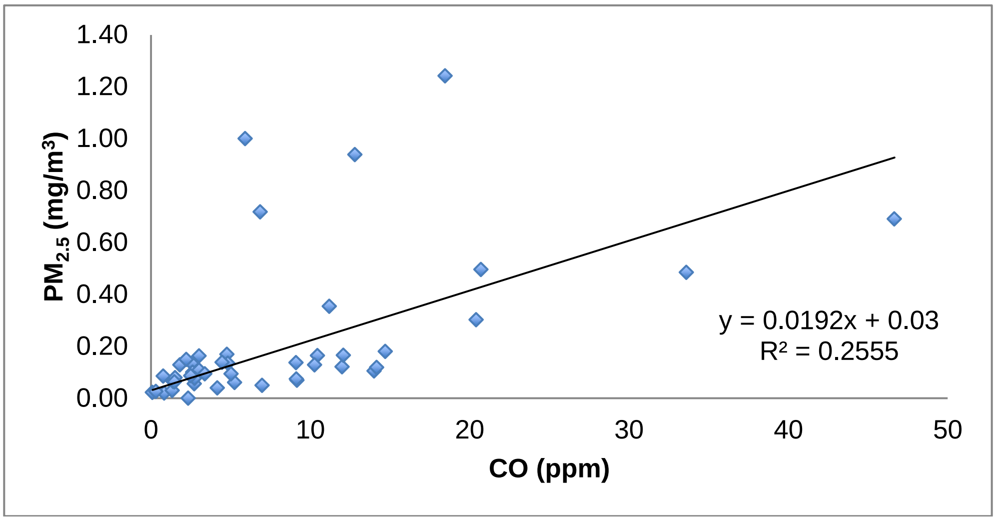


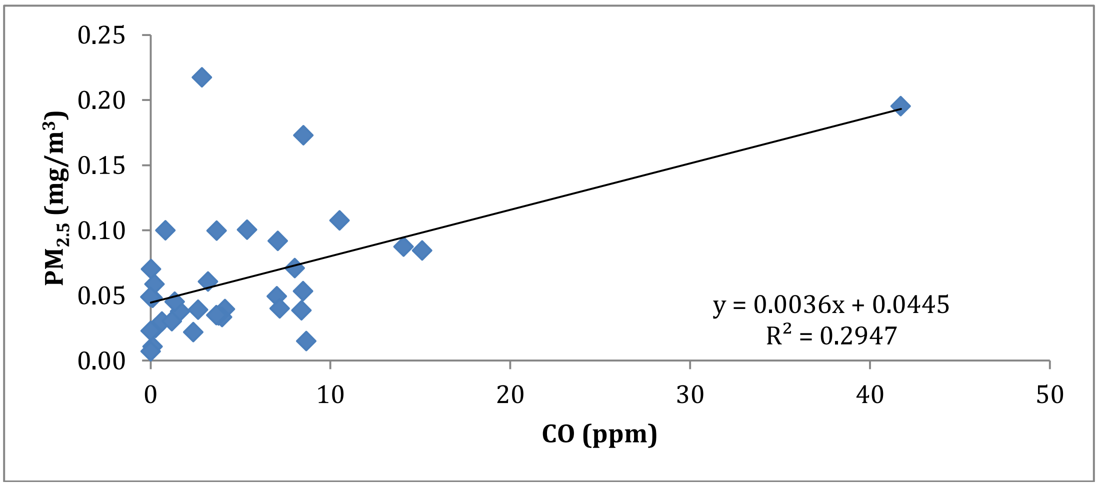
Figure 2.3(b): scatter plot and regression line for the relationship between $PM_{2.5}$ and CO, Vatomandry, with one very high (influencing) outlier removed (intercept forced through 30 µg/m3)

These site-specific results identify a number of important factors. First, the range of CO values in Ambositra are much higher than for Vatomandry. Second, the slope of the regression equations is considerably greater (0.0192) in Vatomandry than in Ambositra (0.0075). Third, the slope for Ambositra is very similar to that for all of the data (0.0082). It was concluded that while the overall equation could be used for Ambositra (using all of the data is likely to be more precise), the same equation could not be applied to the Vatomandry site. Indeed, it was felt that the lack of precision in the equation and small

range of CO would make prediction of $PM_{2.5}$ for the charcoal users in Vatomandry very unreliable.

Ethanol: this is shown in Figure 2.4, and less data are available. As with charcoal, however, the R^2 value (0.29) is low, meaning that individual values of predicted $PM_{2.5}$ will be subject to considerable error, but average group values can still be estimated. The regression equation is $PM_{2.5}$= 0.0036 (CO) + 0.0445.

Figure 2-4: Ethanol users - scatter plot and regression line (with equation and R2 value) for relationship between CO (x-axis, in ppm) and PM2.5 (y-axis, in mg/m3)



An analysis of the CO and $PM_{2.5}$ relationships in the two study sites again showed differences (not illustrated). As with charcoal, the regression line in Ambositra was fairly similar to that for all of the data following removal of the high outlier (y = 0.0023x + 0.0528), while that for Vatomandry differed more considerably (y = 0.013x + 0.0333). As only post-intervention data were available for studying these relationships with ethanol, the site-specific equations were judged too imprecise to consider using them separately for each site. Accordingly, as with the charcoal group, while $PM_{2.5}$ could be predicted for ethanol use in Ambositra using the equation based on all of the data, prediction on $PM_{2.5}$ for the ethanol group in Vatomandry has not been carried out.

Commentary

These regression equations were used to predict the mother's or child's $PM_{2.5}$, based on the personal CO measurements obtained at each round, for all of the groups in Ambositra, and for the wood stove intervention group only in Vatomandry. The choice of equation was determined by the main fuel that the household stated they were using, even if this was at odds with the intervention group they were allocated to.

It is not clear why some households who said their main fuel was ethanol had relatively high levels of CO, reaching values almost half those seen for wood users. It would be expected that ethanol would produce more CO if combustion is poor, but a more likely explanation is that we know many ethanol users (who state it is their main fuel), also use a secondary stove with charcoal or wood (see Section 5). The scatter plot and regression equation in Figure 2.4 should therefore be seen as representing the relationship between CO and $PM_{2.5}$ in the setting of this study, where in fact the majority of households who are mainly using ethanol, also use some wood and/or charcoal.

Mixed fuel use also occurred among the other intervention groups (improved wood, improved charcoal), but substantially lower proportions of these households used secondary stoves and fuels, so this is much less of an issue.

2.7.3. Respiratory symptoms

Questions related to the participants' respiratory health were used to provide an indication of the prevalence of chronic respiratory symptoms in the study population. As we are not able to provide robust estimates of changes in chronic respiratory disease symptoms due to the small sample size in each intervention/comparison group, this section of the questionnaire will only be used at baseline.

The standard International Union Against Tuberculosis and Lung Disease (IUATLD) questionnaire was used after minor adaptation for the local situation. The comprehension of questions and concepts such as wheezing were carefully checked in local settings and language during the surveyor training phase at the start of sampling in each location.

2.7.4. Eye and headache symptoms

Based on current evidence, it is unclear whether indoor air pollution increases the risk of eye infections (including for example trachoma), but there is no question that eye irritation with tearing is common, and is one of the most frequently reported symptoms in surveys of health problems associated with IAP. The information required to assess the prevalence of eye irritation and tearing was therefore collected in the baseline survey.

Information on another common symptom, headache, was also collected to investigate the relationship between reported frequency/severity of headaches and CO levels/ women's exposure.[4]

2.7.5. Risk of burns/ scalds to women

It is important to know if the interventions leading to added risk of burns and scalds as well as to explore if the stove reduces risk of burns. The number and severity of burns was assessed using questionnaire data at baseline and then again at Round 3 five months after the new stoves were installed.

2.8. Methods to Assess Children's Health and Well Being

Rather than measure ALRI incidence directly, this study aims to assess exposure of children, and apply the information obtained on the levels of exposure and reductions observed to an exposure-response function derived from the Guatemala RESPIRE

[4] Headaches and sore eyes constitute significant impairments on wellbeing and quality of life for the women concerned. One of the likely mechanisms is exposure to carbon monoxide gas (CO), as this has commonly been shown to be at a level close to, at, or above the WHO 8-hour guideline level, and often very considerably higher during some phases of using a biomass stove, for example during stove lighting and some types of cooking task. The RESPIRE randomized control trial in Guatemala (in which the University of Liverpool group played a key role) showed significant reduction in the frequency of both sore eyes and headache in the intervention (improved chimney stove group – the *'plancha'*) [Ref: Diaz *et al*. 2007 – see below]. Specifically, the odds of having sore eyes and headache were substantially reduced in the *Plancha* group relative to the group using open fires for the follow-up period: for sore eyes the odds ratio (OR) was 0.18 (equivalent to a 82% reduction), 95% CI 0.11-0.29; for headache the odds ration was 0.63 (equivalent to a 37% reduction) , 95% CI 0.42-0.94. The median breath CO among intervention women was significantly lower than controls. Comparable results, with accompanying reductions in personal CO measurements have been reported from other studies including that carried out by DFID/Practical Action in Nepal, Kenya and Sudan using a before and after design.[4]

study. Publication of the analysis of this relationship is pending. In order to apply this method, the following key steps were followed:

- Measure the change in exposure among children less than 5 years using CO as a proxy for $PM_{2.5}$.
- Analyze the relationships between the measured CO and $PM_{2.5}$ concentrations for biomass, charcoal and ethanol.
- Obtain local estimates of ALRI (age less than 5 years, by age group).
- Determine the reduction in risk associated with the exposure reduction, by using estimates from RESPIRE (ALRI) and the literature (ALRI and other outcomes). Apart from the case of ALRI for which an exposure-response relationship is available, estimates of risk reduction will be restricted to a binary approach, namely exposed vs. unexposed. In the case of clean fuel, if there is marked exposure reduction, this should allow application of such risk reduction estimates.
- Derive predicted change in incidence and prevalence in an appropriate time period.

In order to inform this analysis, 24-hour exposure to CO was measured on one child less than 4 years of age in each household as a proxy for $PM_{2.5}$ exposure. Exposures were assessed using Drager Carbon Monoxide Diffusion Tubes 50/a-D (50-600 ppm*h). Tubes were placed on the baby or child's shirt using plastic tube holders and clips. In general the tube was clipped to the child's left or right shoulder. In consistent lighting, the field supervisors read the tubes immediately after collection, and the average of their measurements was used for analysis. To increase the resolution of the tube readings and reduce error, stain length was measured in millimetres, then converted to ppm CO using a conversion equation derived from laboratory chamber experiments (r-squared > 0.95). For consistent comparison across CO measurement instruments, collocations of tubes and GasBadge real-time CO monitors were performed in a sub-sample of ~50 kitchens over the course of all three rounds of study. An adjustment factor was then calculated and this linear adjustment (r-squared= 0.92) applied to all tube readings to provide GasBadge equivalent readings. These adjusted values were then used in analysis.

2.8.1. Risk of burns/ scalds to children

As with adults the nature and severity of burns in children was assessed before and after the installation of the stoves using questionnaire data.

2.9. Field Team Recruitment and Training

The permanent field team consisted of two leaders from the consortium and two Malagasy health professionals based in the capital Antanarivo, who served as field supervisors. This core team was assisted by four local surveyors, recruited on site in each study area. Local government officials assisted the team by advertising for surveyors based on qualifications submitted by the field team leaders and assembling a shortlist of applicants in advance of the team's arrival.

Before baseline survey the fieldworkers were trained over a four-day period in each of the locations. The first day consisted of multiple presentations and "classroom" trainings, where as the following three days were spent practicing in real households similar to those recruited for the study. The first-day curriculum included:

- Overall project objectives and activities;
- Roles of consortium members, partner organizations and project stakeholders;
- Code of conduct and other expectations of surveyors in the field;
- Instrument purpose and placement protocols; and
- Procedures for administering surveys.

Significant time was allocated to both the survey and equipment placement procedures in the field. The surveyors learned to administer the survey correctly but also focused on how to relate the questionnaire to the local context. First the two field supervisors would role-play the survey, which was an excellent method for teaching how the survey should be done. This also gave an opportunity for the local surveyors to give their input on whether or not the word choices in the survey were linguistically and culturally appropriate in the local context. The first day of training also gave each of the surveyors an opportunity to practice and go over the survey in pairs. A field supervisor was assigned to each pair of local surveyors to ensure they were asking the questions correctly. The field supervisor would also act as interviewee to present the local surveyor with different scenarios that he or she might encounter in the field.

On the following three days, the surveyors practiced placing the equipment in households and administering the survey to women in the community. The focus of these three days was for the surveyors to become comfortable with the survey and the placement of the equipment in the kitchens. The surveyors would do up to four practice surveys each a day and place equipment in two practice kitchens. A field supervisor would accompany the local surveyors to these practice interviews to ensure they were asking the questions correctly. At the end of each training day, the team leaders convened a meeting to answer questions and provide feedback to surveyors on areas that needed improvement.

The field staff was retained throughout the entire survey, which increased consistency and ultimately the quality of the data collection. Prior to the follow up surveys the consultant team conducted a day of training for the surveyors in both Ambositra and Vatomandry. Materials created by the consortium were used in the trainings. Due to the year long delay between baseline and round 2, all materials from the baseline were reviewed, and additional materials were created for the second round of training.

Additionally, during this training, QA/QC procedures were reviewed by the field managers and the local field staff. Particular emphasis was placed on:

1. Additional measures to ensure compliance with the exposure-measurement protocols.

2. Changes to the field team composition to ensure consistent decision-making during the household visits.

Details for the QA/QC procedures can be found in Section 2.12.1.

Data entry training was given to the field supervisors by the field managers.

2.10. Sequencing of Data Collection at Each Round

As outlined previously the initial visit to the household was to confirm that the study criteria were met. The second household visit was conducted to place the CO and particulate equipment in the kitchen and the personal monitors on the women and children. The Day 1 questionnaire [see Annex 5; 17; 19] was also conducted. The next day, the field workers returned to the house to collect the equipment and complete the Day 2 questionnaire [see Annex 6; 20].

Selected repeat visits were also undertaken by the field supervisors for quality assurance purposes during the first week (see section 2.12.1 for further information on quality assurance).

2.11. Timing of data collection

The initial protocol aimed to carry out three rounds of data collection: baseline survey in the wet season and two post-intervention, with the second post-intervention round during the same season (wet) as baseline. The wet season is expected to be the worst case scenario for kitchen air pollution, as windows and doors are closed more frequently, and for exposure, as people spend more time indoors. Due to difficulties in identifying a suitable intervention stove the second round of data collection was delayed and was carried out at the end of the wet season one year after baseline. The final round was then carried out 5 months later in the dry season. (See Table 2.2 and 2.3)

Table 2.2: Dates of stove installation and data collection in Ambositra

Baseline survey	Stove type	Installation date	Date of Round 2 survey	Data of Round 3 survey	Comments
February 13th - March 12th 2009	Charcoal stove	January 27th 2010	March 15th-31st 2010	13th July-18th August 2010	1 household received the stove during final week of the first round of surveying.
	Ethanol stove	February 25th 2010			3 households received the stove in the final week of the first round of surveying.

At the end of January, the awareness-raising campaign commenced immediately in allocated households (all the stove groups plus the awareness-raising-only group).

Table 2.3: Dates of stove installation and data collection in Vatomandry

Baseline	Stove type	Installation	Date of	Data of	Comments

survey		date	Round 2 survey	Round 3 survey	
February 13th - March 12th 2009	All types	Week of March 11th 2010	April 7th-27th 2010	13th July-18th August 2010	No comments

2.12. Quality Assurance

2.12.1. Fieldwork Quality Control

The local surveyors were instructed to conduct spot checks after the exposure monitors had been placed. On each test day, they were instructed to visit the households in the mornings or evenings (depending on the test cycle) to ensure that the GasBadge and CO tubes were being properly worn and to ensure they were wearing them for the full 24 hr period. During the spot check visit, the surveyors answered any questions about the stove and checked on the IAP equipment.

The field team members worked in pairs to complete the fieldwork tasks. Two teams were assigned to work in the same neighbourhood, so that the local surveyors were either paired directly with a field manager or supervisor or had direct access to them if they had any questions or issues. This arrangement also facilitated the field manager's ability to conduct spot checks of the surveyors' work. The composition of the teams was changed several times over the course of the fieldwork, with each person being assigned a new partner at the beginning of the monitoring of a new set of households. The rotation of the field team members provided ongoing training opportunities and increased consistency among the teams.

2.12.2. Reliability and validity of data collection tools

In addition to the fieldwork method described above, the following activities were carried out to ensure the validity and repeatability of the questionnaire:

- Having a native speaker translate the questionnaire from English to Malagasy, and then having it "back-translated" by the field supervisors to ensure no loss or distortion of meaning occurred during the translation process;
- Piloting the questionnaire with local surveyors, local NGOs, and in "practice" homes for ease of use, problem questions, which either caused confusion or were refused answers, and ability to collect the information required.
- Taking photos of equipment in homes to catalogue stoves, type of equipment placed, equipment numbers, and also to verify correct equipment placement by surveyors; and
- Checking by field supervisors that each questionnaire had been completed fully and logically at the end of each day.

Berkeley Air has a standard QA/QC protocol for the IAP instruments, which was included in the first interim report.

2.13. Data entry and management

Each data form was entered into an Access database by the field team. In the baseline round, the data was entered only once into the database, but it was subsequently checked by a different pair of fieldworkers. One person read the entered data from the database out loud to another fieldworker, who simultaneously checked the entered values against the paper copy.

In Rounds 2 & 3, the field team had sufficient time and resources to enter all the data forms twice into separate databases. The databases were then compared for any differences. Where differences were discovered, the data was verified against the original survey and corrected on the master database.

The data was backed up in Madagascar and sent to the UK (survey and personal exposure), and USA (IAP data) for further back-up and transfer to the statistical software package SPSS version 16 for data cleaning and analysis.

2.14. Data analysis methods

2.14.1. Paired, "Difference in Difference" Tests

The Round 2 and Round 3 (and Round 2 and Round 3 combined) intervention groups were compared to the baseline. This comparison was done in a paired fashion, comparing each intervention group to itself. It was presumed that if significant changes were seen in the control group over time, the Round 2 and Round 3 intervention values would be adjusted by the difference seen in the control group (difference in difference approach). Following Round 3, there was no evidence suggesting that IAP levels changed significantly relative to baseline in the control group.

Absolute IAP differences and percent differences were determined, and tests of significance were performed for each comparison. The same was carried out for IAP, exposure (mother, child), and the relevant health outcomes. So, for the ethanol treatment group, we did the following:

- Ethanol in Round 2 versus ethanol baseline (paired)
- Ethanol in Round 3 versus ethanol baseline (paired)
- Ethanol in Round 2+Round 3 versus ethanol baseline (paired)
- Ethanol R2 versus ethanol Round 3 (paired)

The same three tests were carried out for the other intervention groups (improved charcoal, improved biomass, and awareness).

2.14.2. Statistical Modelling with Generalized Estimating Equations (GEE)

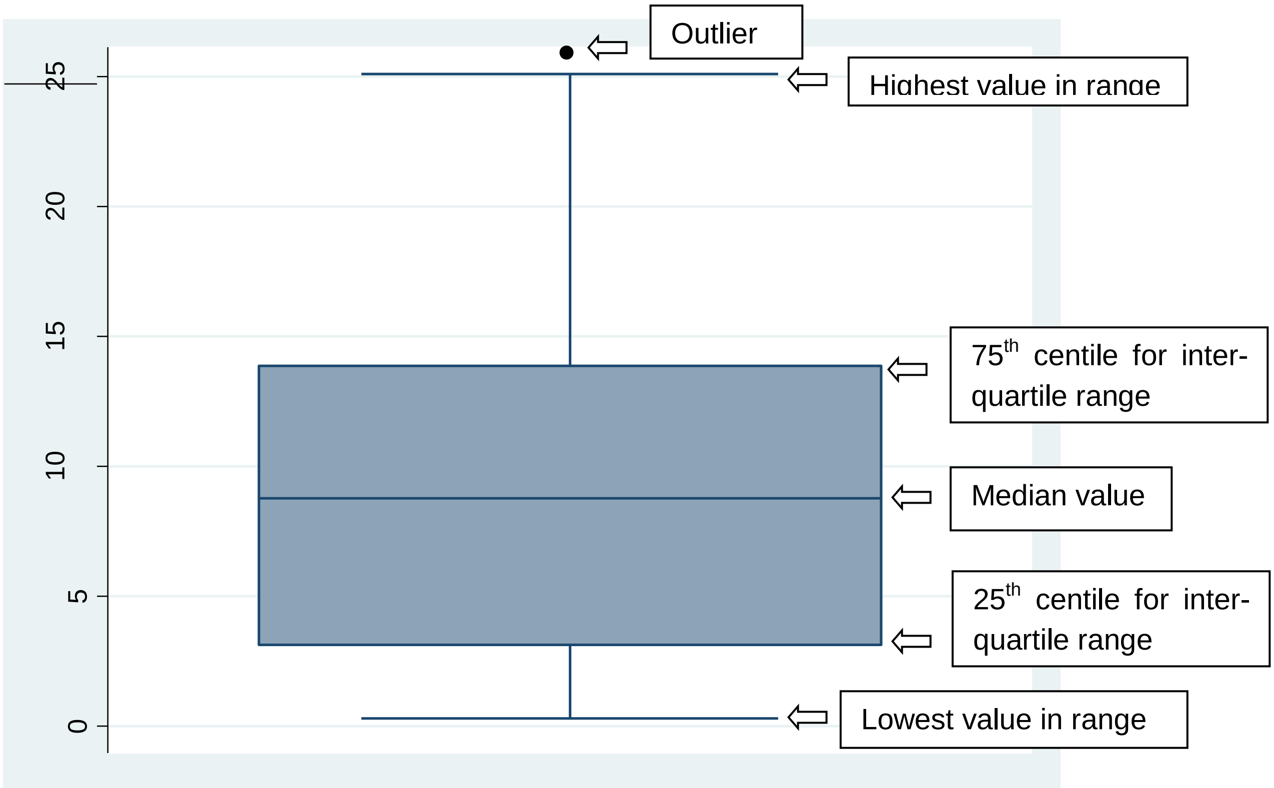
Generalized Estimating Equations (GEE) with robust standard errors and an exchangeable correlation structure ("xtgee") were used to assess the population level effect of each intervention on 24-hr average CO and predicted $PM_{2.5}$ concentration (the latter, Ambositra only). Each study site, Ambositra and Vatomandry, was analyzed separately due to the large differences in air pollution concentrations. The model accounted for differing starting fuels within each intervention group and adjusted for the location of the kitchen, which was found to be a significant covariate (see section on "Factors Affecting IAP"). All analysis was performed in Stata 11 (StataCorp lp, College

Station, TX, USA). The model allowed for the inclusion of data on any household allocated a treatment group following Round 1. In addition, all IAP data were subject to the exclusion criteria outlined in the Baseline (3.2) and Follow-up (3.3) Data Quality sections.

2.14.3. Presentation of data

Many of the descriptive statistics within the report are presented using box and whisker plots. In most cases they have been used to present differences between the intervention groups for a particular variable, such as levels of exposure to CO. Figure 2.5 outlines the key aspects within a box and whisker plot and the function they serve.

Figure 2.5: Key factors within Box and Whisker Plots



2.15. Identification of a safe effective ethanol stove

Based on the preliminary assessments made by the implementing party, the Proimpex, ISPM and CleanCook ethanol stoves were selected for a series of screening and Controlled Cooking Tests (CCTs) in Antananarivo and usability tests in Vatomandry in June/July 2009. Based on the results of the first round CCTs and usability tests, the CleanCook stove was the strongest performer and was well liked by the test and household cooks. The Proimpex stove was least satisfactory and largely excluded from consideration without design modifications. The ISPM stove performed reasonably in the first round CCTs and usability tests, and in response to comments received, an updated version was reassessed in broadly similar screening and CCT tests in Antananarivo in October 2009, but not in repeat household usability tests. The updated ISPM was also tested alongside the original Proimpex, the CleanCook, and the double-burner CookSafe at Aprovecho Research Center in Water Boiling Tests (WBTs) and a safety evaluation (the CCT and usability testing is described in detail in chapter 5 of the Component B Report, and the Aprovecho report is appended to the Component B report).

After a detailed review in the fourth quarter of 2009, the consulting team came to the conclusion that the ISPM stove, even in its improved form, still presented significant performance, reliability and safety risks, mainly due to clogging lines due to the corrosion of its mild steel fuel container. This was thought to compromise the likely success of the household survey and at worst have implications for participants' health. It was agreed that the safety considerations in particular created an imperative to alter the proposed intervention, even though the change resulted in a more controlled evaluation and significant delays. It appeared, based on the information available at the time, that the following three options were feasible, but all required a significant shift in approach or timeframe of the project:

1. Put all interventions on hold and seek a response from ISPM to the test results and recommended changes. With their participation, agree to a timeframe and development pathway including more extended household usability testing in both Vatomandry and Ambositra, and seek to validate an improved design for installation along with the rest of the stove interventions in first half of 2010 with post-intervention testing picking up in the dry season of 2010.
2. Go ahead with fuel wood and charcoal interventions according to the original timeline (fourth quarter 2010) while the ethanol stove is further developed through household usability testing as in option 1 above. A post-intervention study on the wood and charcoal households could be done on schedule during the wet season in first quarter 2010, while the refined ethanol stoves were implemented. The second dry-season post-intervention survey would be conducted in third quarter 2010 and pick up all interventions. This would mean that the ethanol stoves would have only one post-intervention survey.
3. Import a proven ethanol stove in which everyone has confidence, for the purposes of getting clear results, consistent performance and household acceptance. The CookSafe was initially viewed as the preferred imported stove of choice, to eliminate any potential conflict of interest faced by the consulting team with the CleanCook. It was hoped that the logistics could be worked out quickly enough to conduct meaningful field-testing in the wet and dry season 2010.

Ultimately the project implementers and funders agreed that the third option was most likely to deliver a reliable assessment of the ethanol's potential in Madagascar, while still allowing the project to be concluded by the end of 2010. Additional funds were found to pay for a more expensive ethanol stove and the higher quality fuel it requires. In the end, the CleanCook was selected over the CookSafe because the CookSafe was found to be no longer available from distributors in South Africa.

2.16. Final interventions allocated to the households

After extensive testing and consultation, three stoves were identified that were deemed to be appropriately safe and effective for use in households.

The disseminated charcoal burning stove (Figure 2.5) is similar to the Kenya Ceramic Jiko (KCJ). The stove consists of an hour-glass shaped metal cladding with an interior ceramic liner that is perforated to permit the ash to fall to the collection box at the base. A single pot is placed on the rests at the top of the stove.

Figure 2-5: Charcoal burning stove

The disseminated biomass stove, disseminated only in Vatomandry, is a wood-burning stove called Fatana Pipa produced by a company called Bionerr. The stove consists of a metal-covered ceramic bucket with a chimney and supports for one pot (Figure 2.6)

Figure 2-6: Wood burning 'Fatana Pipa'

The ethanol burning stove disseminated to the households is a stainless steel stove called the CleanCook. The type given to the households in this study has one pot stand. The non-pressurized fuel tanks hold the ethanol in a special adsorptive fibre. The burner flame is adjusted or extinguished by means of a simple regulator (Figure 2-7).

Figure 2-7: Ethanol burning CleanCook Stove

All households except those in the control group were exposed to an awareness-raising programme, which sensitized the households to the clean stoves by focusing on the health advantages of clean (less smoky) stoves as apposed to dirty (smoky) stoves.

The Tana Meva team, in association with the local NGOs AJDV and Meres Diligentes, carried out door-to-door visits, distributing flyers (see Annex 12) to each allocated household, and verbally informing them of the key messages;

1. Smoke from the stoves is not good for their health.
2. The participants should move their stove next to a window or door for ventilation because this would decrease the amount of smoke in the room.
3. The participants should keep their children away from the smoke (stove) because it is bad for their health

The participants were asked to not give the fliers to other households or pass on the messages in an attempt to reduce 'contamination' of the control group participants.

2.17. Allocation of interventions

The interventions (including control group status) were assigned to each household using random allocation within two kitchen configuration strata (separate from house and joined to house). The procedure used to randomly allocate the intervention was slightly different at each study site to take into account the two main cooking fuels used baseline in Vatomandry.

2.17.1. Allocation within Ambositra

No wood burning stove households were to be allocated in this location, therefore exclusive wood users were removed from the sample.

There were a total of 3 wood users at baseline:

- 2 wood users who used a three-stone fire were removed from the sample.
- 1 user was included in the sample. As their main stove was documented as a charcoal stove and they purchased charcoal on occasion, it was deemed likely that their fuel-use was 50/50 (wood/charcoal).

Of the remaining participants in Ambositra:

- 9 households had kitchen configuration type 1 (kitchen separate from the main house)
- 132 households had kitchen configuration type 2 (kitchen joined to main house)
- 1 household had no information on kitchen configuration and was allocated to the control group (smallest group) at the end of the allocation process.

Thus, 141 households were included in the study for Ambositra.

For kitchen configuration type 1

The study identification numbers of participants in this group were transferred into Excel.

Each of the 9 participants were given an allocation number between 1 and 9 (each number could only be used once)

Using the website http://www.graphpad.com/quickcalcs/randomize1.cfm the numbers 1-9 were then randomly allocated to one of four groups A-D.

A= Control group

B= Awareness group

C= Improved charcoal stove group

D= Ethanol stove group.

These groups were then transferred into Excel matching the allocation numbers. The assigned allocation group was then entered into the SPSS program.

For kitchen configuration type 2

Random allocation was carried out in the same way as above but with 132 participants given an allocation number between 1 and 132.

2.17.2. Allocation within Vatomandry

Biomass stoves were included among the interventions used at this location so there were 5 allocation groups

A= Control group

B= Awareness group

C= Charcoal stove group

D= Ethanol stove group

E= Biomass stove group

A biomass stove was only allocated to a household that reported their main cooking fuel to be wood during the baseline survey. Similarly, a charcoal stove was allocated to a charcoal user at baseline.

A method was used to reflect/maintain the kitchen configuration proportions within the wood stove and charcoal stove allocation groups. For example:

97 wood fuel users in Vatomandry

63 wood fuel users in Vatomandry with a type 1 kitchen configuration (separate kitchen)

97/63= 1.5

Wood stove allocation group aims to be 36

36/1.5= 24

All 63 wood fuel users with separate kitchens were given an allocation number between 1 and 63 (again each number only used once). 24 of these 63 were randomly chosen to go into the biomass allocation group using the website http://www.graphpad.com/quickcalcs/randomSelect1.cfm

This was then entered into SPSS.

A similar process was used for the 34 wood users in Vatomandry who had a joined kitchen. This resulted in 12 being allocated to the wood stove group.

The same process was used with the charcoal fuel users.

The remaining 61 wood users (97-36) and 47 charcoal users (83-36) were split into the 2 kitchen configuration groups, given new allocation numbers and then randomly allocated to one of 3 groups (control, awareness raising and ethanol).

The final **planned** allocation groups are outlined in Table 2.4. Please note for several reasons the actual final allocation groups did not follow this plan (see Section 2.18 for more information).

Table 2.4: Planned numbers for each allocation group by study site after random allocation

Intervention Group	Ambositra	Vatomandry
Control	35	37
Awareness-raising only	36	37
Charcoal stove	34	35
Ethanol stove	36	35
Biomass stove		36

2.18. Challenges during the study

2.18.1. Significant loss in households between baseline and follow-up

There was significant loss of households between the baseline and intervention period. The nature and extent of this loss is described in detail in Section 14.3. It is believed that the loss of households was a consequence of the following factors:

- There was an unanticipated delay of one year between the baseline monitoring and the first follow-up visit. This was primarily due to the fact that there was no safe, effective stove available to disseminate to the participants and no fallback/development time for an alternative stove to be built into the project design. The delay was caused by having to identify, verify the safety of, and then supply a replacement stove. This delay was entirely out of the consultants' control, although the team had expressed concerns about the stove technology and the study timetable from the outset. The delay would, however, have been mitigated had the initial stove been made available for the initial test screening by the consultants at the start of the project as promised, rather than a full 6 months later, due to stalling on the part of the pre-appointed supplier (probably aware that his stove would fail these first-line tests). The delay was compounded by issues with ethanol supply, due to no ethanol supply availability for 12 months after the date put forward to the consultants initially.
- During this delay, there was also significant political and economic disruption in Madagascar, which contributed to a situation where people were forced to migrate to find work.
- The Round 2 monitoring occurred during the harvest period, which meant that some households had moved temporarily to the countryside.
- The team observed some reluctance amongst a few households to remain in the study based on uncertainty about the price of ethanol fuel and unhappiness regarding the stove allocated.
- Some of the households had issues adapting to the stove that was allocated to them. For example, the Vatomandry households allocated the improved wood stove were required to have or to create a hole in their roof in order to accommodate the chimney. This proved to be a challenge for some households. Also, some ethanol stove households had difficulty with adoption, because they did not receive proper training on how to use the stove.

2.18.2. Confusion at the onset of household allocation

Initially, Meres Diligentes (MD) did not use the random allocation schedule drawn up by the Component A team when they started to disseminate charcoal stoves in Ambositra in January 2010. They used their own list, which was the basis for the original household identification at baseline. Unplanned time and effort was then required to rectify this situation.

2.18.3. Reduced adjustment time before monitoring

The various delays with the stoves and the ethanol supply, along with efforts to adjust the household allocation to mitigate the effect of lost households, resulted in uneven and insufficient adjustment times. The preferred adjustment period for an intervention assessment is six weeks. Of the intervention groups who received stoves, only the charcoal group in Ambositra achieved the six-week standard. Within this group, there was one household that was added to the intervention group towards the end of the sampling and had less than one week to adjust to the new stove. All but three of the households in Ambositra that received ethanol stoves were given a little over two weeks to adjust. The other three had less than one week adjustment time. In Vatomandry, without exception, all the intervention households receiving stoves took delivery of their stoves four weeks before the sampling began.

2.18.4. Disruption of seasonal comparison

Again linked to the implementation delays, the Round 2 surveys were completed on the margins of the end of the wet season rather than at its peak in January-February.

2.19. Measures taken by the consultant team to address these challenges

The Component A team moved to address these challenges as quickly and methodically as possible within limitations presented by factors beyond their control.

2.19.1. Loss to follow-up

At the planning stage it was decided that each study group needed at least 30 participants to produce statistically robust results. Once allocation was carried out by MD and the field team came to interview the participants in Ambositra, it was seen that some groups had fallen below the required 30, as follows:

- 33 Awareness group
- 30 Charcoal stove
- 29 Ethanol stove
- 24 Control group.

In view of the fact that some further losses were expected between rounds 2 and 3 of data collection, and that the ethanol group is of key interest to this study, it was decided to randomly identify three households from the awareness raising group who had not yet been interviewed and move them over to the ethanol group. This created the issue of these three households having only had the stove for 4-5 days prior to being monitored for Round 2. However, the consultant team felt that this was a necessary compromise in order to invest in the data quality for Round 3.

The control group was well below the required 30 households and by the nature of a control group was likely to decrease further before Round 3. This threatened the validity of any comparison between the control and other allocation groups.

To address the low numbers in the control group, a further 10 new households were identified using precise criteria (See annex 13) to ensure they were as similar to those households lost as possible. These households then had baseline data collected for them during the Round 2 monitoring. The baseline dataset and the Round 2 dataset are very similar for the control group. Nonetheless, the team acknowledges that this is not an ideal situation, rather constituting a compromise in order to ensure a valid control group in Round 3.

Loss to follow up also occurred in Vatomandry for similar reasons to Ambositra. After discussion with World Bank representatives, it was decided to move 3 control households over to other allocation groups (2 to the awareness only group and 1 to the charcoal stove group) and then to identify 7 new control group households using the methods described above.

2.19.2. Confusion at the onset of household allocation

In response to the allocation confusion in Ambositra, the consultant team requested that the implementing partner assess and document where the misallocations had been made and correct them as far as feasibly possible.

Some households returned the stove they had been given and assumed their intended allocation status. Others refused to return the stove. Some in the original control group became charcoal stove group participants, as they were already exposed to the charcoal stove and no longer fitted the control group criteria.

The team do not think that contamination of control group participants will result from this issue as those given a stove in error were allowed to stay in that group. It is difficult to know how having the charcoal stove for a short period will impact the data for the four households now in the awareness group. Although we predict that by Round 3 data collection there will be no impact on the IAP and exposure measurements of these participants. However these HH will be looked at carefully during the Round 3 data analysis. The original random allocation framework that was maintained once all reasonable changes were made is outlined in Section 3.8.

2.19.3. Reduced adjustment times for stove users before monitoring

The three households with late allocations still provide valid indoor air pollution data, but their feedback on usability and acceptability or any health-related changes will be of limited value in Round 2. However, by the final round this will have been resolved. The consultant team considered this issue when interpreting the results from the Round 2 data.

2.19.4. Disruption in seasonal comparison

We have been informed that the meteorological stations for Vatomandry and Ambositra closed in 1990 and so only have the monthly average rainfall in each zone during a 30-year period from 1961-1990. From this it appears that the second round of data collection took place as the wet season was coming to an end but well outside the dry season months. However this source of data is not ideal and can only provide an estimate of the timing of the Round 2 survey in relation to the wet/dry seasons.

3. Data Quality

3.1. Quality of the Baseline Questionnaire Data

In order to verify the accuracy of the data entry into the Access database, a member of the team who had not been involved in the fieldwork carried out a check of a random sample of the questionnaires and corresponding data entries. Due to time constraints 15 questionnaires (5% of the total study sample) were selected from the forms completed in Ambositra only.

This process revealed minimal data entry errors within this sample. Some minor issues were identified within the questionnaire that probably occurred during translation, in addition to a few repeated errors in completing the questionnaire, for example not filling in certain sections after a positive response. However these were minor issues most of which could be addressed in the data cleaning and checking with the field team. To reduce the impact of these negligible errors further we:

- Used subsequent fieldworker training sessions to highlight the areas within the questionnaire where mistakes were made in completion.
- Ensure the few issues within the questionnaire were addressed in the English and Malagasy versions prior to the Round 3.

3.2. Quality of the follow-up questionnaire data

The quality assurance checks that were employed during the collection of the Rounds 2 and 3 questionnaire data, such as daily checks of all completed questionnaires for accuracy and consistency by the field supervisor and the double entry of the data collected, led to a dataset that had minimal missing data and a very low possibility of data entry errors. Very few participants refused to answer questions, and the refusals that did happen did not occur consistently in any particular questions.

There is always a potential for information bias when data are collected using a questionnaire, and the chance of bias increases when the interviewer is not 'blinded' to intervention status. In this study, however, many of the questions were of the more objective 'closed' type, which leave less room for interpretation by the interviewer. The team further reduced the potential for information bias through the standardised training of the fieldworkers and the use of clearly written protocols.

Recall bias is also a possibility in an intervention study, especially when people hope to keep the free stove that they have been given for the study and so report symptoms/ perceptions more favourably than they might if they had bought the stove. The potential for recall bias was reduced by ensuring that the interviewers did not have any influence over the stove dissemination. However the possibility of recall and reporting bias should be considered in the interpretation of the more subjective results.

3.3. Quality of Baseline IAP Data

IAP data was omitted for any monitor that did not record at least 1400 minutes (23hrs 20min) of data during the monitoring period. Using this criterion, approximately 7% (10) and 1% (2) of personal CO samples from women were removed from Ambositra and Vatomandry in round 1, respectively. This data loss was attributed to monitor malfunction, potentially from being jolted, resulting in periodic loss of battery connection. This problem affected only personal samples, so no kitchen samples were omitted.

Fuel used during the sampling period was assumed at baseline to be the primary fuel reported by the participant. In Rounds 2-3, group members were allocated using their the fuel corresponding to the treatment group, though fuel mixing certainly occurred and expected in many homes with access to multiple fuel types. Whenever possible, the start times for all instruments within the same household were synchronized for consistency in averages. If, however, synchronizing of time resulted in a monitor no longer reaching 24hrs of recorded data, the recorded start time for that monitor was used. In these cases, monitor start/stop times did not offset by more than 20 minutes and occurred during non-meal times of the day when field workers were visiting homes.

UCB monitors were calibrated using wood smoke in a laboratory chamber in Berkeley, CA, USA. To improve accuracy of pollutant measurement values, a subsample of gravimetric filters collected in households was used in each round to provide field and fuel specific adjustment factors.

3.4. Quality of Follow-up IAP Data

Household IAP data were omitted if less than 1,400 minutes (23 hrs, 20 min) of data were recorded during the monitoring period. In Round 2, 1 (<1%) and 3 (2%) of CO data points were lost in Ambositra and Vatomandry, respectively. In Round 3, 13 (8%) and 8 (5%) of CO data were removed or lost in Ambositra and Vatomandry, respectively. Three (2%) and 6 (4%) of $PM_{2.5}$ data were lost in Round 2 in Ambositra and Vatomandry, respectively, and 4 (3%) and 8 (5%) in Round 3. Loss during follow up rounds was entirely due to monitor malfunction (e.g. battery connection loss due to jolting).

UCB monitors were calibrated using pine wood smoke in the Berkeley Air Monitoring Laboratory combustion chamber in Berkeley, CA, USA. To obtain accurate PM magnitudes, a 25% sub-sample of gravimetric filters were collected in kitchen and used to provide fuel specific adjustment factors for the UCB. In addition, these adjustments account for any differences that might arise in instrument response between the lab and field. A round specific adjustment factor was calculated for ethanol, charcoal, and wood and applied during the data cleaning phases.

GasBadge CO monitors were calibrated using 50ppm span gas in the Berkeley Air Laboratory prior to both Rounds 1 and 2. A unique adjustment factor was calculated for each monitor and applied during the data cleaning phases.

3.5. Quality of the baseline personal exposure data

The methods used for measuring personal exposure involved use of Gasbadge instruments for the women and CO diffusion tubes for the child, with the intention that these be located on or close to the person for the full 24 hours. This method was selected because it has been found acceptable to study participants in a number of prior studies -- specifically the equipment has been kept on or close to the majority of participants, as intended, for 24 hours. However, tolerance of research procedures cannot be taken for granted, and compliance was therefore checked.

In both Ambositra and Vatomandry 90% of the women were wearing the Gasbadge when the field worker arrived on Day 2 of the baseline survey. Over 95% said that they were able to keep the monitor on or with them all or most of the 24 hours, although 87.6% of Vatomandry respondents stated they kept it with them “all of the time” compared to 63.6% for Ambositra. Within Vatomandry, there was no difference between wood and charcoal users in respect of the location of the monitor when the field worker arrived. Wood users were somewhat more likely than charcoal users to report that the monitor was on or with them "half of the time or less", 7.2% vs. 1.2% respectively (p=0.064).

Table 3.1 and 3.2 shows the compliance rates within intervention groups at baseline. In Ambositra there was very little difference between groups with regard to the location of the monitor when the field staff arrived on Day 2 (p=0.767). However the control group had a much lower proportion of participants keeping their Gasbadge with them all of the time (40.%) compared to the other groups (p=0.012).

Table 3.1: Compliance with keeping the CO exposure monitor on or with the person by intervention group - ADULT: Ambositra: Baseline

	Intervention group			
	Ethanol (n=32) N (%)	**Charcoal (n=31) N (%)**	**Awareness (n=33) N (%)**	**Control (n=25) N (%)**
Monitor location on arrival Day 2				
Wearing it	27 (84.4)	30 (96.8)	29 (87.9)	22 (88.0)
Holding it	1 (3.1)	1 (3.2)	1 (3.0)	1 (4.0)
Not with the woman	4 (12.5)	-	2 (6.1)	2 (8.0)
Woman kept monitor on/with her				
All of the time	25 (78.1)	21 (67.7)	20 (60.6)	10 (40.0)
Most of the time	4 (12.5)	10 (32.3)	12 (36.4)	13 (52.0)
Less than half of the time	3 (9.4)	-	1 (3.0)	2 (8.0)

In Vatomandry there was a similar pattern of compliance seen between intervention groups with each one having around 90% of their participants wearing their Gasbadge when the fieldworker arrived (p=0.208). As in Ambositra the control group had the lowest number that kept their monitor for the full duration of monitoring but it was not significantly different to the other groups (p=0.294).

Table 3.2 : Compliance with keeping the CO exposure monitor on or with the person by intervention group - ADULT: Vatomandry: Baseline

	Intervention group				
	Ethanol n=32 N (%)	Biomass n=33 N (%)	Charcoal n=32 N (%)	Awareness n=31 N (%)	Control n=25 N (%)
Monitor location on arrival Day 2					
Wearing it	32 (100)	33 (100)	31 (96.9)	28 (90.3)	28 (92.0)
Holding it	-	-	1 (3.1)	1 (3.2)	-
Not with the woman	-	-	-	2 (6.5)	2 (8.0)
Woman kept monitor on/with her					
All of the time	30 (93.8)	31 (93.9)	29 (90.6)	27 (87.1)	20 (80.0)
Most of the time	1 (3.1)		3 (9.4)	3 (9.7)	3 (12.0)
Less than half time	1 (3.1)	2 (6.1)	-	1 (3.2)	2 (8.0)

For children, the picture was very similar. Over 90% of children in both centres were wearing the tube when the field worker arrived and there was no important difference between wood and charcoal users in Vatomandry. For reported success in keeping the tube on or with the child, over 90% had achieved this all or most of the time. There was clear evidence, however, that this was less complete among wood users than charcoal users in Vatomandry, with 12.4% of wood users stating that the tube was with the child for “half of the time or less”, compared to only 2.4% among charcoal users (p=0.017).

When looking at compliance within intervention groups in Ambositra the control group participants had the lowest proportion of children wearing the monitor when the fieldworker arrived at the home however it was still high at 88% and not significantly different from the other groups (p=0.504). The control group also reported the lowest rate of keeping the tube with the child for the full duration of the monitoring period (68.0%) (p=0.626)

Table 3.3: Compliance with keeping the CO exposure monitor on or with the person by intervention group – CHILD: Ambositra: Baseline

	Intervention group			
	Ethanol (n=32) N (%)	Charcoal (n=31) N (%)	Awareness (n=33) N (%)	Control (n=25) N (%)
Monitor location on arrival Day 2				
Child wearing it	30 (93.8)	30 (96.8)	32 (97.0)	22 (88.0)
Not with the child	2 (6.2)	1 (3.2)	1 (3.0)	3 (12.0)
Monitor on/with child				
All of the time	27 (84.4)	23 (74.2)	24 (72.7)	17 (68.0)
Most of the time	3 (9.4)	7 (22.6)	8 (24.2)	6 (24.0)
Less than half of the time	2 (6.2)	1 (3.2)	1 (3.0)	2 (8.0)

In Vatomandry the compliance does not appear to be very different between groups (Table 3.4) for either location on arrival (p=0.586) or duration of wearing it (p=0.436).

Table 3.4 : Compliance with keeping the CO exposure monitor on or with the person by intervention group - CHILD: Vatomandry: Baseline

	Intervention group				
	Ethanol n=32 N (%)	Biomass n=33 N (%)	Charcoal n=32 N (%)	Awareness n=31 N (%)	Control n=25 N (%)
Monitor location on arrival Day 2					
Child wearing it	28 (87.5)	31 (93.9)	31 (96.9)	29 (93.5)	22 (88.0)
Not with the child	4 (12.5)	2 (6.1)	1 (3.1)	2 (6.5)	3 (12.0)
Monitor on/with child					
All of the time	27 (84.4)	29 (87.9)	28 (87.5)	27 (87.1)	21 (84.0)
Most of the time	1 (3.1)	1 (3.0)	4 (12.5)	2 (6.5)	1 (4.0)
Less than half the time	4 (12.5)	3 (9.1)	-	2 (6.5)	3 (12.0)

3.6. Quality of the follow-up personal exposure data

There were minimal missing data for the adult personal CO measurements (n=3) and these resulted mainly from husbands not allowing their wives to be monitored. There was also minimal loss of child personal CO data in Ambositra (n=3 (2.3%) and no losses in Vatomandry.

Figure 3.1: Mother and baby wearing their personal exposure monitor

Tables 3.5 (a) and (b) show the results for assessment of compliance with placement of the CO Gasbadge for adults in Ambositra, in Rounds 2 and 3. Overall, the compliance was good with 92% of the women found to be wearing the monitor on arrival at Round 2 and 93.8% at Round 3. Compliance was significantly different between groups in Round 2, for both location of monitor on arrival (p=0.016) and duration of wearing it (p=<0.001) (for example better for the ethanol group compared to the charcoal users), although there was less variability in Round 3 (p=0.699 for location of monitor on arrival and p=0.691for duration of wearing it).

Table 3.5 (a): Compliance with keeping the CO exposure monitor on or with the person by intervention group – ADULT: Ambositra: Round 2

	Intervention group			
	Ethanol (n=32)	**Charcoal (n=31)**	**Awareness (n=33)**	**Control (n=36)**
	N (%)	**N (%)**	**N (%)**	**N (%)**
Monitor location on arrival Day 2				
Wearing it	32 (100)	24 (77.4)	32 (97.0)	33 (91.7)
Holding it	-	1 (3.2)	-	1 (2.8)
Not with the woman	-	6 (19.4)	1 (3.0)	2 (5.6)
Woman kept monitor on/with her				
All of the time	31 (96.9)	19 (61.3)	29 (87.9)	30 (83.3)
Most of the time	1 (3.1)	12 (38.7)	2 (6.1)	6 (16.7)
Less than half of the time	-	-	2 (6.1)	-

Table 3.5 (b): Compliance with keeping the CO exposure monitor on or with the person by intervention group – ADULT: Ambositra: Round 3

	Intervention group			
	Ethanol (n=31)	Charcoal (n=30)	Awareness (n=33)	Control (n=34)
	N (%)	N (%)	N (%)	N (%)
Monitor location on arrival Day 2				
Wearing it	29 (93.5)	28 (93.3)	30 (90.9)	31 (91.2)
Holding it	1 (3.2)	-	-	2 (5.9)
Not with the woman	1 (3.2)	2 (6.7)	3 (9.1)	1 (2.9)
Woman kept monitor on/with her				
All of the time	27 87.1)	24 (80.0)	28 (84.8)	29 (85.3)
Most of the time	4 (12.9)	4 (13.3)	5 (15.2)	5 (14.7)
Less than half of the time		2 (6.7)	-	

Tables 3.6 (a) and (b) show the results for assessment of compliance with placement of the CO diffusion tube for children in Ambositra, in Rounds 2 and 3. Overall, the compliance was good with 91% of the children found to be wearing the monitor on arrival at Round 2 and 92.2% at Round 3, but rather variable between groups – (as for adults), slightly better for the Ethanol group than the Charcoal users, for example but not significantly so (location of monitor on arrival (p=0.494) and duration of wearing it (p=0.578). Compliance had improved by Round 3 also with less variation between groups (location of monitor on arrival (p=0.269) and duration of wearing it (p=0.117).

Table 3.6 (a): Compliance with keeping the child's CO tube on or with the person by intervention group: Ambositra Round 2

	Intervention group			
	Ethanol (n=31)	Charcoal (n=31)	Awareness (n=33)	Control (n=36)
	N (%)	N (%)	N (%)	N (%)
Monitor location on arrival Day 2				
Child wearing it	29 (93.5)	26 (83.9)	30 (90.9)	34 (94.4)
Not with the child	2 (6.5)	5 (16.1)	3 (9.1)	2 (5.6)
Monitor on/with child				
All of the time	27 (87.1)	24 (77.4)	27 (81.8)	33 (91.7)
Most of the time	4 (12.9)	5 (16.1)	5(15.2)	3 (8.3)
Less than half of the time	-	2 (6.5)	1 (3.0)	-

Table 3.6 (b): Compliance with keeping the child's CO tube on or with the person by intervention group: Ambositra Round 3

	Intervention group			
	Ethanol (n=31) N (%)	Charcoal (n=30) N (%)	Awareness (n=33) N (%)	Control (n=34) N (%)
Monitor location on arrival Day 2				
Child wearing it	29 (93.5)	30 (100)	32 (97.0)	34 (100)
Not with the child	2 (6.5)		1 (3.0)	
Monitor on/with child				
All of the time	28 (90.3)	28 (93.3)	29 (87.9)	34 (100)
Most of the time	3 (9.7)	1 (3.3)	4 (12.1)	
Less than half of the time	-	1 (3.3)	-	-

Tables 3.7 (a) and (b) show the results for assessment of compliance with placement of the CO Gasbadge for adults in Vatomandry, for Rounds 2 and 3. Overall, the compliance was very good in Round 2, better than in Ambositra, with 95% of the women found to be wearing the monitor on arrival, and more consistent across intervention groups (location of monitor on arrival (p=0.223) and duration of wearing it (p=0.208). Compliance in Round 3 was also good, although slightly lower than in Round 2, and lowest in the charcoal group (location of monitor on arrival (p=0.05) and duration of wearing it (p=0.443).

Table 3.7 (a): Compliance with keeping the CO exposure monitor on or with the person by intervention group - ADULT: Vatomandry: Round 2

	Intervention group				
	Ethanol n=32 N (%)	Biomass n=33 N (%)	Charcoal n=32 N (%)	Awareness n=32 N (%)	Control n=31 N (%)
Monitor location on arrival Day 2					
Wearing it	31 (96.9)	33 (100)	29 (90.6)	29 (90.6)	30 (96.8)
Holding it	1 (3.1)	-	2 (6.2)	3 (9.4)	-
Not with the woman	-	-	1 (3.1)	-	1 (3.2)
Woman kept monitor on/with her					
All of the time	30 (93.8)	33 (100)	29 (90.6)	29 (90.6)	31 (100)
Most of the time	2 (6.2)	-	2 (6.2)	3 (9.4)	-
Less than half of the time	-	-	1 (3.1)	-	-

Table 3.7 (b): Compliance with keeping the CO exposure monitor on or with the person by intervention group - ADULT: Vatomandry: Round 3

	Intervention group				
	Ethanol n=31 N (%)	Biomass n=32 N (%)	Charcoal n=30 N (%)	Awareness n=28 N (%)	Control n=31 N (%)
Monitor location on arrival Day 2					
Wearing it	30 (96.8)	31 (96.9)	25 (83.3)	27 (96.4)	28 (90.3)
Holding it		-	-	-	3 (9.4)
Not with the woman	1 (3.2)	1 (3.1)	5 (16.7)	1 (3.6)	-
Woman kept monitor on/with her					
All of the time	30 (96.8)	30 (93.8)	25 (83.3)	26 (92.9)	29 (93.5)
Most of the time	1 (3.2)	2 (6.1)	2 (6.7)	1 (3.6)	3 (9.4)
Less than half time	-	-	3 (10.0)	1 (3.6)	-

Tables 3.8 (a) and (b) show the results for assessment of compliance with placement of the CO diffusion tube for children in Vatomandry. Overall the compliance was quite good in Round 2, but was very slightly lower than in Ambositra, with 87% of children found to be wearing the monitor when the fieldworker arrived. Slight non-significant variability occurred again between groups with better compliance in the ethanol and biomass groups compared to the charcoal users (and control group) (location of monitor on arrival (p=0.278) and duration of wearing it (p=0.500).

Table 3.8 (a): Compliance with keeping the CO tube on or with the person by intervention group: Child: Vatomandry: Round 2

	Intervention group				
	Ethanol n=32 N (%)	Biomass n=33 N (%)	Charcoal n=32 N (%)	Awareness n=32 N (%)	Control n=31 N (%)
Monitor location on arrival Day 2					
Child wearing it	29 (90.6)	31 (93.9)	25 (78.1)	29 (90.6)	25 (80.6)
Not with the child	3 (9.4)	2 (6.1)	7 (21.9)	3 (9.4)	6 (19.4)
Monitor was on child					
All of the time	28 (87.5)	29 (87.9)	24 (75.0)	29 (90.6)	25 (80.6)
Most of the time	4 (1.25)	4 (12.1)	6 (18.8)	3 (9.4)	6 (19.4)
Less than half of the time	-	-	2 (6.2)	-	-

Compliance remained high at Round 3 (Table 3.8b). The lowest rate was seen in the charcoal group (p=0.018) but still 87% were found to be wearing the tube on arrival. There was no significant difference between the duration of wearing the tube between the groups (p=0.309)

Table 3.8 (b): Compliance with keeping the CO tube on or with the person by intervention group: Child: Vatomandry: Round 3

	Intervention group				
	Ethanol n=30 N (%)	Biomass n=32 N (%)	Charcoal n=30 N (%)	Awareness n=27 N (%)	Control n=31 N (%)
Monitor location on arrival Day 2					
Child wearing it	30 (100)	32 (100)	26 (86.7)	27 (100)	30 (96.8)
Not with the child			4 (12.5)		1 (3.1)
Monitor was on child					
All of the time	30 (100)	31 (96.9)	26 (86.7)	25 (92.6)	28 (90.3)
Most of the time		1 (3.1)	3 (10.0)	2 (7.4)	3 (9.4)
Less than half time			1 (3.3)	-	-

3.7. Contamination of control group participants

In a community that frequently meets at central market places, 'contamination' of the control group through shared information was always a potential risk. People will always talk about projects that introduce innovative interventions and new information. We therefore asked the control participants about the nature and extent of the information they had learned from other participants in the study to explore how, if at all, this might have affected their behaviour related to household energy issues.

In Ambositra 41.2% of the control group and 29.0% in Vatomandry had talked with the neighbours about the project. However information was going both ways, with the control group participants showing neighbours their monitoring equipment and explaining the purpose of the study. Occasionally the control group participants did talk about the intervention stoves and ways to reduce smoke in the kitchen. However this exchange of information appeared to have very little impact on the knowledge the control group had about smoke in the kitchen. Only 14.7% (n=5) and 12.9% (n=4) of control group participants in Ambositra and Vatomandry felt that their involvement had changed what they know about kitchen smoke.

However at Round 3 although none of the control households in Vatomandry reported any recent changes aimed to avoid smoke, surprisingly 25% of the control group in Ambositra had made changes, many of which involved moving their cooking location outside. This may have the effect of inadvertently reducing the control groups' exposure levels, possibly causing the exposure benefits of the intervention stoves to be more conservative. This should be taken into consideration when interpreting these results.

84.2% of control group participants in Ambositra and 96.8% in Vatomandry had heard about the ethanol stove, with slightly lower numbers being informed about the other intervention stoves.

Even though the impact of the flow of information appears to have been minimal in terms of altering behaviour, a project of this nature in any community heightens people's awareness of the dangers of kitchen smoke and some behavioural changes, conscious or sub-conscious are inevitable. Therefore this should be considered when interpreting the data from the control groups.

3.8. Final allocation of interventions

Table 3.9 shows the percentage of the original random allocation framework that was maintained. Loss to follow up, refusal to take part in the study after being allocated to the control group, confusion regarding the allocation schedule in Ambositra, and planned re-allocation among groups by the field team to even out the group sizes all contributed to households not receiving their originally planned allocation. Yet, each group, including the control groups at both sites, had at least 80% of their Baseline households that were still available at round 2 correctly allocated.

Table 3.9: % of allocation as per random grouping in households still available at Round 2

Intervention Group	Ambositra (n=122)		Vatomandry (n=153)	
	N	%	N	%
Control group	22	84.6	21	87.5
Awareness Raising only	31	93.9	26	81.2
Biomass stove	--	--	32	97
Charcoal stove	30	96.8	27	84.4
Ethanol stove	28	87.5	30	93.8

As described in Section 2.19, a number of measures were taken when planning the Round 2 fieldwork, to bring the number of households in each allocation group to above 30 to allow for further loss between Round 2 and 3 surveys. Table 3.10 shows the final numbers in each allocation group once these measures were carried out.

Table 3.10: Final allocation numbers for each intervention group by study site

	Ambositra	Vatomandry
No intervention (control group)	36[a]	31[b]
Awareness Raising only	33	32
Awareness Raising plus biomass stove		33
Awareness Raising plus charcoal stove	31	32
Awareness Raising plus an ethanol stove	32	32
Totals	**132**	**160**

a des ten new households recruited at Round 2

b= includes seven new households recruited at Round 2

3.9. Replacement homes for losses

A total of 17 new control group households (10 in Ambositra and 7 in Vatomandry) were identified using the criteria described in Annex 13 There were no significant differences in a number of important characteristics between the replacement households and those lost to follow-up (Table 3.11)

Table 3.11: Comparison of lost households and their replacement households: Ambositra and Vatomandry

Characteristic	Lost Houses (n=17)		New Houses (n=17)		p value
	Mean	sd	Mean	sd	
Age of participant (years)	29	8.5	31	11.4	0.489
Age of child (months)	18	12.0	19	15.1	0.833
Time at school (years)	6.5	3.6	7.5	3.0	0.385
AME cooked for	3.7	1.5	4.3	1.1	0.234
	N	**%**	**N**	**%**	
Has electricity connection	5	29.4	10	58.8	0.090
Owns a cell phone	11	64.7	14	84.4	0.244
Main cooking fuel: wood	4	23.5	3	17.6	0.672
Main cooking fuel: charcoal	13	76.5	14	82.4	
Kitchen location: joined	14	82.4	10	58.8	0.132
Kitchen location: separate	3	17.6	7	41.2	

3.10. Loss to follow-up

Overall there was 13.2% (n=20) loss to follow-up in Ambositra and 14.4% (n=27) in Vatomandry between the Baseline study and Round 2. The reason for most of these losses was that the participant had moved away. A further 3 households from Ambositra and 7 from Vatomandry were lost between the Round 2 data collection and the final round (Round 3). This gave an overall loss to follow up of 14.9% (n=23) in Ambositra and 18.1% (n=34) in Vatomandry. The % loss to follow-up allowed for in the sample size calculations was 20%. Table 3.12 provides a break down of the numbers of participants completing each stage of the study.

Table 3.12: Numbers of households completing each stage of the study: Ambositra and Vatomandry

Stages of study completed	Ambositra N (%)	Vatomandry N (%)
Completed all 3 rounds of data collection	119 (77.3)	146 (78.1)
Replacement household at round 2	10 (6.5)	7 (3.7)
Completed Baseline and round 2 only	3 (1.9)	7 (3.7)

Baseline only	20 (13.0)	27 (14.4)
Removed as did not fit criteria*	2 (1.3)	0 (0.0)
Total	154 (100)	187 (100)

* These 2 households are not included in the 'lost to follow up' numbers.

A comparison of key socio-demographic and household characteristics for those retained in the study and those lost to follow-up are shown in Tables 3.13 for Ambositra, and Tables 3.14 for Vatomandry.

Table 3.13: Comparison of homes retained in the study and those lost to follow-up at Baseline – Ambositra

Characteristic	Completed all stages (n=119)		Lost to follow-up (n=23)		p value
	Median	IQR	Median	IQR	
Number of school years	8.0	5.0-9.0	5.0	3.0-10.0	0.181[a]
Adult CO exposure	8.3	5-14.3	9.9	3.8-17.4	0.991[a]
Child CO exposure	6.7	3.8-11.5	5.6	2.0-12.4	0.640[a]
AME (meals cooked/day)	3.7	3.0-4.8	3.8	3.0-4.8	0.622[a]
Money available (weekly)	21	14-35	28	14-42	0.278[a]
	N	**%**	**N**	**%**	
Has electricity connection	2	1.7	1	4.3	0.414[b]
Owns a cell phone	82	68.9	15	65.2	0.728[c]
Kitchen joined to house	111	94.1	21	91.3	0.735[c]
Stove type:					
Traditional 3 stone	3	2.5	0	0.0	
Traditional charcoal	106	89.8	18	78.3	
Improved charcoal	8	6.8	5	21.7	0.312[a]
Other	1	0.8	0	0.0	
Main fuel wet season:					
Wood	1	0.8	0	0.0	0.838[b]
Charcoal	118	99.2	23	100.0	

a Mann Whitney U Test, b Fisher's Exact test, c Chi-squared test

For Ambositra, there were no large or statistically significant differences. For Vatomandry there was some evidence that charcoal users were more likely to drop out than wood users, but no other important differences. Neither the extent of losses (14-18%), nor the characteristics of those lost, suggest very substantial bias. The higher rate of loss to follow-up among users of traditional charcoal stoves compared to wood stove users in Vatomandry should be kept in mind when interpreting results.

Table 3.14: Comparison of homes retained in the study and those lost to follow-up at Baseline, Vatomandry

Characteristic	Completed all stages (n=146)		Lost to follow-up (n=34)		p value
	Median	IQR	Median	IQR	
Number of school years	7.0	4.0-9.0	6.5	4.0-9.0	0.829[a]
Adult CO exposure	0.85	0.49-1.69	0.69	0.27-1.52	0.133[a]
Child CO exposure	0.37	0.12-1.24	0.47	0-0.75	0.180[a]
AME (meals cooked/day)	3.6	3.0-4.6	3.7	2.6-4.6	0.226[a]
Money available (weekly)	35	21-49	35	21-44	0.881[a]
	N	%	N	%	
Has electricity connection	8	5.5	1	2.9	0.459[b]
Owns a cell phone	105	71.9	25	73.5	0.850[c]
Kitchen joined to house	69	46.6	13	38.2	0.379[c]
Stove type:					
Traditional 3 stone	83	56.8	11	32.4	
Traditional charcoal	51	34.9	20	58.8	0.046[c]
Improved charcoal	12	8.2	3	8.8	
Main fuel wet season:					
Wood	86	58.9	11	32.4	0.005[c]
Charcoal	60	41.1	23	67.6	

a Mann Whitney U Test, b Fisher's Exact test, c Chi-squared test

4. Baseline Household Information

4.1. Socio-Demographic Information

The respondents were a relatively young group, reflecting the sampling strategy of selecting homes with young children. The average age of respondents was 30.1 years [range 18-60, standard deviation (SD) = 8.19] in Ambositra, and 31.7 years [range 17-61, standard deviation (SD) = 9.53] in Vatomandry. The majority of respondents were married and marital status was very similar in both centres (Table 4.1). Around 10% were single mothers, and between 6% (Ambositra) and 10% (Vatomandry) were separated or divorced.

Table 4.1: Marital status of participants by study site

Marital Status	Ambositra		Vatomandry	
	N	%	N	%
Married	121	84.6	136	75.6
Single mother	11	7.7	20	11.1
Separated	4	2.8	7	3.9
Divorced	5	3.5	12	6.7
Widowed	2	1.4	5	2.8
Total	143	100	180	100

Household structure was also similar in both centres. The average (mean) number of people living in each house was 5.44 (SD = 1.89) in Ambositra, and 5.37 (SD = 2.06) in Vatomandry. The age of the youngest child did however differ, the median being 12 months [IQR[5] = 9-30] in Ambositra and 24 months [IQR = 12-36] in Vatomandry (p=0.01). This difference may be at least partially explained by a government-run family planning program that provides free products and services. This program has been especially popular in Vatomandry, where people are generally less conservative than in other parts of the island. The distribution of sex of the youngest child was similar between Ambositra (47.6% female) and Vatomandry (48.3% female).

4.1.1. Education and literacy

Levels of education and literacy were high. In Ambositra, just over 90% of participants were 'comfortable with' reading and with writing, and around 97% of their husbands were. The situation in Vatomandry was similar, with around 94% of participants and 96% of their husbands being 'comfortable with' reading and with writing. This is a probably a reflection of the fact that education in Madagascar is compulsory and essentially free for children between the ages of six and fourteen, with girls having equal access with boys to educational institutions.
[http://countrystudies.us/madagascar/19.htm]

Levels of education reached are shown in Table 4.2(a) and (b). Around two-thirds of participants and their husbands achieved secondary education in Ambositra, with slightly lower levels of 54% and 59% respectively in Vatomandry. This difference is expected as previously, the education system has been characterized by an unequal

5 The IQR is the Inter Quartile Range (between the 25th and 75th centiles i.e. the range encompassing the central 50% of the values.

distribution of educational resources among the different regions of the country, with the central highlands having more schools and higher educational standards than the coastal regions.

The average (mean) duration of school attendance was 7.1 years [SD = 3.5] in Ambositra and 6.6 [SD = 3.5] in Vatomandry, with quite large variation [0-15 years in Ambositra and 0-17 years in Vatomandry], with equivalent figures for participant's husbands being about 1 year longer in both centres. This is slightly lower than 2006 school life expectancy (SLE)[6] quoted on the CIA World Factbook for Madagascar (male 10 yrs and female 9 yrs) [https://www.cia.gov/library/publications/the-world-factbook/geos/ma.html - People].

Table 4.2(a): Educational level achieved by participant (mother) by study site

Education level	Ambositra		Vatomandry	
	N	%	N	%
No formal education	10	7.0	14	7.8
Primary	39	27.3	60	33.3
Secondary	91	63.6	98	54.4
Higher	3	2.1	8	4.4
Total	143	100	180	100

Table 4.2(b): Educational level achieved by husband (father) by study site

Education Level	Ambositra		Vatomandry	
	N	%	N	%
No formal education	3	2.4	6	4.2
Primary	30	23.8	27	19.0
Secondary	82	65.1	84	59.2
Higher	9	7.1	20	14.1
Don't know	2	1.6	5	3.5
Total	126	100	142	100

4.1.2. Employment, occupation and socio-economic status

For participants (mothers) in both centres, the most commonly reported 'main' occupation was homemaker, but notably less so in Ambositra (56%) than in Vatomandry (79%) (Table 4.3a). The next most commonly reported occupations for women are day labouring, farming own land, craftwork and being an employee in a business, with all of these being correspondingly more common in Ambositra.

For husbands, the most common occupations in both areas are day labouring, being an employee in a business, and craftwork (Table 4.3b). The patterns of occupation differ

[6] SLE represents the expected number of years of schooling that will be completed, including years spent repeating one or more grades.

quite substantially between the two centres, with the men in Ambositra being more likely to be engaged in craftwork and day labouring, while those in Vatomandry are more likely to be a government employee, an employee in a business, or to own their own business.

As with all of these comparisons between the two study areas, it is important to keep in mind that sampling was carried out in relation to main fuel type use, and that the samples therefore do not represent the whole populations of the two towns.

Table 4.3(a): Main occupation of participant (mother)

Occupation of participant	Ambositra		Vatomandry	
	N	%	N	%
Farms his/her own land (owned & rented)	13	9.1	2	1.1
Day labourer (i.e. farming another persons land)	28	19.6	14	7.8
Government employee (. doctor,teacher,police)	0	0	4	2.2
Employee in a business (i.e. factory worker)	7	4.9	7	3.9
Has own business (such as a shop)	1	0.7	5	2.8
Craftsperson (tailor, carpenter, seamstress etc)	13	9.1	2	1.1
Homemaker	80	56.0	143	79.4
Retired	0	0	1	0.6
Other type of job	1	0.7	1	0.6
Currently unemployed	0	0	1	0.6
Total	143	100	180	100

Notwithstanding, it would be expected, for example, that involvement in crafts would be reported more commonly in Ambositra as this is recognised to be a very important economic activity in the town.

Table 4.3(b): Main occupation of husband (father): numbers and percentages are for women with husbands.

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Farms his/her own land (owned & rented)	11	8.7	5	3.6
Day labourer (i.e. farming another persons land)	43	33.9	32	22.9
Government employee (i.e. doctor, teacher)	11	8.7	24	17.1
Employee in a business (i.e. factory worker)	23	18.1	35	25.0
Has own business (such as a shop)	0	0	15	10.7
Craftsperson (tailor, carpenter, seamstress etc)	32	25.2	2	1.4
Retired	0	0	2	1.4
Other type of job	4	3.1	16	11.4
Currently unemployed	3	2.4	9	6.4
Total	127	100	140	100

Other important indicators of socio-economic status reported in the study are water and sanitation, possessions and available financial resources. The majority of homes in both centres had access to water supplies that, potentially at least, should be clean (Table 4.4). In Ambositra, the majority (58%) use a communal standpipe, but 15% still use a spring. In Vatomandry, more than three-quarters (78%) use a deep well, with none reporting that they collect most of their water from the river or a spring.
Latrines were common in both areas, but although only 1.4% reported having no latrine in Ambositra, 29% had none in Vatomandry. For those who do have a latrine, the great majority have these in the house (as opposed to in the yard).

Table 4.4: Source of water for household needs

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Total number (N)	144		180	
Piped in home	19	13.2	8	4.4
Pump (deep well)	16	11.1	141	78.3
Well (pit with bucket)	3	2.1	15	8.3
Communal standpipe	83	57.6	16	8.9
Collect from river	2	1.4	0	0
Spring	21	14.6	0	0
Total	144	100	180	100

Reported household possessions are summarised in Table 4.5. Ownership of motorised transport is uncommon, and bicycles are available to a minority of households – particularly in Ambositra. Electricity connections are available for just over half of homes, 55% in Ambositra and 61% in Vatomandry (see also section 4.27 on fuels and lighting). Around three-quarters have a radio, slightly more in Ambositra than Vatomandry – important in respect of using this medium for publicity - and about half have a TV. It is also of interest to see that around 70% in both centres report having a cell phone.

Table 4.5: Household possessions by study site

Possessions		Ambositra		Vatomandry	
		N	%	N	%
Transport	Motorbike	3	2.1	15	8.3
	Car or truck	5	3.5	12	6.7
	Bicycle	26	18.1	80	44.4
Electrical domestic	Electricity connection	79	54.9	110	61.1
	Access to electricity generator	3	2.1	9	5.0
	Fridge	6	4.2	29	16.1
	Radio	115	79.9	132	73.3
	Hi Fi/ CD player	58	40.3	82	45.6
	TV	67	46.5	94	52.2
Communications	Cell Phone	98	68.1	130	72.2
Sanitation	Bath / shower in house	58	40.3	49	27.2
Animals	Cow	23	16.0	7	3.9

The study team recognised the difficulty of asking directly about income and financial resources, partly due to potential unwillingness to declare this, but also because actual wealth may be complex and drawn from a range of sources – not just income and money.

Table 4.6 shows that, when asked about the adequacy of financial resources for purchasing household needs (bearing in mind this was asked of the woman/mother), the majority (59.7% in Ambositra and 62.8%) in Vatomandry stated that they had 'much too little'. Less than 1 in 10 (7.2% and 4.4% in Ambositra and Vatomandry respectively) stated that they had sufficient.

Table 4.6: Adequacy of financial resources for household needs

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Enough to buy everything needed	10	7.2	8	4.4
Not quite enough	46	33.1	59	32.8
Much too little	83	59.7	113	62.8
Total	139	100	180	100

The actual amount of money available for household purchases each week was reported as (median) 21,000 (IQR = 14,000 to 35,000; Range = 1,000 to 168,000) Ariary in Ambositra and 35,000 (median) Ariary (IQR = 21,000 to 49,000; Range = 3,500 to 140,000) in Vatomandry[7]. Table 4.7 shows the distribution of average available household money by socio-economic status (level of education, access to electricity and ownership of a cell phone). As would be expected, a higher educational status and access to electricity were associated with a higher average household income (although this was only statistically significant in Vatomandry). Ownership of a cell phone was significantly associated with a higher average household income in both Ambositra and Vatomandry.

Table 4.7: Average available household income by socio-economic status

Characteristic	Ambositra Median	Ambositra IQR	Vatomandry Median	Vatomandry IQR
Education:				
Primary or less	21k	14k-28k	28k	20k-40k
Secondary or more	28k	14k-35k	35k	28k-56k
	*p=0.088		*p=0.0002	
Access to electricity:				
No	21k	14k-29k	28k	21k-42k
Yes	28k	14k-35k	35k	28k-56k
	*p=0.084		*p=0.0006	
Own cell phone:				
No	17.5k	14k-28k	21k	21k-35k
Yes	28k	20k-35k	35k	28k-56k
	*p=0.0018		*p<0.0005	

*Wilcoxon test (a statistical test used to assess the statistical significance of differences between average household income by categories of each socio-economic status variable)

4.2. Fuels and stoves

In order to improve detection of the impacts of improved stoves on air quality and health, the field team aimed to select households that used only one purchased fuel: in Ambositra, only charcoal-using homes were recruited into the study, whereas in Vatomandry, the objective was to recruit 60% wood users and 40% charcoal users (as discussed in section 2.2.2). Recognising the potential complexity of patterns of household fuel use, however, questions were asked nonetheless about main and secondary cooking fuel use for the wet and dry seasons, and also about stove type, costs and maintenance/repair. Supplementary questions were then asked about heating (fuels and stoves, and patterns of stove use for heating), about fuels for lighting, and finally about fuel use for small enterprise. All of these topics are described in the following sections.

4.2.1 Cooking fuels

At baseline the survey homes reported cooking fuel use varies very little by season., The main cooking fuel used in the two centres reflects the sampling strategy (Table 4.8). In the Ambositra sample, the predominant fuel is charcoal, whereas in the Vatomandry sample 54% use wood and 46% use charcoal.

[7] At the time of this study, 1000 Ariary was approximately equivalent to 0.55 USD and 0.42 Euro.

Table 4.8: Main cooking fuel use in the (i) wet and (ii) dry seasons

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Main cooking fuel: wet season				
Wood	3	2.1	97	53.9
Charcoal	141	97.9	83	46.1
Main cooking fuel: Dry season				
Wood	2	1.4	97	53.9
Charcoal	141	98.6	83	46.1

Table 4.9 shows fuel use for the wet season (given fuel use did not appear to differ by season) in Vatomandry by socio-economic status; education, access to electricity, cell phone ownership and average household income.

Table 4.9: Main cooking fuel use in the wet season by socio-economic status

Characteristic	Vatomandry				
	Wood		Charcoal		
	N	%	N	%	P value
Education:					
Primary or less	51	52.6	23	27.7	
Secondary or more	46	47.4	60	72.3	0.001
Access to electricity:					
No	50	51.6	20	24.1	
Yes	47	48.4	63	75.9	<0.0001
Own cell phone*:*					
No	39	40.2	11	13.3	
Yes	58	59.8	72	86.7	<0.0001
	Median	**IQR**	**Median**	**IQR**	**P value**
Average monthly income	35k	21k-49k	35k	21k-49k	0.727

Whilst a significantly higher proportion of charcoal users compared to wood users had access to electricity, owned a cell phone and were more likely to have a level of education at least to secondary school, there appeared to be no relationship between actual household income and fuel use.

Patterns of secondary fuel use differed somewhat between the two study centres (Table 4.10). In Ambositra, 91% of respondents said they do not use a second cooking fuel, and of those that did, this was mostly wood. This was the case in both wet and dry seasons. Only two (1.4%) reported using bottled gas, and none reported using kerosene.

In Vatomandry, 27% use a secondary cooking fuel. In both seasons, this secondary fuel use was almost entirely restricted to wood and charcoal (with wood users having charcoal as a second fuel, etc.). Only three homes (1.7%) reported using bottled gas and one kerosene.

Table 4.10: Secondary cooking fuel use in the (i) wet and (ii) dry seasons

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Secondary cooking fuel: wet season:				
No secondary cooking fuel	131	91	115	63.9
Kerosene	0	0	1	0.6
Bottled gas	2	1.4	3	1.7
Wood	8	5.6	23	12.8
Charcoal	3	2.1	35	19.4
Mains electricity	0	0	3	1.7
Secondary cooking fuel: dry season:				
No secondary cooking fuel	131	91.0	115	63.9
Kerosene	0	0	1	0.6
Bottled gas	2	1.4	3	1.7
Wood	9	6.2	23	12.8
Agri-residues	1	0.7	0	0
Charcoal	1	0.7	35	19.4
Mains electricity	0	0	3	1.7

4.2.2 Cooking stoves

The majority of households, 89.6% in Ambositra and 81.7% in Vatomandry, used only one type of stove each day. None of the households in Ambositra used more than two stove types, and only one did so in Vatomandry.

The main type of stove used in the home is shown in Table 4.11. In Ambositra, as would be expected from the fuel use (Table 4.8) the great majority used a charcoal stove, and rather few of these were of the improved type (with ceramic liners). Stove use in Vatomandry similarly reflected fuel use, with a slightly higher proportion of charcoal users having improved stoves. All those burning wood use traditional 3-stone fires.

Table 4.11: Main type of stove used in the home at Baseline by study site

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Traditional (3-stone) fire	5	3.5	94	52.2
Traditional metal charcoal stove	124	86.7	71	39.4
Improved charcoal stove with ceramic	13	9.1	15	8.3
Other	1	0.7	0	0

As already noted, a minority used a secondary stove most days, and this is also reflected in overall rates of use of secondary stoves (Table 4.12) which were lower in Ambositra than in Vatomandry at 12.5% and 34.4% respectively. Use of improved stoves and cleaner fuels (LPG, kerosene and electricity) is very limited in these samples.

Table 4.12: Secondary stoves used in the home at Baseline by study site

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
None	126	87.5	118	65.6
Traditional (3-stone) fire	7	4.9	19	10.6
Traditional metal charcoal stove	5	3.5	32	17.8
Improved charcoal stove with ceramic liner	4	2.8	5	2.8
LPG stove	2	1.4	3	1.7
Kerosene pressure stove	0	0	1	0.6
Electric stove	0	0	2	1.1

4.2.3 Purchase and cost of charcoal

Further in keeping with the household selection strategy, all households in Ambositra used charcoal for either primary or secondary cooking fuels and 65% of people in Vatomandry. The amounts purchased varied among households considerably (range 200-14000 Ar). However of those who did purchase charcoal for cooking, the average total spent in one week during the wet season was very similar in the two study centres (median spent 2500 Ar in both centres (p=0.728).

4.2.4 Collection, purchase and cost of wood

As already noted, the patterns of wood use for cooking fuel varied considerably between the study households in the two centres by design.

54% of households in Vatomandry using wood for cooking. Table 4.13 shows, of those who used wood, the means of procurement was similar in both the wet and dry seasons, with the majority of participants buying their wood fuel (87.5%). Subsequently in those households who bought wood, the average amount spent in one week did not change between seasons and was similar in each study area (2800Ar wet and dry season). Notably this is also similar to the amount spent on charcoal during the wet season.

Table 4.13: Means of wood fuel procurement in Vatomandry

Characteristic	Vatomandry	
	N	%
Source of wood in WET season:		
All bought	105	87.5
Most bought	5	4.2
About half bought	6	5.0
Most collected	0	0
All collected	4	3.3
Source of wood in DRY season:		
All bought	106	87.6
Most bought	3	2.5
About half bought	5	4.1
Most collected	1	0.8
All collected	2	1.7

In line with selection criteria, gathering of wood for fuel was rare in both the wet and dry season. Only 2 people collected all their fuel in the dry season in Vatomandry.

Table 4.14: Patterns of wood collection in Vatomandry

Characteristic	Vatomandry Median	Vatomandry IQR
Time taken for each trip to gather wood (hours):		
Wet season	3	2-4
Dry season	3	2-3
Total weight of wood collected per week (Kilograms):		
Wet season	50	20-60
Dry season	200	125-800

4.2.5 Perceptions of current fuel

In response to an unprompted open question the most frequently reported positive aspect of charcoal was that it 'saves time' (38.6% and 35.0% of people in Ambositra and charcoal users in Vatomandry respectively; Table 4.15). These time savings were mainly due to the fuel "cooking faster" but possibly also through being able to light the stove faster compared to wood. The low numbers of people who collect their wood fuel probably means that this response does not relate to a reduced time commitment for collecting or accessing charcoal fuel compared to wood. Two-thirds (64%) of wood users in Vatomandry also said that they liked to cook with wood as it saved time.

Table 4.15: Reported positive characteristics of main fuel used at Baseline

Characteristics	Ambositra (n=132)		Vatomandry Total (n=180)		Wood (n=97)		Charcoal (n=83)	
	N	%	N	%	N	%	N	%
Economical	12	9.1	33	18.3	25	25.8	8	9.6
Saves time	51	38.6	91	50.6	62	64.0	29	35.0
Has good availability	4	3.0	4	2.2	3	3.1	1	1.2
Clean	21	15.9	22	12.2	0	0	22	26.5
Easy to use	21	15.9	26	14.4	4	4.1	22	26.5
Food well cooked	1	0.8	4	2.2	3	3.1	1	1.2
Very little smoke	13	9.9	6	3.3	0	0	6	7.2
Safe	1	0.8	1	0.6	0	0	1	1.2
Only fuel available	27	20.5	3	1.7	2	2.1	1	1.2
Familiar with the fuel	16	12.1	9	5	8	8.3	1	1.2
Other	4	3.0	2	1.1	0	0	2	0.2

When asked an open question regarding their dislikes about their current main fuel (Table 4.16) the most frequent response in both study sites types was that it was too smoky (43.1% Ambositra, 41.4 % Vatomandry). The smoke level was also the most frequent response for wood users (51%) and charcoal users (28.8%) in Vatomandry. The participants in Ambositra appeared to be more aware of the “bad health affect” of their fuel than in Vatomandry, with 43.9% reporting this as a dislike compared to 8.3% in Vatomandry. The dirtiness created by the fuel seemed to be an issue more for participants in Vatomandry for both fuels (46.9% wood users and 23.3% of charcoal users).

Table 4.16: Reported negative characteristics of main fuel used at Baseline

Characteristics	Ambositra (n=130)		Vatomandry Total (n=169)		Vatomandry Wood (n=96)		Vatomandry Charcoal (n=73)	
	N	%	N	%	N	%	N	%
Bad effect on health	57	43.9	14	8.3	3	3.1	11	15.1
Too long to cook/ no free time	0	0	13	7.7	7	7.3	6	8.2
Causes suffocating	26	20	1	0.6	0	0	1	1.4
Dirty	14	10.8	62	36.7	45	46.9	17	23.3
Damages pots	1	0.8	5	3.0	1	1.0	4	5.5
Smoky	56	43.1	70	41.4	49	51.0	21	28.8
Expensive	8	6.2	12	7.1	3	3.1	9	12.3
Risk of burning the house	3	2.3	1	0.6	1	1.0	0	0
Difficult to use	3	2.3	8	4.7	5	5.2	3	4.1
Not always available	0	0	2	1.2	0	0	2	2.7
Other	0	0	7	4.1	4	4.2	3	4.1

*Participants could give more than one answer

4.2.6 Preferences for cooking fuel

Participants were asked what type of fuel they would like to use. Table 4.17 shows their response, stratified by types of fuel they were currently using as their main cooking fuel in Vatomandry.

In both study sites the majority (58% of people in Ambositra and 60% in Vatomandry) stated that their preferred fuel for cooking was LPG (bottled gas). This was the most popular choice for both wood and charcoal users in Vatomandry and the charcoal users in Ambositra. Only 2.8% of all current charcoal users were happy with their fuel choice, however all wood users wanted to change, many to charcoal (20% in Vatomandry).

Table 4.17: Preferred cooking fuel by study site

Characteristics	Ambositra (n=138)		Vatomandry Total (n=175)		Wood (n=95)		Charcoal (n=80)	
	N	%	N	%	N	%	N	%
Ethanol	9	6.5	12	6.9	6	6.3	6	7.5
Kerosene	16	11.6	16	9.1	11	11.6	5	6.2
LPG (Bottled gas)	80	58.0	105	60.0	50	52.6	55	68.8
Wood	3	32.2	0	0			0	0
Charcoal	0	0	19	10.9	19	20.0		
Mains electricity	25	18.1	21	12.0	9	9.5	12	15
Other	1	0.7	0	0	0	0	0	0
No change	4	2.9	2	1.1	0	0	2	2.5

1: % of current main cooking group within study site
2: % of total study site group

The people who stated they would prefer to use LPG or electricity for their main cooking fuel rather than their current fuel did so because they believed it was cleaner, faster and easy to use. The factors preventing them from using their preferred fuel were mainly related to expense of the fuel as well as access to the fuel and stoves. The 20% of wood using households in Vatomandry who would prefer to be using charcoal chose it because they felt it is an easier fuel to use but claimed expense-related issues prevented them from switching, even though it appeared to be the same cost (see Section 4.2.4.

4.2.7 Lighting fuels

Just over half of homes in both centres used electricity for lighting, with kerosene being the second most important principal lighting fuel (Table 4.18).

Table 4.18: Fuels used for lighting in the home at Baseline by study site

Characteristic	Ambositra (n=144)		Vatomandry (n=180)	
	N	%	N	%
Main fuel used for lighting:				
Ethanol	0	0	1	0.6
Kerosene	57	39.6	71	39.4
Charcoal	1	0.7	0	0
Mains electricity	76	52.8	107	59.4
Battery	1	0.7	0	0
Candles	9	6.2	1	0.6
Secondary fuel used for lighting:				
None	64	44.4	67	37.2
Kerosene	11	7.6	50	27.8
Mains electricity	1	0.7	0	0
Local generator	0	0	2	1.1
Candles	66	45.8	61	37.2

All the homes that reported using electricity for lighting indicated that they had access to electricity in an earlier question. Only 3.2% (n=6) of homes with access to electricity used an alternative source for lighting. Most homes reported using secondary lighting fuels. In Ambositra, this was candles (46%) with a few using kerosene (8%), while in Vatomandry although candles were the most important (37%), kerosene was used by just over one quarter (28%). The use of kerosene is important as this has been shown to result in moderately high levels of indoor air pollution, especially when burned in simple wick-type lamps .

The cost of lighting fuels was estimated at a median (IQR) of 1,400 [IQR = 1,000 to 2,800] Ariary in Ambositra and 1,500 [IQR = 1,400 to 5,000] Ariary in Vatomandry.

4.2.8 Space heating

On account of its location on the Indian Ocean, space heating was not required in Vatomandry. In Ambositra, respondents were asked if they ever use their stove for warmth in the home, and if so how it was used in relation to cooking and during which season(s). The majority (66%) stated that they did not use the stove for heating the home. For those who did, the method (stove and fuel) was predominantly charcoal, the same as for cooking, and for almost half, obtaining heat for the home was restricted only to the time when the stove was alight for cooking purposes.

Table 4.19: Stoves used for space heating in the home at Baseline by study site

Characteristic	Ambositra (n=144) N	%
Type of stove used for heating (n=144):		
None	94	65.3
Traditional (3-stone) fire	3	2.1
Traditional metal charcoal stove	44	30.6
Improved charcoal stove with ceramic liner	3	2.1
Pattern of stove use for heating (n=53):*		
Only while cooking	24	45.1
During daytime additional to cooking	17	32.1
During night additional to cooking	10	18.9
During day and night additional to cooking	2	3.8

- % of those using stove for space heating

Of the people who used their stove for space heating, 84% used it in the dry season for 1-2 months (84%). Only 6% of households that used their stove for space heating did so during the wet season.

4.2.9 Fuel use for small enterprise

A minority of participants reported using household fuels for small enterprise, 17.4% in Ambositra and 22.8% in Vatomandry. Commonly these enterprises cook snacks or meals for resale, and in Vatomandry, some fisherman also smoke fish over wood fires. Table 4.20 shows the fuels used and how frequently: these results again reflect the predominant fuel type for the homes, but it is of interest that the fuel was used 6 or 7 days per week by 68% in Ambositra and 78% in Vatomandry of those small enterprises.

Table 4.20: Fuel used for small enterprise at Baseline by study site

Characteristic	Ambositra N	Ambositra %	Vatomandry N	Vatomandry %
Fuel type used for small enterprise				
Bottled gas	1	4.0	0	0
Wood	2	8.0	20	48.8
Charcoal	22	88.0	21	51.2
Days per week fuel used for small enterprise*				
1-2	2	8.0	5	12.2
3-5	6	24.0	4	9.8
6-7	17	68.0	32	78.1

* % of use for enterprise

This activity amounted to a not insignificant proportion of total household fuel use, particularly in Vatomandry where 46% (of those using fuel for this purpose) used half or more, and 15% used ‘almost all’ (Table 4.21 and Figure 4.1).

Table 4.21: Fraction of all household fuel that is used for small enterprise (this would exclude lighting fuel)

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
None	119	82.6	139	77.2
Fraction of all HH fuel*				
Very little	7	28.0	4	9.8
Quarter	11	44.0	13	31.7
Half	4	16.0	16	39.0
Three-quarters	3	12.0	2	4.9
Almost all	0	0	6	14.6

- Of those using for enterprise

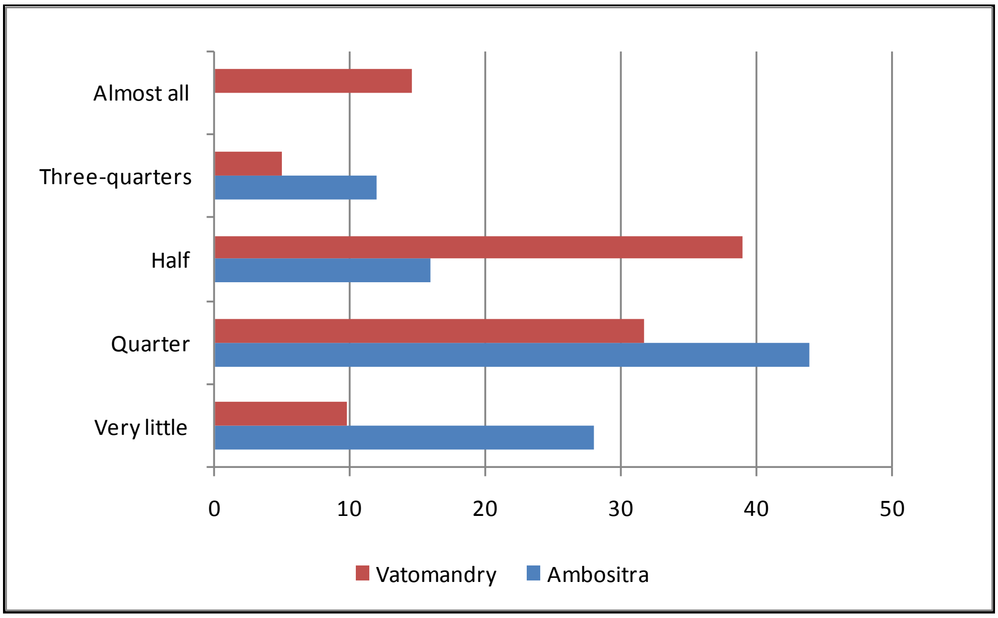


Figure 4-1: Fraction of all household fuel that is used for small enterprise (this would exclude lighting fuel), among those using for enterprise purposes.

4.2.10 Kitchen configuration

The kitchen configuration was examined as it can have a considerable impact on the levels of indoor air pollution and the exposure of the participants and their families.. As expected the location of the kitchen in relation to the main house was significantly different in each of the two study sites ($p<0.0005$), (Table 4.22). Only 6.3% of Ambositra households had a kitchen separate from the house compared to 54.4% in Vatomandry. Nearly half (49%) of households in Ambositra had a kitchen within their main home compared to only a quarter (26.7%) in Vatomandry. There was also a significant association between the study site and whether the kitchen was enclosed or semi-open: 91.6% of households in Ambositra had an enclosed kitchen compared to 63% in Vatomandry ($p<0.0005$).

Table 4.22: Kitchen configuration at Baseline by location and fuel type

Characteristics	Ambositra (n=143)		Vatomandry Total (n=180)		Vatomandry Wood (n=97)		Vatomandry Charcoal (n=83)	
	N	%	N	%	N	%	N	%
Kitchen in building separate from house	9	6.3	98	54.4	63	64.9	35	42.2
Separate kitchen attached to rest of main house	64	44.8	34	18.9	15	15.5	19	22.9
Kitchen is within the main living area of the house	70	49.0	48	26.7	19	19.6	29	34.9
Kitchen is enclosed	131	91.6	117	65.0	63	64.9	54	65.1
Kitchen is semi-open	12	8.4	63	35.0	34	35.1	29	34.9

In Vatomandry there was a clear relationship between fuel type and the kitchen configuration with more wood users (64.9%) having a kitchen separate from the house than charcoal users (42.2%). (p=0.009)

4.2.11 Time related issues

The mean time the main stove was usually alight each day was similar in both study areas- 6.61 hrs (SD 2.67) in Ambositra and 7.0 hours (SD 2.47) in Vatomandry. There was no apparent difference between the fuel (and therefore stove) types in Vatomandry either with both charcoal and wood users having their stove alight for 7 hours in one day (p=0.989- T-test).

4.2.12 Discussion of Baseline household Information

This review of socio-economic circumstances shows the samples in the two study areas to be fairly similar. Levels of education and literacy are quite high, and only slightly lower among women, in keeping with country's policy on education.

Fuel use predominantly reflects the deliberate sampling strategy used to meet the goals of the project. Consequently, the samples should not be seen as representing the whole of Ambositra and Vatomandry. Thus, while wood is used extensively in and around Ambositra, very few wood users are in the sample as in this community this fuel is not purchased (and hence such home could not reasonably have been expected to make a rapid transition to a market based, purchased fuel such as charcoal or ethanol).

In Vatomandry, 54% of the sample used wood and there was good evidence that these households were less well off than charcoal users in the town, with lower level of education, lower rates of electricity connection and lower possession of a cell phone. On the other hand, reported income was similar.

There was however other important differences between homes by fuel type, in particular the configuration of the kitchen. In Vatomandry wood users were much more likely to have the kitchen in a separate structure that was not attached to or part of the main house and living area. This has important implications for exposure of the young child, and probably also for the mother (cook).

Most households used only one type of stove, and likewise most stated that they keep to the same fuel and stove in the wet and dry seasons. Very few used an improved charcoal stove, and all wood users relied on the traditional 3-stone fire. We believe that this consistency eased the introduction of single interventions in the houses,

A number of questions were asked about the likes and dislikes women had regarding the fuels they currently use, and what their preferences would be for alternatives. Their answers raised a number of interesting issues. Probably the most important among these is that around 60% in both centres stated LPG as their preferred alternative fuel, with very few mentioning ethanol. This suggests that considerable effort needs to be put into raising awareness of the suitability and advantages of ethanol if this is to become and widely accepted alternative. It would also be useful to find out more about the costs, markets and availability/supply of LPG.

5. Follow-up household information

5.1. Socio-demographic Characteristics at Follow-Up

Many factors unrelated to the intervention could potentially influence the key outcomes of this study; therefore random allocations to the study groups were used with the aim of creating groups as similar as possible with regard to key characteristics. Table 5.1 and 5.2 show a range of socio-demographic characteristics according to each intervention group at Round 2 in Ambositra and Vatomandry.

Table 5.1 shows the distribution of these demographic characteristics by intervention in Ambositra. It can be seen that even with the move away from the original allocation schedule, the intervention groups in Ambositra appear fairly comparable in respect of the key characteristics listed (no differences achieving statistical significance).

Table 5.1: Characteristics of Study groups at time of Round 2 Survey – Ambositra

	Intervention group				
Mean (SD)	**Ethanol (n=32)**	**Charcoal (n=31)**	**Awareness (n=33)**	**Control (n=36)**	p value[a]
Age (years)	32.7 (7.5)	31.2 (10)	32.4 (7.6)	32 (8.9)	0.920
AME cooked for	3.9 (1.4)	4.0 (1.5)	4.3 (2.0)	4.3 (1.6)	0.557
Median (IQR)					p[b]
Household money (weekly)	35,000 14k-36.5k	27,000 16.9k-35k	28,000 20k-35k	21,000 14k-35k	0.484
n %					p[c]
Secondary/ higher education	22 68.8	22 71.0	21 63.6	26 72.2	0.879
Electricity connection	16 50.0	19 61.3	18 54.5	14 53.8	0.841
Cell phone	24 75.0	23 74.2	20 60.6	16 61.5	0.458
Husband in professional employment	9 28.1	13 41.9	9 27.3	11 30.6	0.571
n %					p[d]
Separate kitchen	2 6.2	1 3.2	1 3.0	2 5.6	0.723d

a ANOVA, b Kruskall-Wallis, c Chi-Squared test, d Fisher's Exact test

A similar analysis for Vatomandry, however, showed important differences between the study groups. The wood stove users and the awareness group participants appear to have a higher average age than the other groups. A higher proportion of ethanol and charcoal stove users reached secondary or higher education (p=0.016) than in the other groups - which may be a reflection of the less educated/poorer households using wood fuel. There was, however, no evidence of a difference in weekly household income among the groups. It might be that the group with additional education will adopt a new technology more easily.

The control group also seem to be much more likely to have a kitchen which is separate from the main house p=0.001). This is discussed in more detail in the kitchen configuration section (Section 5.7).

All of these differences in key variables have been allowed for in the overall multivariate model, reported in (Section 10 and 11), in which confounding by age, educational level and separate kitchen are addressed.

Table 5.2: Characteristics of Study groups at time of Round 2 Survey – Vatomandry

	Intervention group					
Mean (SD)	**Ethanol n=32**	**Biomass n=33**	**Charcoal n=31**	**Aware-ness n=33**	**Control n=36**	p value [a]
Age (years)	30.5 (5.9)	36.5 (12.2)	31.9 (8.1)	36.0 (11.6)	32.2 (7.5)	0.034
AME cooked for	3.8 (1.3)	4.2 (1.8)	3.9 1.5)	4.3 (1.9)	4.2 (1.4)	0.568
Median (IQR)						p^b
Household money (weekly)	35k 21k-40.3k	28k 14k-42k	35k 21k-42k	35k 22.8k-40k	35k 21k-42k	0.638
n (%)						p^c
Secondary/ higher education	23 71.9	15 45.5	25 78.1	15 46.9	16 51.6	0.016
Electricity connection	19 59.4	18 54.5	26 81.2	19 59.4	14 58.3	0.188
Cell phone	22 68.8	20 60.6	28 87.5	24 75.0	17 70.8	0.177
Husband in professional employment	15 46.9	17 51.5	11 34.4	15 46.9	12 38.7	0.640
Separate kitchen	6 18.8	17 51.5	13 40.6	18 56.2	22 71.0	0.001

a ANOVA, b Kruskall-Wallis, c Chi-Squared test

5.2. Main stove use at follow-up

The main type of stove used in the home at Round 2 and 3 is shown in Table 5.3 and 5.4. The highlighted cells show the % (n) of households using their project stove as their main stove.

At Round 2 the use of the ethanol stove as the main cooking device was at the lowest frequency in Ambositra (81.2%). Yet this level of use might be considered extremely high considering the short time between installation and the follow up survey. The cooks had very little time to become accustomed to a new stove, and the ethanol stove was less like their previous method of cooking than perhaps either the biomass or charcoal stoves. A more representative measure of acceptability and how well the project stoves meet cooking needs is seen from the results for Round 3, which show an increase to 97% of the ethanol stove group in Ambositra using the ethanol stove as their main cooking device, but a reduction to 77% in

Vatomandry. There was a subsequent increase in the number of households in the ethanol stove group in Vatomandry using a 3-stone fire as their main stove between Rounds 2 and 3.

When asked about the reasons why they did not use their ethanol stove each day, most responded with reasons related to access to the fuel. The fact that the Vatomandry homes were less smoky even before intervention could mean that the participants have a reduced stimulus to source clean fuels on a regular basis, compared to participants from the more polluted households in Ambositra.

The charcoal stove was used as the main stove at consistently high rates. Possibly due to the lower need to adapt cooking techniques compared to the CleanCook Stove, 100% were using the intervention charcoal stove as the main stove at both study sites by Round 3. The biomass stove was also being used as the main stove by 93% of the intervention group in Vatomandry. This is a very slight decrease from the 100% at Round 2. When one participant was asked why she no longer used her stove as the main stove she responded, “It is difficult to use, difficult to cook rice with. I don’t really know how to use it.”

Table 5.3: Type of stove used as the main stove by intervention groups – Ambositra n(%)

Main stove used	Intervention group: Ethanol		Charcoal		Awareness		Control	
	Round 2 n=32	Round 3 n=31	Round 2 n=31	Round 3 n=31	Round 2 n=33	Round 3 n=33	Round 2 n=36	Round 3 n=34
Ethanol stove	26 (81.2)	30 (96.8)	-	-	-	-	-	-
Project charcoal stove	-	-	28 (90.3)	31 (100)	-	-	-	-
Traditional metal charcoal stove	4 (12.5)	1 (1.8)	3 (9.7)	-	27 (81.8)	24 (72.7)	31 (86.1)	31 (91.2)
‘Improved charcoal stove’: Not project	2 (6.2)	-	-	-	6 (18.2)	9 (27.3)	5 (13.9)	3 (8.8)

Table 5.4: Type of stove used as the main stove by intervention groups – Vatomandry n (%)

Main stove used	Intervention group									
	Ethanol		Biomass		Charcoal		Awareness		Control	
	Round 2 N=32	Round 3 n=31	Round 2 n=33	Round 3 n=33	Round 2 n=32	Round 3 n=30	Round 2 n=32	Round 3 n=28	Round 2 n=31	Round 3 n=31
Ethanol stove	29 (90.6)	24 (77.4)	-	-	-		-	-	-	-
Project charcoal stove	-	-	-	-	29 (90.6)	30 (100)	-	-	-	-
Project biomass stove	--	-	33 (100)	31 (93.9)	-	-	-	-	-	-
Traditional metal charcoal stove	1 (3.1)	1 (3.2)	-	-	1 (3.1)	-	13 40.6	10 35.7	14 45.2	11 35.5
'Improved charcoal stove': Not project	-	2 (6.5)	-	-		-	-	1 (3.6)	1 (3.2)	2 (6.5)
3-stone fire	2 (6.2)	4 (12.9)	-	2 (6.1)	1 (3.1)	-	18 (56.2)	17 (60.7)	15 (48.4)	17 (54.8)

5.3. Secondary stove use at follow up

Secondary stove use was not common in the households when measured at Baseline – 89.6% in Ambositra and 81.7% in Vatomandry typically used only one type of stove each day. However, the use of a secondary stove had increased by Round 2, particularly in the ethanol stove group, and this pattern of multiple stove use persisted at Round 3. Tables 5.5 and 5.6 show the amount of secondary stove use by intervention groups and the stove used, for each round of data collection.

In Ambositra there is a significant difference between the use of a secondary stove between the intervention groups ($p=<0.005$) at Round 2 and Round 3 ($p<0.005$). The ethanol stove group uses a secondary stove significantly more than the others. 84.4% of the ethanol group used a secondary stove at Round 2, which may reflect the transitions in kitchen management needed to integrate a very different type of stove and fuel, and/or the impact, in some cases, of the added cost of the ethanol fuel (see Section 5.12 Perceptions of stove for further discussion). Although the number of households using a secondary stove had fallen only slightly by Round 3 (80.6%), there had clearly been a shift in the type of stove used as the secondary stove in the ethanol group. At Round 2 18.8% of the group were using their ethanol stove as the secondary cooking device whereas by Round 3 this had fallen to 3.2% reflecting a shift of the ethanol stove from secondary to main stove.

Table 5.5: Use of a secondary stove by intervention group: Ambositra

	Intervention group							
	Ethanol		Charcoal		Awareness		Control	
	Round 2 n=32	Round 3 n=31	Round 2 n=31	Round 3 n=31	Round 2 n=33	Round 3 n=33	Round 2 n=36	Round 3 n=34
Uses a secondary stove	27 (84.4)	25 (80.6)	16 (51.6)	13 (41.9)	8 (24.2)	11 (33.3)	5 (13.9)	7 (20.6)
Secondary stove type								
Ethanol stove	6 18.8	1 (3.2)	-	-	-	-	-	-
3-stone fire	1 (3.1)	1 (3.2)	3 (9.7)	4 (12.9)	5 (15.2)	7 (21.2)	2 (5.6)	3 (8.8)
Traditional metal charcoal	16 (50.0)	18 (58.1)	9 (29.0)	8 (25.8)	2 (6.1)	1 (3.0)	1 (2.8))	-
'Improved charcoal stove': Not project	4 (12.5)	4 (12.9)	4 (12.9)	1 (3.2))	1 (3.0)	3 (9.1)	2 (5.6)	4 (11.8)
Electric	-	1 (3.2)	-	-	-	-	-	-

The secondary stove use in the charcoal stove group although much lower than the ethanol group remained slightly higher than the awareness and control groups by Round 3. The reasons for needing a secondary stove are explored more in Section 5.12.

Figure 5-1: Secondary Stove Use at Round 3 Ambositra

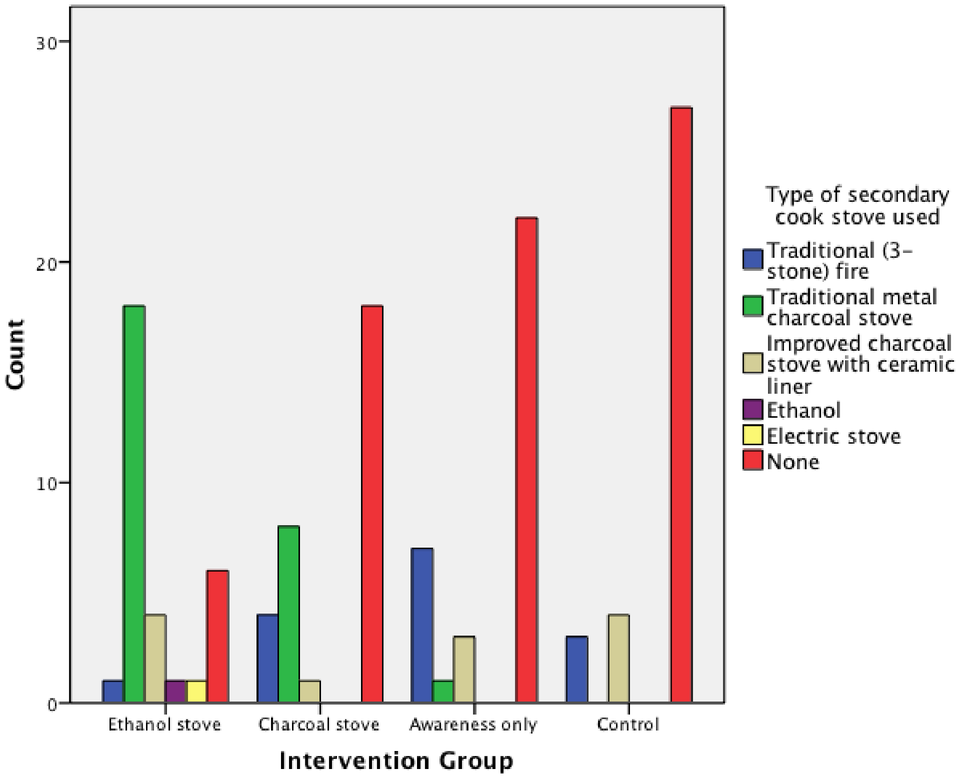


Table 5.6 shows that at Round 2 there was also a significant difference in secondary stove use in Vatomandry (p=0.002) with the ethanol group again reporting a higher level (75%). This increased at Round 3 to 83.9% with 3 more households using their ethanol stove as the secondary stove than at Round 2. The difference in secondary stove use between the intervention groups remained significant at Round 3 (p=<0.005)

Figure 5-2: Secondary Stove Use at Round 3 Vatomandry

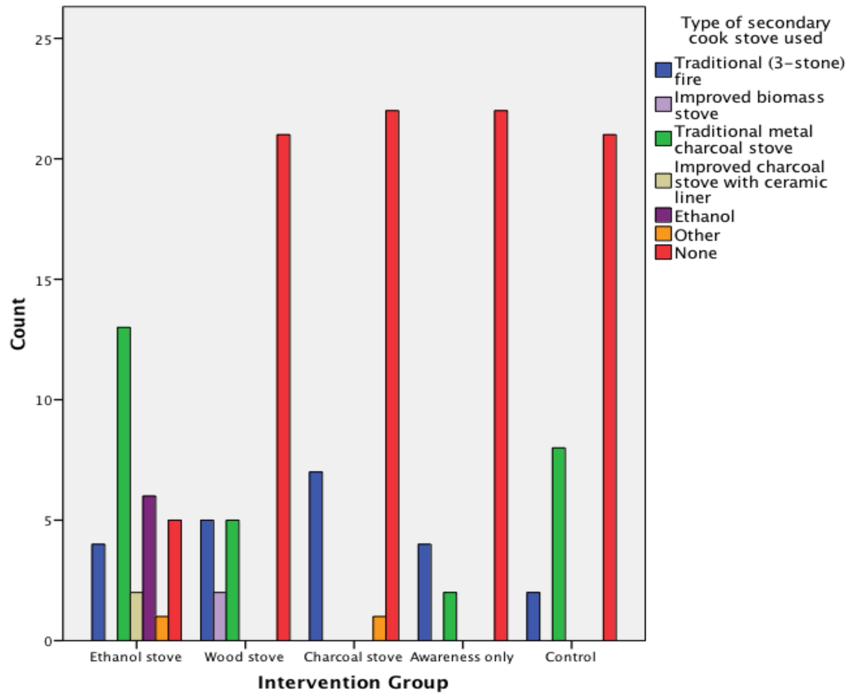


Table 5.6: Use of a secondary stove by intervention group: Vatomandry

Main stove used	Intervention group									
	Ethanol		Biomass		Charcoal		Awareness		Control	
	Round 2 n=32	Round 3 n=31	Round 2 n=33	Round 3 n=33	Round 2 n=32	Round 3 n=30	Round 2 n=32	Round 3 n=28	Round 2 n=31	Round 3 n=31
Uses a secondary stove	24 75.0	26 83.9	14 42.4	12 36.4	15 46.9	8 26.7	8 25.0	6 21.4	14 45.2	10 32.3
Secondary stove type										
Ethanol stove	3 (9.4)	6 19.4	-	-	-	-	-	-	-	-
3-stone	4 (12.5)	4 (12.5)	8 (24.2)	5 (15.2)	6 (18.8)	7 (23.3)	4 (12.5)	4 (14.3)	7 (22.6)	2 (6.5)
Traditional metal charcoal stove	11 (34.4)	13 (41.9)	3 (9.1)	5 (15.2)	4 (12.5)	-	3 (9.4)	2 (7.1)	7 (22.6)	8 (25.8)
'Improved charcoal stove': Not project	5 (15.6)	2 (6.5)	1 (3.0)	-	5 (15.6)	-	1 (3.1)	-	-	-
Improved biomass	-	-	-	2 (6.1)	-	-	-	-	-	-
LPG	1 (3.1)	-	1 (3.0)	-	-	-	-	-	-	-
Other	-	1 (3.2)	1 (3.0)	-	-	1 (3.3)	-	-	-	-

Secondary stove use in the charcoal and wood stove intervention groups was similar to that seen in the awareness and control groups, which overall tends to be much higher in Vatomandry than Ambositra. There was a drop in the use of a secondary stove as the participants became more familiar with the intervention stove between Rounds 2 and 3.

The traditional charcoal stove was the most frequently used secondary stove in both Ambositra and Vatomandry, with the three-stone fire also being used in Vatomandry. These results show that some households, including the majority in the ethanol group, will have been using a mix of fuels during the Round 2 and Round 3 monitoring, and it is assumed that they were doing so throughout the post-intervention follow-up period (see cooking fuel section (5.7) for further discussion on this)

5.4. Cost, repair and replacement of current stove

5.4.1. Perceived costs of project stoves

To assess the participants' perceptions of the stoves' value in a study where the stove was given at no cost, people were asked how much they would expect to pay for it. At Round 2 the range of the responses was very wide. In Ambositra participants thought the ethanol stove would cost between 10,000 to 250,000 Ar, with an over-all median cost of 100,000Ar - higher than that anticipated by the Vatomandry ethanol stove users (60,000Ar at Round 2). The anticipated cost of the biomass stove in Vatomandry ranged from 3,000 Ar to 200,000 Ar, perhaps reflecting a variation in how much the users liked the stove. The charcoal stove was valued at a notably lower cost at both study sites maybe because it is very similar to the traditional charcoal stove in many ways. The question was repeated again at Round 3, 5 months after the households received the stove. The estimated stove cost in Ambositra remained unchanged. Interestingly the estimated cost of the ethanol stove increased in Vatomandry even though more households were no longer using it as their main stove. The expected cost of the wood stove decreased, which may indicate dissatisfaction with its ability to meet all cooking needs.

Table 5.7: Expected median (IQR) costs of the project stoves at Round 2 and Round 3(Ar)

Ambositra		Vatomandry		
Ethanol stove n=31	Charcoal Stove n=31	Ethanol Stove n=31	Wood Stove n=33	Charcoal Stove n=30
100,000	4000	60,000	50,000	5000
60,000-150,000	3000-5000	50,000-80,000	20,000-80,000	4000-6750
100,000	4000	80,000	30,000	6000
60,000-150,000	3000-5000	40,000-90,000	20,000-60,000	4000-6250

5.4.2. Repair to intervention stoves

None of the ethanol or wood stoves required any repairs in the 5 months between installation and Round 3 but there do seem to have been problems with some of the intervention charcoal stoves. 6.5% of households in the charcoal intervention group in Ambositra and 21.9% in Vatomandry have required repair since installation. Most repairs involved the liner within the stove.

Figure 5.3 shows the observed condition of the main stove at Round 3 by intervention groups. As expected the intervention group stoves are in an overall better condition than the stoves in the control or awareness-only homes. However it should be noted that 7 of these stoves reported in the ethanol group in Vatomandry were not the intervention stove because the project as the participants identified another stove as their main stove.

Figure 5-3: Condition of main stove in Ambositra: Round 3

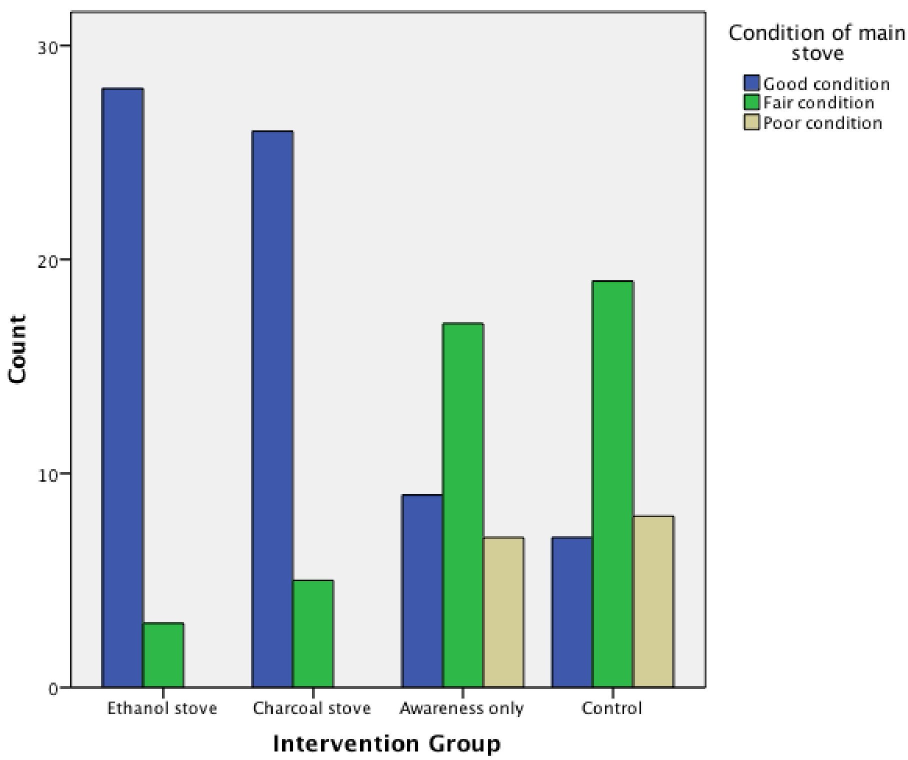
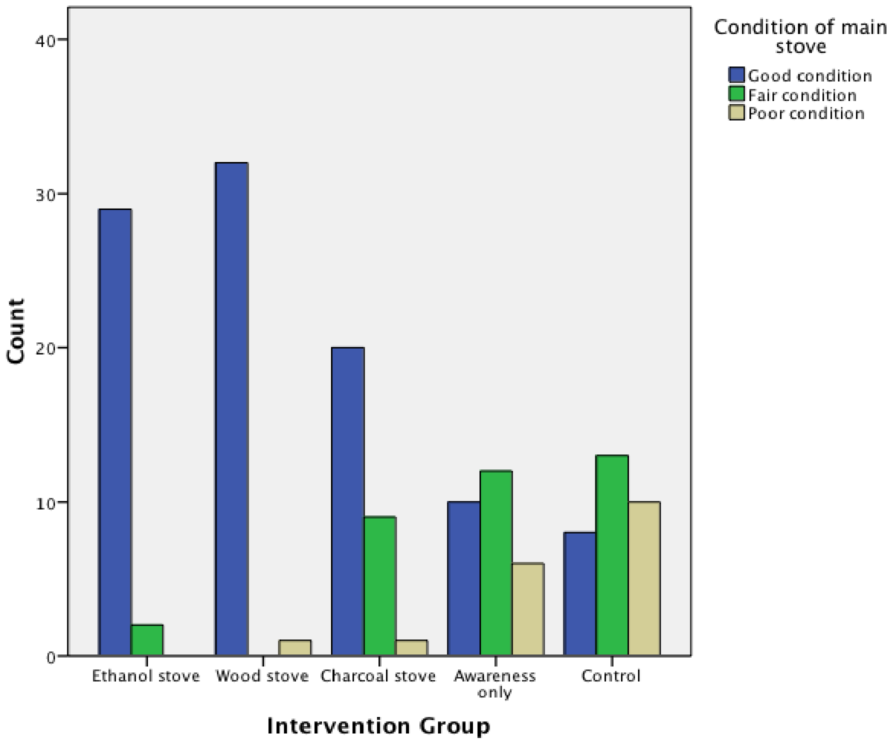


Figure 5-4: Condition of main stove in Vatomandry: Round3



5.4.3. Costs and repairs to traditional stoves

The average price of the stoves used by the awareness and control groups was the same in each group in Ambositra (Median Ar 2,500; IQR 2000- 3000). In Vatomandry the average cost of the awareness group stove was slightly higher (Median Ar 2700; IQR 2000-5000) than the control group (median Ar 2000; IQR 1450-3000). It is worth noting that this is considerably lower than the participant perceived price of all intervention stoves except the charcoal stove.

The frequency of repairs to the stoves belonging to the control and awareness group households and the amount spent on these repairs are shown in Table 5.8.

Table 5.8: Number (%) of households repairing their current stove and median amount (Ar) paid

	Ambositra		**Vatomandry**	
	Awareness (n=33)	**Control** (n=34)	**Awareness (n=28)**	**Control** (n=31)
Number (%) needing repair	19 (57.5)	23 (67.6)	5 (17.9)	11(35.5)
Median (IQR) cost of repairs	**500** 500-1000	**1000** 600-1500	**800** 250-800	**1000** 500-2400

This shows that people are willing to carry out repairs that cost a relatively large amount of money, indicating a willingness to invest money in their stoves.

5.5. Time related issues at follow-up

5.5.1. Time fire alight

At Baseline the mean time the main stove was usually alight each day was similar in both study areas- 6.61 hrs (SD 2.67) in Ambositra and 7.0 hours (SD 2.47) in Vatomandry. There was no apparent difference between the fuel (and therefore stove) types in Vatomandry either with both charcoal and wood users having their stove alight for 7 hours per day (p=0.989, T-test).

Overall, the mean time the fire was alight per day at Round 3 was very similar at both study sites (6.77 hours (SD3.02) in Ambositra and 6.16 (SD2.41) in Vatomandry.) In Ambositra, when comparing the time with the fire alight between Baseline and Round 3 in the households available at both stages of the study, there was no significant change (P=0.928). Whereas in Vatomandry there was an overall very small but statistically significant decrease in the time spent with the stove alight (0.72 hrs each day P=0.003).

The tables below show the mean time stoves were alight per day at Round 3 for each intervention group. At both sites there is a significant difference between the groups, with the ethanol group having the shortest cooking time of 4.37 hours per day (Ambositra) and 5.09 hours in Vatomandry.

Table 5.9: Time fire alight at Round 3 by Intervention Group:Ambositra

Intervention Group				P value*
Ethanol (n=31)	Charcoal (n=31)	Awareness (n=33)	Control (n=34)	
4.37 (SD 2.40)	6.98 (SD 2.51)	7.32 (SD 2.37)	8.25 (SD 3.32)	<0.05

**P-value from Anova*

Table 5.10: Time fire alight at Round 3 by Intervention Group: Vatomandry

Intervention Group					P value*
Ethanol (n=31)	Biomass (n=33)	Charcoal (n=30)	Awareness (n=28)	Control (n=31)	
5.09 (SD 1.56)	6.04 (SD 2.37)	6.69 (SD 2.37)	6.71 (SD 2.97)	6.37 (SD 2.40)	0.05

**P-value from Anova*

In Ambositra households with an ethanol stove spent on average 2.17 hours less with their stove alight each day compared to Baseline. All other groups showed a very small increase in time spent with the stove alight (Table 5.11).

Table 5.11: Difference in hours stove alight in one day between Baseline and Round 3: Ambositra (Round 3 minus Baseline)

Intervention Group				Total
Ethanol (n=31)	Charcoal (n=31)	Awareness (n=33)	Control (n=24)	
-2.17 (SD 2.84) *P=<0.000	0.12 (SD 3.20) *P=0.835	0.98 (SD 2.68) *P=0.04	1.16 (SD 3.92) *P=0.161	0.03 (SD 3.37) *P=0.928

**P-value from paired t-test*

A similar pattern was seen in Vatomandry. Households with an ethanol stove spent on average 2.64 hours less with their stove alight each day compared to Baseline. The other groups reported small changes in time of <1 hour per day but none was statistically significant.

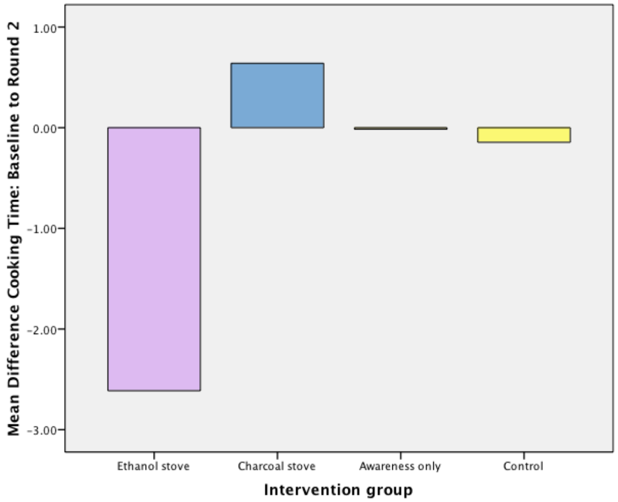
Table 5.12: Difference in hours stove alight in one day between Baseline and Round 3: Vatomandry

Intervention Group					Total
Ethanol (n=31)	Biomass (n=33)	Charcoal (n=30)	Awareness (n=28)	Control (n=24)	
-2.64 (SD 2.62) P=<0.000	-0.63 (SD 2.74) P=0.197	-0.42 (SD 1.68) P=0.893	0.70 (SD 3.72) P=0.332	-0.90 (SD 2.45) P=0.09	0.72 (SD 2.90) P=0.003

**P-value from paired t-test*

Data was also collected on the reported time spent with stove alight during the 24-hour exposure monitoring periods at all rounds (Figure 5.5). The participants in the ethanol stove group at both sites are clearly spending significantly less time with the stove alight since installation of the ethanol stove (Ambositra; Baseline-Round 2 mean difference 2.61 (SD 3.1) p=<0.001; Baseline to Round 3 mean difference 2.07 (SD 2.8) p=<0.001. Vatomandry; Baseline-Round 2 mean difference 1.83 (SD 2.9) p=0.001; Baseline to Round 3 mean difference 2.83 (SD 2.8) p= <0.001.)

Figure 5.5(a) and 5.5(b): Mean difference (hrs) between rounds in time spent with fire alight during monitoring: Ambositra



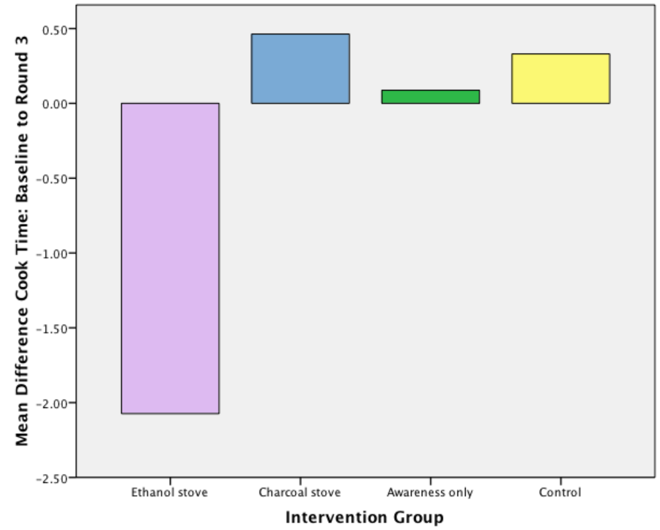
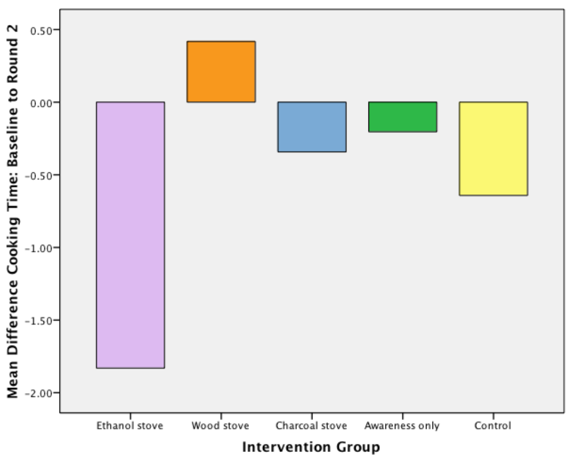
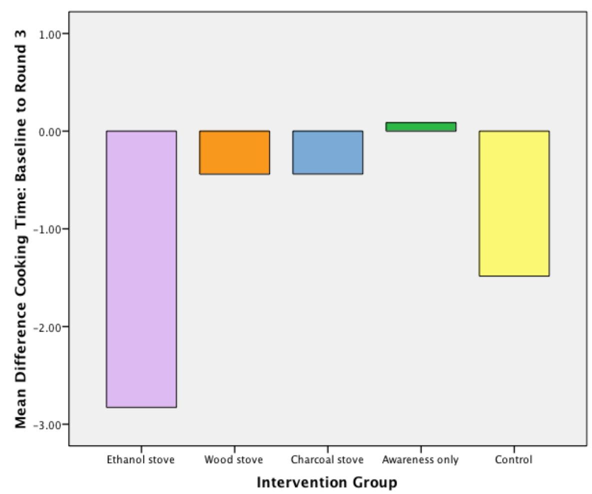


Figure 5.5 (c) and 5.5(d): Mean difference (hrs) between rounds in time spent with fire alight during monitoring: Vatomandry





The decrease in the time that the stove was alight in the control group households between Baseline and Round 3 in Vatomandry is borderline significant (mean difference 1.48 (SD 3.5) p=0.06). This could be a product of an increased awareness just by having the cooking/energy related questions being asked in questionnaire and by having the monitors on. This will be considered further when exploring how much influence the project within the community has had on the control group cooking habits.

5.5.2. Changes in time spent cooking

Changes in time spent actively cooking

The participants were asked at Round 3 if they believed their participation in the project had led to an increase, decrease or in fact no change in the time they spent cooking actively at the stove. Even though the control group in Vatomandry had a borderline significant reduction in the time their stove was alight, the majority (97%+) of the awareness and control group participants at each study site reported that there had been no change in the amount of time they spent cooking since starting the project. The response was more varied for the stove intervention groups (Table 5.13) with more households reporting reductions in time in the ethanol and wood stove groups than those using the charcoal stove.

Table 5.13: How the project stove compares to previous stove in speed of cooking: Round 2

	Ambositra		Vatomandry		
	Ethanol n=31	Charcoal n=30	Ethanol n=31	Biomass n=32	Charcoal n=30
A lot less time	15 (48.4)	1 (3.3)	5 (16.1)	5 (15.6)	-
A bit less time	15 (48.4)	16 (53.3)	16 (51.6)	22 (68.8)	12 (40.0)
Same	-	9 (30.0)	8 (25.8)	3 (9.4)	17 (56.7)
A bit more time	1 (3.2)	4 (13.3)	2 (6.5)	2 (6.2)	1 (3.3)
A lot more time	-	-	-	-	-

The participants who had reported changes in the time spent cooking were asked about the amount of time this involved. In the households that reported saving time there was a significant difference in the amount saved per week between groups in Vatomandry but not Ambositra (Table 5.14). The large reduction seen in time the stoves are alight in the ethanol group did not appear to create a comparable amount of free time away from the stove- approximately 2 hours less per day with the stove alight yet the participants felt that they actively cooked for only one hour less. This may be a product of wanting to be nearer to a clear stove.

Table 5.14: Average (Median (IQR) reduction in time (hr) spent actively cooking since taking part in the project per week

Ambositra		Vatomandry		
Ethanol n=31	Charcoal n=30	Ethanol n=31	Biomass n=32	Charcoal n=30
7.0 (3.5-9.2)	5.25 (3.5-7.0)	7.0 (4.4-7.0)	7.0 (7.0-10.5)	3.5 (3.5-7.0)
P value from Mann_Whitney (non-parametric) hypothesis test: p= 0.108		*P value from Kruskall Wallis (non-parametric) hypothesis test: p=0.03*		

Speed of cooking

Table 5.15 shows the perceptions of how fast the project stove cooks food compared to the respondent's previous stove. The reports were very diverse even within each stove group and did not seem to be related to the respondent's baseline stove (results not shown).

Table 5.15: How the project stove compares to previous stove in speed of cooking: Round 2

	Ambositra		Vatomandry		
	Ethanol n=32	Charcoal n=31	Ethanol n=32	Biomass n=33	Charcoal n=32
Much faster	13 (40.6)	5 (16.1)	6 (18.8)	17 (51.5)	3 (9.4)
Bit faster	13 (40.6)	18 (58.1)	12 (37.5)	13 (39.4)	18 (56.2)
Same	3(9.4)	4 (12.9)	4 (12.5)	2 (6.1)	7 (21.9)
Bit slower	3 (9.4)	4 (12.9)	9 (28.1)	1 (3.0)	4 (12.5)
Much slower	0	1 (3.2)	1 (3.1)	0	0

Round 3 perceptions are shown in figures 5.6 and 5.7 and show similar trends to Round 2

Figure 5-6: Perceived speed of cooking relative to old stove by intervention group: Ambositra

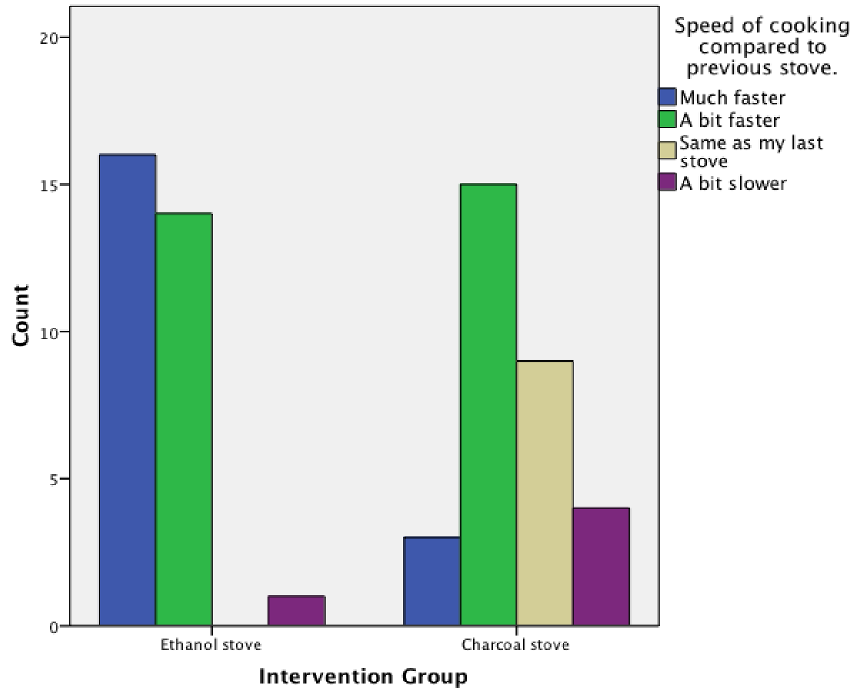
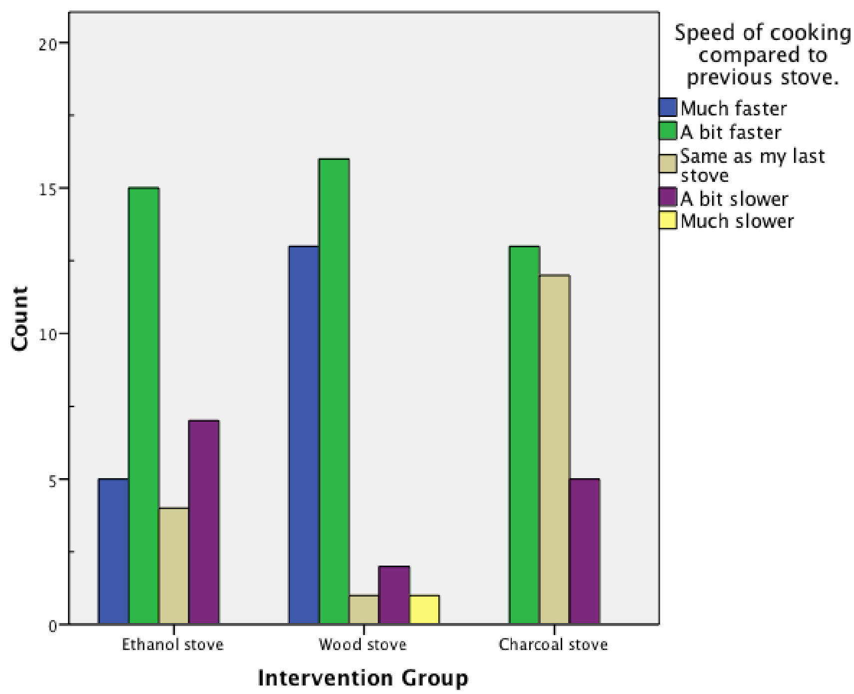


Figure 5-7: Perceived speed of cooking relative to old stove by intervention group: Vatomandry



Changes in time spent kitchen cleaning

A cleaner burning more efficient stove can potentially reduce the time a cook spends cleaning her cooking utensils and kitchen allowing her additional time to carry out other activities. The installation of the ethanol stove appears to have reduced the cleaning time in both study sites. In Ambositra 71% (n=22) of the ethanol stove group reported that they spend a bit less time cleaning as a “result of the project”. On average (median IQR) they reported that they spent 1.5 (0.6-1.9) hours less per week. 32.3% (n=10) of the Vatomandry ethanol stove group reported that they spend a lot less time cleaning since taking part in the project and 58.1% (18) said it was a bit less time. Overall they report a median reduction in time spent cleaning of 1.2 hours (0.6-1.5) per week.

The charcoal stove had a more varied response with most households in Ambositra (73.3% n=22) stating that their participation in the project had not changed the amount of time spent cleaning their pots and kitchen. However in Vatomandry it was only 56.7% of the group reporting no change and 36.7% (n=11) believing that they cleaned for a bit less time.

The majority of the wood stove users also felt that they spent a bit less time cleaning since taking part in the project (56.7% n=17) with a reported average (median) of 1.2 hours less (0.6-2.3) per week.

5.6. Perceptions of the project stoves

All participants in the stove groups were asked about their perceptions of the stove at Round 2 within a period of 3-6 weeks of receiving the stove. The immediate reaction was positive and is described in detail below. The participants’ perceptions of the study stoves were explored again in Round 3, when they had had the stove for 5 months. This data confirmed the positive responses and widespread adoption of the project stoves. Nonetheless explanations for not using the ethanol stoves as the main stove were given; areas of frustration were highlighted and suggestions for improving the stoves put forward.

5.6.1. General perceptions of the project stoves

Ethanol Stove

The Initial reaction to the ethanol stove was very positive. In response to an unprompted open question, the most frequently reported positive aspect of the ethanol stove was:

- It is clean (56.2% (n=18) Ambositra and 40.6% (n=13) in Vatomandry)
- It saves time (40.6% (n=13) Ambositra, 34.3% (n=11) in Vatomandry)
- It is easy to use (50.0% (n=16) Ambositra).
- 53.1% (n=17) of the ethanol stove users in Vatomandry reported that they believed the stove “makes life easier”.

After 5 months use at Round 3 all of the ethanol stove households in both Ambositra and Vatomandry thought that the stove had good impacts on their daily lives. Ease of use was given as the first positive impact of the stove by 41.9%. of ethanol stove households in Vatomandry In Ambositra the responses were more varied, meaning there were fewer households in each category. However 29.0% reported that the time saved in cooking was their most important positive impact of the stove and 25.8% stated it was the fact that their kitchen is cleaner due to the reduction of smoke.

At Round 2 34.4% (n=11) of participants with ethanol stoves in Ambositra and 18.8% (n=6) in Vatomandry reported that they had problems that prevented them from using their stoves. All of these people in Vatomandry cited the cost of the ethanol fuel as the reason and in Ambositra 28.1% (n=9) said it was due to the cost of fuel while 6.3% (n=2) said it was the distance to the ethanol store. When questioned at Round 3 16.1% (n=5) of households in Ambositra and 3.2% (n=1) in Vatomandry stated that there had been a problem with their stove, Again most of these were related to the cost and access to the ethanol fuel (See Section: 5.11.1 for further discussion on procurement of ethanol fuel)

Charcoal Stove

Almost two-thirds (64.5% Ambositra and 62.5% Vatomandry) of those using the project charcoal stove reported that they had no dislikes about the stove when asked at Round 2. 6.5% (n=2) in Ambositra and 21.9% (n=9) in Vatomandry reported that the liner within the stove had broken within the short time since installation but this did not appear to stop them using the stove.

The positive response to the stove increased as the households used the stove more -- no negative impacts were reported by 80.6% in Ambositra and 75.0% in Vatomandry at Round 3. Of the problems that were reported, the stove being smoky and again the inner liner breaking easily were the most frequently mentioned issues. In fact by Round 3 64.5% (n=20) and 53.1% (n=17) of the charcoal stoves in Ambositra and Vatomandry respectively had a broken inner liner, which did not prevent the use of the stove but could impact on its efficiency and could potentially lead to the stove being abandoned over time.

At Round 2 the charcoal stove was described as ‘economical’ by 83.9% (n=26) of the households in the Ambositra charcoal stove group and 81.2% (n=26) in Vatomandry. This continued to be the most frequently reported positive impact at Round 3.

Wood Stove

At Round 2 the aspect liked most by the wood-stove users was that it was economical (66.7% n=22) and also the view that there was now “no more big smoke” (36.4% n=12). However 55.5% of the households that received a project wood stove reported a problem with the stove at Round 2. The main issues were related to the size of the stove (too large) and the fact that it took time to cut down the wood to the correct size so that it fitted into the fire. This was reduced to 9.1% (n=3) by Round 3, which maybe a result of the participants getting used to the stove. One participant had their kitchen re-built to accommodate the larger stove size.

5.6.2. Comparisons with previous stoves used

Table 5.16 shows the responses given when participants were asked at Round 2 how the project stove compares to the stove they had used previously. The majority of households who had received a project stove (92.1% in Ambositra and 87.6% in Vatomandry) believed the new stove to be a bit or much better than their previous stove. The results were notably more favourable for the ethanol stoves.

Table 5.16: How the project stove compares to previous stove: Round 2

	Ambositra		Vatomandry		
	Ethanol n=32	**Charcoal n=31**	**Ethanol n=32**	**Wood n=33**	**Charcoal n=32**
Much better	20 (62.5)	8 (25.8)	26(81.2)	22 (66.7)	9 (28.1)
Bit better	11 (34.4)	19 (61.3)	5 (15.6)	8 (24.2)	14 (43.8)
Same	1 (3.1)	4 (12.9)	1 (3.1)	3 (9.1)	8 (25.0)
Bit worse	0	0	0	0	1 (3.1)

Table 5.17 shows that project stoves continued to be positively compared to previous stoves after 5 months of use. In fact continued use led to more households in Ambositra believing the ethanol stove was much better than their previous stove (83.9%) than at Round 2.

Table 5.17: How the project stove compares to previous stove: Round 3

	Ambositra		Vatomandry		
	Ethanol n=31	**Charcoal n=31**	**Ethanol n=31**	**Biomass n=33**	**Charcoal n=30**
Much better	26 (83.9)	8 (25.8)	26 (83.9)	21 (63.6)	4 (13.1)
Bit better	5 (16.1)	17 54.8)	5 (16.1)	10 (30.3)	12 (40.0)
Same	-	6 (19.4)	-	1 (3.0)	13 (43.3)
Bit worse	-	-	-	1 (3.0)	1 (3.3)

5.6.3. Ease of use

The ethanol stove users were expected to learn how to cook on a very different stove using an unfamiliar fuel type. Nevertheless at Round 2, three to six weeks after receiving it, all respondents in the ethanol stove group at both sites reported that it was ‘very easy’ or ‘easy’ to cook a typical meal with this device. This was still the case at Round 3, except for one household in Vatomandry that claimed the stove was very difficult to use although this may have been an error as they then went on to say that they could cook all food they wanted to on it.

Although apparently easy to use the ethanol stove may not have been meeting all of the cooking needs of the participants. At Round 2 some of the ethanol stove users reported experiencing difficulty cooking some of their usual foods (43.7% (n=14) in Ambositra and 31.2% (n=10) in Vatomandry). This was very soon after installation and with time this perception was reduced but still evident at 29.0% in Ambositra (n=9) and 22.6% (n=7) in Vatomandry. The food type they were unable to cook most commonly was dry beans and zebu meat. Further investigation is required to explore how much of the diet these foods make up and if there were problems cooking these foods on previous stoves in order to assess the impact that not being able to cook these foods might have. As discussed previously this could be associated with the ethanol users adapting to a very different type of stove and fuel and might change with longer term use.

Although only 29% (n=9) of the project charcoal stove households in Ambositra and 25% (n=8) in Vatomandry reported that the stove was about the same as their previous stove in terms of ease of use, no one reported that the stove was 'quite' or 'very' difficult to use compared to their previous stove. There were however fewer problems cooking the usual food types reported by the wood and charcoal users at both sites. By Round 3 all of the charcoal stove users in Vatomandry were able to cook all of their usual food types and 83.9% in Ambositra. The wood stove was similarly able to cook all food types for 93.9% and in fact 94% (n=31) of those who received a wood stove in Vatomandry reported that the stove was 'very easy' or 'easy' to use at both Rounds 2 and 3.

In Ambositra the majority of people reported that the project stove was 'just the right size for their cooking needs,' with just 19.4% (n=6) charcoal users reporting that it was a bit too small. Vatomandry respondents voiced similar opinions about the ethanol and charcoal stove. However the wood stove seemed to be too large for some people, with 27.3% (n=9) reporting that the stove was either much bigger or bigger than they needed. 36.3% (n=12) of the wood stoves users in Vatomandry also reported that the pot stand was much too big or too big to fit the pots they usually cooked with, whereas this did not seem to be a problem with the other stoves.

These issues were raised when at Round 3 the participants were asked if they would make any changes to the stove. Table 5.18 shows the number of participants who would make changes and examples of the changes they would make. The comments were similar from both sites.

Table 5.18: Frequency and nature of the suggested changed to the project stoves

	N (%)	Suggested changes
Ethanol stove	17 (27.4)	2 burner stove and increase the size
Wood Stove	5 (15.1)	Increase number of pot stands. Reduce the overall size of the stove
Charcoal stove	18 (29.0)	Stove is too small. Needs a stronger liner. Needs a two pot capacity.

5.6.4. Perceived safety of project stove

Only two households over both study sites perceived the ethanol stove to be dangerous when asked at Round 2. This was due to the smell of the ethanol and potential for explosion in both cases. However at Round 3, 7 (11.3%) households over both sites believed the ethanol stove to be ‘ a bit dangerous’. “Afraid that the pot will fall off the stove” and that “on occasions the stove was turned off but flames continued” were two examples of why the households thought the ethanol stove was more dangerous than their previous stove.

The small number of participants (7.9% (n=5) from both study sites) who thought the charcoal stove was dangerous cited general fire/ cooking safety reasons that were not particular to the study stove. The wood stove was clearly causing some concern to the households using it as 18.2% (n=6) felt it was dangerous due to the chimney getting hot and potentially causing a house fire. This persisted at Round 3 with 12.1 % still fearful of house fire started by the stove.

5.6.5. Perceived worth of the intervention stoves in all study groups

To assess the perceived worth of the intervention stoves all of the study participants, including the control and awareness group, were asked to select in order of preference three items from a list of ‘luxury’ household products that included the three intervention stoves.

The tables below shows the numbers (%) that ranked the cook stoves as the first item they would buy if they had the available funds.

Table 5.19: Numbers ranking the intervention stoves as most preferable item: Ambositra

	Intervention Group			
Stove type	**Ethanol** n =31	**Charcoal** n =31	**Awareness** n=33	**Control** n=34
Ethanol stove	23 (74.2)	18 (58.1)	18 (54.6)	16 (47.1)
Charcoal stove	1 (3.2)	2 (6.5)	0	3 (8.8)

Table 5.20: Numbers ranking the intervention stoves as most preferable item: Vatomandry

	Intervention Group				
	Ethanol n=31	**Wood n=33**	**Charcoal n=30**	**Awareness** n=28	**Control n=31**
Ethanol stove	16 (51.6)	14 (42.4)	21 (70.0)	14 (50.0)	15 (48.4)
Wood Stove	1 (3.2)	5 (15.1)	2 (6.7)	2 (7.1)	2 (6.5)
Charcoal stove	0	3 (9.1)	2 (6.7)	3 (10.7)	2 (6.5)

A television was the other highest-ranking item with 12.9% (n=4) and 25.8% (n=8) of the ethanol *stove* users in Ambositra and Vatomandry preferring to buy a TV before the ethanol stove.

In all intervention groups a television was the preferred option above the wood stove in Vatomandry and the charcoal stove at both study sites.

5.7. Kitchen configuration at follow-up

As at Baseline the kitchens in the houses available at Round 3 were more likely to be joined to the main house (either as part of the main living area or as a room attached to the house) in Ambositra (96.1%) than Vatomandry (51.3%) (p=<0.000)

Kitchen configuration was a factor taken into consideration in the random allocation process and Table 5.21 shows how similar the kitchen configuration was between the allocation groups at Baseline (Ambositra p= 0.540; Vatomandry p=0.147).

Table 5.21: Kitchen configuration by intervention groups at all rounds: Ambositra

Kitchen joined to the main house	**Intervention group**				**P value***
	Ethanol	**Charcoal**	**Awareness**	**Control**	
Baseline	n=32	n=31	n=33	n=25	
	28 (87.5)	30 (96.8)	31 (93.9)	24 (96.0)	0.540
Round 2	n=32	n=31	n=33	n=36	
	30 (93.8)	30 (96.8)	32 (97.0)	34 (94.4)	0.950
Round 3	n=31	n=31	n=33	n=34	
	28 (90.3)	31 (100)	32 (97.0)	33 (97.1)	0.272

** Fisher's exact tests for differences between intervention groups*

However in Vatomandry, there had been a dramatic move towards having a kitchen attached to the house in the ethanol study group in the time between the Baseline and Round 2 survey. This could be due to the desire to bring a new, less smoky stove to a more central part of the house. Observations from field staff supported this: "Households brought ethanol stoves to their living places giving cleanness and security as a reason."

As noted above, along with other possible confounding factors, this change will be taken into account in the multivariate analysis.

Table 5.22: Kitchen configuration by intervention groups at all rounds: Vatomandry

Kitchen joined to the main house	Intervention group					
	Ethanol	Wood	Charcoal	Awareness	Control	P value*
Baseline	n=32	n=33	n=32	n=31	n=25	
	13 (40.6)	12 (36.4)	21 (65.6)	13 (41.9)	12 (48.0)	0.147
Round 2	n=32	n=33	n=32	n=31	n=32	
	26 (81.2)	16 (48.5)	19 (59.4)	13 (41.9)	10 (31.2)	0.001
Round 3	n=31	n=32	n=30	n=28	n=31	
	27 (87.1)	15 (46.9)	16 (53.3)	8 (28.6)	12 (38.7)	<0.000

**Chi-squared test for differences between intervention groups*

5.8. Cooking fuels: Patterns of use at follow-up

While charcoal continued to be the main fuel used by most study households in Ambositra 84.4% of the ethanol stove households had adopted ethanol as their main fuel at Round 2, increasing to 96.8% by Round 3. The households in the ethanol stove group not using ethanol as their main fuel were using charcoal (Table 5.23).

Table 5.23: Main Cooking Fuels at Round 2 and 3 by intervention group: Ambositra n (%)

Main fuel	Intervention Group			
Round 2 (wet)	Ethanol n=32	Charcoal n=30	Awareness n=33	Control n=36
Ethanol	27 (84.4)			
Charcoal	5 (15.6)	30 (100)	33 (100)	36 (100)
Round 3 (dry)	n=31	n=31	n=33	n=34
Ethanol	30 (96.8)			
Charcoal	1 (3.2)	31 (100)	33 (100)	34 (100)

The main fuel used in the stove intervention groups in Vatomandry reflected the stove they received. There was a slight decrease in ethanol being used as the main fuel between Rounds 2 and 3 (from 96.9% to 80.6%) with a move back to wood and charcoal in a small number of households. The use of wood as the main fuel in the wood stove group had no significant change and the charcoal stove users were all using charcoal as their main fuel by Round 3. The awareness and control group participants moved between charcoal and wood at each round with no strong trend towards one fuel or another (Table 5.24).

Table 5.24: Main Cooking Fuels at Round 2 and 3 by intervention group: Vatomandry n (%)

Main fuel	Intervention Group				
Round 2 (wet)	Ethanol n=32	Biomass n=33	Charcoal n=32	Awareness n=31	Control n=36
Ethanol	31 (96.9)				
Wood		32 (97.0)	2 (6.4)	16 (51.6)	18 (56.2)
Charcoal	1 (3.1)	1 (3.0)	30 (93.8)	13 (41.9)	13 (40.6)
Other				2 (6.4)	1 (3.1)
Round 3 (dry)	**n=31**	**n=33**	**n=30**	**n=28**	**n=31**
Ethanol	25 (80.6)				
Wood	3 (9.7)	31 (93.9)		17 (60.7)	17 (54.8)
Charcoal	3 (9.7)	1 (3.0)	30 (100)	11 (39.3)	13 (41.9)
Other		1 (3.0)			1 (3.2)

As expected a change in the type of fuel used for the main cooking fuel between rounds was minimal in Ambositra where most people beyond the ethanol group use charcoal. In Vatomandry even though there were more options for cooking fuel all of the study groups displayed very little shift between fuels, including the awareness and control groups.

Table 5.25: Shift of main fuel use between rounds in Vatomandry

Baseline to Round 2	
Awareness Group: Vatomandry	**Control Group: Vatomandry**
3 (9.7%) Wood to charcoal 2 (6.5%) Wood to other fuels i.e. kerosene	3 (11.5%) Wood to charcoal 1 (3.9%) Charcoal to wood 1(3.9%) Charcoal to electricity
Round 2 to Round 3	
1 (3.6%) Kerosene to wood 1 (3.6%) Charcoal to wood 1 (3.6%) Sawdust to wood 1 (3.6%) Wood to charcoal	No change

As seen with the stove use patterns, secondary fuel use was much more common among ethanol stove users than any of the other intervention groups. 77.4% of the ethanol stove group in Ambositra and 83.9% in Vatomandry were using a secondary fuel at Round 3 (Table 5.26). As expected secondary fuel use was very low in all of the other intervention groups in Ambositra, which is in line with the mono-fuel patterns in this community. The few households that did use a secondary fuel tended to use wood.

Table 5.26: Households using secondary cooking fuel at Round 2 and 3 by intervention group: Both sites

Ambositra (%)									
Ethanol		**Wood**		**Charcoal**		**Awareness**		**Control**	
Round 2 n=32	Round 3 n=31			Round 2 n=32	Round 3 n=30	Round 2 n=32	Round 3 n=28	Round 2 n=31	Round 3 n=31
25 (78.1)	24 (77.4)			3 (9.3)	5 (16.1)	5 (15.6)	7 (21.2)	2 (6.5)	3 (8.8)
Vatomandry (%)									
Ethanol		**Wood**		**Charcoal**		**Awareness**		**Control**	
Round 2 n=32	Round 3 n=31	Round 2 n=33	Round 3 n=33	Round 2 n=32	Round 3 n=30	Round 2 n=32	Round 3 n=28	Round 2 n=31	Round 3 n=31
24 (75.0)	26 (83.9)	9 (27.3)	8 (26.7)	9 (28.1)	9 (27.2)	7 (21.8)	6 (21.4)	15 (48.4)	10 (32.3)

In order to understand how much of the total fuel use ethanol was contributing towards; the pattern of secondary fuel use in the ethanol stove group was explored in more detail. Most ethanol stove users in both study sites complimented their ethanol fuel with charcoal. In both communities, approximately 25% of households in the ethanol stove group who were using a secondary fuel, made up at least half of their cooking fuel needs with charcoal (Table 5.27).

Table 5.27: Secondary Cooking Fuels at Round 3 by intervention group

Study site	Secondary fuel type	Fraction of total fuel use		
		½	¼	<¼
Ambositra (n=24)	Wood	-	-	1 (4.2)
	Charcoal	9 (29.0)	6 (19.4)	6 (19.4)
	Ethanol	-	-	1 (4.2)
	Mains electricity	-	1 (4.2)	-
Vatomandry (n=26)	Wood	2 (7.7)	1 (3.9)	1 (3.9)
	Charcoal	8 (25.8)	5 (16.1)	2 (7.7)
	Ethanol	4 (15.4)	2 (7.7)	-
	Crop- residue	-	1 (3.9)	-

5.9. Lighting fuels

The types of fuels used for lighting did not change considerably over the course of the study. Unlike with the cooking fuel use the lighting fuel choice was a modern clean energy source in many households. A very slight increase in the use of mains electricity was seen at both sites (Ambositra 61.2% from 52.8% at Baseline and Vatomandry 60.8% from 59.4% at Baseline), with a subsequent decrease in the reported use of kerosene as a lighting fuel. When asked if the household had made any changes to the way they light their homes as a result of the study only 2 households (0.7%) said they had. The use of kerosene is important, as this has been shown to result in moderately high levels of indoor air pollution, especially when burned in simple wick-type lamps.

There was no significant difference between the intervention groups in the amounts of the two main lighting fuels (mains electricity and kerosene) used (p=0.580 in Ambositra and p=0.464 in Vatomandry). See figures 5.8 and 5.9

Figure 5-8: Main lighting fuels in Ambositra by intervention group: Round 3

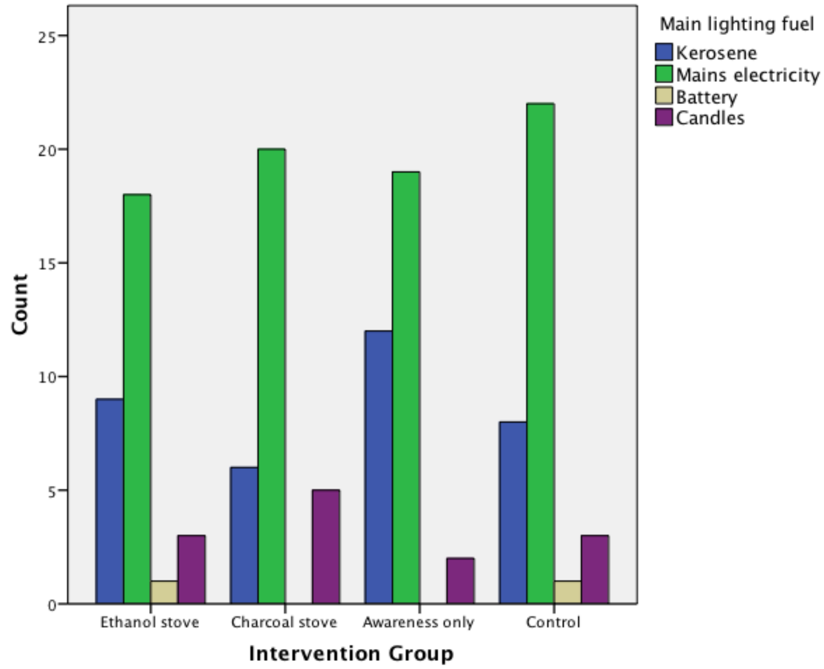
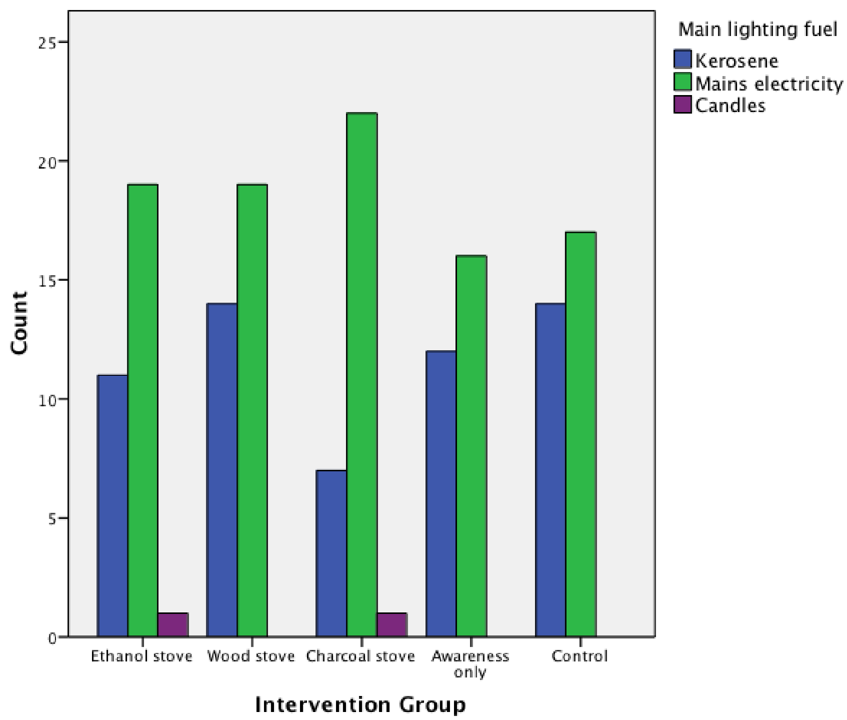


Figure 5-9: Main lighting fuels in Vatomandry by intervention group at Round 3



Most homes reported using secondary lighting fuels (66.7% Ambositra and 64.1% Vatomandry). In Ambositra this was mainly candles, which made up 83.7% of all secondary lighting fuel and in Vatomandry although candles were the most important (60% of households using a secondary lighting fuel), kerosene was used by just over one third (37.7%). Tables 5.28 and 5.29 show the secondary lighting fuel use by intervention group at each study site.

Table 5.28: Secondary lighting fuel use at Round 3 in Ambositra by intervention group

	Intervention group			
	Ethanol n=31	**Charcoal** n=31	**Awareness** n=33	**Control** n=34
Kerosene	1 (3.1)	2 (6.5)	3 (9.1)	7 (19.4)
Candles	17 (53.1)	19 (61.3)	20 (60.6)	16 (44.4)
Battery	-	-	1 (3.0)	
None	13 (40.6)	10 (32.3)	9 (27.3)	11 (30.6)

Table 5.29: Secondary lighting fuel use at Round 3 in Vatomandry by intervention group

	Intervention Group				
	Ethanol n=31	**Biomass** n=33	**Charcoal** n=30	**Awareness** n=28	**Control** n=31
Kerosene	5 (15.6)	9 (27.3)	8 (2.5)	5 (16.1)	8 (25.0)
Mains electricity	1 (3.1)	-	-	-	-
Candles	12 (37.5)	10 (30.3)	16 (50.0)	11 (35.5)	10 (31.2)
Battery	1 (3.1)	-	-	-	1 (3.1)
Local generator	1 (3.1)	-	-	-	-
None	11 (34.4)	14 (42.4)	6 (18.8)	12 (38.7)	12 (37.5)

The reported weekly cost of lighting fuels was estimated at a median (IQR) of 1,800Ar [IQR = 1,000 to 3000] Ariary in Ambositra and 2000 [IQR = 1,075 to 5,000] Ariary in Vatomandry. This is slightly more than at Baseline but when the comparison was limited to households with data available at Baseline and Round 3 the difference in amount spent on fuel was not statistically significant and may just reflect the natural increase in fuel prices over the interim year (p=0.225 in Ambositra and 0.817 in Vatomandry (Wilcoxon Signed Rank Test).

5.10. Space heating at follow-up

Although only one-third of homes in Ambositra (and none in Vatomandry) said that they used their stoves for space heating at baseline, of those that did more than half did so at times other than when cooking. This implies that use of stoves for space heating needed to be monitored during follow-up to determine whether – and to what extent –

the intervention stoves meet the needs of families since, if they do not, additional heat sources may be utilized.

As at Baseline no space heating was required in the households in Vatomandry at either follow up rounds. In Ambositra, only one household, which was in the control group, reported a change in the way they heated their home as a result of taking part in the survey. Overall at Round 3, 31.2% of households in Ambositra reported that they use their stove for space heating, which was similar to Baseline (34%).

At Baseline there was no marked difference between the way the intervention groups used space heating in their homes (p=0.123). The intervention stoves were installed at the end of the wet season and so the majority of the experience with the stove has been during the dry/cold season. For this reason we expected to see a generally higher reporting of space heating in Round 3 compared to the other rounds and this was the case in the control group (44.1% using space heating at Round 3 compared to 16.7% at Baseline) (Table 5.30).

Table 5.30: Number (%) of households in each intervention group using space heating at each round of monitoring, Ambositra.

	Intervention group				
	Ethanol n=31	**Charcoal n=31**	**Awareness n=33**	**Control n=24**	**P value**
Baseline (wet)	14 (45.2)	11 (35.5)	14 (42.4)	4 (16.7)	0.123
Round 2 (wet)	7 (22.6)	8 (25.8)	10 (30.3)	6 (25.0)	0.915
Round 3 (dry)	4 (12.9)	15 (48.4)	14 (42.4)	15 (44.1)	0.014

P value from chi-squared test comparing space heating between groups for each stage

The households in the ethanol stove group show a decrease in the number using a stove for space heating at each subsequent round. By Round 3 only 12.9% of ethanol stove households reported using space heating, and the differences among the intervention groups was statistically significant (p=0.014). The reasons for this change are not clear. Ethanol does not produce a high level of ambient heat compared to a 3-stone fire or an inefficient traditional charcoal stove, and so after adoption of an ethanol stove, one would expect a higher use of space heating with an alternative stove. However this does not seem to be the case. Other households reported using charcoal stoves and occasionally 3-stone fires during and in addition to cooking to warm their homes.

5.11. Procurement of fuel at follow-up

5.11.1. Perceived changes in time spent procuring fuel since being involved in the project

At Round 3 all participants were asked about changes in the amount of time spent procuring fuel for cooking since being involved in the project. The responses are shown in Figures 5.10 and 5.11. In both study sites the awareness and control group participants reported that there had been no change in the time spent getting fuel since taking part in the project. The households using the intervention charcoal and wood stove also appear to be spending about the same amount of time getting fuel as they did prior to the study. However at both sites, the ethanol-stove users seemed to have experienced a varied effect on their time spent getting fuel since taking part in the study. Comments from other questions suggest that this maybe related to the location of the store relative to the participants house. The store in Ambositra is also reported to be very slow to serve.

Figure 5-10: Perceived changes in time spent procuring fuel as a result of the project: Ambositra

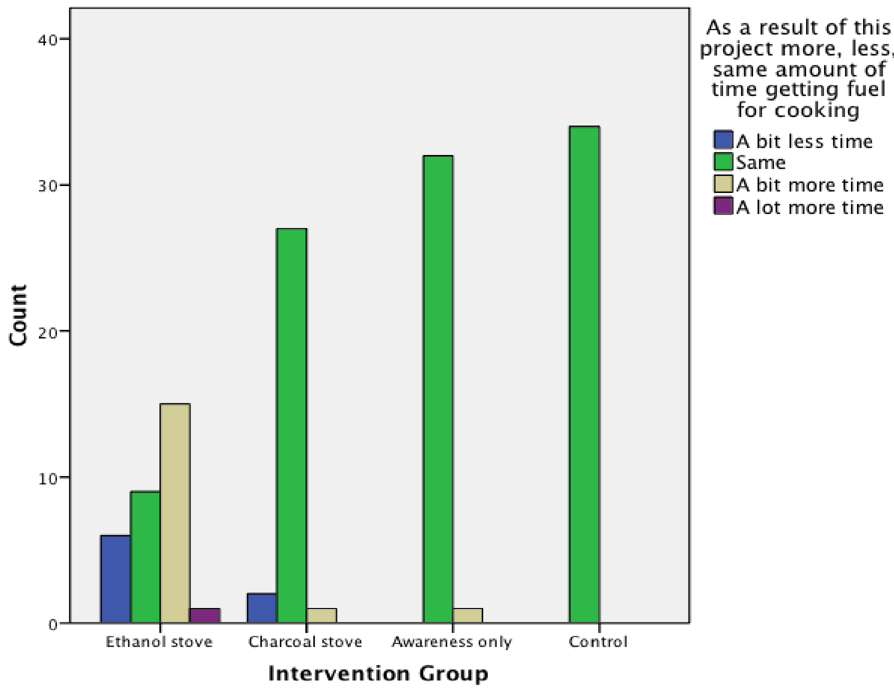
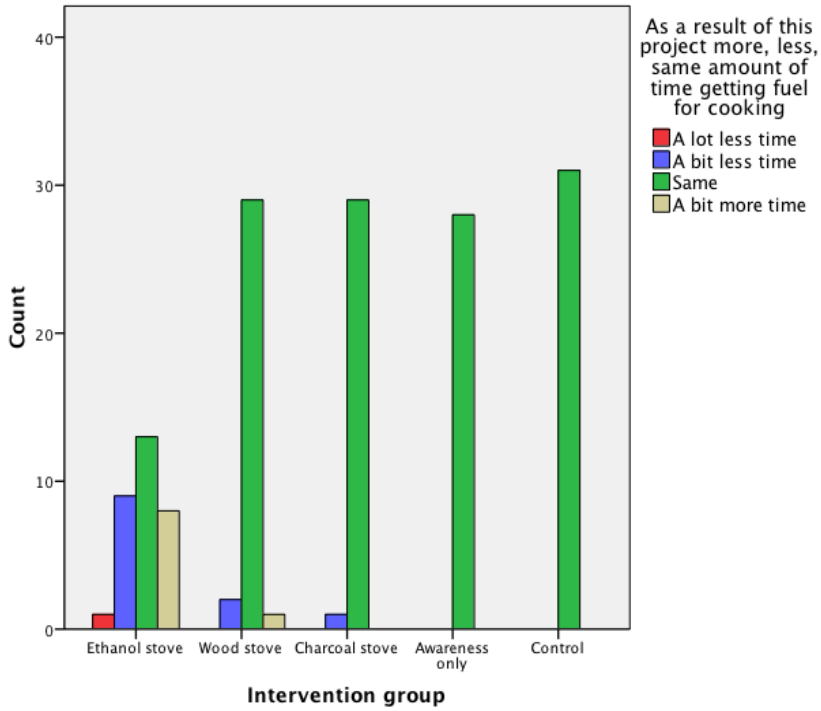


Figure 5-11: Perceived changes in amount of time spent procuring fuel as a result of the project: Vatomandry



5.11.2. Perceived changes in amount spent on fuel use since being involved in the project

The perceived amounts spent of fuel closely reflected the actual reported amounts. When asked at Round 3 about perceived changes in amounts spent on fuel since taking part in the project, the majority (75.0%) of households in the wood stove intervention group in Vatomandry stated that the 'project' has saved them money. (Figures 5.12 and 5.13). 58.1% of the ethanol and 56.7% of the charcoal stove groups in Ambositra also thought the project had saved them money. However the majority of people thought the project had no effect on the amount they spent of fuel in the ethanol (48.4%) and charcoal (60.0%) groups in Vatomandry.

Figure 5-12: Perceived changes in amount spent on fuel as a result of the project: Ambositra

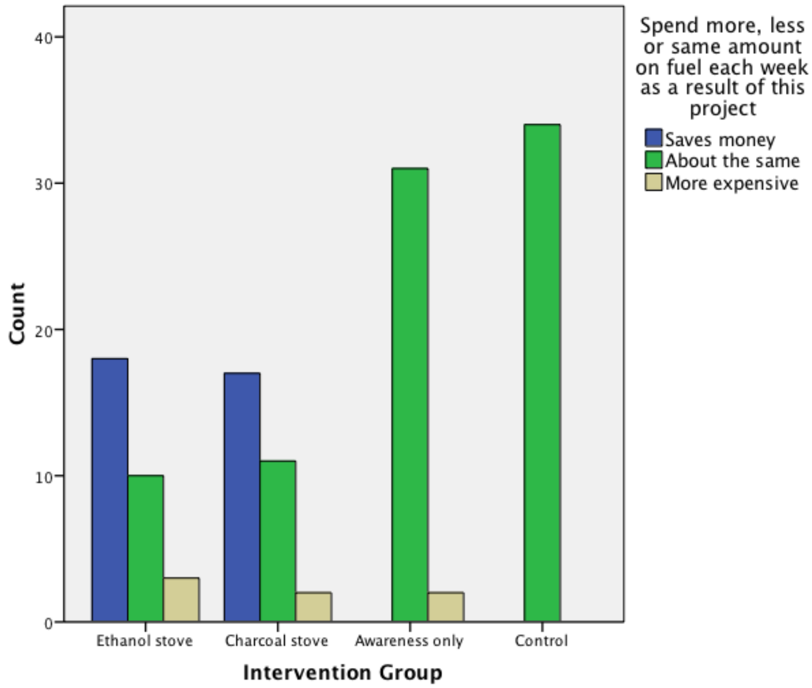
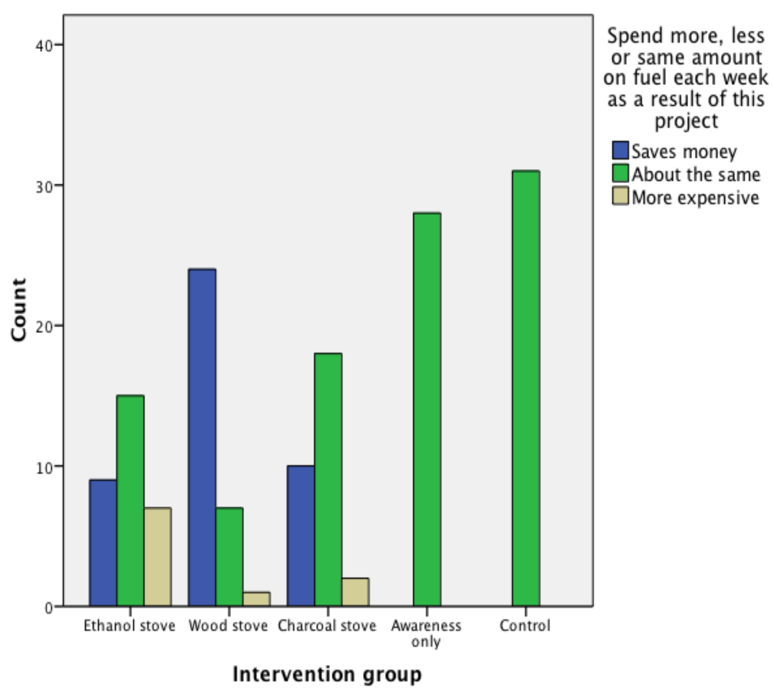


Figure 5-13: Perceived changes in amount spent on fuel as a result of the project: Vatomandry



5.11.3. Procurement of ethanol at follow-up

Ethanol fuel was only used by the households that received an ethanol stove. All fuel was bought from the local ethanol shop for between 500 and 800 Ar per litre in Ambositra and for a fixed price of 500 per litre in Vatomandry.

The mean amount spent on ethanol per week at Round 2 was 2846 Ar (SD 1973) in Ambositra and 1984 Ar (SD835) in Vatomandry. At Round 3 this dropped slightly in Ambositra to 2580 Ar (SD1103). Vatomandry households showed an increase in amount spent per week on ethanol to 2080 (SD 837) by Round 3. As the price of the fuel was fixed this suggests that those who continued to use the ethanol stove as their main stove in Vatomandry had increased the intensity of their use between rounds. Overall there is a significantly higher weekly consumption of ethanol in Ambositra (5.16 litres (SD 2.208) compared to Vatomandry (4.16 litres (SD 1.68) at Round 3 (p=0.04).

A comparison of the amount of time spent procuring cooking fuel before and after installation of the ethanol stove was greatly influenced by the location of the household in relation to the ethanol shop. (Table 5.31)

Table 5.31: Perceived changes in time spent procuring ethanol since starting the project

As a result of the project do you think you spend more, same or less time collecting fuel?	Ambositra n (%)	Vatomandry n (%)
A lot less time		1 (3.2)
A bit less time	6 (19.4)	9 (29.0)
The same amount of time	9 (29.0)	13 (41.9
A bit more time	15 (48.4)	8 (25.8)
A lot more time	1 (3.5)	

Some households reported that the ethanol shop was too far, particularly in Ambositra. However many households liked the convenience of being able to go to a store and buy the fuel instead of waiting for the charcoal seller to “pass by” or having to go and search for fuel. They also found it easier to transport compared to charcoal and wood.

When the ethanol stove users were asked about any problems that stopped them using the ethanol stove, very few were reported. However lack of access to fuel due to insufficient funds (n=5 (8.1%) and not being able to get to the store (n=3 (4.8%) had stopped a small number of participants over both sites from using their stove. A separate question which asked “Do you have any problems getting enough fuel for your needs?” revealed that in Ambositra the ethanol shop is often closed or the wait inside the store is sometimes unacceptably long.

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5.11.4. Procurement of charcoal at follow-up

Charcoal was used as a cooking fuel by all intervention groups in both study sites. The median cost per kg in Ambositra changed very little over the course of the study (all prices in Ar);

- Baseline: Small Bag: 200 Large Bag: 100
- Round 2: Small Bag: 200 Large Bag: 166
- Round 3: Small Bag: 200 Large Bag: 166

The cost of charcoal in Vatomandry appeared to be less, particularly for larger quantities in the follow up rounds .

- Baseline: Small Bag: 200 Large Bag: 133
- Round 2: Small Bag: 200 Large Bag: 83.3
- Round 3: Small Bag: 200 Large Bag: 100

However when asked at Round 3 about problems accessing the type and amount of fuel they needed for their households needs many charcoal users reported that the fuel is now very expensive and difficult to find particularly in the rainy season. Charcoal is purchased equally from travelling salesmen and local shops at both study sites

Figure 5-14: Wood and charcoal for sale in Vatomandry

The tables below show the average (median) weight and cost of charcoal used per week at each study round for each intervention group. In Ambositra there was no significant difference in the weight purchased and amount spent on charcoal between intervention groups at Baseline. However after installation of the stoves the households using the ethanol and charcoal intervention stoves had dramatically reduced their consumption of charcoal, creating a statistically significant difference between the groups at Rounds 2 and 3. The ethanol stove group more than halved the amount of charcoal they were buying and subsequently reported lower amounts spent on charcoal each week. Similar reductions in total weight of charcoal were seen in the charcoal stove group but for some reason, unlike the ethanol group, these saving were not carried over to reduction in expenditure (Tables 5.32, 5.33 and 5.34).

Table 5.32: Ambositra numbers (%) in each intervention group using charcoal for a cooking fuel at rounds 2 and 3

Round 2	Ethanol (n=32)	Charcoal (n=31)	Awareness (n=33)	Control (n=36)
	25 (78.1)	31 (100)	33 (100)	36 (100).
Round 3	**(n=31)**	**(n=31)**	**(n=33)**	**(n=34)**
	23 (74.2)	31 (100)	33 (100)	34 (100).

Table 5.33 Average quantities of charcoal purchased (median (IQR) kg) by intervention group: Ambositra

	Intervention Group				P value*
Baseline	**Ethanol (n=32)**	**Charcoal (n=31)**	**Awareness (n=33)**	**Control (n=26)**	
	17.50 (11.00-30.00)	25.00 (15.00-30.00)	15.00 (8.75-30.00)	21.00 (13.00-30.00)	0.159
Round 2	**(n=32)**	**(n=31)**	**(n=33)**	**(n=36)**	
	7.50 (4.06-18.75)	14.00 (10.00-21.00)	21.00 (15.00-30.00)	21.75 (14.00-30.00)	<0.001
Round 3	**(n=31)**	**(n=31)**	**(n=33)**	**(n=34)**	
	7.50 (0.00-14.00)	15.00 (14.00-21.00)	17.50 (14.00-28.00)	19.25 (14.25-30.00)	<0.001

**P-value from Kruskal-Wallis test*

Table 5.34: Average amounts (Ar) spent on charcoal per week (median (IQR) by intervention group: Ambositra

Baseline	Intervention Group Ethanol (n=32)	Charcoal (n=31)	Awareness (n=33)	Control (n=26)	P value*
	2500 (1500-3000)	2800 1400-4000	2800 1450-3750	2800 1625-4000	0.859
Round 2	**(n=32)**	**(n=31)**	**(n=33)**	**(n=36)**	
	1250 600-2950	2400 1400-2800	3000 2050-4350	3000 2575-4000	<0.001
Round 3	**(n=31)**	**(n=31)**	**(n=33)**	**(n=34)**	
	1250 0-2800	2800 2100-4200	3500 2650-4900	3750 2500-5700	<0.001

**P-value from Kruskal-Wallis test*

The intervention groups in Vatomandry differed significantly (p=0.001) at Baseline with regard to the amount of charcoal purchased each week, with the control group procuring the smallest amount. The groups remained significantly different after intervention. The ethanol stove group showed a dramatic reduction in the amount of charcoal purchased between Baseline and Round 2 with a resulting drop in expenditure on charcoal. There was however a small re-bound at Round 3 which could be the result of the shift to using the ethanol stove more as a secondary stove rather than the main cooking device.

Table 5.35: Vatomandry numbers (%) in each intervention group using charcoal at Rounds 2 and 3

Round 2	Ethanol (n=32)	Wood (n=33)	Charcoal (n=32)	Awareness (n=31)	Control (n=32)
	17 (53.1)	8 (24.2)	30 (100)	17 (54.8)	22 (68.8)
Round 3	**(n=31)**	**(n=33)**	**(n=30)**	**(n=28)**	**(n=31)**
	19 (61.3)	10 (30.3)	30 (100)	13 (46.4)	21 (67.7)

The pattern of charcoal procurement in the Vatomandry charcoal stove group is more difficult to explain. At Round 2 there had been no change in the amount of charcoal purchased per week compared to baseline, maybe due to the fact that data was collected just weeks after installation, which may have been too soon to detect any impact. However there was a decrease in the amount spent per week, which could possibly be a product of cheaper fuel prices in the market or a result of buying larger quantities. At Round 3 there was an unexpected large increase in the weight purchased, and the average (median) amount spent per week returned to that reported at baseline.

Yet many households reported that the stove was 'economical'. This could be an indication that the households perceive the stove to be less smoky and are therefore using it for longer periods, requiring more fuel. However this conclusion is not supported by the data on the time that the fire is alight each day, which showed a small reduction for the charcoal stove use (Tables 5.35, 5.36, 5.37)

Table 5.36: Average quantities of charcoal purchased (median (IQR) kg) by intervention group: Vatomandry

	Intervention Group					
Baseline	**Ethanol (n=32)**	**Wood (n=33)**	**Charcoal (n=32)**	**Awareness (n=31)**	**Control (n=25)**	**P value***
	13.25 0.00-20.13	0.00 0.00-7.25	15.00 15.00-30.00	10.50 0.00-15.00	7.50 0.00-17.50	0.001
Round 2	**(n=32)**	**(n=33)**	**(n=32)**	**(n=31)**	**(n=32)**	
	3.75 0.00-15.00	0.00 0.00-3.50	15.00 15.00-30.00	7.00 0.00-30.00	10.50 0.00-30.00	0.001
Round 3	**(n=31)**	**(n=33)**	**(n=30)**	**(n=28)**	**(n=31)**	
	7.00 0.00-15.00	0.00 0.00-10.75	30.00 5.00-30.00	0.00 0.00-30.00	10.50 0.00-20.00	<0.001

**P-value from Kruskal-Wallis test with biomass stove group removed*

Table 5.37: Average amounts spent charcoal per week (median (IQR) Ar) by intervention group: Vatomandry

Baseline	Intervention Group Ethanol (n=32)	Wood (n=33)	Charcoal (n=32)	Awareness (n=31)	Control (n=25)	P value*
	2050 0-2725	0 0-1325	2500 2000-4000	2000 0-2500	1250 0-2500	0.001
Round 2	**(n=32)**	**(n=33)**	**(n=33)**	**(n=31)**	**(n=32)**	
	550 0-1475	0 0-375	1450 1250-2500	1000 0-2500	1400 0-2750	<0.002
Round 3	**(n=31)**	**(n=33)**	**(n=30)**	**(n=28)**	**(n=31)**	
	750 0-2100	0 0-1000	2500 1500-3000	0 0-2725	1500 0-2800	<0.001

**P-value from Kruskal-Wallis test with biomass stove group removed*

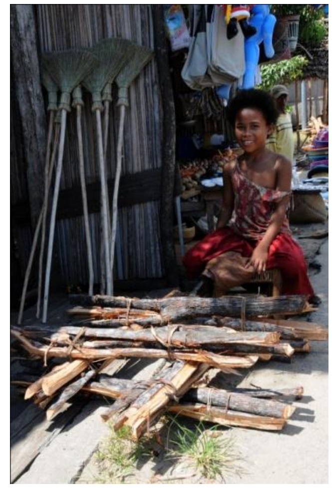
5.11.5. Procurement of wood at follow-up

As at Baseline and according to the selection criteria, the use of wood fuel for household energy in Ambositra was very low, with only 14% of households using some wood at Round 3. In Vatomandry 60.1% (n=92) households reported using wood fuel at Round 3. Table 5.38 shows the amount of households using wood in each intervention group at all stages of the study.

Table 5.38: Number (%) of households using wood fuel at each stage of the study by intervention group in Vatomandry.

Baseline	Ethanol (n=32)	Wood (n=33)	Charcoal (n=31)	Awareness (n=31)	Control (n=25)
	21 65.6%	33 100%	10 32.3%	21 67.7%	21 84.0%
Round 2	**(n=32)**	**(n=33)**	**(n=32)**	**(n=31)**	**(n=32)**
	11 34.4%	32 97.0%	8 25.0%	21 67.7%	24 75.0%
Round 3	**(n=31)**	**(n=33)**	**(n=30)**	**(n=28)**	**(n=31)**
	12 38.5%	32 97.0%	8 26.7%	21 75.9%	19 61.3%

The few households that did use wood in Ambositra tended to collect their wood fuel, whereas in Vatomandry the majority buy their fuel at rates very similar to those seen at Baseline: Round 2 85.4% of wood fuel users bought all of their fuel and at Round 3 this was 87.0%. The wood stove intervention group had a higher rate of purchasing their wood fuel: 90.9% at Baseline; 87.5% at Round 2 and 90.6% at Round 3).



After a slight decrease at Round 2 (2100Ar) the average (median) amount spent on wood per week at Round 3 was unchanged from Baseline levels (2800Ar). This could indicate a lower consumption of more expensive wood as many households had reported that wood fuel was becoming very expensive.

In the wood stove intervention group there was a significant decrease in the average (median) amount spent on wood fuel per week (Baseline 3200Ar (28,000-49,000) Round 3 2500Ar (14,000-35,000) p=0.014 N=31 Wilcoxon Rank Test). This was also noted in the wood stove users' perceptions of change after they received the intervention stove (See Section 5.11 for further discussion). No other intervention group showed significant changes in the amount spent per week.

Table 5.36 shows the average amount of wood used (kg) per week by each intervention group. The actual changes in the weight of wood purchased between Baseline and Round 3 were non-significant. However this might be a product of the small numbers buying wood in the ethanol stove group, which did reduce the weight purchased by over 10kg per week.

Table 5.39 Median (IQR) amounts (kg) of wood bought per week for each intervention group in those households that bought their wood.

Baseline	**Ethanol (n=20)**	**Wood (n=33)**	**Charcoal (n=9)**	**Awareness (n=20)**	**Control (n=20)**
	53.0 30.0-84.0	63.0 50.0-105	42.0 19.0-70.0	56.0 42.0-80.5	56.0 42.0-70.0
Round 2	**(n=10)**	**(n=30)**	**(n=7)**	**(n=18)**	**(n=22)**
	61.5 35.0-91.8	35.0 17.5-70.0	35.0 30.0-75.0	70 35.0-91.9	70.0 42.5-87.5
Round 3	**(n=10)**	**(n=31)**	**(n=7)**	**(n=19)**	**(n=18)**
	40.0 15.0-78.8	52.0 35.0-87.5	35.0 17.5-35.0	70.0 52.5-87.5	70.0 48.1-91.9
P value*	0.76 n=10	0.09 n=31	0.893 n=6	0.122 n=18	0.102 n=15

**P value from Wilcoxon Signed Rank Test for all available pairs Baseline and Round 3*

The increase in the average amount of wood purchased per week in the awareness group reflected the decrease in the average (median) weight (kg) of charcoal used per week. The control group households appear to have increased the amounts of both charcoal and wood that they buy.

5.12. Impact of the awareness raising campaign: reported behavioural change

All households except those in the control group were exposed to an awareness-raising programme, which focused on the health advantages of clean (less smoky) stoves as apposed to dirty (smoky) stoves (see Annex 12).

To assess if and how this raising of awareness had changed cooking habits the participants were asked about “recent changes in the ways in which you do your cooking to avoid smoke?” It was hypothesized that the awareness raising only group would indicate how they used the information they were given to improve their kitchen environment. However by Round 3 only 30.3% of awareness group in the Ambositra and 17.9% in Vatomandry had made any changes to avoid smoke. Of those who did make changes the most recurrent change was to take their stove outside and/or to increase the ventilation in the room where they cook. However the majority of the ethanol stove group in both locations (83.9% Ambositra and 90.3% in Vatomandry) stated that they use their stove to reduce smoke and cook outside more often including when using other fuels such as charcoal.

However at Round 3 although none of the control households in Vatomandry reported any recent changes aimed to avoid smoke, surprisingly 25% of the control group in Ambositra had made changes, many of which involved moving their cooking location outside. This may have the effect of inadvertently reducing the control group exposure levels, possibly causing the exposure benefits of the intervention stoves to be more conservative. This should be taken into consideration when interpreting these results.

5.13. Utilisation of time savings

Participants who reported saving time as a result of taking part in the project were asked what they did with the extra time they now have available. The answers were similar at both study sites. The majority of the women spent more time looking after their household, particularly doing more laundry. About a third of the women who felt that they have more available free time used it working in their business, which was usually a shop or farm. No one reported starting up a new business and only very few reported spending more time with their children.

5.14. Discussion of follow-up household information

This section has focused on the impact of the project interventions on the cooking habits and fuel procurement patterns in the households. It has looked at the participant’s perceptions of the stoves and explored the nature and extent of the stoves ability to meet the cooking needs of the household. The rates of initial adoption as well as continued use after five months has been reported. The success of the awareness raising campaign has been considered.

Adoption of new devices

After 4-8 weeks of use, the rates of initial adoption of the interventions as the main cooking device were high (overall adoption of charcoal and ethanol stove as the main stove: 85.7%; overall adoption of ethanol, woodstove and charcoal as the main stove: 93.1%.) However there are many factors that influence whether or not a cook continues to use a new stove after a few months once the stimulus provided by the innovation has gone. These include:

- Whether the stove meets her cooking needs;
- The speed and ease of the cooking process including lighting the stove;
- If the fuel is easily procured at the right price;
- If the perceived benefits, e.g. less smoke, are perceived to be worth any regular and new demands, e.g. cutting wood smaller than for a previous stove.
- If the stove is safe and durable; and
- The ease and cost of any necessary repairs.

Overall the cook needs to see a benefit in continued use of a new technology. If she doesn't, there is a high risk of total abandonment of the stove or relegation to secondary or tertiary status after a few months -- or once the study is over. Therefore stove adoption and use can only be reliably assessed once the stove has been in use for at least two seasons and preferably a full year. The Round 3 patterns of stove use provide a good indication of stove adoption after the end of the wet season and the beginning of the dry within these two communities. Durability in relation to cost, ease and cost of repairs, and willingness and ability to pay for a new fuel over a prolonged period should be reassessed after a full year of use.

Ethanol stove and fuel

Stove Adoption

A high number of participants (Ambo 81.2% and Vatomandry 90.6%) who received an ethanol stove adopted it quickly as their main cooking device despite having to adapt to a new stove, fuel and way of cooking.

At Round 3 survey, 5 months post installation, none of the ethanol stoves seem to have been abandoned entirely, and all participants believed the stove had a good impact on their lives. The ethanol stove was been used as the main stove by nearly all participants in Ambositra (96.8%) although it was frequently used with the supplementation of a secondary stove.

After the initial high usage rates of the ethanol stove as main stove in Vatomandry, just over three-quarters of the group (77.4%) were using the stove as their main cooking device at Round 3. This kind of 'slippage' is not uncommon and can be due to several factors. Overall there did not seem to be a pattern to those households not using their ethanol stove as their main device. Of the seven households in Vatomandry, three were using charcoal stoves as their main stove, and four were using 3-stone fires with a mixture of collecting and buying their wood fuel.

The use of a secondary stove after intervention is significantly higher in the ethanol group compared to the other study groups post intervention and to all households at baseline, suggesting that the ethanol stove while popular is not meeting all of the cooking needs.

Ethanol Fuel

The initial selection criteria for study participants was designed to identify households paying for their fuel to avoid a situation where the participants do not use their stove because they can't afford the fuel. Nonetheless the relatively high expense of the ethanol fuel was the main reason people were not using their stove as the main device. The weekly expenditure for ethanol was similar to that of charcoal and wood, however many of the ethanol stove users were also using a secondary fuel, which they were not previously, so the overall fuel expenditure was often higher than before the stove adoption.

Accessibility to the ethanol fuel (shop closed or too far from home) was sometimes preventing the participants using their stove.

Cooking on the ethanol stove

Saving time, cleaner kitchens and ease of use were seen as the most positive impacts of the stove.

Based on both participant estimates and reported cooking times during the 24-hour monitoring period, the ethanol stove reduced cooking time by over 2 hours each day compared to baseline estimates. This reduced cooking time was reflected when participants in Ambositra were asked about the perceived speed of cooking, compared to the previously used stove, but in Vatomandry there was still a few households that reported that the stove was a bit slower than their previous stove, even after 5 months use. There does not appear to be any relationship between reporting negative impacts and whether the stove is used as the main or secondary stove at Round 3.

Approximately one quarter of ethanol stove users at each site still reported that they could not cook all the foods they wanted to, and these households were more likely to be using a secondary fuel. It is not explained what it is about the ethanol stove and fuel that prevents them from cooking certain food types, and this should be explored further. The main suggested changes (dissemination of a two burner stove and increasing the size of the stove) suggest that the intervention stove (the CleanCook) had limited capacity for some households within these communities.

Safety

There were no incidents directly related to the ethanol stove that would question its durability or safety. (Section 13.4 discusses ethanol ingestion and attempted ethanol ingestion in more detail).

In summary the ethanol stove is well liked and meets most of the needs of the cooks in these communities. It appears that the adoption of the ethanol stove has been more complete in Ambositra than Vatomandry -- with higher use as the main stove and higher average ethanol consumption per week. The design and location of the houses in Vatomandry mean that they are usually well ventilated, and as a result, the participants in this community experience a much lower level of cooking-related smoke in their homes compared to Ambositra. This may reduce the perceived need and impetus to change cooking habits to an unfamiliar stove and fuel, particularly if it costs more and is not always easy to access.

Charcoal stoves

Initial Adoption

There was a reported 100% adoption of the intervention charcoal stove as the main cooking stove after 5 months use at both study sites. However a secondary stove use rate in Ambositra, higher than seen at baseline or within the post-intervention awareness and control groups, suggests that the stove does not meet all of the cooking needs. The initial use of secondary stove was high in Vatomandry, but it decreased to nearer baseline levels by Round 3, indicating a successful adaptation period. Exploration of the participants' perceptions suggests that the secondary stove use is necessary, as the stove is deemed to be too small, and a second pot-holder would improve the rate of sole use.

Charcoal Fuel Use

The stove was widely reported to be very economical, and this was supported by the dramatic reduction in the average (median) amount of charcoal purchased each week in Ambositra after adoption of the intervention. The fact that there was no change in the amount spent in this group but a steady increase in the amount spent by the awareness and control groups, is indicative of an increase in the local charcoal price during the course of the study. However further investigation into market prices of charcoal showed that the average reported price per kg of charcoal stayed fairly consistent throughout the study at both sites, with more variation in price as the quantities increased.

The pattern of charcoal use in the intervention group in Vatomandry is not as consistent with a more economical stove and does not reflect the trends in market price. A higher consumption could suggest that a less smoky stove is allowing for longer periods of cooking, but the reported time the stove was alight decreased slightly. The majority of charcoal users in Vatomandry also believed that the stove had no effect on the amount spent on fuel.

Cooking on the charcoal stove

Overall more than three-quarters of participants who were using the charcoal stove had no negative impacts to report. The stove was faster or much faster than the previously used stove and did not appear to require adaptation of cooking methods. The fact that the stove was similar to those used prior to the study may have decreased its attraction when it was ranked against other desirable household items. Even though this group appeared happy with the charcoal stove, they clearly perceived the ethanol stove as having many more advantages.

The propensity for the charcoal stoves' inner liner to crack or break needs to be addressed, however, before the users become intolerant of breakages, which could lead to stove abandonment.

Wood stove

Initial Adoption

The wood stove was given to households in Vatomandry only. Initial adoption as the main cooking stove was 100%, which decreased only slightly by Round 3 (93.9%), as two households moved to other fuels. Secondary stove use stayed around 40% after intervention, which is slightly higher than reported at baseline but similar to the control group.

Wood Fuel

There was a significant decrease in the average (median) amount spent on wood fuel per week after installation of the intervention stove. The overall perception was that the stove saved money and was economical.

Cooking on the wood stove

The key positive factors related to this stove included the fact that it was economical and reduced the 'big smoke', and nearly all recipients (93.9%) felt that the stove was better (a bit or much) than their previous stove.

Interestingly, 15% of the woodstove group had ranked it above the ethanol stove and other luxury items, indicating a positive perception and a recognition of its worth after 5 months of use.

There were a few issues with the biomass stove that were consistently reported, none of which however prevented use of the stove. The first is related to its size: it was often reported to be too large to comfortably fit into the home. Also women complained that they had to spend extra time cutting down the wood to fit into the stove. Previous experience has shown that the women may either eventually stop using this stove or continue using it with large pieces of wood potentially breaking the stove. This should be addressed either by providing some cutting service or a modification of the stove.

Safety of the wood stove

Participants expressed concerns that the stove's chimney could start a house fire. This concern needs to be further assessed to establish if a real risk exists and to inform potential design modifications.

Impact of awareness raising campaign.

There was very little change in behaviour aimed to reduce exposure to indoor air pollution in all the groups that were exposed to the awareness-raising campaign. The campaign did have some limitations, which probably had a big impact on its ability to make widespread sustained changes to cooking practice. The contact with households took place on only a few occasions, through focus group discussions and visits to the home, and appeared to be only at the beginning of the follow-up period. Behaviour-change literature indicates that sustained messaging and support is key to the successful adoption of new cooking practices and kitchen management. It will be

interesting however to examine what prompted 25% of the Ambositra control group households to change their cooking habits.

6. Air Pollution Results Baseline

6.1. Kitchen Concentrations

As expected, PM and CO kitchen IAP concentrations (Table 6.1) in all fuel categories and locations exceeded WHO guidelines for PM and CO. Pollutant concentrations were found to be significantly different between the two towns for charcoal[8] (p-value < 0.001), which may be a result of kitchen characteristics such as ventilation, as well as cooking habits. For example, calculated person meals in Vatomandry were significantly higher (p-value = 0.05) than Ambositra during the sampling period, which is suggestive of greater stove use.

Table 6.1: 24-hr average CO (ppm) and $PM_{2.5}$ (µg/m[3]) concentrations by location, compared to WHO guidelines (bold)

Characteristic		Ambositra N	Ambositra	Vatomandry N	Vatomandry	P-value¥	WHO Guideline
$PM_{2.5}$	Charcoal	141	378 (381)	85	601 (2,597)	<0.01	**10 µg/m[3*]**
	Wood	0	----	97	1,494 (2,080)	----	
	P-value¥		----		<0.001		
	All Fuels*	119	368 (369)	180			
CO	Charcoal	140	44.6 (33.8)	83	11.2 (14.2)	<0.01	**8.7 ppm[**]**
	Wood	0	----	96	17.5 (22.6)	----	
	P-value¥		----		0.07		
	All Fuels *	140	44.6 (33.8)	179	14.6 (19.3)		

[*] WHO Guideline for $PM_{2.5}$ (annual average)
[**] WHO 8-hr Guideline for CO (equivalent to 10 mg/m[3] at STP)
[¥] Wilcoxon Two-Sample Test
Values in parentheses represent 1 standard deviation

Within Vatomandry, where both types of fuel were present in the sample, homes using wood had 46% (p-value < 0.001) and 56% (p-value = 0.07) greater 24hr average PM and CO concentrations, respectively, in comparison to charcoal users. While IAP results from Vatomandry did exhibit an observable trend in CO and PM between fuel types, the ratio for charcoal seemed to be different from the ratio observed in Ambositra homes.

These reported $PM_{2.5}$ concentrations are based on laboratory-calibrated UCB Particle Monitor data and adjusted using a subsample of gravimetric samples collected in-field.

[8] For this baseline analysis (IAP and health related issues) households were categorised by the fuel they stated as their 'main fuel' in the day 1 questionnaire and not by the fuel they used during the monitoring period.

Three reported wood users in Ambositra were removed for IAP analysis due to inconsistencies in their reported fuel use.

Table 6.2: 24hr-average CO (ppm) and $PM_{2.5}$ ($\mu g/m^3$) indoor air concentrations for the entire sample population compared to WHO guidelines (bold).

Characteristic	CO		$PM_{2.5}$	
	N	8.7 ppm**	N	10 $\mu g/m^3$*
Charcoal	226	32.2 (32.4)	226	461 (1,619)
Wood	96	17.5 (22.6)	97	1,494 (2,080)
p-value¥		<0.001		<0.001
All Fuel	319	27.7 (30.5)	323	771 (1,829)

* WHO Guideline for $PM_{2.5}$ (annual average)
** WHO 8-hr Guideline for CO (equivalent to 10mg/m^3 at STP)
¥ Wilcoxon Two-Sample Test
Values in parentheses represent 1 standard deviation

Amongst all homes using charcoal, average CO and PM concentrations were 3.7 and 77 times greater, respectively, than the WHO Guideline values (Table 6.2). Similar exceedances were observed amongst wood users, who reported 24hr concentrations 2.0 and 150 times the WHO Guidelines for CO and PM, respectively.

6.1.1. Ambient PM Measurements

Twenty-four hour ambient (outdoor) $PM_{2.5}$ was monitored in each region using Airmetrics MiniVol Samplers. The ambient air sampling was performed at safe locations near to the study households. The ambient monitoring results are shown in Table 3.25 below.

Table 6.3: 24hr-average $PM_{2.5}$ ambient air concentrations ($\mu g/m^3$).

Location	Ambient $PM_{2.5}$ ($\mu g/m^3$)
Ambositra (N=3)	10.1 (2.8)
Vatomandry (N=6)	31.9 (16.1)
p-value¥	0.06

Values in parentheses represent 1 standard deviation

The ambient $PM_{2.5}$ concentrations in each region were low, quite typical, and not statistically different. Ambient air did not have a significant impact on the Baseline $PM_{2.5}$ kitchen concentrations, as the kitchen concentrations were much higher than the outdoor concentrations.

6.1.2. Number of person-meals cooked

The sum of the number of people cooked for in each of the meals prepared by a household during the 24-hour sampling period is called the "person-meals". Person-meals are a standard measure of the amount of cooking a household performs.

According to the standard Kitchen Performance Test protocol, standard-adult-equivalent-meals were calculated by applying the following weighting factors to each age/gender group: males 15 years and older are the "standard adult" and are equal to 1.0 (not weighted); a weighting factor of 0.8 was applied to females over 15 years; and a weighting factor of 0.5 was applied to all children less than 15 years old. Standard-adult-equivalent-meals were calculated by summing the number of standard-adult-equivalents cooked for during each meal prepared in the household during the 24-hour sampling period.

The average number of adult-equivalent-meals cooked in Ambositra was 10.5 (with a standard deviation of 4.7), while in Vatomandry it was 11.8 (standard deviation 6.3). The adult-equivalent-meals were significantly different between the two locations (p-value = 0.05). The number of adult-equivalent-meals will be tracked in each of the two post-intervention sampling phases and compared to these Baseline values, allowing for a standard method for measuring any changes in the amount of cooking performed in each household.

6.2. Factors Affecting IAP

6.2.1. Effects of small enterprise on IAP

A substantial portion of the study population reported using fuel for small household enterprises, which can also contribute to exposure and IAP concentrations. Tables 3.26 and 3.27 show both kitchen IAP concentrations and personal exposure to CO categorized by whether homes reported using fuel for business/enterprise. Since locations were found to have significantly different IAP and personal exposure, analysis was performed by study location rather than aggregated.

Table 6.4: Kitchen concentration of CO (ppm) and $PM_{2.5}$ ($\mu g/m^3$) categorised by fuel use for households with and without small enterprise

Characteristic	Ambositra			Vatomandry		
	N	CO	$PM_{2.5}$	N	CO	$PM_{2.5}$
Small enterprise	25/24	58.9 (35.5)	1,000 (830)	40/41	16.4 (22.5)	1,730 (2,940)
No small enterprise	115/115	41.5 (32.8)	940 (980)	139/139	14.1 (18.4)	1,890 (5,440)
p-value[¥]		***0.02***	*0.5*		*0.53*	*0.89*

[¥] Wilcoxon Two-Sample Test

Values in parentheses represent 1 standard deviation

Table 6.5: Personal exposure to CO (ppm) categorized by fuel use for households with and without small enterprise

Characteristic	N	Ambositra	N	Vatomandry
Small enterprise	22	11.5 (9.8)	40	1.6 (1.5)
No small enterprise	122	11.6 (10.2)	134	1.3 (2.3)
p-value[¥]		*0.91*		***0.03***

[¥] Wilcoxon Two-Sample Test

Values in parentheses represent 1 standard deviation

Results showed some effects of business fuel use on increasing CO in Ambositra by 42% (p-value = 0.02), and personal CO exposure in Vatomandry by 23% (p-value = 0.03). In all cases, $PM_{2.5}$ showed no significant increase resulting from business. IAP and personal exposure do not follow a specific trend within locations, suggesting that there may be differences in enterprise, resulting in different exposure characteristics in Ambositra, or perhaps non-monitored stoves are being used in Vatomandry for business. Regardless, because of the substantial number of homes using their fuel and stoves for enterprise, there is a need to characterize how this affects overall IAP, exposure, and adoption in greater detail during upcoming rounds. Also, since conclusions of stove use using person-meal calculations assume that the stove is primarily used for domestic duties, there is the potential for underestimation of overall stove use.

6.2.2. Effect of kitchen location on IAP

The relationship between kitchen location and kitchen indoor air pollution was examined by region and fuel type, as shown in the two tables below.

Table 6.6: Relationship between kitchen location and 24-hour kitchen CO concentrations (ppm)

Location	Fuel	n	Detached	n	Attached to Living Area	n	In Living Area	Pr > Chi-Square*
Ambositra	Charcoal	9	53.9 (43.6)	63	46.2 (38.9)	67	41.6 (30.0)	0.83
Vatomandry	Charcoal	35	10.4 (8.8)	19	15.6 (24.0)	29	9.4 (10.2)	0.48
	Wood	63	20.5 (25.3)	14	19.1 (19.7)	19	6.2 (5.8)	0.005

*Kruskal-Wallis Test

Table 6.7: Relationship between kitchen location and 24-hour kitchen $PM_{2.5}$ concentrations (µg/m^3)

Location	Fuel	Detached n		Attached to Living Area n		In Living Area n		Pr > Chi-Square*
Ambositra	Charcoal	9	1.27 (1.52)	63	1.09 (1.04)	67	0.78 (0.75)	0.3
Vatomandry	Charcoal	35	2.59 (9.95)	19	0.92 (2.01)	29	0.54 (0.84)	0.005
	Wood	63	2.32 (3.12)	14	2.95 (3.95)	19	1.03 (0.93)	0.25

*Kruskal-Wallis Test

Tables 3.28 and 3.29 show that kitchen IAP is generally lower in “In Living Area” kitchens versus “Detached” and “Attached” kitchens. While In Living Area kitchens have lower IAP in all six of the sub-groups shown above, it is statistically lower in only two of the sub-groups -- CO in Vatomandry wood households and $PM_{2.5}$ in Vatomandry charcoal households. Overall, detached and attached kitchens have very similar kitchen IAP levels.

6.2.3. Other factors than can affect IAP

There are many factors that can influence kitchen indoor air pollution. The table below (Table 3.30) presents a summary of some such descriptive statistics by location for the Baseline sampling. Given the Before-After study design, these descriptive statistics will be compared between the sampling rounds and are shown here for completeness.

Fuel moisture can influence IAP concentrations and exposure as wetter fuels require more care by the fire tender during lighting and produce greater amounts of smoke. Overall, the vast majority of reported fuel moisture in the Baseline was very dry, 100% and 88% for Ambositra and Vatomandry, respectively. This finding is consistent with the field team’s observation that almost all fuel – both wood and charcoal – is stored inside the house. The only time that wood fuel could be exposed to rain is in the marketplace.

Table 6.8: Summary of selected conditions during Baseline sampling by location

Characteristic		Ambositra	Vatomandry	All Homes
Fuel Moisture	Very dry	100%	88%	88%
	Moderately wet	0%	10%	9%
	Wet	0%	2%	2%
Precipitation	No Rain	24%	68%	49%
	Light Rain	50%	17%	31%
	Heavy Rain	26%	15%	20%
Home Lighting	Mains Electricity	51%	39%	44%
	Kerosene	41%	55%	49%
	Candles	8%	6%	7%
	Other	<1%	0%	<1%

Home lighting is also a potential non-stove source of IAP. Baseline results suggest that the majority of homes in both populations relied heavily on electricity, as well as kerosene lamps. Future analyses, particularly after rounds 2 and 3, will more closely assess the impact of lighting on overall IAP, however based on experience; we expect the contribution to be minimal.

6.2.4. Discussion of Baseline kitchen concentrations

6.2.4.1. Comparison of IAP results to IAP in other parts of Africa

Country and community specific cooking habits, homes, climate, fuel, and other regional factors are all known to influence IAP. As apparent in this analysis, these distal factors can even result in differences between regions within the same country. To our knowledge no IAP measurements have ever been performed in Madagascar, however observed pollutant concentrations in this study population were comparable to IAP concentrations measured in other African countries. For example, mean 24hr $PM_{2.5}$ concentrations in Ethiopian homes using wood fires was 1,250 $\mu g/m^3$, which is approximately 25% lower than wood users measured here in Madagascar. CO concentrations in the same Ethiopian homes, however, were lower by approximately 50% relative to homes in this study. A study in Ghana, also using wood as their primary fuel, had average concentrations of 650 $\mu g/m^3$ for $PM_{2.5}$, which is approximately 70% lower than homes in this study using the same fuel. The same study in Ghana found average CO concentrations to be 12.3ppm, which is approximately 30% lower than CO levels measured for wood users in Madagascar.

7. Air Pollution Results at Follow-up

7.1. 24-hr Average Kitchen CO Concentrations in Ambositra

The 24-hr average kitchen CO concentrations in Ambositra are shown in Table 7.1 below by round and treatment group. The data are grouped by treatment group, disregarding if the primary fuel was different than the treatment fuel in the case of ethanol. Figure 7.1 displays the same information. Estimates of changes to indoor pollutant concentrations from Baseline resulting from interventions, as well as the corresponding standard errors and p-values, were obtained using generalized estimating equations (GEE) in order to account for repeated measurements at the household level. All GEE models were run with robust standard errors. One could interpret the change estimates as the mean change in pollutant concentration resulting from the intervention if a randomly selected individual from the population (e.g. a charcoal user in Ambositra) were given the intervention.

Table 7.1: 24-hr average kitchen CO concentrations (ppm) in Ambositra by round and treatment group (assumes treatment group, disregards if primary fuel is different than treatment fuel in the case of ethanol)

	Round 1 (Baseline)			Round 2			Round 3			Estimated Change from Baseline		
	N	Arith.Mean	Median	N	Arith.Mean	Median	N	Arith.Mean	Median	ppm	%	p-value
Ethanol	31	42 (30)	36	32	9 (11)	4	29	8 (9)	7	**-33 (5)**	**-79%**	**<0.01**
Improved Charcoal	29	45 (31)	33	32	33 (24)	28	28	35 (28)	29	-9 (5)	-20%	0.09
Improved Wood	----	----	----	----	----	----	----	----	----	----	----	----
Awareness Charcoal	33	52 (46)	37	33	51 (38)	41	34	49 (44)	38	-0.1 (5)	< -1%	0.987
Awareness Wood	----	----	----	----	----	----	----	----	----	----	----	----
Charcoal/Control Charcoal	26	50 (34)	44	36	55 (39)	47	30	50 (37)	35	-1 (6)	-2%	0.898
Wood/Control Wood	----	----	----	----	----	----	----	----	----	----	----	----

*Values in parentheses represent 1 std. deviation or Std. Error

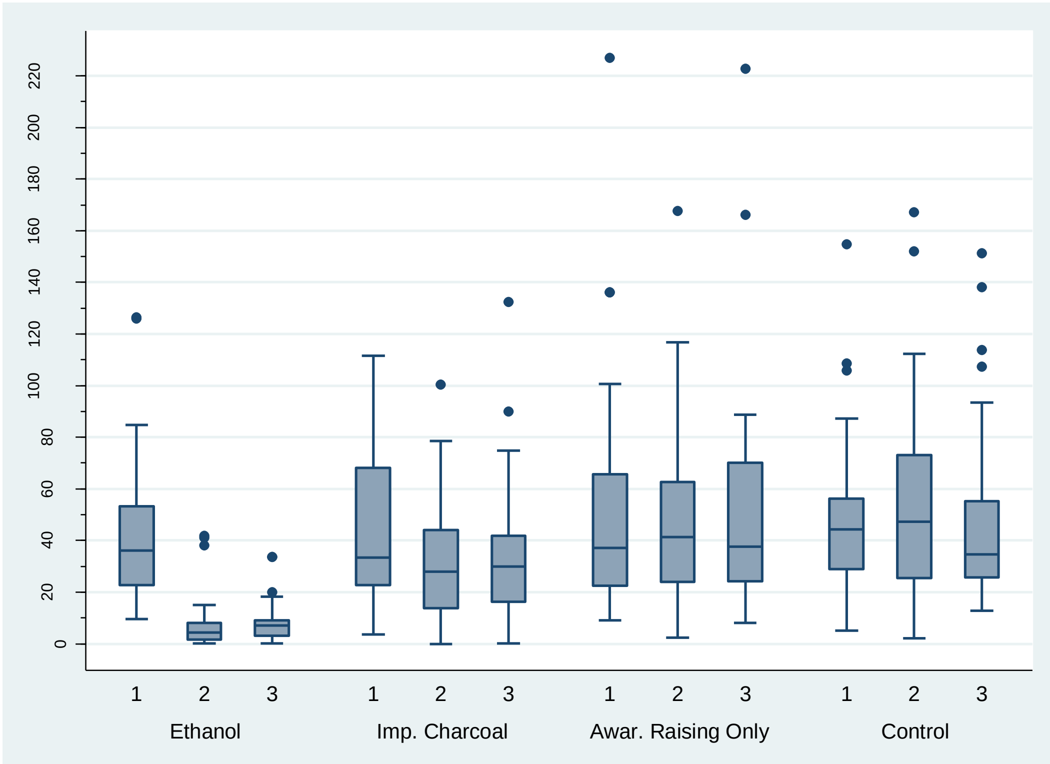


Figure 7-1: Ambositra: 24-hr kitchen CO concentrations (ppm) by round and intervention

Significant reductions in 24-hr kitchen CO concentrations in Ambositra were observed in Rounds 2 and 3 for the ethanol group compared to Baseline (Round 1), corresponding to an average reduction of 33 ppm (79%). There was a slight indication of an increase in the kitchen CO concentrations between Rounds 2 and 3 based on the median (Figure 7.1), but the mean change was insignificant (p-value = 0.90). This slight increase between rounds is almost certainly due to increased use of secondary fuels, which were reported as higher in Round 3 relative to Round 2.

Mean CO concentrations in Ambositra kitchens with improved charcoal stoves showed a mild but insignificant change from Baseline of -8.5 ppm (95% CI: -18, 1), corresponding to a reduction. It seems plausible that given a slightly larger sample size, this reduction would be significant; however, the improved charcoal stove still produced considerable CO levels.

The Awareness Raising Group in Ambositra, composed entirely of charcoal users, did not show any change in kitchen CO levels from Baseline (p-value: 0.987, 95% CI: -11, 11) and had 24-hr averages closely resembling those measured in the Control Group.

The Control Group in Ambositra did not show any change in kitchen CO levels between Rounds 1, 2, and 3 (p-value: 0.898, 95%CI: -13, 11), suggesting conditions remained generally constant over time and that any possible contamination of the Control Group by any of the interventions had little or no effect.

7.2. 24-hr Average Kitchen CO Concentrations in Vatomandry

The 24-hr average kitchen CO concentrations in Vatomandry are shown in Table 7.2 below by round and treatment group. The data are grouped by the allocated treatment group, disregarding if the primary reported fuel was different than the treatment fuel in the case of ethanol. Figure 7.2 displays the same information.

Table 7.2: 24-hr average kitchen CO concentrations (ppm) in Vatomandry by round and treatment group (assumes treatment group, disregards if primary fuel is different than treatment fuel)

	Round 1 (Baseline)			**Round 2**			**Round 3**			**Estimated Change from Baseline**		
	N	Arith.Mean	Median	N	Arith.Mean	Median	N	Arith.Mean	Median	ppm	%	p-value
Ethanol	31	15 (23)	8	31	1 (2)	0.4	31	0.8 (1)	0.2	----	----	----
Ethanol (Wood Baseline)	15	14 (21)	8	15	1 (2)	0.1	16	1 (1)	0.2	**-13 (5)**	**-93%**	**0.01**
Ethanol (Char Baseline)	16	15 (26)	9	16	0.9 (1)	0.7	15	0.7 (1)	0.2	**-14 (6)**	**-93%**	**0.02**
Improved Charcoal	32	11 (10)	7	31	12 (13)	7	30	12 (12)	7	1 (2)	9%	0.576
Improved Wood	33	19 (26)	9	33	5 (8)	2	32	9 (16)	2	**-12 (5)**	**-63%**	**<0.01**
Awareness Charcoal	11	15(14)	11	14	9 (9)	6	12	8 (6)	6	-7 (4)	-47%	0.08
Awareness Wood	21	15 (12)	11	16	14 (11)	9	18	14 (10)	12	-1 (3)	-7%	0.590
Control Charcoal	8	10 (9)	6	13	11 (11)	6	13	10 (10	9	-1 (5)	-10%	0.898
Control Wood	16	26 (31)	15	17	16 (11)	14	16	18 (20)	11	-8 (8)	-80%	0.265

*Values in parentheses represent 1 std. deviation or Std. Error

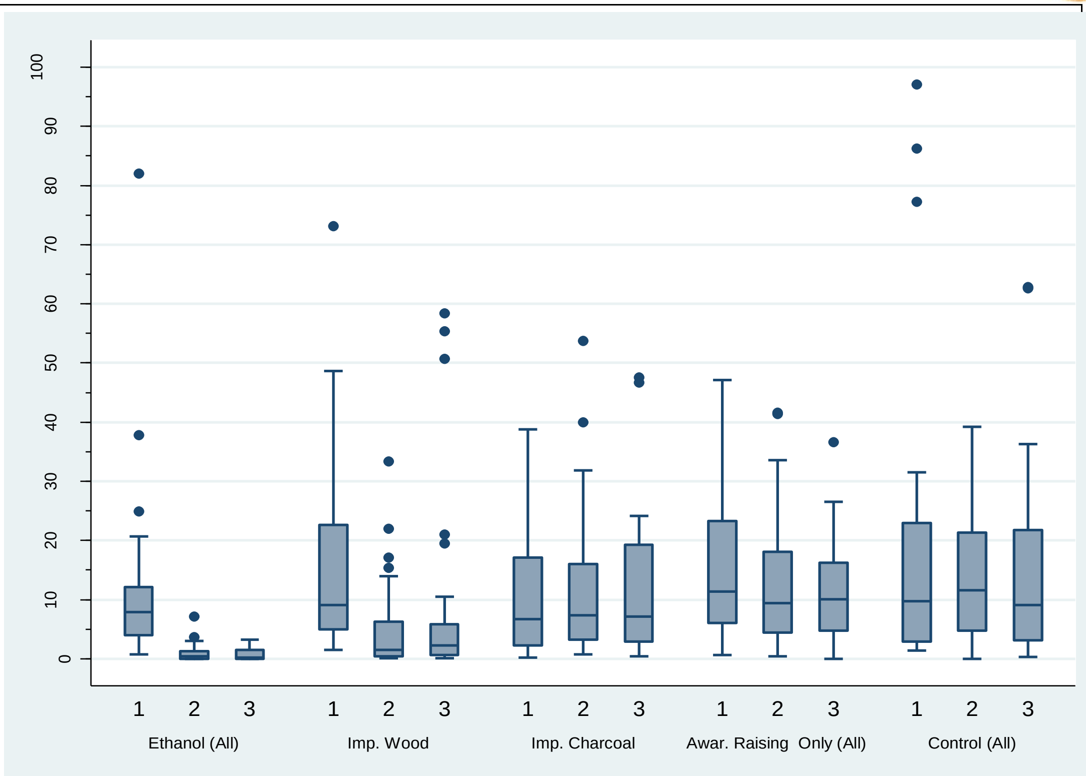


Figure 7-2: Vatomandry: 24-hr kitchen CO concentrations (ppm) by round and intervention (see accompanying figures below for expanded ethanol, awareness, and control group concentration by fuel type)

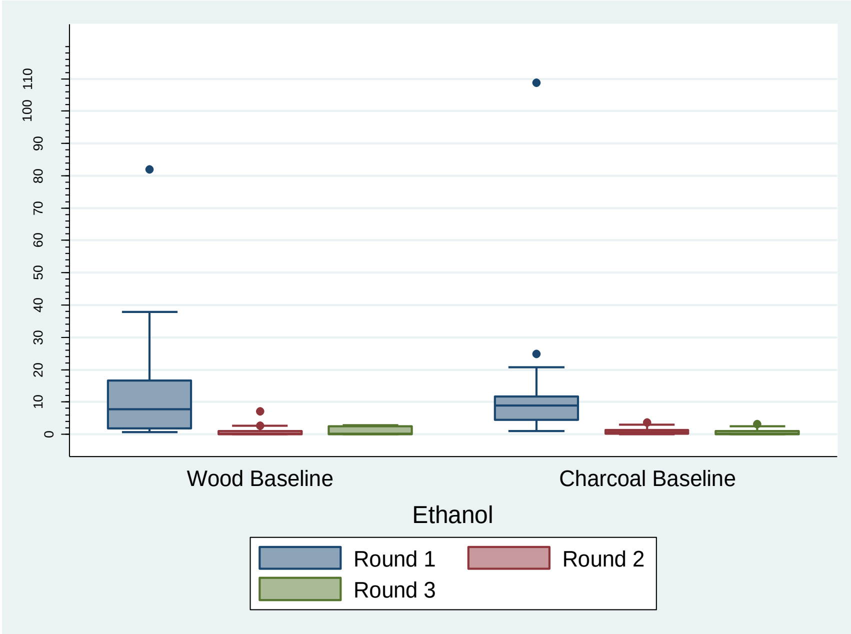


Figure 7-3: (Expanded) Vatomandry: 24-hr average kitchen CO concentrations in ethanol treatment households, by round and fuel used at Baseline.

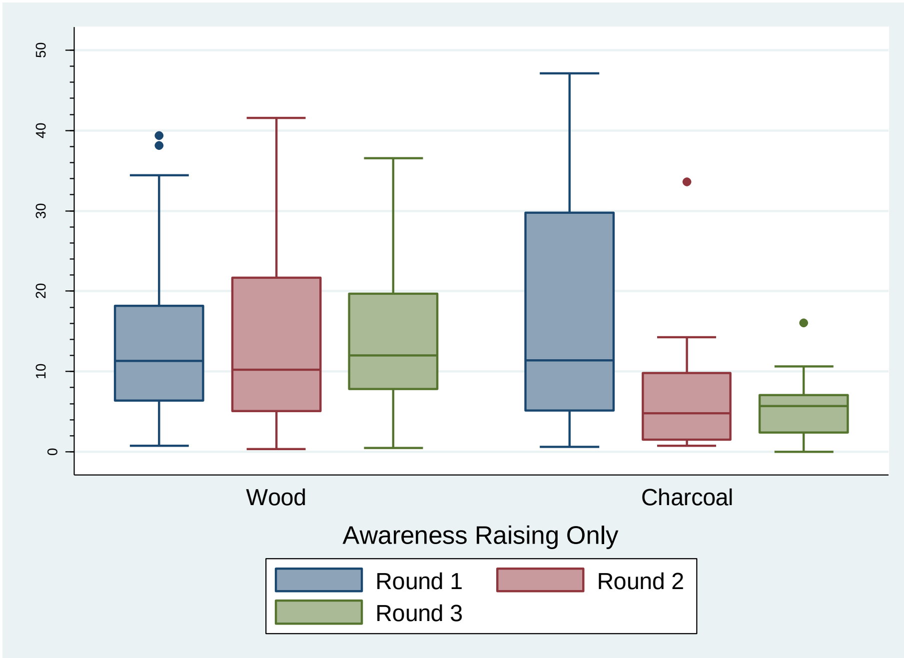


Figure 7-4: (Expanded) Vatomandry: 24-hr average kitchen CO concentrations in Awareness Raising treatment households, by round and reported fuel type (primary).

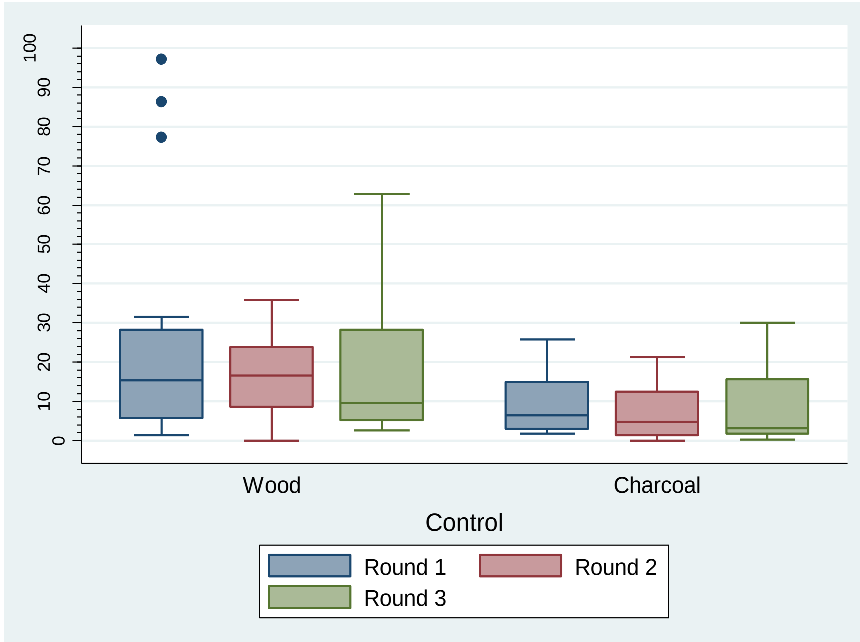


Figure 7-5: (Expanded) Vatomandry: 24-hr average kitchen CO concentration in the Control group, by round and reported fuel type (primary).

In Vatomandry wood users at Baseline showed characteristically higher 24-hr kitchen CO concentrations relative to charcoal users at Baseline (Table 7.2).

Kitchen CO concentrations in Vatomandry were reduced dramatically in the ethanol and improved wood stove groups in Rounds 2 and 3 compared to their Baseline values (Table 7.2, Figures 7.2 – 7.5). Wood users who switched to ethanol showed kitchen CO reductions of 13 ppm (p-value: 0.01, 95% CI: -24, -3) from Baseline, while charcoal Baseline users who switched to ethanol showed a similar reduction of 14 ppm (p-value: 0.023, 95% CI: -26, -2). Improved wood stove users showed kitchen CO reductions of 12 ppm (p-value: < 0.01, 95% CI: -21, -3) from Baseline. As was the case in Ambositra, a slight, but insignificant increase in kitchen CO concentrations was observed between Rounds 2 and 3 in the ethanol groups, presumably due to increased use of wood or charcoal as supplementary fuels.

The improved charcoal stove showed no effect on the kitchen CO concentrations in Vatomandry (p-value: 0.576, 95%CI: -3, 5).

Awareness raising showed no effect on kitchen CO levels in Vatomandry among wood users, although charcoal users in the awareness raising group showed reduced CO concentrations in Rounds 2 and 3 compared to their Baseline value, as shown in Figure 7.4. However, this apparent difference may largely be due to random variability in daily average concentrations at Baseline, considering that both the improved charcoal group and the charcoal using controls experienced CO levels roughly 33% lower than those charcoal users in the awareness group.

Neither control group showed changes in kitchen CO levels in Vatomandry between Rounds 1-3 (Wood: p-value: 0.265, 95% CI: -23, 6; Charcoal: p-value: 0.898, 95% CI: -10, 9), suggesting conditions remained generally constant over time and that any possible contamination of the Control Group by any of the interventions had little to no effect.

7.3. 24-hr Average Kitchen $PM_{2.5}$ Concentrations in Ambositra

The 24-hr average kitchen $PM_{2.5}$ concentrations in Ambositra are shown in Table 7.3 below by round and treatment group. The data are grouped by treatment group, disregarding if the primary fuel was different than the treatment fuel in the case of ethanol. The same information is displayed in Figure 7.6.

Table 7.3: 24-hr average kitchen $PM_{2.5}$ concentrations (ug/m^3) in Ambositra by round and treatment group (assumes treatment group, disregards if primary fuel is different than treatment fuel)

	Round 1 (Baseline)			Round 2			Round 3			Estimated Change from Baseline		
	N	Arith.Mean	Median	N	Arith.Mean	Median	N	Arith.Mean	Median	ug/m^3	%	p-value
Ethanol	31	389 (489)	194	32	156 (424)	60	31	142 (83)	122	**-221 (82)**	**-57%**	**<0.01**
Improved Charcoal	31	345 (358)	159	31	351 (310)	249	32	403 (383)	264	35 (63)	10%	0.585
Improved Wood	----	----	----	----	----	----	----	----	----	----	----	----
Awareness Charcoal	33	390 (342)	301	34	502 (479)	292	33	520 (802)	267	104 (103)	27%	0.314
Awareness Wood	----	----	----	----	----	----	----	----	----	----	----	----
Charcoal/Control Charcoal	26	328 (226)	279	36	473 (484)	270	34	489 (492)	282	157 (86)	78%	0.07
Control Wood	----	----	----	----	----	----	----	----	----	----	----	----

*Values in parentheses represent 1 std. deviation or Std. Error

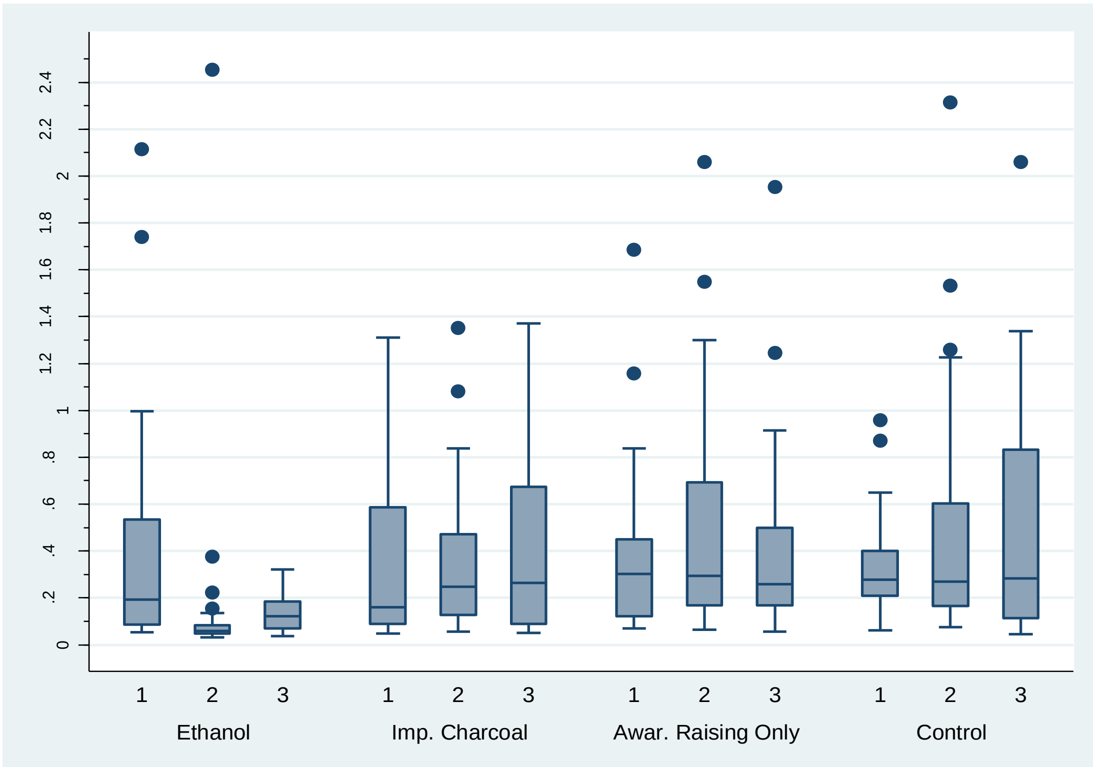


Figure 7-6: Ambositra: 24-hr kitchen $PM_{2.5}$ concentrations (ug/m^3) by round and intervention group (see accompanying figures below for expanded ethanol, awareness, and control group concentration by fuel type)

Significant reductions in $PM_{2.5}$ were observed in the ethanol group in Ambositra in Rounds 2 and 3 compared to the Baseline. As seen in the ethanol group kitchen CO concentrations, there was an increase in $PM_{2.5}$ concentrations between Rounds 2 and 3, likely due to the increased use of wood or charcoal as secondary or even primary fuels in Round 3 relative to Round 2 (Table 7.3). A reduction in kitchen $PM_{2.5}$ in Ambositra across both rounds of 220 ug/m^3 (p-value: <0.01, 95% CI: -59, -389) resulted in 24-hr average kitchen $PM_{2.5}$ concentrations of 156(424) and 142(83) ug/m^3 in Rounds 2 and 3, respectively.

The improved charcoal stove showed no effect on the kitchen $PM_{2.5}$ concentrations in Ambositra (p-value: 0.585, 95%CI: -90, 160 ug/m^3), unlike the kitchen CO concentrations which indicated a mild but insignificant reduction.

In Ambositra the awareness raising group did not show any change in $PM_{2.5}$ kitchen concentrations (p-value: 0.314, 95%CI: -97, 305), which is consistent with the findings for kitchen CO in Ambositra.

Control group members in Ambositra did not show any change in average kitchen $PM_{2.5}$ concentrations between Rounds 1, 2, and 3 (p-value: 0.07, 95% CI: -11, 324 ug/m^3). (Note: there was a shift in the control group towards using more separate kitchens, which was associated with increased $PM_{2.5}$ levels relative to kitchens in the main living area).

7.4. 24-hr Average Kitchen $PM_{2.5}$ Concentrations in Vatomandry

The 24-hr average kitchen $PM_{2.5}$ concentrations in Vatomandry are shown in Table 7.4 below by round and treatment group. The data are grouped by treatment group, disregarding if the primary fuel was different than the treatment fuel in the case of ethanol. The same information is shown in Figure 7.7

Table 7.4: 24-hr average kitchen $PM_{2.5}$ concentrations (ug/m^3) in Vatomandry by round and treatment group (assumes treatment group, disregards if primary fuel is different than treatment fuel)

	Round 1 (Baseline)			Round 2			Round 3			Estimated Change from Baseline		
	N	Arith.Mean	Median	N	Arith.Mean	Median	N	Arith.Mean	Median	ug/m^3	%	p-value
Ethanol	32	453 (433)	264	30	80 (102)	44	31	94 (54)	80	----	----	----
Ethanol (Wood Baseline)	16	655 (500)	712	15	104 (140)	42	16	98 (55)	79	**-554 (127)**	**-85%**	**<0.01**
Ethanol (Char Baseline)	16	251 (226)	137	15	54 (24)	56	15	89 (56)	79	**-180 (54)**	**-72%**	**<0.01**
Improved Charcoal	32	1063 (4182)	143	29	227 (306)	143	30	277 (268)	150	-814 (720)	-77%	0.259
Improved Wood	33	1465 (2143)	685	33	276 (265)	184	32	711 (746)	388	**-971 (359)**	**-66%**	**<0.01**
Awareness Charcoal	11	470 (534)	269	14	273 (248)	208	12	229 (287)	148	-185 (138)	-39%	0.179
Awareness Wood	22	1882 (2054)	1099	17	444 (350)	320	18	910 (766)	673	**-1232 (411)**	**-65%**	**<0.01**
Control Charcoal	8	107 (95)	81	13	245 (242)	140	13	219 (228)	107	98 (76)	92%	0.197
Control Wood	16	2457 (2976)	1063	16	686 (792)	338	16	1052 (1249)	440	-1558 (803)	-63%	0.052

*Values in parentheses represent 1 std. deviation or Std. Error

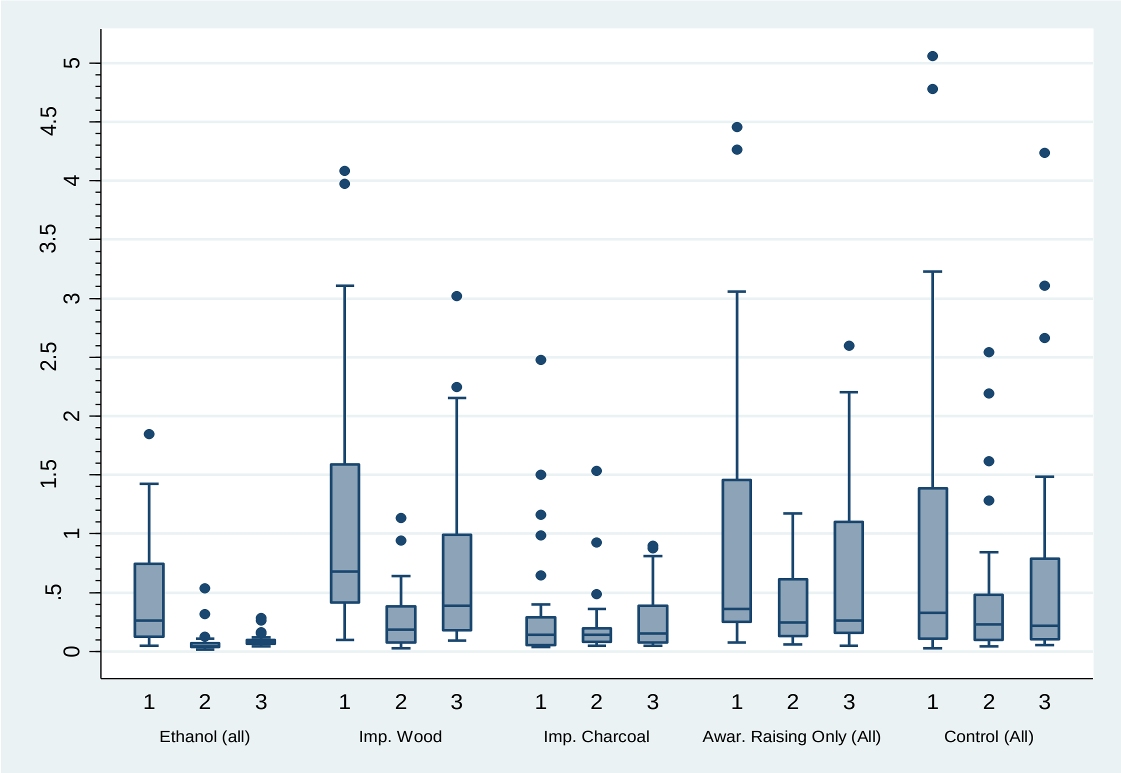


Figure 7-7: Vatomandry: 24-hr $PM_{2.5}$ concentrations by round and intervention group.

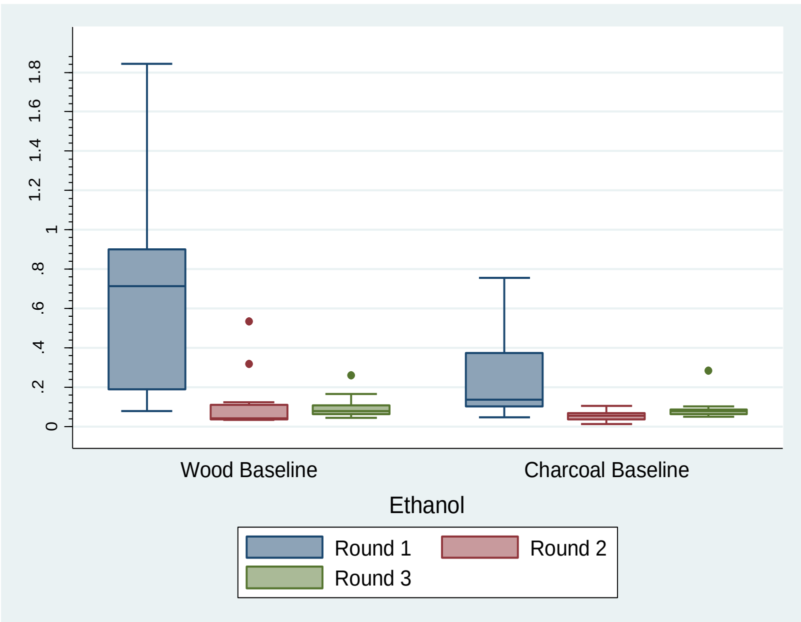


Figure 7-8: (Expanded) Vatomandry: 24-hr average kitchen $PM_{2.5}$ concentrations in Ethanol treatment households, by round and fuel used at Baseline.

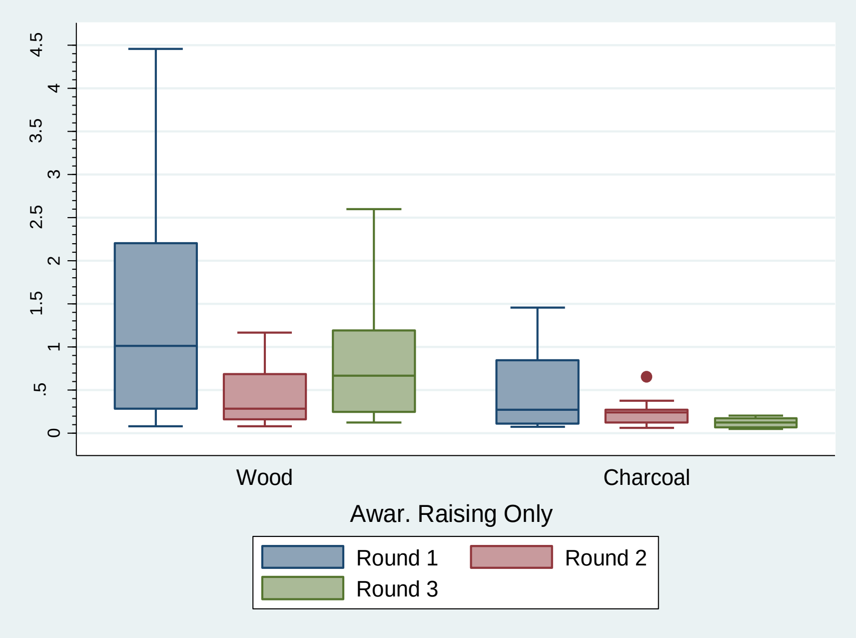


Figure 7-9: (Expanded) Vatomandry: 24-hr average kitchen $PM_{2.5}$ concentration in the Awareness Raising Only treatment group, by round and reported fuel type (primary).

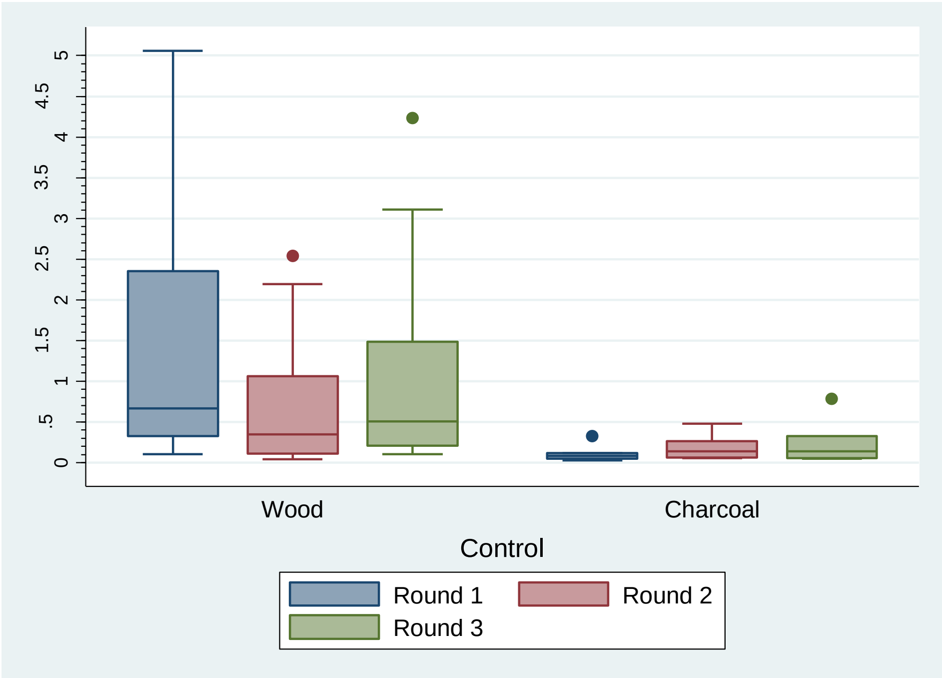


Figure 7-10: (Expanded) Vatomandry: 24-hr average kitchen $PM_{2.5}$ concentration in the Control Group, by round and reported fuel type (primary).

Kitchens with ethanol stoves in Vatomandry showed significant reductions in 24-hr kitchen $PM_{2.5}$ concentrations of 85% and 72% from Baseline for wood and charcoal users, respectively (Wood: p-value: <0.01, 95% CI: -804, -305; Charcoal: p-value: <0.01, 95% CI: -286, -75), as shown in Table 7.4 and Figure 7.8

Improved wood stove users in Vatomandry had a significant reduction in $PM_{2.5}$ kitchen concentrations of 66% relative to Baseline (p-value: <0.01, 95% CI: -1676, -268). Average CO and $PM_{2.5}$ levels in improved wood stove kitchens in Round 3 in Vatomandry were about twice those measured in Round 2, though this difference was not significant (p-value = 0.15).

Improved charcoal stoves in Vatomandry had no effect on 24-hr $PM_{2.5}$ kitchen concentrations (p-value: 0.259, 95% CI: -2226, 599).

Charcoal users in the Vatomandry control group did not show a significant change from Baseline (p-value: 0.197, 95% CI: -51, 248), while Vatomandry wood controls showed a nearly significant reduction from Baseline (p-value: 0.052, 95% CI: -3133, 16).

We note that 11 households in the Vatomandry Baseline had very high kitchen $PM_{2.5}$ levels (above 4000 ug/m^3). Ten of these 11 outlying households were randomized into the control and awareness groups, purely by chance. This small, but influential group of households helps to explain the extremely large variances observed among wood users in Vatomandry, specifically in the control and awareness groups.

7.5. Factors influencing IAP concentrations

7.5.1. 24-hr average ambient $PM_{2.5}$ concentrations

The results from 24-hr ambient $PM_{2.5}$ ambient samples taken in Ambositra and Vatomandry in Rounds 1-3 are displayed in Table 7.5 below. These gravimetric $PM_{2.5}$ samples were collected in multiple locations near and around participant households. It should be noted that the ambient measurements taken during Baseline were based on a single sampling site in each location, whereas the Round 2 and 3 ambient PM samples were taken at various sampling sites across each location.

Table 7.5: 24-hr average ambient $PM_{2.5}$ concentration (µg/m^3) by location and round

	Round 1		**Round 2**		**Round 3**		
	n		n		n		Prob > F
Ambositra	3	10 (3)	7	34 (21)	6	35 (37)	0.38
Vatomandry	6	32 (16)	8	38 (15)	9	38 (21)	0.76

* Values in parentheses represent 1 standard deviation.

Ambient $PM_{2.5}$ concentrations were very similar in all three rounds in both locations. Although the Round 1 Ambositra value was slightly lower than all of the others, it was based on only 3 samples, and it is not significantly different from the other values. These low concentrations suggest that ambient $PM_{2.5}$ sources were not highly influential on kitchen concentrations of $PM_{2.5}$ or on personal exposure relative to $PM_{2.5}$ from cooking sources.

7.5.2. Kitchen Location

Among charcoal and wood users, cooking inside the main household was found to be significantly associated with lower $PM_{2.5}$ and CO concentrations relative to cooking in a separate building. Reasons for this might be physical characteristics of the kitchen, namely that kitchens separate from the main house tend to be smaller, or be due to behavioural differences associated with having an open combustion source in a main living area.

7.5.3. Person meals comparison

The amount of cooking performed and the time spent cooking affect the amount of fuel burned and therefore the amount of pollutants emitted into the kitchen. As an indicator of the amount of cooking, the team used surveys to measure person-meals, or the number of standard adults for whom meals were cooked over the course of the 24-hr monitoring period. The difference in the mean number of person meals between rounds was tested, and the results are summarized in Table 7.6.

Table 7.6: Mean 24-hr person meals (std. adult meals) by round and location

Person Meals

	Ambositra		Vatomandry		t-test
	A. Mean	Std.Dev	A.Mean	Std.Dev	(unpaired)
Round 1	10.9	5.0	11.9	6.4	0.17
Round 2	11.5	5.6	11.6	5.5	0.94
Round 3	11.0	5.4	11.2	5.0	0.71
ANOVA (Prob>F)	0.578		0.606		

* $w_{children <15 yrs} = 0.5$, $w_{female >15 yrs} = 0.8$, $w_{male 15\text{-}59 yrs} = 1$, $w_{male >59 yrs} = 0.8$

Results indicate that person-meals did not change significantly across rounds, suggesting that the amount of cooking for household members or guests did not likely play a role in any differences we observed in indoor air pollutant concentrations between Rounds 1, 2, and 3.

7.6. Discussion of IAP

The ethanol stove reduced kitchen $PM_{2.5}$ and CO levels in both locations by a significant level from the Baseline. A comparison of the 24-hr kitchen CO averages shows that the ethanol stove can significantly reduce kitchen CO levels below the 8-hr WHO guideline level of 8.7 ppm. Although the ethanol stove significantly reduced $PM_{2.5}$ concentrations in the kitchen, the Round 2 and 3 levels in Vatomandry were still about nine times the very stringent annual WHO guideline for $PM_{2.5}$ of 10 µg/m^3, while in Ambositra they were approximately fifteen times the guideline. The average Vatomandry ethanol household kitchen concentrations of $PM_{2.5}$ in Round 2 and Round 3 were only three to four times above the 24-hr WHO guideline level of 25 µg/m^3, although the 24-hr averaging time is not considered fully appropriate for exposures that occur every day throughout the year, such as cooking smoke exposure. An increase between Round 2 and 3 in reported supplemental fuel mixing or primary fuel substitution was observed in the ethanol group and may explain the slight increase in CO and $PM_{2.5}$, to varying degrees, across both locations. In addition, it is possible that some proportion of IAP reduction in Vatomandry ethanol users may be due to the observed tendency to cook within the main household (larger volume) than in a separate structure (smaller volume) following the introduction of the improved stove. This effect, however, would be expected to be a small contributor considering that similar IAP reductions were observed in Ambositra where such kitchen location migration did not occur.

The improved wood stove also showed an ability to reduce kitchen $PM_{2.5}$ and CO at significant or near significant levels (only relevant to Vatomandry), particularly in Round 2, though the reductions were not as dramatic as with the ethanol stove, and the average $PM_{2.5}$ concentration was not close to the WHO guideline in either round. The ethanol stove and improved wood stove decreased the overall variability in IAP between users in Round 2 and Round 3 relative to the Baseline.

The improved charcoal stove was not effective at reducing average kitchen CO or $PM_{2.5}$ concentrations in either Ambositra or Vatomandry, as the stove was not found to have a significant effect for either pollutant in the GEE model. Furthermore, in the series of controlled cooking tests that this team conducted in an earlier phase of the study, the improved charcoal stove had essentially the same (slightly lower) thermal efficiency as the traditional charcoal stove (19.8% vs. 20.8%, respectively), implying that it may not provide any charcoal savings. While the emissions of the two charcoal stoves were not measured, the similarity of the thermal efficiencies implies that the emissions of CO and $PM_{2.5}$ for the two stoves are likely similar. Hence, the fact that we did not see a significant reduction in kitchen air pollution from the improved charcoal stove may not be surprising.

Awareness-raising had no effect on Round 2 and Round 3 kitchen $PM_{2.5}$ (p-value = 0.348) or kitchen CO (p-value = 0.987) in Ambositra compared to the Baseline. In Vatomandry, where awareness-raising was conducted in both wood and charcoal using households, a significant reduction in $PM_{2.5}$ of -1232 $\mu g/m^3$ (p-value < 0.01) was measured among wood users, but no effect was detected for charcoal users (p-value = 0.179). No effect of awareness-raising on 24-hr average kitchen CO concentrations was measured in Vatomandry, regardless of fuel type.

8. Adult Personal Exposure at Baseline

8.1. Women's CO Exposure

Distribution of personal carbon monoxide values
Studies of personal exposure typically show that, within a community, the majority of people have values around an 'average' for that group, but that a few have quite high values and a very few have extremely high values. It is important to look at and illustrate this so-called 'distribution', as it has important implications for understanding exposure values and for how the results should be presented and analysed.

Figure 8.1 shows this 'distribution' for women's exposure in Ambositra at Baseline, which confirms that these values (as is seen in many other studies) are what is known as 'positively skewed'. This means that the distribution is pulled out to the right, and while most are in the range 0-20 ppm, a few are in the range 20-40, and a very few have values up to almost 80 ppm. It is also important to emphasise that typically individual exposure values vary quite markedly from day to day. One consequence of this is that we cannot assume that the few with very high values will experience such high exposures every day, although it is reasonable to expect that they will tend to be living in environments that do result in above average exposure.

The same shape of the 'distribution' is seen for women's 24-hour personal exposure in Vatomandry at Baseline, although the levels are much lower, most being in the range 0-5 ppm (Figure 8.2).

Similar considerations apply to the values of personal exposure for the children, illustrated in Section 9.1.

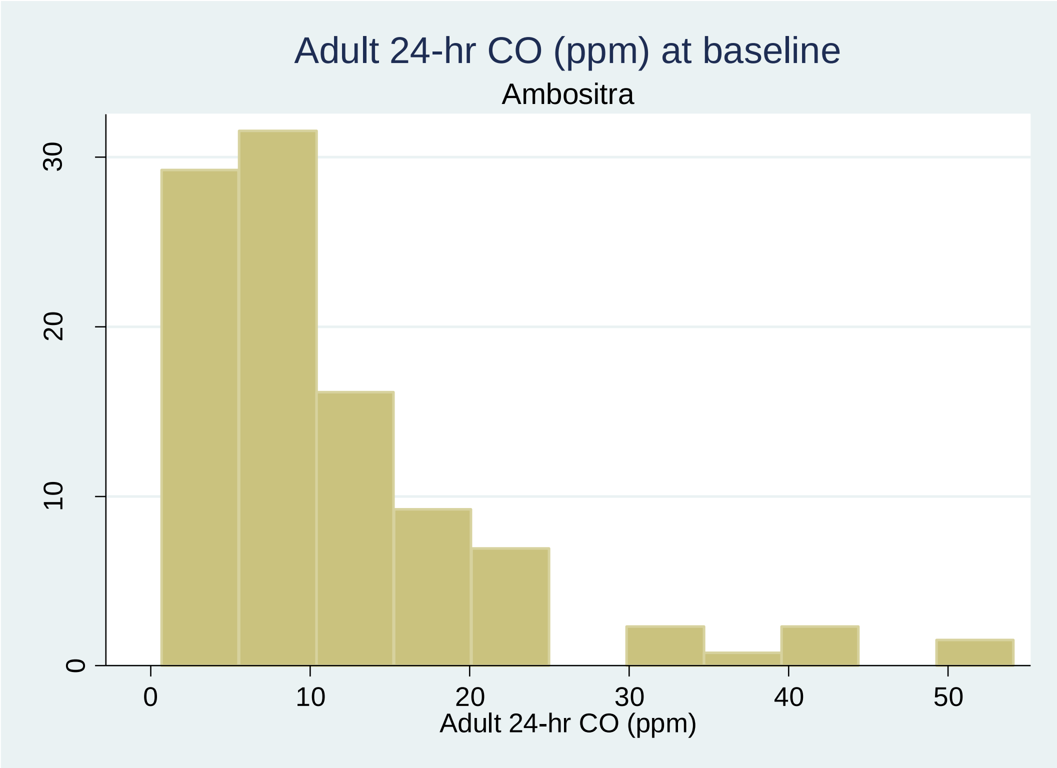


Figure 8-1: Distribution of average (24 hour) CO (ppm) exposure for adult women in Ambositra

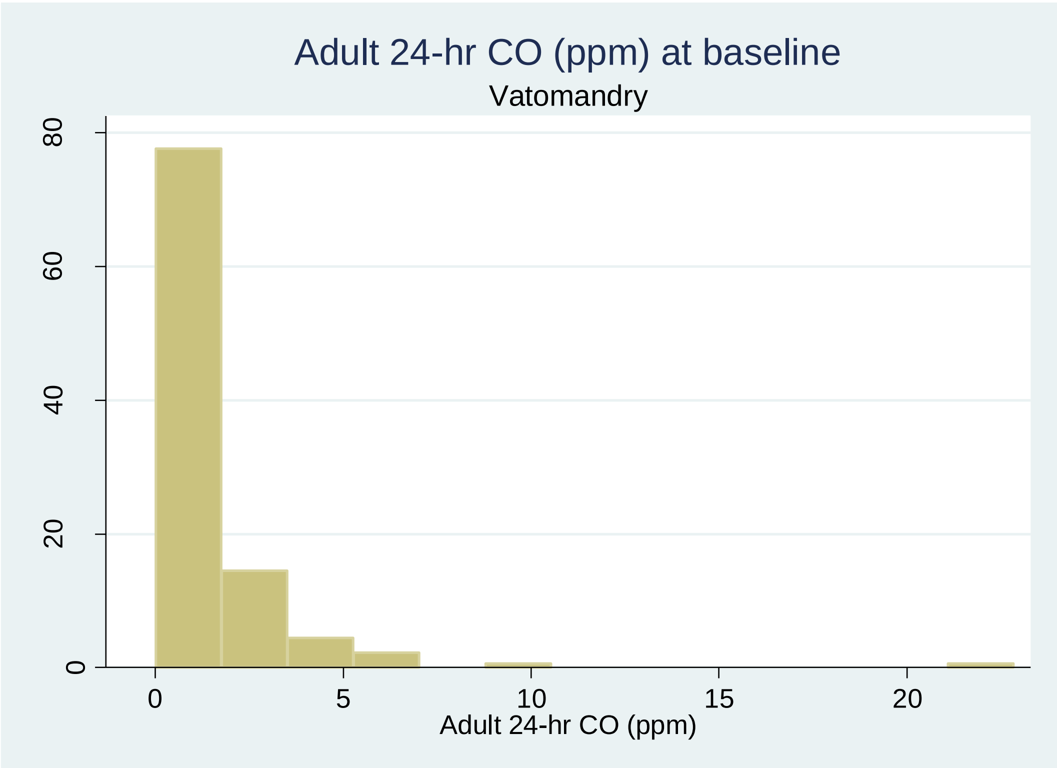


Figure 8-2: Distribution of average (24 hour) CO (ppm) exposure for adult women in Vatomandry

Use of carbon monoxide as a proxy for $PM_{2.5}$

A second important issue to note is that carbon monoxide (CO) exposure is being used, not just as a measure of air pollution in its own right, but also as a proxy for smoke exposure from the fuel used [see section 2.7.2.1). Although CO is a toxic gas for humans and may be responsible for some of the health effects of solid fuel combustion including reduced birth weight, the most important pollutant for respiratory diseases in adults and children is small particulate matter (for example $PM_{2.5}$ as measured in the kitchens in the current study). The relationship between CO and $PM_{2.5}$ is very different for charcoal and wood: for any given level of CO, wood combustion (in simple stoves typical of low income countries) will be producing considerably more $PM_{2.5}$ than charcoal. Kitchen structure, stove type and setting will also affect these relationships: accordingly, the relationships between CO and $PM_{2.5}$ have been studied for each fuel type in Vatomandry, and in the two study centres separately for charcoal.

With such ‘skewed’ distributions, it is most appropriate to present the average and the spread of values using the median and inter-quartile range (IQR), rather than the mean (arithmetic average) and standard deviation (SD). The median is the value that has 50% of the measurements below it, and 50% above it, and is used in preference to the mean as it is not so affected by the small number of very high values. For making comparisons between groups (e.g. between wood and charcoal users, etc), it is also more appropriate to use non-parametric tests, as is done in the following sections.[9]

For the same reasons, the summary analyses using multiple regression (GEE) are run with, in addition to the 'natural' values, the log transformed values, which make the skewed distributions more ‘normal’ and suitable for the hypothesis test used.

As noted from Figures 8.1 and 8.2, the overall levels of personal exposure to CO were considerably higher in Ambositra. The median CO (in ppm) was 8.45; IQR=4.64 to 14.7 for Ambositra compared to a median of 0.82; IQR=0.42 to 1.65 in Vatomandry ($p<0.0001$).

These results are consistent with comparisons of kitchen IAP concentrations as well as household design. Unlike Ambositra, most homes in Vatomandry had detached kitchens, separated from the main living quarters. This kitchen design, combined with lower overall kitchen CO concentrations may have contributed to an almost 6 fold lower median 24hr exposure for women, relative to Ambositra. Observations by the field team provide additional insight into understanding the reasons for these differences (Box 8.1).

Box 8.1.

[9] The use of these tests is indicated in the relevant tables, and are (i) Wilcoxon’s test for 2-groups, and (ii) Kruskal-Wallis for more than two groups.

Kitchens in Vatomandry are not made from solid walls like in Ambositra. They usually make their kitchens from palm branches that let air in and out. The kitchens in Vatomandry seemed to us more ventilated than Ambo even though it was hot. They put their stoves next to window or door. We also saw families in Ambositra sitting around their stove and this is in contrast to Vatomandry.

Usually families in Vatomandry have a separate kitchen and only the cook goes in for some time to carry out the cooking. One other fact is that most households seemed lower class (within the local classification) in Vatomandry. As a result, the lower class households could possibly cook less food less frequently -these households may only cook once in a day or twice in contrast to more wealthy families who cook a number of times in a day and a variety of food. For example in the poorer households they may only boil rice or cassava once a day. This could have minimized overall emission and exposure.

We also didn't see many children in Vatomandry kitchens - this might be because of hot climate, small size kitchen or because the mother herself is not spending much time inside the kitchen.

Table 8.1 shows the women's average 24-hour CO exposure in Ambositra and Vatomandry by type of fuel (as used in the wet season when the CO readings were taken) and whether there were any cigarette smokers in the house including the amount smoked per day. Average levels of CO did not differ according to passive smoking status, including number of cigarettes smoked, however, in Vatomandry, charcoal use was associated with significantly higher levels of CO than wood use (p=<0.001). The fact that, by contrast, both $PM_{2.5}$ and CO kitchen levels were higher for wood than for charcoal (See Section 7) suggests that the behaviour of women (cooks) in wood-using homes may differ, with less time spent in the polluted environment than is the case for charcoal.

Table 8.1: Baseline average (24 hour) CO exposure (ppm) in women by fuel type and passive smoking

Characteristic	Ambositra			Vatomandry		
	N	Median	IQR	N	Median	IQR
CO Average	130	8.4	5.0, 14.7	179	0.8	0.4, 1.7
Fuel type (wet):						
Wood	-	-	-	97	0.7	0.4, 1.2
Charcoal	129	8.5	5.0, 14.8	82	1.1	0.5, 2.5
					P=<0.001[1]	
Passive smoking:						
Yes	53	7.5	4.2, 14.5	54	0.9	0.4, 1.8
No	77	9.4	5.1, 15.1	124	0.8	0.4, 1.6
		P=0.385[1]			P=0.386[1]	
Number of cigarettes smoked in house:						
1-4	26	8.0	3.3, 14.9	10	1.2	0.5, 2.0
5-9	14	7.4	5.9, 20.5	12	1.0	0.6, 2.8
10+	13	7.6	5.3, 11.0	32	0.9	0.4, 1.7
		P=0.636[2]			P=0.586[2]	

[1] *Mann Whitney (non-parametric) hypothesis test*
[2] *Kruskall Wallis (non-parametric) hypothesis test*

The possible impact of kitchen location on women's personal exposures has already been mentioned, and this is further explored in Table 8.2.

Table 8.2: Baseline, relationship between kitchen location (proximity to the living area) and women's 24-hour personal CO exposure (ppm)

Kitchen Configuration	Ambositra			Vatomandry		
	N	Median	IQR	N	Median	IQR
Joined to main house	121	9.3	5.1, 15.1	81	0.9	0.5, 2.1
Separated from main house	8	3.3	0.7, 6.5	98	0.7	0.3, 1.3
		P=0.002			P=0.006	

P values from Mann Whitney (non-parametric) hypothesis test

Most kitchens were attached or within the living area in Ambositra, but a more balanced pattern was seen in Vatomandry. For Ambositra, there is clear evidence that exposures are higher when the kitchen is in the living area. For Vatomandry, the difference in exposures between the kitchen configuration groups is small but statistically significant.

8.2. Baseline levels of Adult CO & $PM_{2.5}$ Exposure by Intervention Group

The levels of personal adult CO and (predicted) $PM_{2.5}$ exposure at Baseline are shown for Ambositra in Tables 8.3 (a) and (b), and the levels of personal adult CO for Vatomandry in Tables 8.4. Values for children are presented in section 9.

For Ambositra, median CO values in households that were subsequently allocated to Ethanol, Charcoal and Awareness, were very similar (between 7.1 and 8.5 ppm), but those allocated to control (the n=22 which remained in Round 2) had a somewhat higher median of 10.0 ppm. However, the difference in median CO among these groups was not statistically significant. For predicted $PM_{2.5}$ the median levels were all very similar at around 90 µg/m3 to 112 µg/m3, and the differences non-significant. These results indicate that, in terms of personal exposure to CO and $PM_{2.5}$ the intervention groups were comparable at Baseline.

Table 8.3 (a): Median (IQR) adult CO (ppm) at Baseline by intervention group: Ambositra

Intervention Group				P value*
Ethanol (n=29)	Charcoal (n=27)	Awareness (n=32)	Control (n=22)	
7.06 4.24-14.41	8.45 5.56-15.25	7.15 5.51-12.03	10.01 5.03-17.92	0.758

**P-value from Kruskal-Wallis test*

Table 8.3 (b): Median (IQR) adult predicted $PM_{2.5}$ ($\mu g/m^3$) at Baseline by intervention group: Ambositra

Intervention Group				P value*
Ethanol (n=29)	Charcoal (n=27)	Awareness (n=32)	Control (n=22)	
87.9 64.8- 148.1	99.3 75.6- 155.0	88.6 75.2- 132.0	112.1 71.3- 177.0	0.800

**P-value from Kruskal-Wallis test*

For Vatomandry, median 24-hr CO values in households that were subsequently allocated to Ethanol, Charcoal and Awareness, were also quite similar at between 0.65 and 1.07 ppm, with differences non-significant, and considerably lower than for Ambositra. For predicted $PM_{2.5}$, the median level for the wood group was 81.9 µg/m3 (62.6-124.4), similar to the level seen in Ambositra. For the reasons described in the methods section, predicted $PM_{2.5}$ values have not been calculated for the other fuel and intervention groups in Vatomandry.

Table 8.4 a): Median (IQR) adult 24-hr CO (ppm) at Baseline by intervention group: Vatomandry

Intervention Group					P value*
Ethanol (n=32)	Biomass (n=33)	Charcoal (n=32)	Awareness (n=31)	Control (n=25)	
0.90 0.62-1.93	0.76 0.52-1.30	1.07 0.35-1.93	0.85 0.48-1.95	0.65 0.38-1.66	0.580

**P-value from Kruskal-Wallis test*

Note: Please see Section 9.3 for a discussion of adult personal exposure at baseline

9. Children's Personal Exposure at Baseline

9.1. Children's CO exposure

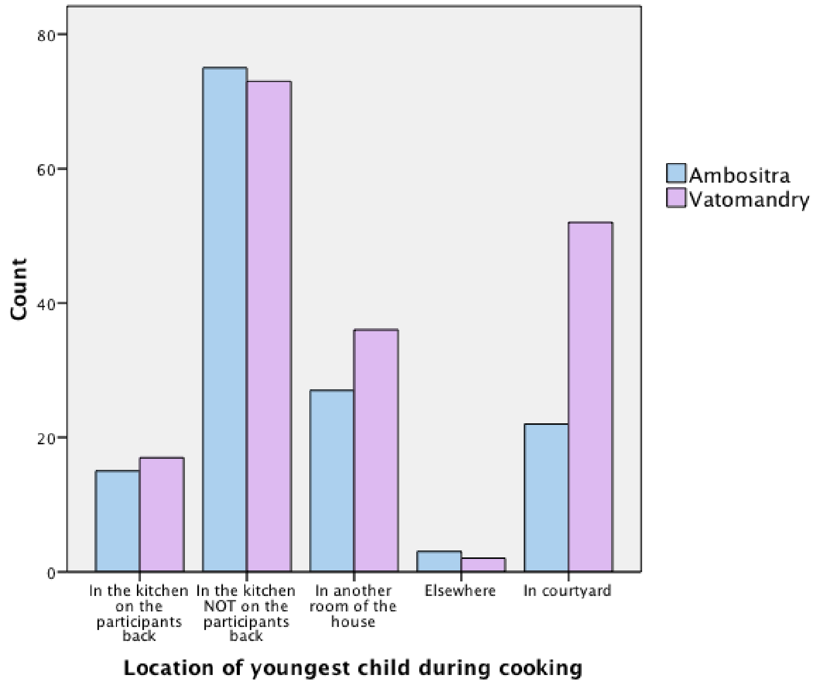
A critical determinant of children's exposure is their location at times when the fire is alight. Table 9.1 and Figure 9.1 show where the child was located when cooking was being carried out (for Vatomandry the table is stratified by fuel type).

In keeping with the setting (climate) and lifestyle descriptions presented in foregoing sections, children in Ambositra were more likely to be in the kitchen (64%) than those in Vatomandry (50%). Nearly 30% of the study children in Vatomandry were reported to be usually in the courtyard during cooking (slightly more so for wood compared to charcoal users), compared to only 15% in Ambositra.

Table 9.1: Usual location of youngest child during cooking at Baseline

Characteristic	Ambositra		Vatomandry					
			Total		Wood use		Charcoal use	
	N	%	N	%	N	%	N	%
Total number (N)	144		180		97		83	
In the kitchen ON the participants back	15	10.4	17	9.4	10	10.3	7	8.4
In the kitchen NOT ON the participants back	77	53.5	73	40.6	35	36.1	38	45.8
In another room of the house	27	18.8	36	20.0	19	19.6	17	20.5
In courtyard	22	15.2	52	28.9	32	33.0	20	24.1
Elsewhere	3	2.1	2	1.1	1	1.0	1	1.2

Figure 9.1: Usual location of youngest child during cooking



The distributions of 24-hour CO exposure (ppm) in the study children are shown in Figures 9.2 and 9.3 for Ambositra and Vatomandry respectively.

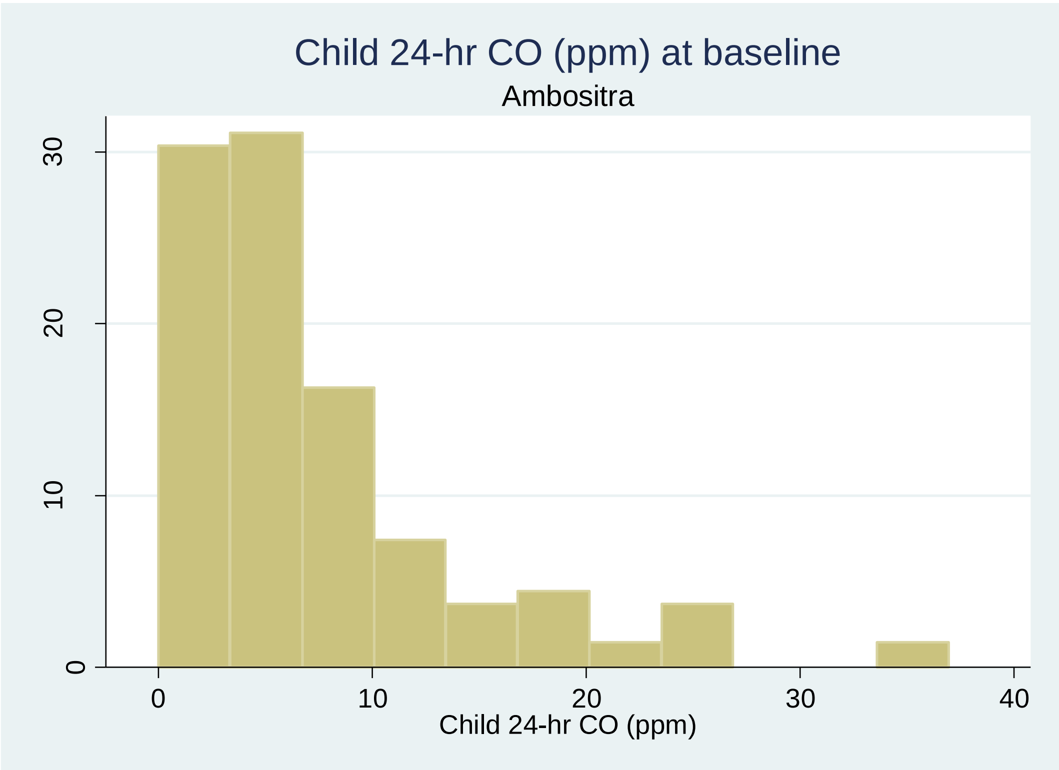


Figure 9.2: Distribution of CO (24 hr) (ppm) exposure for children in Ambositra.

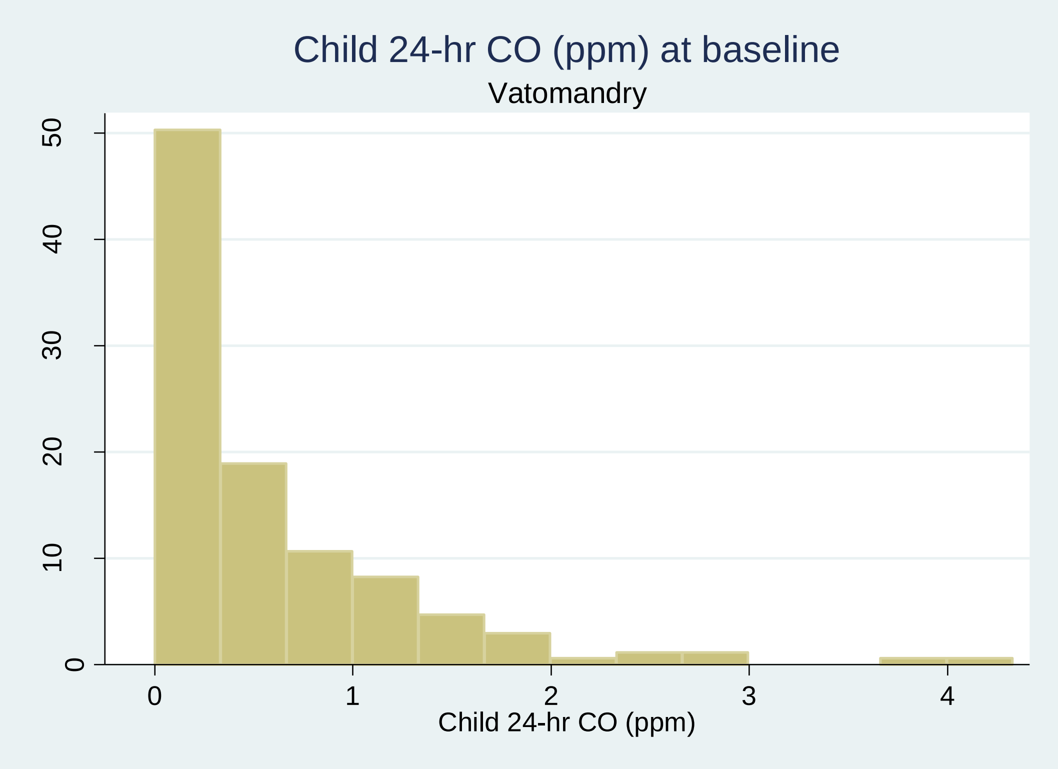


Figure 9.3: Distribution of CO (24 hr) (ppm) exposure for children in Vatomandry.

As with adult levels, the distributions of CO exposure were positively skewed with significantly higher levels in Ambositra (median 24-hr CO ppm=5.12; IQR=2.82 to 8.98) compared to Vatomandry (median 24-hr CO ppm=0.29; IQR=0.09 to 0.80) ($p<0.0001$).

Table 9.2 shows the average child 24-hr CO exposure in the study regions by type of fuel (used in the wet season when the CO readings were taken) and whether there were any cigarette smokers in the house, including the average number of cigarettes smoked. As with levels of 24-hr CO ppm for the adults, average exposure did not differ according to passive smoking status, including number of cigarettes smoked. In addition there did not appear to be a relationship between child CO exposure and fuel use.

Table 9.2: Average child CO exposure by fuel type and passive smoking

Characteristic	Ambositra N	Ambositra Median	Ambositra IQR	Vatomandry N	Vatomandry Median	Vatomandry IQR
CO Average	135	5.1	2.8, 9.0	169	0.3	0.1, 0.8
Fuel type (wet):						
Wood	-	-	-	88	0.3	0.1, 1.0
Charcoal	134	5.3	2.8, 9.0	81	0.3	0.04, 0.8
					P=0.428[1]	
Passive smoking:						
Yes	55	4.7	2.8, 8.4	51	0.3	0.00, 1.0
No	80	5.5	2.9, 9.5	117	0.4	0.1, 0.8
		P=0.359[1]			P=0.608[1]	
Number cigarettes smoked in house:						
1-4	26	4.4	1.6, 10.4	10	0.4	0.1, 1.3
5-9	14	4.9	3.3, 7.2	11	0.3	0.2, 0.6
10+	15	4.7	3.3, 8.1	30	0.3	0.00, 0.8
		P=0.859[2]			P=0.631[2]	

[1] *Mann Whitney (non-parametric) hypothesis test*
[2] *Kruskall Wallis (non-parametric) hypothesis test*

In interpreting these findings, it is important to keep in mind that the recorded child exposure is the consequence of a complex mixture of factors:

- Kitchen air pollution levels
- Time spent by the child in the kitchen
- The location of the kitchen relative to where the child spends most of his/her time
- Various other factors affecting ventilation and dispersal of pollution, including the weather conditions
- Compliance with use of the tube
- Various sources of error in making the measurements, most of which are more or less random, thereby adding ‘noise’.

It is clear that there are important differences in the time children spend in the kitchens, and in the location of the kitchen, and that both of these factors appear to have an influence. These issues will be addressed in the multivariate analysis in Section 11 as fully as possible.

9.2. Baseline levels of Child CO & $PM_{2.5}$ Exposure by Intervention Group

The levels of personal child 24-hr CO and (predicted) $PM_{2.5}$ exposure at Baseline are shown for Ambositra in Tables 9.3 (a) and (b), and the levels of personal child 24-hr CO for Vatomandry in Table 9.4.

For Ambositra, median personal child 24-hr CO exposure in households that were subsequently allocated to Ethanol, Charcoal and Awareness, was very similar (between 4.06 and 5.01ppm). However a somewhat higher median CO exposure (8.77ppm) was observed in those allocated to control (based on the 24 who remained in Round 2), consistent with the findings for adults, although differences were not statistically significant (p=0.213). Accordingly, for predicted $PM_{2.5}$ average levels were similar for each intervention group except the control group, which had a higher median, although not significantly so. However the results suggest that, the intervention groups may not be comparable at Baseline for both CO and levels of $PM_{2.5}$.

Table 9.3 (a): Median (IQR) child 24-hr CO (ppm) at Baseline by intervention group: Ambositra

Intervention Group				P value*
Ethanol (n=31)	Charcoal (n=29)	Awareness (n=33)	Control (n=24)	
4.06 (1.50-8.04)	5.01 (3.38-9.65)	4.40 (2.91-7.59)	8.77 (3.10-14.4)	0.213

P-value from Kruskal-Wallis test

Table 9.3 (b): Median (IQR) child predicted $PM_{2.5}$ ($\mu g/m^3$) at Baseline by intervention group: Ambositra

Intervention Group				P value*
Ethanol (n=31)	Charcoal (n=29)	Awareness (n=33)	Control (n=24)	
63.3 (42.3- 95.9)	71.1 (57.7- 109.1)	66.1 (53.8- 96.0)	101.9 (55.4- 148.3)	0.255

P-value from Kruskal-Wallis test

For Vatomandry, average child 24-hr CO exposure values in households that were subsequently allocated to Wood, Charcoal, Awareness and Control, were similar (median levels between 0.28 and 0.29 ppm). However, for the Ethanol group the median CO exposure level was higher at 0.59 ppm, although not significantly so. The median predicted $PM_{2.5}$ exposure in the wood intervention group was 44.2$\mu g/m^3$ (IQR 28.4-82.9).

Table 9.4: Median (IQR) child 24-hr CO (ppm) at Baseline by intervention group: Vatomandry

Intervention Group					P value*
Ethanol (n=31)	Wood (n=31)	Charcoal (n=32)	Awareness (n=27)	Control (n=23)	
0.59 (0.09-1.02)	0.29 (0.09-0.78)	0.28 (0.09-0.58)	0.28 (0.00-1.03)	0.28 (0.09-1.02)	0.519

P-value from Kruskal-Wallis test

9.3. Discussion of Baseline personal exposure

Compliance with and tolerance of the women's Gasbadge monitors and children's CO tubes was good, although a minority of wood users did less well. To address this, efforts were be made in the next rounds of field work to substantially improve compliance.

Levels of women and children's exposure were substantially higher in Ambositra than Vatomandry. For CO, this reflects the observed differences in ambient kitchen CO concentrations, although not for kitchen $PM_{2.5}$ as levels were higher in Vatomandry.

The ratio between the two study sites is greater for personal exposure than for kitchen CO levels. The reasons for this are likely to be complex, but from the information available a number of explanations are evident:

- Kitchens are more likely to be detached in Vatomandry than Ambositra, particularly for wood users. In Ambositra, very few are detached.
- Personal exposure for women is lowest in the detached kitchens.
- Homes and kitchens in Vatomandry are more open, and hence more ventilated.
- The young (study) children spend less time in the kitchen in Vatomandry, and are more likely to be outdoors in the courtyard.

It was also found that, among wood users in Vatomandry, women's exposure to CO (ppm) was actually lower than for charcoal users. Although not calculated for all fuel types in Vatomandry, the women's $PM_{2.5}$ exposure, however, may not be lower among wood users. This is because we expect that, for any given level of CO exposure, the equivalent $PM_{2.5}$ will be higher for wood users than for charcoal users.

When looking at the Baseline levels of personal exposure to CO and $PM_{2.5}$ (Ambositra only) there were no statistically significant differences between the intervention groups at Baseline, for both study sites, and for both women and children. The differences that were observed (higher CO and $PM_{2.5}$ in the control group in Ambositra for women and children, and higher CO in the Ethanol group for children in Vatomandry) will be taken into account in the multivariate analysis.

10. Adult Personal Exposure at Follow-Up

10.1. Post intervention personal CO levels in adults: Ambositra

The median (IQR) values for adult 24-hr CO exposure in the four study groups at follow up (Round 2 and Round 3) are shown in Table 10.1.

The ethanol group had substantially lower average 24-hr COppm levels than control, awareness and improved charcoal groups at both Round 2 (p<0.001) and Round 3 (p<0.001). There only appeared to be a reduction in CO exposure for the ethanol intervention from Baseline with little or no difference in CO levels from Baseline to Round 2 and Round 3 in the other groups.

Table 10.1: Ambositra - Adult median (IQR) values for 24-hr CO exposure (ppm), by intervention group at Round 2 and 3

	Intervention Group				P value*
Baseline	**Ethanol (n=29)**	**Charcoal (n=27)**	**Awareness (n=32)**	**Control (n=22)**	
	7.06 4.24-14.41	8.45 5.56-15.25	7.15 5.51-12.03	10.01 5.03-17.92	0.758
Round 2	**(n=32)**	**(n=31)**	**(n=31)**	**(n=35)**	
	1.54 0.36-3.05	7.57 2.89-14.46	10.89 4.71-20.14	9.42 4.03-14.40	<0.001
Round 3	**(n=29)**	**(n=30)**	**(n=32)**	**(n=30)**	
	2.16 1.44-4.35	8.86 5.42-17.27	11.31 6.72-20.84	13.52 8.00-22.97	<0.001

**P-value from Kruskal-Wallis test to compare all groups within each round*

The average (median, inter-quartile range) differences between adult 24-hr CO exposure at Baseline and at Round 2 and Round 3 for the four study groups are shown in Table 10.2. The numbers of households included at each round are those that were available in both Baseline and Round 2, or Baseline and Round 3, in order to carry out the paired hypothesis tests of changes, so dropouts and any replacement homes are excluded.

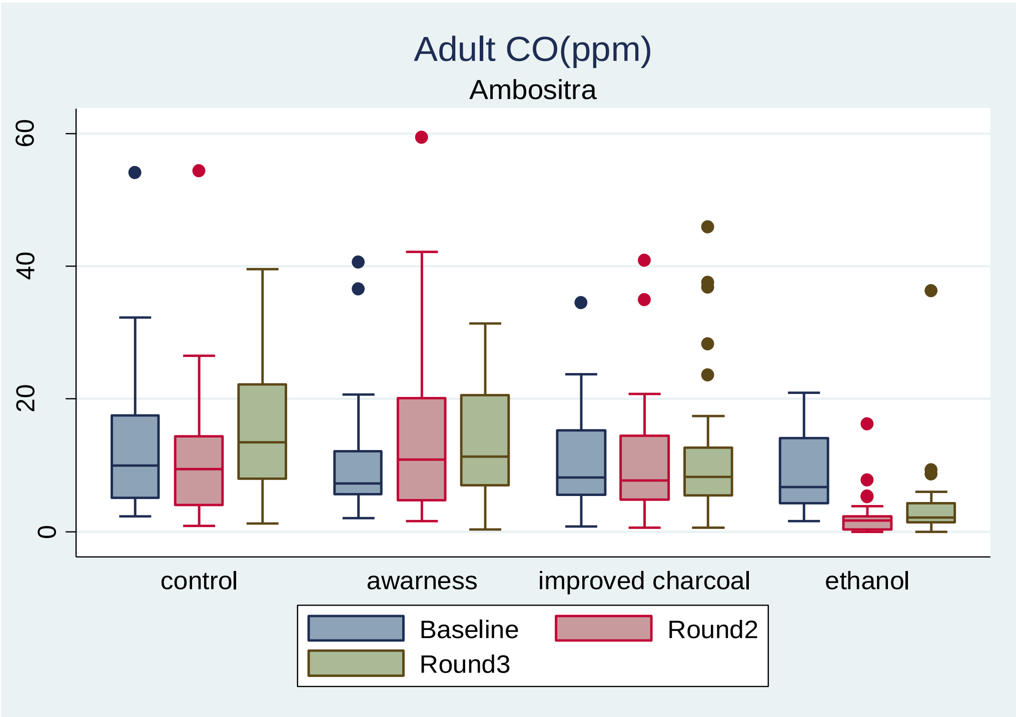
Only the ethanol group showed a large and statistically significant reduction at each of the follow-up Rounds. Figure 10.1 illustrates the change in exposure relating to adult 24-hr COppm from Baseline to Rounds 2 and 3 for each of the intervention groups.

Table 10.2: Ambositra - Adult median (IQR) values for 24-hr CO exposure (ppm), for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group			
	Ethanol	Charcoal	Awareness	Control
Round 2	n=29	n=27	n=31	n=21
	-5.77 -10.10, -3.61	-1.26 -4.38, 6.56	1.25 -4.22, 7.44	-0.46 -7.36, 4.56
P value*	<0.0005	0.648	0.308	0.878
Round 3	n=26	n=27	n=31	n=18
	-4.30 -8.12, -2.01	2.33 -5.25, 5.06	0.96 -2.55, 5.43	1.77 -4.49, 12.67
P value**	0.0003	0.349	0.281	0.327

*Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3.*

Figure 10-1: Distributions of adult CO exposure data, at Baseline, Round 2 and Round 3 by intervention group, Ambositra



*

One outlier was excluded (for the improved charcoal group in Round 3 a value of 89.3 COppm was removed to produce the chart). This had very little impact on the illustrated median.

10.2. Post intervention personal 24-hr CO levels in Adults: Vatomandry

The median (IQR) values for adult 24-hr COppm exposure in Vatomandry are shown for each of the five study groups in Table 10.3, and the distributions in Figure 10.2. The values were far lower than those observed in Ambositra. Although the ethanol group had the lowest average COppm, the wood stove group was also reduced somewhat in comparison with the control, awareness and charcoal groups, which is consistent with the reductions in kitchen air pollution also seen for the improved wood stove. Overall differences between the five groups were highly statistically significant for Round 2 ($p<0.003$) but not for Round 3 ($p=0.123$).

Table 10 3: Vatomandry: Adult median (IQR) values for 24-hr CO exposure (ppm), for all groups at Round 2 & Round 3

	Intervention Group					
Base-Line	**Ethanol (n=32)**	**Wood (n=33)**	**Charcoal (n=32)**	**Awareness (n=31)**	**Control (n=25)**	**P value***
	0.90 0.62-1.93	0.76 0.52-1.30	1.07 0.35-1.93	0.85 0.48-1.95	0.65 0.38-1.66	0.580
Round 2	**(n=31)**	**(n=31)**	**(n=31)**	**(n=31)**	**(n=32)**	
	0.28 0.04-0.74	0.32 0.17-0.85	0.76 0.34-1.28	0.67 0.26-1.41	0.64 0.32-1.58	0.003
Round 3	**(n=30)**	**(n=29)**	**(n=28)**	**(n=28)**	**(n=28)**	
	0.27 0.07-1.48	0.67 0.18-1.53	1.21 0.24-2.65	0.97 0.31-1.99	1.08 0.50-2.65	0.123

**P-value from Kruskal-Wallis test to compare all groups within each Round*

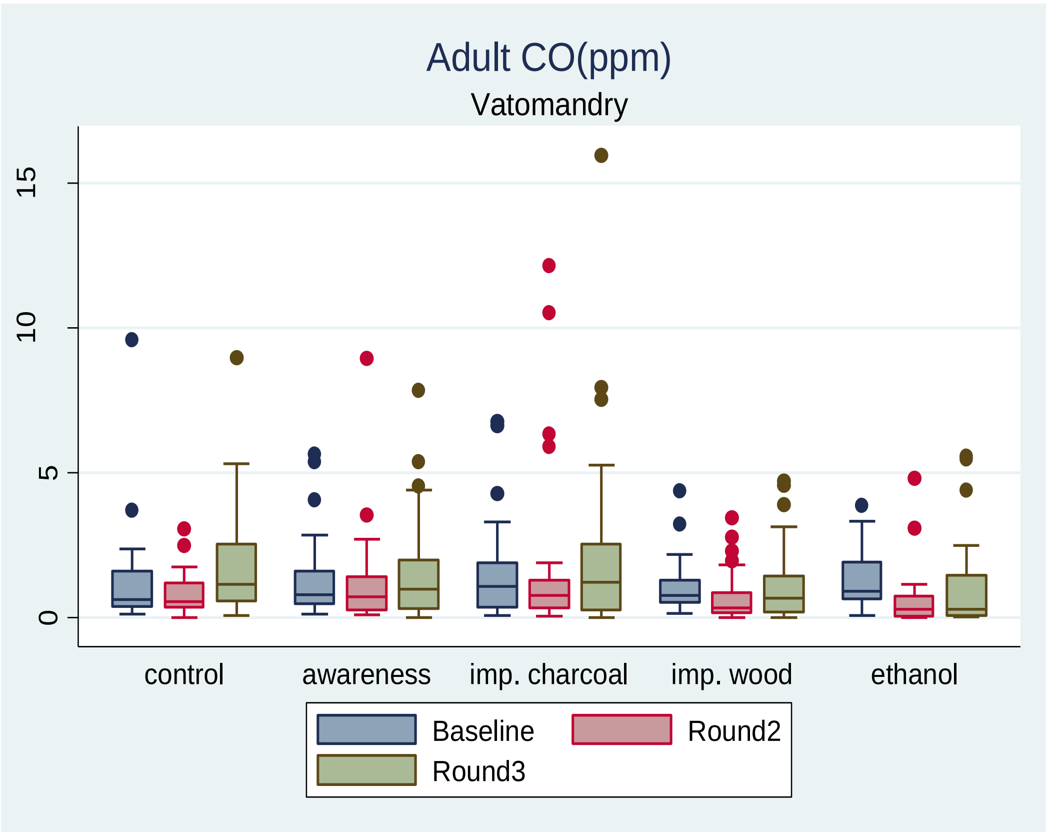
The average (median, IQR) differences between adult COppm 24-hr exposure at Baseline and at Round 2 and Round 3 for the five study groups in Vatomandry are shown in Table 10.4. Only the ethanol group and improved wood groups showed a statistically significant reduction at Round 2 as compared with Baseline ($p<0.05$). At Round 3 none of the groups achieved a significant reduction in exposure compared with Baseline. Figure 10.2 illustrates the change in exposure relating to adult COppm from Baseline to Rounds 2 and 3 for each of the five study groups.

Table 10.4: Vatomandry - Adult median (IQR) values for 24-hr CO exposure (ppm), for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group				
	Ethanol	Wood	Charcoal	Awareness	Control
Round 2	n=31	n=31	n=31	n=31	n=25
	-0.64	-0.30	-0.01	-0.38	0.59
	-1.49, -0.35	-0.88, -0.06	-0.91, 0.69	-0.88, 0.42	-1.42, 0.61
P value*	0.0005	0.042	0.624	0.161	0.732
Round 3	n=30	n=29	n=28	n=28	n=21
	-0.63	-0.30	0.10	-0.06	0.24
	-1.46, 0.72	-0.60, 0.60	-0.84, 1.09	-0.69, 1.44	-0.82, 1.22
P value**	0.125	0.538	0.554	0.905	0.412

*Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3*

Figure 10-2: Distributions of adult COppm exposure data, at Baseline, Round 2 and Round 3 by intervention group, Vatomandry



10.3. Post intervention personal predicted $PM_{2.5}$ levels in Adults

The median (IQR) values for adult predicted $PM_{2.5}$ in Ambositra are shown for each of the five study groups at Round 2 and 3 in Table 10.5, and the distributions in Figure 10.3. At both Round 2 and Round 3, the Ethanol group had significantly lower levels of predicted $PM_{2.5}$ in comparison with the other intervention groups and control. In comparison with Baseline, only the ethanol group showed any substantial reductions (p=<0.001 for difference between both Baseline and Rounds 2 and 3 See Table 10.6). These changes are clearly illustrated in Figure 10.3.

Table 10.5: Median (IQR) predicted $PM_{2.5}$ ($\mu g/m^3$) levels by intervention groups: Adults in Ambositra

	Intervention Group				P value*
Baseline	**Ethanol (n=29)**	**Charcoal (n=27)**	**Awareness (n=32)**	**Control (n=22)**	
	87.9 64.8- 148.1	99.3 75.6- 155.0	88.6 75.2- 132.0	112.1 71.3- 177.0	0.800
Round 2	**(n=32)**	**(n=30)**	**(n=31)**	**(n=35)**	
	48.9 45.5- 55.5	92.6 53.3- 152.7	119.3 68.6- 195.1	107.2 63.1- 148.1	<0.001
Round 3	**(n=29)**	**(n=30)**	**(n=32)**	**(n=30)**	
	52.3 49.7- 60.2	102.7 74.5- 171.6	122.7 85.1- 200.8	140.8 95.6- 218.3	<0.001

**P-value from Kruskal-Wallis test to compare all groups within each Round*

Figure 10-3: Distributions of adult predicted $PM_{2.5}$ ($\mu g/m^3$) at Baseline, Round 2 and Round 3 by intervention group - Ambositra

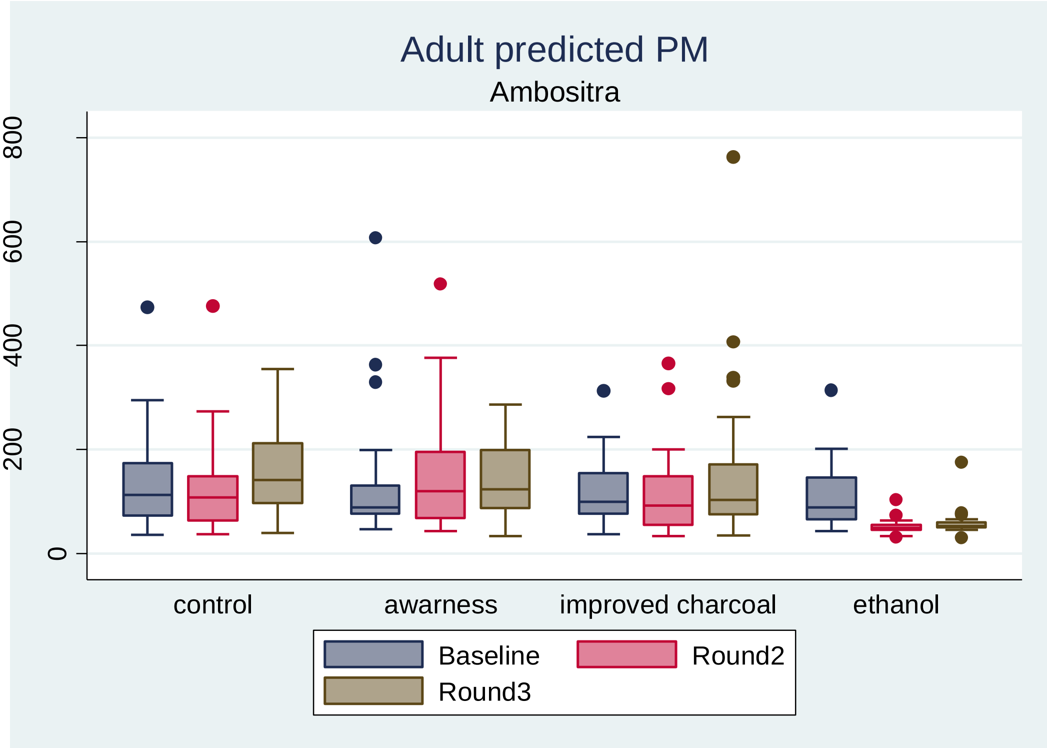


Table 10.6 Ambositra - Adult median (IQR) values for predicted $PM_{2.5}$ ($\mu g/m^3$ exposure, for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group			
	Ethanol	Charcoal	Awareness	Control
Round 2	n=29	n=27	n=31	n=21
	-37.5	-10.3	10.2	-3.7
	-92.9, -19.2	-35.9, 53.8	-34.6, 61.0	-60.3, 37.3
P value*	<0.001	0.648	0.399	0.876
Round 3	n=26	n=27	n=31	n=18
	-34.5	19.1	7.8	14.5
	-64.2, -13.3	-43.0, 41.5	-20.9, 44.5	-36.8, 103.9
P value**	<0.001	0.349	0.347	0.327

*Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3*

In Vatomandry, as expected from the reductions in personal CO exposure, the average (median IQR) of predicted PM_2 in the wood stove group was reduced from the Baseline level of 81.9 µg/m3 (62.6-124.4) to 43.7µg/m^3 (34.4-88.8) at Round 2 with a slight rebound seen at Round 3 to 53.4µg/m^3 (34.9-133.7). (P value from paired test comparing Baseline and Round 2 p=0.02 and Baseline and Round 3 p=0.452)

10.4. Summary analysis: Adult personal exposure

10.4.1. Methods for Summary Analysis

In order to summarise the effects of the interventions on personal exposure, to make use of all of the available data, and to allow for the possible effect of confounding and changing circumstances over the course of the study, a multiple regression approach has been used. Generalised estimating equations (GEE) with robust variability estimation were calculated for longitudinal modelling of personal exposure data for adults and children, using xtgee in Stata, version 9.

This summary analysis of effects on exposure has been applied to both the measured COppm and – for Ambositra only - the predicted $PM_{2.5}$ data (as predicted $PM_{2.5}$ in Vatomandry has only been analysed for the wood group it has not been included in this summary analysis of all five groups). The analyses have been carried out with untransformed and log(n) transformed distributions, due to the predominantly (but not exclusively) positively skewed distributions of exposure data: this allows comparison and identification of any important differences in conclusions that may arise from these properties of the exposure data distributions.

Results are presented as the difference between each individual intervention group, and the control group, for example 'Awareness vs. Control', and 'Ethanol vs. Control'. Further commentary on the results is provided with the respective tables.

Comparisons between interventions have been made including the Baseline data, which provides summary estimates of intervention effects, allowing for any differences between groups at Baseline.

Results are presented in two ways, **first** without any adjustment for other variables, and **second** adjusting for a number of variables. The variables (confounding factors) are of two types, (i) those which are fixed over the whole period of the study (termed 'fixed covariates'), and (ii) those which vary between rounds (termed 'time-varying covariates'), and are listed in the table below:

Table 10.7: Variables Adjusted for in the Summary Analysis

Fixed Covariates			Time-varying covariates		
Variable	Model included in:		Variable	Model included in:	
	Mother	Child		Mother	Child
Age of mother	X	X	Season (wet vs. dry)	X	X
Age of child		X	Adult male equivalents cooked for	X	X
Asset index (range 2-9)	X	X	Kitchen location (separate vs. joined to/in house)	X	X
Marital status	X	X			
Income (4 categories based on income distribution in each study location)	X	X	Location of child while cooking (kitchen vs. outside kitchen)		X

These variables were selected apriori as variables that were likely to be associated with the outcomes (exposure to CO/PM) and therefore could confound the relationship between intervention and exposure. Asset index was used as a proxy for socio-economic status.

10.4.2. Results from summary analysis: Adult Personal Exposure (including Baseline)

The summary results in the tables below show the effects of each intervention on personal COppm and predicted $PM_{2.5}$ compared to the Control group, and (in the adjusted parts of the tables) allowing for the effects of fixed and time-varying confounding factors. For each site, results are given for adults (first untransformed data, then transformed – see explanation below), and then for children. The results are presented separately for Ambositra and Vatomandry.

The information provided is the beta value (regression coefficient, or β value), which is the effect estimate in the units of the pollutant being studied. This is followed by the 95% confidence interval, and then the p-value. Thus, for CO exposure with Improved Charcoal among adults in Ambositra, the adjusted effect was to reduce exposure by 1.68 ppm compared with the Control Group, with a 95% CI of -6.04 to +2.69, and a p-value of 0.45 (non-significant). This allows for any confounding, and also any imbalances in the Baseline exposure and characteristics.

For the log(n) transformed values some further interpretation is given. Since these are based on log values of exposure, the regression results represent the proportionate reduction in exposure compared to the control group. To obtain this proportion, it is necessary to take the exponential ($\log(n)^x$) of the values in the tables. For example, for Ethanol CO (adjusted), the untransformed result is a reduction of 8.54 ppm compared with the control group (Table 10.8). The log transformed result is -1.36 (-1.841, -0.878) (not shown please see Annex 20 for full data from GEE analysis), so the proportionate reduction is $\log(n)^{-1.360}$ = 0.257 or a 74.3% reduction. The 95% CI, expressed as a percentage reduction is 58.4% to 84.1%, and this is significant at $p<0.0005$, averaged over Rounds 2 and 3. The tables present these proportionate reductions in exposure together with associated confidence intervals.

10.4.3. Summary Analysis of Personal Exposure levels in Adults: Ambositra

The results for Ambositra show that only Ethanol achieved substantial and statistically significant reductions in adult CO and $PM_{2.5}$ exposure, and these reductions were 8.5 ppm for CO and 71 µg/m^3 for predicted $PM_{2.5}$. These findings are confirmed by both untransformed and log transformed analyses, and are highly significant ($p<0.0005$). The percentage reductions for the ethanol group are 74.3% for CO and 45.3% for $PM_{2.5}$.

Table 10.8: Adult Exposure by Intervention (no transformation) for Ambositra

Intervention	Adult CO			Adult $PM_{2.5}$		
	B	95% CI	p value	β	95% CI	p value
Unadjusted						
Awareness	-1.116	-4.671, 2.439	0.538	-4.0	-33.2, +25.2	0.790
Improved Charcoal	-1.387	-5.375, 2.601	0.495	-10.9	-43.7, +22.0	0.517
Ethanol	-8.208	-11.17, -5.247	<0.0005	-68.0	-90.1, -45.9	<0.0005
Adjusted*						
Awareness	-1.367	-5.442, 2.708	0.511	-6.6	-39.9, +26.7	0.698
Improved Charcoal	-1.676	-6.042, 2.689	0.452	-13.6	-49.5, +22.4	0.460
Ethanol	-8.543	-12.14, -4.947	<0.0005	-71.0	-98.1, +44.0	<0.0005

***Adjusted for**

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), season (wet vs dry). Fixed covariates: asset index (1-9), marital status, age, income (4 categories)

Table 10.9: Adult Exposure by Intervention (log(n) transformed) shown as % difference between intervention groups relative to control group for Ambositra

Intervention	Adult CO			Adult $PM_{2.5}$		
	%	95% CI	p value	%	95% CI	p value
Unadjusted						
Awareness	-5.7	-32.8, +32.2	0.733	-2.9	-21.2, +19.6	0.784
Improved Charcoal	-18.3	-42.4, +16.1	0.260	-10.9	-28.4, +11.1	0.306
Ethanol	-75.1	-83.6, -62.1	<0.0005	-45.2	-53.5, -34.7	<0.0005
Adjusted*						
Awareness	-7.9	-37.4, +35.4	0.675	-4.5	-24.7, +21.2	0.705
Improved Charcoal	-20.9	-46.9, +17.6	0.246	-12.5	-31.7, +12.2	0.293
Ethanol	-74.3	-84.1, -58.4	<0.0005	-45.3	-56.0, -32.1	<0.0005

***Adjusted for**

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), season (wet vs dry). Fixed covariates: asset index (1-9), marital status, age, income (4 categories)

10.4.4. Summary Analysis of Personal Exposure levels in Adults: Vatomandry

Table 10.10 shows the GEE analysis for adult 24-hr COppm exposure by intervention status for Vatomandry using both untransformed and log(n) transformed distributions. Using the untransformed data, only the improved wood intervention achieved a significant reduction in CO compared with the Control group (p=0.047), although the reduction in CO for the ethanol group was also of borderline significance (p=0.061). Both interventions reduced CO exposure by a Round 0.50 ppm. The transformed analyses found that both improved wood and ethanol interventions significantly reduced COppm (p<0.005), these different statistical results being a consequence of the skewed distributions referred to earlier: the p-value from the transformed analysis will generally be the more reliable. The reductions in CO were 45.3% and 53.9% for wood and ethanol respectively. Due to the very low levels and ranges of COppm in Vatomandry and uncertainty in the CO- $PM_{2.5}$ relationships, calculation of predicted $PM_{2.5}$ for all groups was not carried out and therefore could not be included in this combined analysis.

Table 10.10: Adult 24-hr COppm exposure by intervention group (no transformation and ln transformation - shown as % difference between intervention groups relative to control group) for Vatomandry

Intervention	Adult CO (no transformation)			Adult CO (ln transformation)		
	B	95% CI	p value	%	95% CI	p value
Unadjusted						
Awareness	0.359	-0.401, 1.119	0.354	+0.9	-35.3, +57.3	0.969
Improved Charcoal	0.569	-0.215, 1.353	0.155	+10.2	-30.1, +73.8	0.675
Improved Wood	-0.367	-0.850, 0.115	0.136	-39.3	-60.8, -5.8	0.026
Ethanol	-0.306	-0.779, 0.167	0.205	-49.5	-67.5, -21.5	0.002
Adjusted*						
Awareness	0.226	-0.558, 1,010	0.572	-7.6	-40.6, +43.6	0.725
Improved Charcoal	0.416	-0.340, 1.171	0.281	+6.5	-32.3, +67.5	0.784
Improved Wood	-0.524	-1.041,-0.006	0.047	-45.3	-63.8, -17.6	0.004
Ethanol	-0.510	-1.044, 0.024	0.061	-53.9	-69.8, -29.6	<0.0005

***Adjusted for**

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), season (wet vs. dry). Fixed covariates: asset index (1-9), marital status, age, income (4 categories)

Note: Please see Section 11.7 for a discussion of adult personal exposure at follow-up.

11. Child Personal Exposure at Follow-Up

11.1. Location of child during cooking

As discussed earlier, the location of the child during cooking has a significant impact on their exposure to CO and PM. At baseline children in Ambositra were more likely to be in the kitchen (64.0%) than those in Vatomandry (50.0%). . The pattern of location is very similar to that seen at Baseline with children in Ambositra still more likely to be in the kitchen (51.1%) than in Vatomandry (41.0%). However these % were lower at follow up which maybe the result of the child becoming older and able to move away from its mother or there could be a number of other explanations including the change in seasons.

Figure 11.1 and 11.2 shows the child's usual location during cooking for both study sites at follow-up by intervention group. The children at in the ethanol group at both locations were the most likely to be in the courtyard- with the charcoal stove participants keeping their children in the kitchen the most in Ambositra and control group in Vatomandry. Any confounding effect that the location of the child may have on the comparison of exposure levels between groups has been taken in to consideration in the summary analysis presented at the end of this section.

Figure 11-1: Location of child during cooking in Ambositra: Round 3

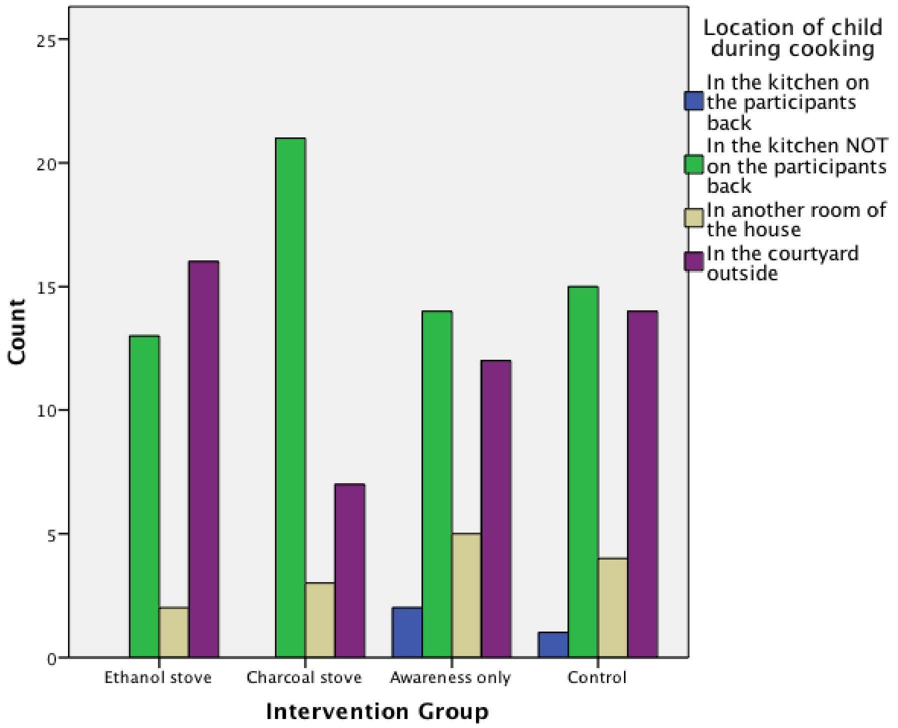
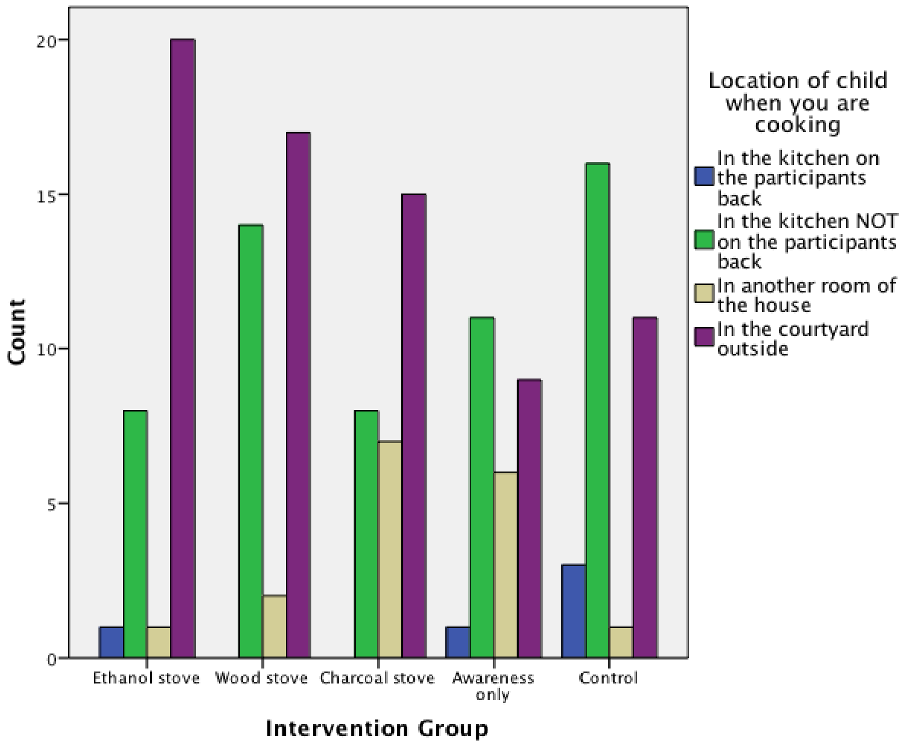


Figure 11-2: Location of child during cooking in Vatomandry: Round 3



11.2. Post intervention: Personal CO Levels in Children: Ambositra

The median (IQR) values for child 24-hr COppm exposure in Ambositra are shown for each of the four study groups in Table 11.1. Consistent with the results for the adults, child exposure in the ethanol group had considerably lower average CO levels compared with the other three groups, which did not show any important differences. Overall differences among the four groups were highly statistically significant, principally due to the much lower median in the ethanol group.

Table 11.1: Ambositra - Child median (IQR) values for 24-hr CO exposure (ppm), for intervention groups at all study Rounds.

	Intervention Group				P value*
Baseline	Ethanol (n=31)	Charcoal (n=29)	Awareness (n=33)	Control (n=24)	
	4.06 (1.50-8.04)	5.01 (3.38-9.65)	4.40 (2.91-7.59)	8.77 (3.10-14.4)	0.213
Round 2	**(n=30)**	**(n=30)**	**(n=33)**	**(n=36)**	
	1.26 0.60-3.50	4.40 3.11-8.88	6.30 2.54-11.21)	6.30 3.19-11.37)	<0.001
Round 3	**(n=31)**	**(n=31)**	**(n=33)**	**(n=34)**	
	2.26 1.26-4.40	7.60 4.76-13.02	7.15 3.74-12.10	8.56 3.98-18.72	<0.001

**P-value from Kruskal-Wallis test to compare all groups within each round*

The average (median, interquartile range) values for child CO 24-hr exposure in the four intervention groups at Baseline, Round 2 and Round 3 are shown in Table 11.2, and the distributions in Figure 11.3. In order to make valid comparisons, only homes present at comparison Rounds (Baseline & Round 2 and Baseline & Round 3) are included in the table and for hypothesis testing, so dropouts and any replacement homes are excluded.

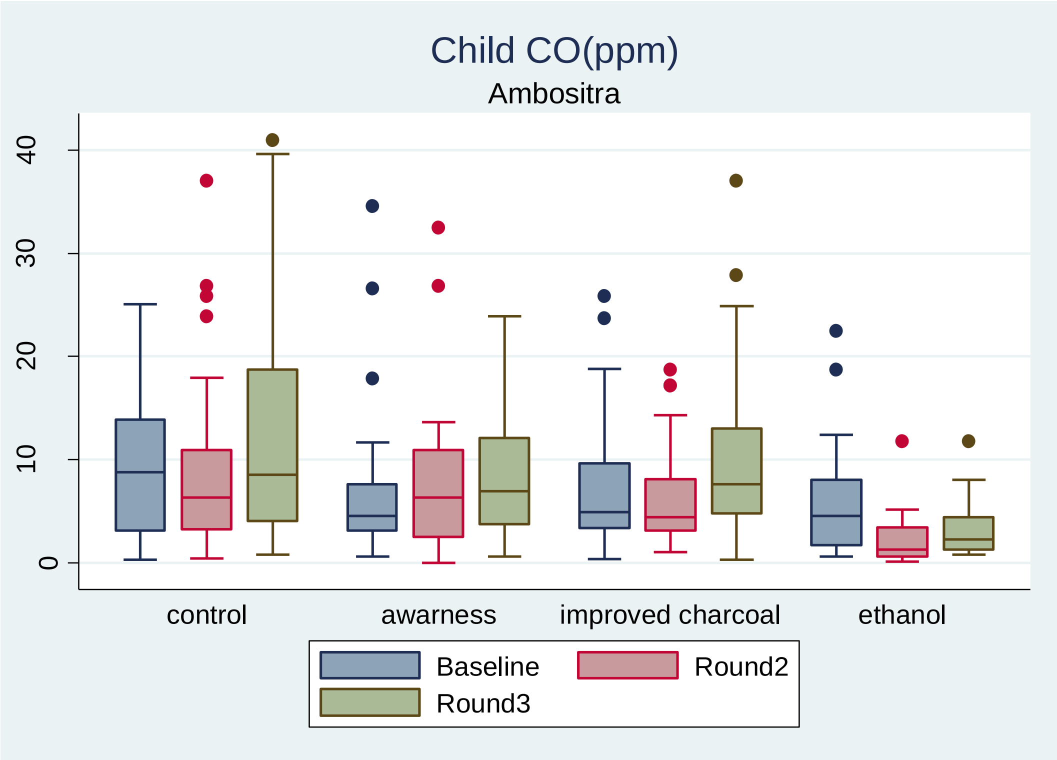
The ethanol intervention group demonstrated a significant reduction in average COppm at both Round 2 ($p<0.0005$) and Round 3 ($p=0.046$). There was no evidence of a reduction in COppm at either follow up Round for the other three intervention groups ($p>0.05$).

Table 11.2: Ambositra - Child median (IQR) values for 24-hr CO exposure (ppm), for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group			
	Ethanol	Charcoal	Awareness	Control
Round 2	n=30	n=28	n=33	n=24
	-2.68 -6.65, -0.48	-0.27 -4.60, 2.54	0.36 -0.85, 4.64	1.01 -7.72, 4.08
P value*	<0.0005	0.569	0.242	0.819
Round 3	n=30	n=29	n=33	n=22
	-0.64 -4.83, 1.03	0.67 -2.67, 5.86	1.07 -1.45, 5.97	2.15 -4.55, 8.76
P value**	0.046	0.230	0.050	0.211

*Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3.*

Figure 11-3: Distributions of child 24-hr COppm exposure data, at Baseline, Round 2 and Round 3 by intervention group, Ambositra



* One outlier was excluded (for the awareness group in Round 2 a value of 78.8 COppm was removed to produce the chart). This had very little impact on the illustrated median.

11.3. Post intervention: Personal CO Levels in Children: Vatomandry

The median (IQR) values for child CO exposure in Vatomandry are shown for each of the five intervention groups in Table 11.3. Overall levels of personal COppm were low, and there were no important or statistically significant differences between the groups.

Table 11.3: Median child CO ppm (IQR), Vatomandry.

Base-line	Ethanol (n=31)	Wood (n=31)	Charcoal (n=32)	Awareness (n=27)	Control (n=23)	P value*
	0.59 (0.09-1.02)	0.29 (0.09-0.78)	0.28 (0.09-0.58)	0.28 (0.00-1.03)	0.28 (0.09-1.02)	0.519
Round 2	**(n=32)**	**(n=33)**	**(n=32)**	**(n=31)**	**(n=32)**	
	0.60 0.19-0.81	0.39 0.19- 0.81	0.60 0.29- 0.81	0.81 0.39- 0.81	0.60 0.29- 0.81	0.470
Round 3	**(n=30)**	**(n=32)**	**(n=30)**	**(n=27)**	**(n=31)**	
	0.60 0.47-1.15)	0.60 0.30- 0.98	0.81 0.57-2.00	0.81 0.39- 1.03	0.81 0.39- 1.50	0.072

***P-value from Kruskal-Wallis test to compare all groups within each round*

The average (median, interquartile range) values for child COppm 24-hr exposure in the five study groups at Baseline, Round 2 and Round 3 are shown in Table 11.4, and the distributions in Figure 11.4.

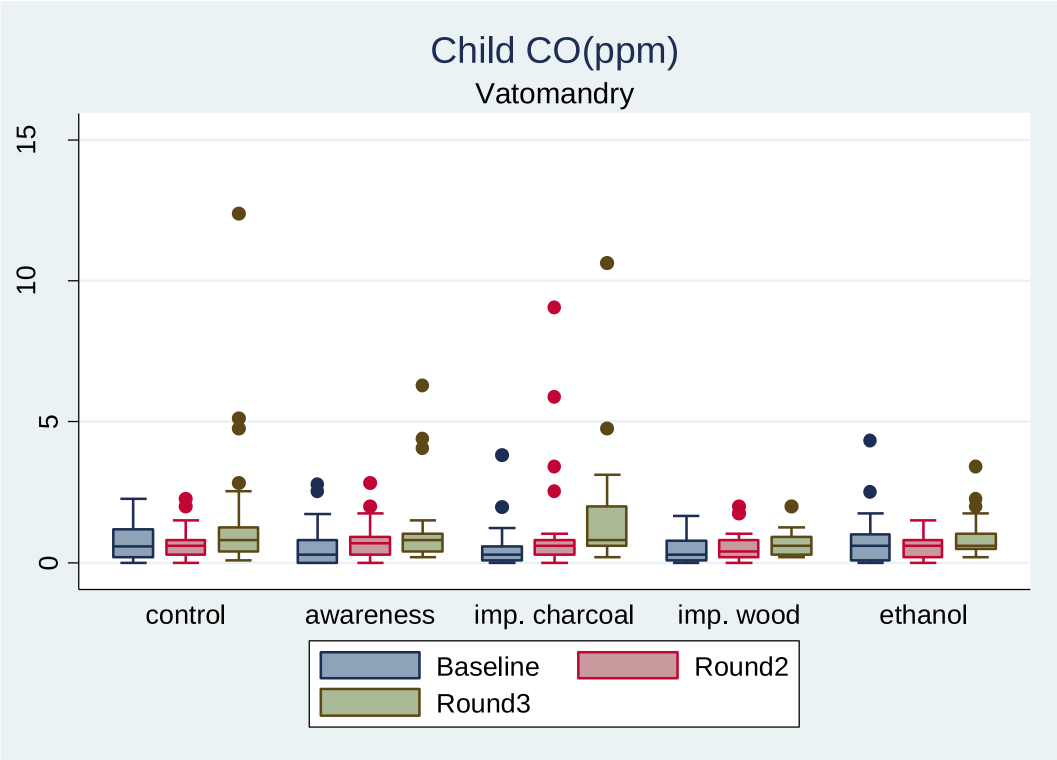
Only the ethanol group showed a reduction in COppm at Round 2, although not statistically significant. The charcoal group shows a significant increase in COppm at both Round 2 (p=0.03) and Round 3 (p=0.001). In fact the child exposure results were characterised by unexplained increases in measured levels of CO exposure in all groups over the course of study (Table 11.4). This will be discussed further in Section 11.7:Discussion of Follow Up Exposure of Women and Children.

Table 11.4: Vatomandry - Child median (IQR) values for 24-hr CO exposure (ppm), for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group: Ethanol	Wood	Charcoal	Awareness	Control
Round 2	n=31	n=31	n=32	n=27	n=23
	-0.10 -0.60, 0.21	0.02 -0.37, 0.52	0.20 -0.16, 0.58	0.09 -0.28, 0.53	0.09 -0.64-0.60
P value*	0.122	0.427	0.032	0.161	0.709
Round 3	n=30	n=31	n=30	n=24	n=23
	0.22 -0.59, 0.61	0.11 -0.20, 0.53	0.66 -0.18, 1.58	0.31 -0.29, 0.74	0.25 0.001, 1.41
P value**	0.688	0.147	0.001	0.016	0.050

** Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3*

Figure 11-4: Distributions of child CO exposure data, at Baseline, Round 2 and Round 3 by intervention group, Vatomandry



11.4. Post intervention: predicted $PM_{2.5}$ levels in Children

The median (IQR) values for children's predicted $PM_{2.5}$ in Ambositra are shown for each of the five study groups at Round 2 and 3 in Table 11.5, and the distributions in Figure 11.5. Large significant differences can be seen between groups in Round 2 (p=<0.001) and Round 3 (p=<0.001) with the largest reduction seen in the ethanol group.

Table 11.5: Median (IQR) predicted $PM_{2.5}$ (μg/m^3) levels by intervention groups: Children in Ambositra

	Intervention Group				P value*
Baseline	**Ethanol (n=31)**	**Charcoal (n=29)**	**Awareness (n=33)**	**Control (n=24)**	
	63.3 (42.3- 95.9)	71.1 (57.7- 109.1)	66.1 (53.8- 96.0)	101.9 (55.4- 148.3)	0.255
Round 2	**(n=30)**	**(n=29)**	**(n=33)**	**(n=36)**	
	49.0 46.6- 57.1	66.1 55.5- 109.2	81.6 50.8- 121.9	81.6 56.2- 123.2	<0.001
Round 3	**(n=31)**	**(n=31)**	**(n=33)**	**(n=34)**	
	52.6 49.0- 60.4	92.3 69.0- 136.8	88.7 60.6- 129.2	100.2 62.6- 183.5	<0.001

**P-value from Kruskal-Wallis test to compare all groups within each round*

Figure 11-5: Distributions of child predicted $PM_{2.5}$ (μg/m^3) at Baseline, Round 2 and Round 3 by intervention group - Ambositra

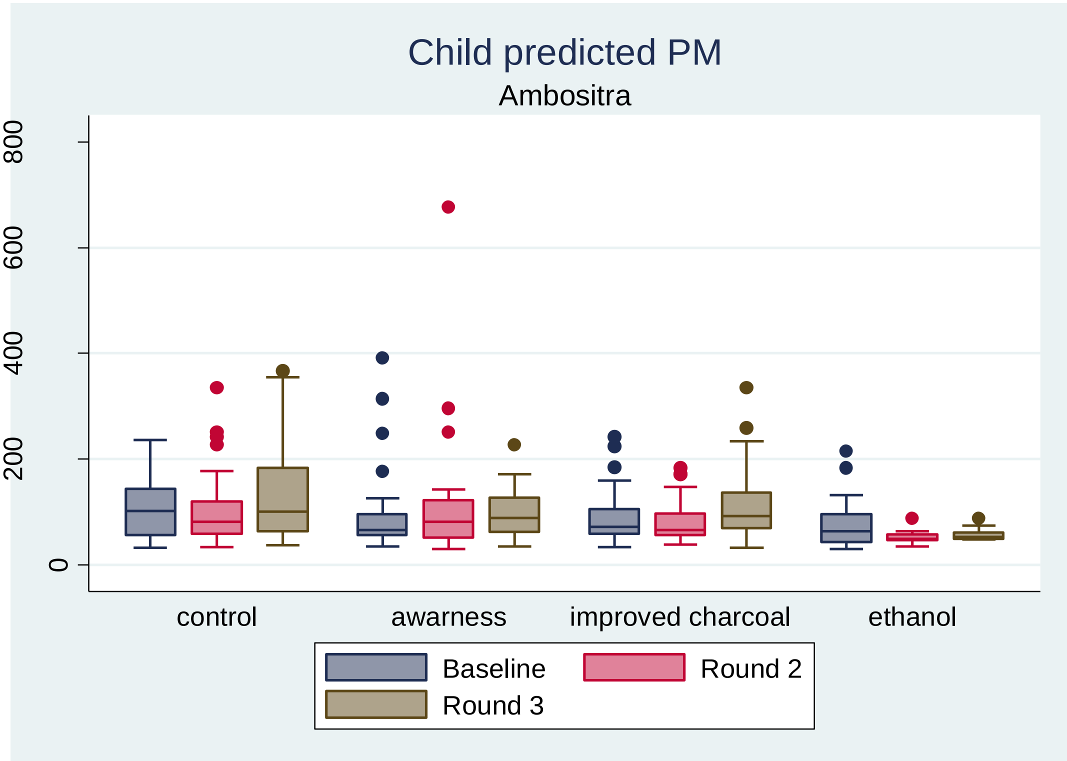


Table 11.6 shows that the only significant reductions in predicted $PM_{2.5}$ are seen for the ethanol stove group that were highly significant (<0.001) at Round 2 but were also significant (p=0.02) at Round 3.

Table 11.6: Ambositra - Child median (IQR) values for 24-hr predicted PM $_{2.5}$ (μg/m^3), for difference between Baseline and Rounds 2 and 3 (Round 2 and Round 3 levels minus Baseline)

Study Stage	Intervention Group			
	Ethanol	Charcoal	Awareness	Control
Round 2	n=30	n=28	n=33	n=24
	-14.1	-2.2	3.0	8.3
	-43.5, 4.1	-37.7, 20.8	-7.0, 38.1	-63.3, 33.4
P value*	<0.001	0.569	0.304	0.819
Round 3	n=30	n=29	n=33	n=22
	-10.5	5.5	8.7	17.7
	-40.4, 10.3	-21.9, 48.1	-11.9, 49.0	-37.3, 71.8
P value**	0.02	0.230	0.09	0.211

*Wilcoxon signed rank test * Comparing Baseline and Round 2. **Comparing Baseline and Round 3*

In Vatomandry the average (median IQR) of predicted $PM_{2.}$ for children in the wood stove group was slightly up from the Baseline level of 44.2μg/m^3 (28.4-82.9) to 52.2μg/m^3 (35.6-85.6) at Round 2 with another increase seen at Round 3 to 68.6μg/m^3 (44.2-103.2). Neither increase was statistically significant from the Baseline levels (Wilcoxon signed rank test for comparing Baseline to Rounds 2 p=0.596 and for Baseline to Round 3 p=0.136)

11.5. Results from summary analysis: Child personal Exposure (including Baseline): Ambositra

For child exposure in Ambositra, only the ethanol stove resulted in statistically significant reductions in exposure to COppm and predicted $PM_{2.5}$; reductions of 7.03 ppm for CO and 56.0 μg/m3 for $PM_{2.5}$ were observed (both p<0.0005) (Table 11.7).

Table 11.7: Child Exposure by Intervention (no transformation) for Ambositra

Intervention	Child CO β	Child CO 95% CI	Child CO p value	Child $PM_{2.5}$ β	Child $PM_{2.5}$ 95% CI	Child $PM_{2.5}$ P value
Unadjusted						
Awareness	-2.197	-5.383, 0.989	0.177	-14.9	-41.0, +11.2	0.264
Improved Charcoal	-2.304	-5.100, 0.490	0.106	-18.6	-41.6, +4.4	0.112
Ethanol	-6.657	-9.094,-4.221	<0.0005	-54.5	-72.9, -34.1	<0.0005
Adjusted*						
Awareness	-2.306	-5.829, 0.789	0.200	-15.7	-44.5, +13.1	0.285
Improved Charcoal	-2.560	-5.680, 0.458	0.108	-20.6	-46.2, +4.9	0.114
Ethanol	-7.034	-9.888, -4.180	<0.0005	-56.0	-78.9, -33.0	<0.0005

Adjusted for

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), location of child whilst cooking, season (wet vs dry). Fixed covariates: asset index (1-9), marital status, mother's age, child's age, income (4 categories)

These highly significant reductions were confirmed in the analysis using ln transformed data (Table 11.8), which showed 63% reduction in CO and 40% reduction in predicted $PM_{2.5}$.

Table 11.8: Child Exposure by Intervention (ln transformation) shown as % difference between control group and intervention groups for Ambositra

Intervention	Child CO %	Child CO 95% CI	Child CO p value	Child $PM_{2.5}$ %	Child $PM_{2.5}$ 95% CI	Child $PM_{2.5}$ p value
Unadjusted						
Awareness	-15.7	-41.8, +22.1	0.367	-13.0	-29.5, +7.5	0.197
Improved Charcoal	-13.3	-38.9, +22.9	0.422	-11.8	-27.7, +7.7	0.218
Ethanol	-63.4	-75.0, -46.3	<0.0005	-39.3	-49.1, -27.7	<0.0005
Adjusted*						
Awareness	-17.8	-44.5, +21.7	0.326	-13.5	-31.1, +8.8	0.215
Improved Charcoal	-17.5	-42.4, +18.1	0.293	-13.2	-29.9, +7.4	0.191
Ethanol	-63.5	-75.5, -45.7	<0.0005	-39.6	-50.4, -26.5	<0.0005

***Adjusted for**

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), location of child whilst cooking, season (wet vs dry). Fixed covariates: asset index (1-9), marital status, mother's age, child's age, income (4 categories)

11.6. Results from summary analysis: Child Personal Exposure (including Baseline): Vatomandry

In Vatomandry, only the Improved Wood intervention resulted in significantly lower COppm than in the controls, 0.46 ppm adjusted reduction (p=0.013). The transformed analyses confirmed the significant reduction of 31% in CO for Improved Wood (p=0.010).

Table 11.9: Child 24-hr COppm exposure by intervention group (no transformation and ln transformed distributions – shown as % difference between control and intervention groups) for Vatomandry

Intervention	Child CO (no transformation) β	Child CO (no transformation) 95% CI	Child CO (no transformation) P value	Child CO (ln transformation) %	Child CO (ln transformation) 95% CI	Child CO (ln transformation) P value
Unadjusted						
Awareness	-0.118	-0.485, 1.119	0.527	+0.5	-26.1, +36.8	0.974
Improved Charcoal	+0.188	-0.312, 1.353	0.461	+8.1	-21.2, +48.1	0.630
Improved Wood	-0.381	-0.709, 0.115	0.023	-23.4	-41.5, +0.2	0.051
Ethanol	-0.183	-0.529, 0.167	0.301	-4.8	-28.9, +27.5	0.742
Adjusted*						
Awareness	-0.207	-0.608, 0.194	0.312	-9.3	-33.6, +24.0	0.540
Improved Charcoal	+0.133	-0.368, 0.633	0.604	-2.6	-30.7, +36.9	0.879
Improved Wood	-0.459	-0.821,-0.096	0.013	-31.1	-48.2, -8.5	0.010
Ethanol	-0.224	-0.573, 0.126	0.210	-14.4	-37.3, +16.8	0.325

***Adjusted for**

Time varying covariates: adult male equivalent cooked for, kitchen location (separate vs joined), location of child whilst cooking, season (wet vs dry). Fixed covariates: asset index (1-9), marital status, mother's age, child's age, income (4 categories)

The Beta-coefficients show the average reductions in exposure over the two rounds in each of the intervention groups relative to the control group, adjusted for the potential confounders. It was noted that, in the univariate analyses (Table 11.3), the personal CO exposure increased between baseline and Round 2 and 3 in the control group, and also in the intervention groups, although to a lesser extent. In the ethanol group there was little change between the baseline and post-intervention rounds. This explains why, in the summary multivariate analysis, there appears to be reductions in personal CO for both ethanol and wood interventions, as relative to the changes in the control group (which was an increase), there were important reductions in exposure levels in the ethanol and wood groups.

11.7. Discussion of Follow-up Exposure of Women and Children

Exposure in Women

In Ambositra the very clear finding was that only the ethanol intervention reduced the exposure levels in the women. In this group there was a quite substantial reduction of 75% for the exposure to CO and 45% for the predicted $PM_{2.5}$. The median post intervention level of predicted $PM_{2.5}$ was approx 50µg/m^3. (The WHO indoor air quality guidance for 24hr mean levels of $PM_{2.5}$ is 25µg/m^3 and the per annual average is 10µg/m^3 [10])

For Vatomandry the exposure levels of CO are much lower. The reductions in CO were 45.3% and 53.9% for wood and ethanol stoves respectively. For predicted $PM_{2.5}$, which was only calculated for the wood stove intervention group in this location, there was a reduction from 80µg/m^3 at baseline to 50µg/m^3 at follow up (P value from paired test comparing Baseline and Round 2 p=0.02 and Baseline and Round 3 p=0.452)

Exposure in Children

The impacts of the interventions on the exposure levels in the children in Ambositra reflected the adults very closely with again only the ethanol intervention resulting in substantial reductions. These were a 60% reduction in CO and 40% in predicted $PM_{2.5.}$ A post intervention level of exposure to predicted $PM_{2.5.}$ of around 50µg/m^3 was seen.

In Vatomandry the child exposure results were characterised by unexplained increases in measured levels of CO exposure in all groups over the course of study. In the summary comparative analysis relative to the control group (which showed increased levels of exposure) the wood stove group significantly and the ethanol stove group, somewhat less (non-significantly) did reduce exposure. The reasons for this absolute increase over time are however unclear although there are a number of possible explanations. One of these is the increase over the course of the study in the compliance in wearing the CO monitors. However this is unlikely to be an important factor as changes were quite small. Another explanation

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[10] WHO (World Health Organisation). 2006. WHO Air Quality Guidelines: Global Update for 2005. Copenhagen: World Health Organisation Regional Office for Europe.

With the type and amount of data collected for this study (e.g. 2 post intervention measurements), it is reasonable to compare with either the annual or the 24-hr WHO indoor Air Quality Guidelines. The annual measurement is the 'annual mean', which the average value presented in this study provides a good estimate of, given that it was measured in two seasons on 30+ homes. The 24 hr mean level is the 99% level, so gives an idea of what individual homes should not exceed, more than occasionally (3 occasion/year).

could be external to the immediate home environment, for example seasonal factors, which will affect all homes in the community in the same way. The baseline results may, for example, have been atypically low, for reasons we do not have information on. This emphasises the value of including a control group in the study, and the safest interpretation of these results is to conclude that, relative to home with no specific intervention, the ethanol and wood groups did achieve a reduction in child exposure levels in Vatomandry. However this was at best small, possibly due to children being outdoors at lot more.

The notably lower exposure levels and better ventilation in Vatomandry would suggest that any future studies in this type of setting need larger numbers with repeated monitoring to overcome the imprecision created by the day to day variation in these factors.

12. Baseline Health related issues

12.1. Women's Health

As discussed in the proposal and inception report, the assessment of women's respiratory health was conducted at baseline only in order to contribute to estimates of chronic bronchitis and COPD in the communities concerned. The sample size and timeframe in the post-intervention sub-groups would not have been sufficient to allow useful analysis of changes. For other (generally much more common symptoms), namely eye irritation and headache, it was proposed to study the impacts of the interventions, and this has been done. The frequency, severity and causes of burns to women were also assessed, and the impact of interventions on risk of burns was also monitored post-intervention, although at the planning stage it was not anticipated that changes could be demonstrated due to what was expected to be a relatively low incidence of burns and the available sample sizes in each intervention group.

12.1.1. Respiratory symptoms

The key symptoms indicating chronic bronchitis (CB) and risk of chronic obstructive pulmonary disease (COPD), namely cough, phlegm and shortness of breath (on exertion) were combined (as indicated below) to study the prevalence of these symptoms in the two study areas, and by type of fuel. As age is usually an important determinant of prevalence of these symptoms, results are shown by age group as well as overall.

As COPD is associated with airflow limitation, the Global Initiative for Chronic Obstructive Lung Disease (GOLD) Guidelines[11] advocates that spirometry is essential for the diagnosis of this disease. However, obtaining robust spirometric data collection in a field situation is resource intensive and beyond the scope of this study. We are therefore not aiming to identify people with COPD. Instead we have used the symptomatic aspects of the GOLD staging of COPD to define two outcomes representing earlier and later stages of chronic respiratory disease. The first or 'early stage chronic respiratory symptoms' is defined as women with morning cough and phlegm for 3 months of the year for 2 or more years. The GOLD Guidelines describe this as a clinically and epidemiologically useful term for chronic bronchitis. This chronic cough and sputum production may precede the development of airflow limitation by several years and if early intervention occurs at this point to remove the exposure, the progression of disease can be slowed or stopped altogether.

The second group, 'chronic respiratory symptoms' are defined as: women who are short of breath on exertion, with morning cough and phlegm for 3 months of the year for 2 or more years. This includes the symptoms that, according to the GOLD Guidelines are characteristic of moderate COPD, particularly the shortness of breath developing on exertion.

Chronic respiratory symptoms

The set of 'chronic respiratory symptoms' were reported overall by 2.1% of the women in Ambositra and 6.1% of the women in Vatomandry. This latter prevalence (Vatomandry) is moderately high for women with an average age of 31.7 years. There was some statistical evidence that these symptoms were more common in Vatomandry than Ambositra (p=0.076), but were clearly more common

[11] [http://www.goldcopd.com/index.asp?l1=1&l2=0]

in wood users (almost all in Vatomandry) (p=0.006), Table 12.1 (a) and (b). Results were the same in an analysis carried out exclusively on participants from Vatomandry. Examination of the prevalence rates by age showed that these differences are not explained by age effects, and that (somewhat surprisingly) the symptoms were if anything more common among the youngest age group (17-26 years).

Table 12.1(a): Prevalence (%) of chronic respiratory symptoms* by age group and study area

Age group	N	Ambositra	Vatomandry	p-value**
17-26	102	1.8	10.9	0.052
27-33	117	0.0	4.1	0.181
34 and older	105	4.4	5.0	0.895
Total	324	2.1	6.1	0.076

Table 12.1(b): Prevalence (%) of chronic respiratory symptoms* by age group and fuel type

Age group	N	Wood	Charcoal	p-value**
17-26	102	17.4	2.5	0.008
27-33	117	5.9	1.2	0.146
34 and older	105	7.0	3.2	0.375
Total	324	9.0	2.2	0.006

*Women who are short of breath on exertion, with morning cough and phlegm for 3 months of the year for 2 or more years
**Chi-squared test

Early stage chronic respiratory symptoms
Analysis was also carried out for ‘early stage chronic respiratory symptoms’, and showed very similar results, but with (as expected) slightly higher prevalence, Table 12.2(a) and (b). The higher prevalence in Vatomandry (8.9% vs. 2.8%) was now statistically more reliable (p=0.023), and also very clearly so for wood users (p=0.001) with an overall high prevalence of 13.1% vs. 3.1% for charcoal users. Again the results were similar in an analysis of data exclusively from Vatomandry.

Table 12.2(a): Prevalence (%) of early stage chronic respiratory symptoms* by age group and study area

Age group	Number	Ambositra	Vatomandry	p-value**
17-26	101	1.8	13.0	0.027
27-33	116	2.3	6.9	0.288
34 and older	105	4.4	8.3	0.429
Total	322	2.8	8.9	0.023

Table 12.2(b): Prevalence (%) of early stage chronic respiratory symptoms* by age group and fuel type

Age group	Number	Wood	Charcoal	p-value**
17-26	101	21.7	2.6	0.001
27-33	116	9.1	3.6	0.230
34 and older	105	11.6	3.2	0.090
Total	322	13.1	3.1	0.001

*Women who have morning cough and phlegm for 3 months of the year for 2 or more years
**Chi-squared test

Other respiratory symptoms including wheeze and chest tightness were included in the questionnaire. The prevalence of these symptoms was unexpectedly high, at over 40%. As these symptoms are notoriously difficult to describe, especially when working across languages, it would be valuable to carry out some further work to check the meaning and associated concepts of illness.. By contrast, terms for cough and phlegm are generally much more easily translated and clearly understood, and hence the results reported thus far should have reasonable validity.

Table 12.3 shows the average 24 hour exposure to CO in adult women by the prevalence of chronic respiratory symptoms and early stage chronic respiratory symptoms. In Ambositra women who reported having symptoms indicative of chronic and early stage chronic respiratory symptoms had a higher average CO exposure than those who did not, although differences were not statistically significant. Conversely, for Vatomandry, average CO exposure was actually significantly lower in women who reported having chronic and early stage chronic respiratory symptoms (although background levels of CO exposure in Vatomandry were generally low).

Table 12.3: Average CO exposure by occurrence of chronic and early stage chronic respiratory symptoms

Characteristic	Ambositra			Vatomandry		
	N	Median	IQR	N	Median	IQR
Chronic symptoms						
Yes:	3	17.7	3.2, 40.6	11	0.4	0.2, 0.7
No:	140	8.4	4.8, 14.1	169	0.9	0.5, 1.7
		P=0.360			P=0.004	
Early stage chronic symptoms						
Yes:	4	10.5	3.3, 29.2	16	0.5	0.3, 0.7
No:	138	8.4	4.9, 14.1	163	0.9	0.5, 1.7
		P=0.824			P=0.014	

One explanation for these findings in Vatomandry is the different fuels being used. As previously mentioned (in section on Personal Exposure), for any given level of CO, PM2.5 in wood users will be expected to be higher (possibly substantially higher) than for charcoal users, and PM is the key pollutant in respect of respiratory health effects. More consistent findings are seen for Ambositra, and this may be the result of dealing with only one fuel type so that the CO/PM2.5 relationship is more consistent across the sample of homes.

12.1.2. Headaches

Headaches were common, with 85% of women in Ambositra and 82% of women in Vatomandry, stating that they experienced headaches in the last 12 months. Of those who did have headaches, around one-third (32.8% in Ambositra and 37.2% in Vatomandry) believed that these were due to smoke from the fire.

In both centres, headaches were frequent, with around half of the women saying these occurred on a few days per week (35-39%) or more often (Table 12.4). Around one-third of the women in both centres stated that the headaches were 'very strong'. The frequency and severity of headaches was similar for users of wood and charcoal.

Table 12.4: Reported frequency and severity of headaches

Characteristic	Ambositra		Vatomandry					
			Total		Wood		Charcoal	
	N	%	N	%	N	%	N	%
Frequency of headaches								
Less than once a week	29	23.8	47	31.8	37	38.9	40	48.2
Once per week	21	17.2	32	21.6	22	23.2	10	12.1
Few days per week	48	39.3	52	35.1	28	29.5	24	28.9
Most days	11	9.0	3	2.0	1	1.1	2	2.4
Every day	12	9.8	14	9.5	7	7.4	7	8.4
Severity of headaches								
Mild	42	34.4	47	31.8	24	28.9	23	35.4
Fairly strong	39	32.0	47	31.8	29	34.9	18	27.7
Very strong	42	33.6	54	36.5	30	36.1	24	36.9

[1] % of those reporting headaches in last 12 months

Carbon monoxide may well be directly implicated in causing headaches. Table 12.5 shows the average adult CO exposure by headache frequency and severity in Ambositra and Vatomandry.

Table 12.5: Average CO exposure by frequency and severity of headaches

	Ambositra			Vatomandry		
	N	Median	IQR	N	Median	IQR

Frequency of headaches[1]						
Less than once a week	29	9.3	5.9, 15.3	47	0.8	0.4, 1.7
Once per week	21	5.1	3.2, 11.7	32	0.7	0.4, 1.7
Few days per week	47	8.2	4.9, 13.9	52	0.8	0.3, 1.4
Most days	12	9.9	6.0, 18.6	3	2.5	0.6, 22.8
Every day	12	11.3	6.2, 15.7	14	1.2	0.6, 3.7
		P=0.453*			P=0.146*	
Severity of headaches [1]						
Mild	42	9.7	5.7, 15.5	47	0.9	0.4, 1.9
Fairly strong	39	7.6	3.2, 14.1	47	0.7	0.4, 1.2
Very strong	21	5.6	3.1, 9.1	54	0.8	0.4, 2.4
		P=0.424*			P=0.326*	

*Kruskall Wallis hypothesis test [1] % of those reporting headaches in last 12 months

For both Ambositra and Vatomandry, levels of CO were slightly higher in women who reported having headaches more frequently (most days/ every day) although this was not statistically significant. There was no relationship between increasing severity of headaches with higher average exposure to CO.

12.1.3. Eye irritation

Eye irritation is caused by components of smoke such as aldehydes, but not by CO: these irritant gases are produced in greater quantities from wood burning than they are from charcoal.

Around half (50.9%) of the women in Ambositra reported eye irritation in the last 12 months while cooking, while in Vatomandry this was somewhat higher at 79.4%. Among those that did report eye irritation, there was also a difference in frequency between the two study areas. In Ambositra, for most (70%), eye irritation occurred on only a few of the times that she cooked, whereas in Vatomandry nearly half (43%) of the women stated this occurred half or more of the times she cooked and for 20% it was every time (Table 12.6). This appears to be related to the higher use of wood in Vatomandry as a significantly higher proportion of wood users (88%) reported eye irritation when cooking than charcoal users (56.7%); p<0.0005, which would be as expected given the greater emission of irritant gases from wood fuel.

Table 12.6: Reported frequency and severity of eye irritation

Characteristic	Ambositra	Vatomandry		
		Total	Wood	Charcoal

	N	%	N	%	N	%	N	%
Frequency of eye irritation*								
A few of the times I cook	51	69.9	82	57.3	40	47.1	42	72.4
About half of the times I cook	9	12.3	12	8.4	11	12.9	1	1.7
Most of the times I cook	6	8.2	21	14.7	16	18.8	5	8.6
Every time I cook	6	8.2	28	19.6	18	21.2	10	17.2
Severity of eye irritation*								
Mild	19	26.0	31	21.7	15	17.7	16	27.6
Moderate	45	61.6	86	60.1	53	62.4	33	56.9
Severe	8	11.0	26	18.2	17	20.0	9	15.5

* % of those reporting eye irritation when cooking

The severity of the irritation was described as 'moderate' by most women (around 60%), and this was similar in both areas. In Vatomandry, a higher proportion of wood users than charcoal users reported more frequent (p=0.008), and but there was no significant difference in reported severity between fuel types (p=0.35)).

Table 12.7 shows the average adult CO exposure in the study women by frequency and severity of eye irritation. There did not appear to be any relationship between levels of CO exposure with the experience of eye irritation from cooking in terms of frequency and severity. This finding may also be explained by the relationship between CO (which is not the irritant gas) and PM (and associated irritant gases from wood), as the latter can be expected to be higher in a wood-using home for a given level of CO than in a charcoal-using home.

Table 12.7: 24 hour average CO exposure (ppm) by frequency and severity of eye irritation

Characteristic	Ambositra			Vatomandry		
	No.	Median	IQR	No.	Median	IQR
Frequency of eye irritation when cooking						
A few of the times I cook	51	9.2	4.9, 14.1	82	0.9	0.5, 1.7
About half of the times I cook	8	11.7	3.3, 17.1	12	0.6	0.2, 0.9
Most of the times I cook	6	6.3	3.1, 7.4	21	0.6	0.3, 1.2
Every time I cook	6	7.2	3.8, 13.8	28	0.9	0.6, 1.6
		P=0.453*			P=0.146*	
Severity of eye irritation when cooking						
Mild	19	6.5	3.8, 11.7	31	1.1	0.6, 1.7
Moderate	44	9.9	5.04, 17.4	86	0.7	0.4, 1.3
Severe	8	7.4	5.91, 10.5	26	0.8	0.5, 1.8
		P=0.424			P=0.326	

**Kruskall Wallis hypothesis test*

12.1.4. Burns (women)

Almost one half of respondents, 47.9% in Ambositra and 47.8% in Vatomandry, reported that they had been burned or scalded in the last 12 months. The frequency, severity and causes are summarised in Table 12.8. The situation was quite similar in the two areas, with more than half (of those being burned, 55% in Ambositra and 69% in Vatomandry) reporting this had occurred one or two times in the last 12 months, but some reporting up to 20 or more occasions. Around 45% of these burns led to some scarring, 10% being ‘large’, defined as being as large, or larger, than 10 Ariary coin/lychee nut (this approach to describing severity is based on previously published work). A variety of reasons were given as causes of the burns/scalds, the most important being hot fuel falling from the fire, touching the hot stove, and being scalded when a pot fell over. Although only four in total, a few women reported that their clothing caught fire. There was no evidence of a significant association between whether someone was burnt or scalded in the last 12 months and the type of fuel they use (p=0.110).

Table 12.8: Reported frequency, severity and causes of burns and scalds to women respondents

Characteristics	Ambositra		Vatomandry					
			Total		Wood		Charcoal	
	N	%	N	%	N	%	N	%
Burnt or scalded in last 12 months	69	47.9	86	47.8	41	42.3	45	54.2
No. of occasions burnt in last 12 months [1]								
1-2	36	54.6	59	68.6	28	68.1	31	68.9
3-5	13	19.6	13	15.1	6	14.6	7	15.6
6-20	13	19.6	14	16.3	7	9.8	7	15.6
21+	4	6	0	0	0	0	0	0
Severity of the burns in last 12 months [1]								
No scar	39	56.5	47	54.7	23	56.1	24	53.3
Small scar (smaller than 10 Ariary coin)	23	33.3	31	36.0	15	36.6	16	35.6
Large scar (large as/larger than 10 Ar coin/)	7	10.1	8	9.3	3	7.3	5	11.1
Cause of burn [1]								
Hot fuel fell out of the open fire	22	31.9	37	42.5	23	56.1	14	31.1
Touched hot stove (charcoal, gas)	15	21.7	20	23.0	6	14.6	14	31.1
Scalded when pot fell over	27	39.1	26	29.9	11	26.8	15	33.3
Clothes caught fire	1	1.4	3	3.4	2	4.9	1	2.2
Other	4	5.8	1	1.1	0	0	1	2.2

[1] % of those who reported being burnt/ scalded in last 12 months

12.2. Children’s health

As discussed in the proposal and preliminary report, the assessment of impacts on children’s respiratory health is being carried out primarily through indirect means, by combining information on exposure levels and reductions, with data on ARI rates and risk estimates from epidemiological studies of IAP and child pneumonia. In this study, direct assessment has been made of burns, and risk of burns, among children under 5 years.

12.2.1. Burns

It is of concern that 26% of respondents in Ambositra and 23% in Vatomandry reported that one or more of their children under 5 years of aged had been burned or scalded in the last 12 months. Of those reporting burns, most (76% in Ambositra, 86% in Vatomandry) stated there had been one burn, but 21% and 14% respective stated that this had occurred between 2 and 4 times, and one respondent from Ambositra reported child burns occurring on more than 4 occasions.

The severity, as determined by presence and size of a scar, and the causes, are summarised in Table 12.9. The majority (52 – 63%) of these burns left scars, and 12 – 16% of these were classified as 'large scars'. No further information was obtained on the precise severity, extent and sequellae of these burns.

Table 12.9: Severity and causes of burns to children under 5 years in the preceding 12 months

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Severity of the burns in last 12 months*				
No scar	14	36.8	20	47.6
Small scar (smaller than 10 Ariary coin)	18	47.4	16	38.1
Large scar (as large/larger than 10 Ariary coin/lychee nut)	6	15.8	5	11.9
How child was burnt/scalded?				
Child fell in to an open fire	0	0	1	2.4
Child burnt by contact with hot embers or stove	20	52.6	17	40.5
Child scalded when pot fell over	14	36.8	24	57.1
Child's clothes caught fire	1	2.6	0	0
Other	3	7.9	0	0

All respondents were also asked about how concerned they were about the risk of one of their children under 5 years being burned or scalded in their own kitchen. Figure 12.1 shows that there was a generally high level of concern, and that this was similar in the two study areas.

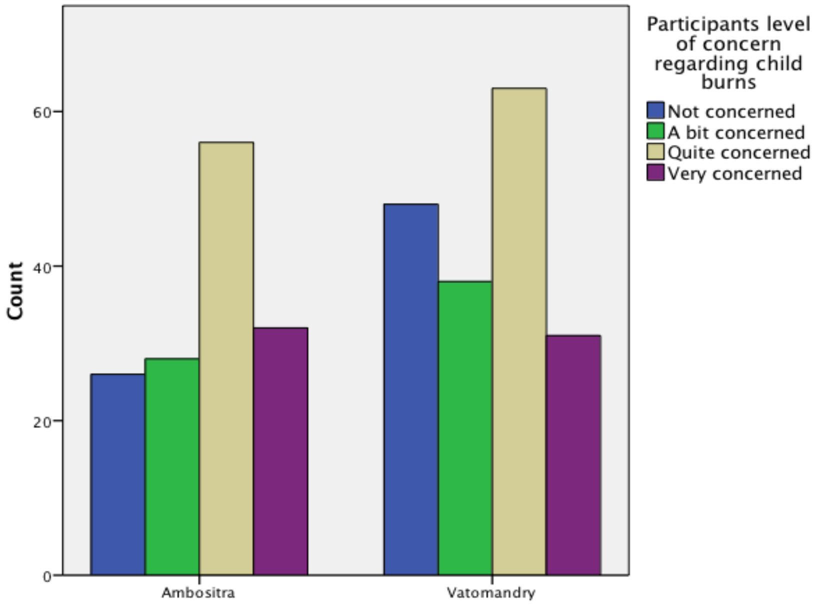


Figure 12-1: Level of concern at baseline about the risk of burns and scalds occurring to respondent's children under 5 years in the kitchen.

12.2.2. Baby feeding

Table 12.10 shows the baby feeding practices adopted by the study women up to the first 6 months (or until age of child if younger). This variable was included as exclusive breast feeding has been shown to reduce the risk of child ALRI. Whilst the majority of women used breast milk as the primary source of baby feeding a significantly higher proportion of women in Vatomandry (91.7%) used breast milk exclusively than mothers from Ambositra (63.9%); p < 0.0005.

Table 12.10: Baby feeding practices in first 6 months of life

Characteristic	Ambositra		Vatomandry	
	N	%	N	%
Breast milk only	92	63.9	165	91.7
Breast and bottle milk	42	29.2	13	7.2
Bottle milk only	3	2.1	2	1.1
Other	7	4.9	0	0.0

P<0.0005 (Chi-Squared)

12.3. Health services use

As outlined in Table 12.11, the pattern of accessing care for respiratory illnesses was similar in both study sites as well as between adults and children.

Overall government services and private doctors were accessed most frequently although the number of visits in the previous 12 months remained low for all services. The majority of those accessing government health services did so only 1-2 times in a 12- month period (13.8% of Ambositra study population and 11.7% of Vatomandry). Pharmacies were used by less people but those that did access this facility tended to go more often with the majority of adults going 3-5 times in both

Ambositra and Vatomandry and the majority of children in Vatomandry. The use of traditional healers was more common in Ambositra than Vatomandry.

Table 12.11: Use of health care services for respiratory related illnesses in last 12 months

Characteristic	Ambositra			Vatomandry		
Adults	**Frequency of visits: number (%)**		**Median total cost Ar. (IQR)**	**Frequency of visits: number (%)**		**Median total cost Ar. (IQR)**
Government health service	1-2	20 (13.8)	5780	1-2	21 (11.7)	6000
	3-5	3 (2.1)		3-5	9 (5)	
	6+	1 (0.7)		6+	3 (1.7)	
Pharmacy	1-2	2 (1.4)	3350	1-2	5 (2.8)	2600
	3-5	7 (3.9)		3-5	8 (4.4)	
	6+	2 (1.4)		6+	3(1.7)	
Traditional healer	1-2	2 (1.4)	1300	1-2	1 (0.6)	6000
	3-5	1 (0.7)		3-5	0	
	6+	1 (0.7)		6+	0	
Private doctor	1-2	10 (6.9)	9500	1-2	10 (5.6)	7000
	3-5	6(4.2)		3-5	6 (3.3)	
	6+	1 (0.7)		6+	1 (0.6)	
Children	**Frequency of visits: number (%)**		**Median total cost Ar. (IQR)**	**Frequency of visits: number (%)**		**Median total cost Ar. (IQR)**
Government health service	1-2	21 (14.6)	8000	1-2	15 (8.3)	8000
	3-5	17 (11.8)		3-5	23 (12.8)	
	6+	9 (6.3)		6+	9 (5.0)	
Pharmacy	1-2	5 (3.5)	8000	1-2	1 (0.6)	1875
	3-5	2 (1.4)		3-5	9 (5.0)	
	6+	2 (1.4)		6+	2 (1.1)	
Traditional provider	1-2	3 (2.1)	1200	1-2	0	0
	3-5	2 (1.4)		3-5	0	
	6+	2 (1.4)		6+	0	
Private doctor	1-2	12 (8.4)	13000	1-2	6 (3.3)	40000
	3-5	9 (6.3)		3-5	2 (1.1)	
	6+	5 (3.5)		6+	1 (0.6)	

The median cost of each service ranged considerably. As might be expected, most money was spent accessing the private doctor for both adults and children.

12.4. Smoking

The great majority of the study women did not smoke cigarettes, with only n=6; smokers (1.9%). However, in both Ambositra (40.3%) and Vatomandry (30.7%) there was at least one adult who smoked cigarettes in the house (Table 3.48). Whilst there was a higher proportion of other smokers in Ambositra than Vatomandry, there were, on average, a significantly higher number of cigarettes smoked in Vatomandry (median=10) than Ambositra (median=5); p=0.0003.

Table 12.12: Smoking in household

Characteristic	Ambositra		Vatomandry		P value
	N	%	N	%	(chi-squared)
Participant smokes/ has smoked in last year	4	2.8	2	1.1	0.269
Someone else smokes in house	58	40.3	55	30.7	0.074
	Med	**IQR**	**Med**	**IQR**	**P value (Wilcoxon)**
Number of cigs smoked in house per day	5	3-10	10	5-15	0.0003

12.5. Discussion of baseline health related issues

Women's health

The level of chronic respiratory symptoms, particularly among wood users (Vatomandry) is of concern. Although it is felt that the results presented here for chronic cough and phlegm are reliable, there are a number of issues warranting further enquiry in follow-up.

First, it was surprising to find a higher prevalence of symptoms in the younger women. Second, the frequency of wheeze and related symptoms is unexpectedly high, and this warrants further enquiry into local meaning, notwithstanding the attention already given to this matter during questionnaire development and piloting (see methods).

Headache and eye irritation were common, and consistent with patterns of fuel use. Burns and scalds to women (cooks) are clearly common, and were monitored during follow-up. There is a very low prevalence of smoking among the women, and although other family members smoke at home in a substantial minority of homes, there was no strong evidence that this had influenced personal exposure levels of women or their children.

Children's health

The predicted impacts of the interventions on child health, specifically pneumonia, are discussed in Section 14.

There is clear evidence of a problem in terms of burns and scalds to young children resulting from household energy use, although it is not possible from the data available to assess the true severity and longer-term consequences of these injuries.

13. Health Related Issues at Follow-up

13.1. Adult reported symptoms

13.1.1. Headache

Follow-up information on headaches was only collected at Round 3. In Ambositra only one person in the Ethanol group claimed to have headaches since installation of the stove (therefore ethanol group not included in Table 13.1). However in Vatomandry 19.4% of the ethanol stove group did report infrequent headaches with no specific cause. The highest frequencies of headaches were in the Awareness and Control groups, with Improved Charcoal at an intermediate level. Along with Ethanol, Improved Wood in Vatomandry had the lowest reported levels.

The most frequently cited reason for the headaches was smoke from the stove but stress, weather (and humidity) were also mentioned.

Table 13.1: Reported frequency (%) and severity of headaches: Ambositra: Round 3

	Intervention group		
	Charcoal n=31	**Awareness n=33**	**Control n=34**
Headaches in last 5 months/ since installation of stove	11 (35.5)	24 (72.7)	25 (73.5)
Frequency of headaches			
Once per week or less	1 (3.2)	5 (15.1)	7 (19.5)
Few/ most days per week	7 (22.6)	16 (48.5)	14 (38.9)
Every day	3 (9.7)	3 (9.1)	4 (11.1)
Strength of headaches			
Mild	4 (12.9)	6 (18.2)	3 (8.3)
Fairly strong	4 (12.9)	11 (33.3)	16 (44.4)
Very strong	3 (9.7)	7 (21.2)	6 (16.7)

Table 13.2: Reported frequency and severity of headaches: Vatomandry: Round 3

	Intervention group				
	Ethanol n=32	Wood n=33	Charcoal n=31	Aware-ness n=28	Control n=31
Headaches in last 5 months/ since installation of stove	6 (18.8)	3 (9.1)	11 (35.5)	20 (71.4)	22 (71.0)
Frequency of headaches					
Once per week or less	5 (15.6)	1 (3.0)	3 (9.7)	5 (17.9)	7 (22.6)
Few/ most days per week	-		8 (25.1)	14 (50.0)	12 (38.7)
Every day	1 (3.1)	3 (6.1)	-	1 (3.6)	3 (9.7)
Strength of headaches					
Mild	2 6.2	1 (3.0)	8 (25.1)	4 (14.3)	9 (29.0)
Fairly strong	4 12.5	1 (3.0)	2 (6.2)	8 (28.6)	5 (16.1)
Very strong	-	1 (3.0)	1 (3.1)	8 (28.6)	8 (25.1)

13.1.2. Eye irritation

As with headaches, information on eye irritation at follow-up was only collected at Round 3. There was minimal eye irritation reported by the ethanol stove users in Ambositra; only one person said that they had experienced eye irritation since installation of the stove (therefore ethanol group not included in Table 13.3)

Table 13.3: Reported frequency (%) and severity of eye irritation: Ambositra: Round 3

	Intervention group		
	Charcoal n=31	Awareness n=33	Control n=24
Eye Irritation in last 5 months/ since installation of stove	10 (32.3)	24 (72.7)	21 (61.8)
Frequency of eye irritation			
A few of the times I cook	6 (19.4)	14 (42.4)	14 (38.9)
About half the time I cook	-	1 (3.0)	1 (2.8)
Most of the times I cook	4 (12.9)	5 (15.2)	-
Every time I cook	-	4 (12.1)	6 (16.7)
Strength of eye irritation			
Mild	-	8 (24.2)	8 (22.2)
Moderate	8 (25.8)	15 (45.5)	10 (27.8)
Severe	2 (6.5)	1 (3.0)	3 (8.3)

Of those who experienced eye discomfort the majority felt that the symptoms had not changed since installation of charcoal stove or since receiving the awareness raising information. The control group participants also felt that the project involvement had not contributed towards any change in symptoms.

In Vatomandry, the Ethanol Group, followed by the Improved Wood Group, had the lowest frequency of eye irritation, which was less frequent with cooking, and less severe than other groups, Table 13.4. Almost half (46.7%) of the intervention Charcoal stove users in Vatomandry reported continued eye irritation at Round 3 which occurred most of the times they cook: more than three quarters (78.6%) of these believed the eye irritation was unchanged by the installation of the stove. Over half (54.5%) of the households reporting eye irritation in the awareness group (Vatomandry) felt that their symptoms were unchanged since receiving the awareness raising information.

Table 13.4: Reported frequency and severity of eye irritation: Vatomandry: Round 3

	Intervention group				
	Ethanol n=32	**Wood n=33**	**Charcoal n=32**	**Aware-ness n=28**	**Control n=31**
Eye Irritation in last 5 months/ since installation of stove	5 (15.6)	7 (21.2)	14 (46.7)	22 (71.0)	23 (74.2)
Frequency of eye irritation					
A few of the times I cook	3 (9.4)	2 (6.1)	4 (12.5)	8 (28.6)	12 (38.7)
About half the time I cook	1 (3.1)	1 (3.0)	2 (6.2)	2 (7.1)	-
Most of the times I cook	-	2 (6.1)	7 (21.9)	6 (21.4)	8 (25.8)
Every time I cook	1 (3.1)	2 (6.1)	1 (3.1)	6 (21.4)	3 (9.7)
Strength of eye irritation					
Mild	2 (6.2)	4 (12.1)	6 (18.8)	4 (14.3)	8 (25.8)
Moderate	3 (9.4)	3 (9.1)	8 (25.0)	14 (50.0)	11(35.5)
Severe	-	-	-	4 (14.3)	4(12.9)

13.1.3. Burns (adults)

The Ethanol stove users reported only one case of being burnt since installation of the stove- which was in Vatomandry. The other intervention groups continued to experience burns at rates similar to those seen at baseline, Tables 13.5 and 13.6.

Table 13.5: Reported frequency (%) and severity of burns: Adults, Ambositra: Round 3

	Intervention group		
	Charcoal n=31	Awareness n=33	Control n=34
Burnt in last 5 months/ since installation of stove	3 (9.7)	8 (24.2)	8 (22.2)
Number of times burnt			
1-2	3 (9.7)	3 (9.1)	2 (5.6)
3-5	-	5 (15.1)	3 (8.4)
>5	-	-	4 (10.6)
Severity of burn			
No scar	3 (9.7)	7 (21.2)	6 (16.7)
Small Scar	-	1 (3.0)	2 (5.6)

Most of the burns occurred when hot fuel fell from the fire. The one burn in the ethanol stove group was caused by touching the stove. The wood stove and the charcoal stove burns were both more likely to be caused by touching the hot stove than by any other means.

Table 13.6: Reported frequency (%) and severity of burns: Adults, Vatomandry: Round 3

	Intervention group				
	Ethanol n=31	Wood n=33	Charcoal n=31	Aware-ness n=28	Control n=31
Burnt in last 5 months/ since installation of stove	1 (3.1)	5 (15.2)	4 (12.5)	7 (25.0)	14 (45.2)
Number of times burnt					
1-2	1 (3.1)	3 (9.1)	2 (6.2)	2 (7.1)	4(12.9)
3-5	-	1 (3.0)	1 (3.2)	5 (17.9)	5 (16.1)
>5	-	-	1 (3.2)	-	5 (16.1)
Severity of burn					
No scar	-	5 (15.2)	3 (9.4)	4(14.3)	9 (29.0)
Small Scar	1 (3.1)	-	1 (3.2)	3 (10.7)	4(12.9)
Large Scar	-	-	-	-	1 (3.2)

13.2. Child and family reported symptoms

13.2.1. Burns in children

The prevalence of burns in the children during the 12 months before baseline was of some concern (26% in Ambositra and 23% in Vatomandry). However the number of burns since stove installation seems to have been reduced dramatically in the Ethanol groups (and Wood in Vatomandry). The ethanol stove groups at both study sites reported that there had been no burns to children under 5 since installation of the stove (time period of 5 months). The wood stove group in Vatomandry also reported no burns in the same time period. Three burns were reported in the charcoal stove intervention group in Ambositra, all were caused by different means and each resulted in a small or no scar. The one burn reported in the charcoal stove group in Vatomandry left a large scar after a pot fell off the stove.

Burns in children under the age of 5 continued to be a problem in the control and awareness group households. In Ambositra, 21.2% of the awareness group participants and 20.5% of the control participants reported that there child under 5 had been burnt in the last 5 months. One of the children in the awareness group had been burnt on three occasions during that time. Three of the reported burns had left a large scar.

The awareness and control group participants in Vatomandry experienced similar patterns. One child had been burnt four times in 5 months. The burns were caused by a range of means including scalding when a pot fell; hot fuel falling out of a fire; touching a hot stove.

The respondents were asked about how concerned they were about the risk of one of their children under 5 being burned or scalded in their kitchen. Figures 13.1 and 13.2 show that the level of concern was much greater in the households which did not receive an intervention stove, although persisted in some of the charcoal stove households to some degree. The concern lay in the fact that the children like to be near their mothers when cooking and often played near to the stove without considering the possible dangers.

Figure 13-1: Level of concern about the risk of burns and scalds occurring to respondent's children under 5 years in the kitchen.

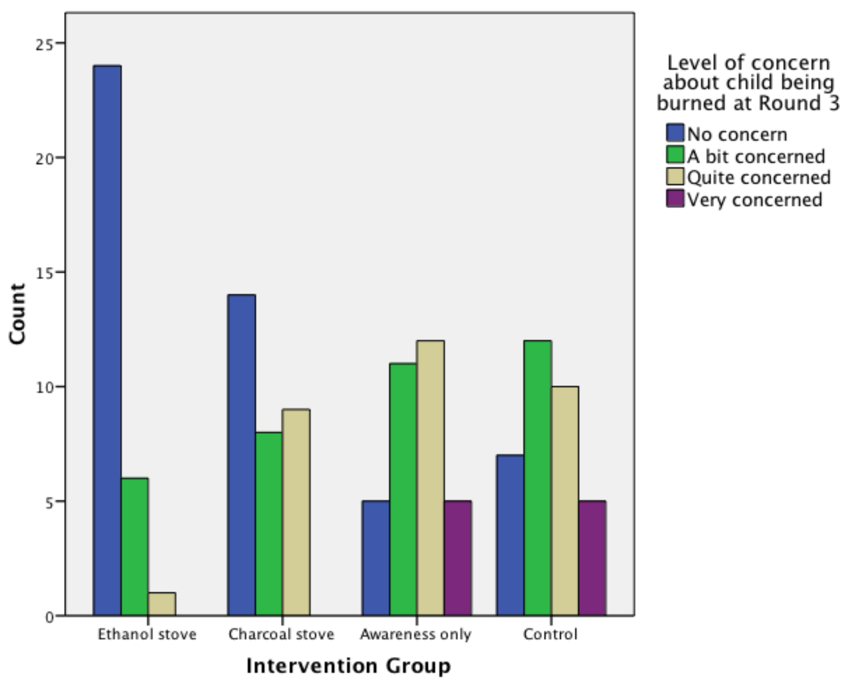
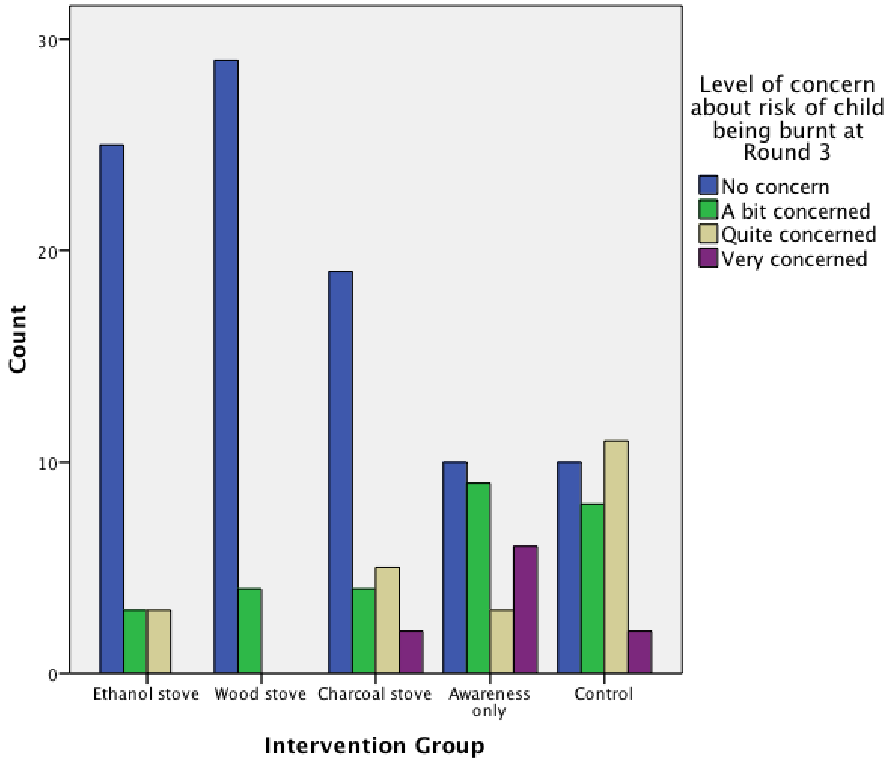


Figure 13-2: Level of concern about the risk of burns and scalds occurring to respondent's children under 5 years in the kitchen.



13.3. Summary analysis of health outcomes

13.3.1. Methods in summary analysis

A similar approach was taken to summarising impacts on health outcomes (headaches, eye irritation and burns) as was used for the data on personal exposure. General estimating equations (GEE) with robust variability estimation (to account for use of multiple measurements for each home) were calculated for longitudinal modelling of health outcomes by intervention group, using xtgee in Stata, version 9. Results are presented in the tables as 'odds ratios' (OR) with 95% confidence intervals and p-values, and can be interpreted easily: thus, an OR of 1.0 means the effect is no different from the control group, while an OR of less than 1.0, for example, 0.65 (0.45 – 0.80) would mean a protective effect with a 40% reduction in risk (95% CI 20% to 55%). An OR greater than 1.0 would mean that risk was increased, for example an OR of 1.3 implying a 30% increase.

Health variables included the prevalence of headache, eye irritation and burns for adults and burns for children at each round (there were no data on burns – either for adults or children - for Round 2). The following tables include data from Baseline and Round 3 and present unadjusted and adjusted odds ratios. Potential confounders include:

Table 13.7: Variables Adjusted for in the Summary Analysis

Fixed covariates:	Time varying covariates:
Age,	Time (round),
Asset index (range 2-9),	Season (wet vs. dry),
Marital status,	Adult male equivalent cooked for (amecook),
Income (4 categories based on the distribution of income for each study location).	Kitchen location (separate from house vs. joined).

The interventions were all compared with the Control group as a reference.

13.3.2. Results for Health Status Summary Analysis: Ambositra

The adjusted analyses showed that both improved charcoal and ethanol reduced the prevalence of headache and eye irritation, with the strongest effects for the ethanol group (Table 13.8). In the ethanol group, the likelihood of reporting headaches was reduced by 93% ($p<0.0005$) and eye irritation by 72% ($p=0.005$). In the charcoal group the reduction in the occurrence of headaches and eye irritation was 77% ($p=0.001$) and 56% ($p=0.031$) respectively. For adult burns there was a statistically significant reduction in risk of 74% for the ethanol group ($p=0.011$) and of 70% in the improved charcoal group ($p=0.022$) compared to the control group. For child burns, there was a marginally significant reduction in risk of almost 64% for the ethanol group ($p=0.086$), but no strong evidence of reduced risk in the other groups.

Table 13.8: Health effects by intervention – AMBOSITRA

Intervention	OR	Headache 95% CI	P value	OR	Eye Irritation 95% CI	P value
Unadjusted						
Control	1.0			1.0		
Awareness	0.94	0.43, 2.03	0.872	1.20	0.60, 2.43	0.606
Improved Charcoal	0.33	0.15, 0.73	0.006	0.36	0.18, 0.72	0.004
Ethanol	0.14	0.07, 0.29	<0.0005	0.24	0.12, 0.50	<0.0005
Adjusted*						
Control	1.0			1.0		
Awareness	0.86	0.37, 1.97	0.719	1.38	0.61, 3.09	0.439
Improved Charcoal	0.23	0.10, 0.53	0.001	0.44	0.20, 0.93	0.031
Ethanol	0.07	0.03, 0.16	<0.0005	0.28	0.12, 0.68	0.005
Intervention	**OR**	**Adult Burns 95% CI**	**P value**	**OR**	**Child Burns 95% CI**	**P value**
Unadjusted						
Control	1.0			1.0		
Awareness	0.80	0.32, 2.04	0.647	1.18	0.45, 3.06	0.739
Improved Charcoal	0.51	0.22, 1.21	0.125	0.83	0.32, 2.19	0.713
Ethanol	0.43	0.19, 0.95	0.037	0.46	0.17, 1.29	0.141
Adjusted*						
Control	1.0			1.0		
Awareness	0.51	0.17, 1.52	0.228	1.02	0.34, 3.10	0.971
Improved Charcoal	0.30	0.11, 0.84	0.022	0.55	0.18, 1.70	0.297
Ethanol	0.26	0.09, 0.73	0.011	0.36	0.11, 1.16	0.086

***Adjusted for**

Time varying covariates: time (round), adult male equivalent cooked for, kitchen location (separate vs joined), season (wet vs dry). Fixed covariates: asset index (1-9), marital status, age, income (4 categories)

13.3.3. Results for Health Status Summary Analysis: Vatomandry

The adjusted analyses showed that improved charcoal, improved wood and ethanol all reduced the prevalence of both headache and eye irritation, with the overall strongest effects for the ethanol group (Table 13.9). In the ethanol group, the likelihood of reporting headaches was reduced by 87% (p<0.0005) and eye irritation by 86% (p<0.0005). For self reported burns in adults the reduction in risk was 68% (p=0.008) in the ethanol group. For burns in children, there was a significant reduction in risk of almost 79% for the Improved wood group (p=0.023), but no strong evidence of reduced risk in the other groups, including ethanol.

Table 13.9: Health effects by intervention – VATOMANDRY

		Headache			Eye Irritation	
Intervention	**OR**	**95% CI**	**P value**	**OR**	**95% CI**	**P value**
Unadjusted						
Control	1.0			1.0		
Awareness	0.66	0.31, 1.43	0.292	0.61	0.26, 1.40	0.242
Improved Charcoal	0.22	0.10, 0.47	<0.0005	0.16	0.07, 0.36	<0.0005
Improved Wood	0.14	0.07, 0.26	<0.0005	0.21	0.11, 0.43	<0.0005
Ethanol	0.17	0.09, 0.26	<0.0005	0.11	0.05, 0.24	<0.0005
Adjusted*						
Control	1.0			1.0		
Awareness	0.79	0.35, 1.80	0.575	0.73	0.30, 1.73	0.470
Improved Charcoal	0.18	0.07, 0.44	<0.0005	0.20	0.08, 0.49	<0.0005
Improved Wood	0.12	0.06, 0.26	<0.0005	0.24	0.11, 0.52	<0.0005
Ethanol	0.13	0.06, 0.28	<0.0005	0.14	0.06, 0.32	<0.0005
		Adult Burns			**Child Burns**	
Intervention	**OR**	**95% CI**	**P value**	**OR**	**95% CI**	**P value**
Unadjusted						
Control	1.0			1.0		
Awareness	0.60	0.25, 1.47	0.268	1.30	0.50, 3.35	0.593
Improved Charcoal	0.75	0.35, 1.59	0.449	0.70	0.26, 1.88	0.475
Improved Wood	0.43	0.19, 0.97	0.042	0.23	0.07, 0.77	0.017
Ethanol	0.30	0.13, 0.65	0.002	0.45	0.17, 1.25	0.125
Adjusted*						
Control	1.0			1.0		
Awareness	0.63	0.26, 1.59	0.336	1.35	0.49, 3.73	0.564
Improved Charcoal	0.78	0.34, 1.78	0.559	0.82	0.27, 2.51	0.734
Improved Wood	0.46	0.20, 1.08	0.074	0.21	0.06, 0.81	0.023
Ethanol	0.32	0.13, 0.74	0.008	0.50	0.15, 1.61	0.243

***Adjusted for**

Time varying covariates: time (round), adult male equivalent cooked for, kitchen location (separate vs joined), season (wet vs dry). Fixed covariates: asset index (1-9), marital status, age, income (4 categories)

13.4. Ingestion of fuel

When introducing a liquid fuel into households that have small children the risk of ingestion of fuel needs to be considered and measured. Many households already used kerosene for lighting fuel before introduction of ethanol and so have experience of liquid fuel use and storage.

Most households stored their liquid fuel in soft drink bottles or cans, Figure 13.3. In Ambositra, 10 (7.6%) reported that a child had attempted to drink a liquid fuel in the previous 5 months, and two of these occasions involved ethanol. Of the six occasions in Vatomandry, one involved ethanol. This is clearly a risk that needs further attention, for both kerosene and ethanol.

Figure 13-3: Ethanol shop in Ambositra showing soft drink bottles being filled with ethanol

13.5. Perceptions of change in overall family health

At Round 3, all participants were asked about the perceived changes in health among their family members since the installation of the stove (or last 5 months for awareness only or control group). Tables 13.10 and 13.11 show the main responses to the question "Since receiving your stove (*or* In the last five months) **has the project** had any affect on your health? Is it the same, worse or better than before?" For the Ethanol (and possibly the charcoal) groups in Ambositra, and for Ethanol and Improved wood in Vatomandry, more respondents felt that their own health and that of the children under 5 years of age was better, in comparison with the other groups.

Table 13.10: Ambositra: Perceptions (Numbers, %) of changing in health since stove installation or in the last 5 months

	Intervention group			
	Ethanol n=31	Charcoal n=31	Awareness n=33	Control n=34
Women's' health				
Worse or a lot worse	3 (9.7)	2 (6.5)	13 (39.4)	9 (26.5)
The same	5 (16.1)	19 (61.3)	17 (51.5)	20 (58.8)
A bit better	18 (58.1)	10 (32.3)	3 (9.1)	5 1(4.7)
A lot better	5 1(6.1)	-	-	-
Health of child <5 yrs				
Worse or a lot worse	3 (9.7)	3 (9.7)	9 (27.2)	9 (26.5)
The same	7 (22.6)	16 (51.6)	18 (54.5)	21 (61.8)
A bit better	18 (58.1)	11 (35.5)	6 (18.2)	4 (11.1)
A lot better	3 (9.7)	1 (3.2)	-	-

Table 13.11: Vatomandry: Perceptions (Numbers, %) of changing in health since stove installation or in the last 5 months

	Intervention group				
	Ethanol n=31	Wood N=33	Charcoal n=30	Awareness n=28	Control n=31
Women's' health					
Worse or a lot worse	-			1 (3.6)	2 (6.2)
The same	14 (45.2)	10 (30.3)	28 (93.3)	26 (92.9)	29 (90.6)
A bit better	12 (38.7)	19 (57.6)	2 (6.7)	1 (3.6)	-
A lot better	5 (16.1)	4 (12.1)	-	-	-
Health of child <5 yrs					
Worse or a lot worse	1 (3.2)	-	1 (3.3)	1 (3.6)	2 (6.2)
The same	11 (35.5)	11 (33.3)	25 (83.3)	26 (92.9)	29 (90.6)
A bit better	12 (38.7)	14 (42.4)	3 (9.4)	1 (3.6)	-
A lot better	7 (22.6)	8 (24.2)	1 (3.3)	-	

13.6. Discussion of follow-up health related issues

The follow-up phase of the study examined the frequency of headaches, eye irritation and burns in women and frequency and severity of burns in children. Mothers were also asked about their level of anxiety regarding the risk of children being burnt in the kitchen.

When comparing with the control group in the summary analysis, we found that the ethanol stove led to substantial and highly significant reductions in headaches, eye irritation and burns amongst women in Ambositra. There was also a non-significant reduction of burns in children. Of the other groups in Ambositra only the improved charcoal group showed benefits, which were seen for headache, eye irritation and burns in adults. However the reductions in risks were generally less than those seen for the ethanol groups. Non- significant reductions in burns were seen in the ethanol stove group for children but no strong evidence of reduced risk in the other groups.

In Vatomandry the same analysis showed large and highly significant reductions in the women's reported headache and eye irritation for the charcoal, wood and ethanol intervention groups. The ethanol group reported substantially less burns in women and wood stove group showed marginally significant reductions. Only the wood stove group showed significant reductions in burns in children.

Perceptions of risk of burn

The mothers levels of concern about risk of burn were very consistent not only with the relatively high frequency of burns at baseline but also the reduction in risk that were seen with the ethanol stove and some of the other interventions at follow up.

Ingestion of fuel

The issue of ingestion of fuel is highlighted as it presents a potential serious risk of lung injury particularly with kerosene. The risk of ingestion of ethanol is less well documented although anecdotally we understand children are less likely to drink it. The fact that both of these liquid fuels are purchased and stored in soft drink bottles requires attention.

Perceptions of health

At end of the follow up period the women respondents were asked about their impression on the overall impact of the intervention (in case of control group the time in study) and whether it had beneficial, neutral or negative effects on the health of the family. In Ambositra the most positive assessments in improvements were seen in the ethanol group, with some evidence of benefits in the charcoal intervention group.

In Vatomandry again the ethanol group showed the clearest evidence of perceived benefits to family health. With at least as positive benefits reported by the intervention wood stove users. The other three groups showed very little evidence of change.

14. Modelled health impacts from exposure reduction in Madagascar

14.1. Introduction

The proposal for this study indicated that it would not be possible, within the time frame or resources available, to directly measure the impacts of the ethanol intervention on health outcomes such as child pneumonia, and other major disease conditions that have been linked to IAP from solid fuel use – for example chronic obstructive pulmonary disease (COPD) and ischemic heart disease (IHD). It was however proposed that the expected impacts on these diseases could be modelled, using the comparative risk assessment (CRA) methodology of the global burden of disease (GBD), along with emerging evidence on the relationship between exposure level and disease risk (the latter at least for child pneumonia). At the time of preparation of this report, the critical 'exposure-response' information required for a more nuanced analysis of partial reductions in exposure (which was to be drawn from the RESPIRE trial in Guatemala, and from a synthesis of effect estimates from the new CRA[12] reviews) is not available. Both of these sources are in process of peer review/publication, although anticipated by April-June 2011. Consequently, a preliminary analysis based on existing published CRA (2004) effect estimates for comparison of solid fuel use with clean fuel are reported here. Further work using the exposure-response information can be carried out and made available to the project as soon as this is available.

14.2. Methods and assumptions

Drawing on published reviews from the previous CRA of risk and burden calculation involving child pneumonia, COPD and lung cancer[13], and recent evidence that proposes inclusion of effects on IHD[14], the impact of progressively introducing ethanol as a cooking fuel for the Madagascan population currently relying on solid fuels has been estimated. This assumes that ethanol, being a clean fuel, delivers reductions in $PM_{2.5}$ in excess of 90%, and that it is used for all cooking needs in households. This is done for all three health outcomes, namely child ALRI, COPD and IHD. It is recognized that this assumption that ethanol reduced exposure by >90% does not reflect the actual experience of the study, where many households did not use ethanol exclusively, and observed reductions in exposure were substantially less than 90%, and varied between sites (larger reductions in Ambositra) and between women and children (Table 14.1).

Table 14.1: Percentage reductions in CO and PM2.5 compared to the control group for the Ethanol user groups

[12] CRA: Comparative Risk Assessment. This is the assessment of disease burden that can be attributed to a range of risk factors, all of which are assessed using a common methodology for the Global Burden of Disease project. The first step is systematic reviews and meta-analyses to obtain estimates of the relative risk of each disease outcome for those exposed, compared to those unexposed (or, where the available evidence makes this possible, exposed less). For IAP, available epidemiological studies only allowed the derivation of risk estimates for those exposed to solid fuel use for cooking compared to those not exposed (e.g. using clean fuels).

[13] Smith KR et al. (2004). Indoor air pollution from household use of solid fuels. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. M. Ezzati. Geneva, World Health Organisation.

[14] Wilkinson P et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet. 2009 Dec 5;374(9705):1917-29. Epub 2009 Nov 26.

Pollutant	Ambositra		Vatomandry	
	Mother	Child	Mother	Child
CO	**-74%**	**-64%**	**-54%**	**-14%**
Predicted $PM_{2.5}$	**-45%**	**-40%**	**N/A**	**N/A**

As noted above, the exposure-response data required to fully model these sub-optimal reductions in exposure are not currently available for use in this modelling, although some indication of the diminution of impact will be discussed – based on an approximation of the relative risk reduction with a 50% reduction in exposure (drawn from published preliminary analysis of the RESPIRE study).

It is however not unreasonable to look initially at this more ideal situation (>90% reduction in exposure), as most of the barriers to more exclusive use of ethanol could feasibly be addressed (e.g. supply, multiple burners, etc), and at least some of (probably a substantial proportion of) the residual exposure for both women and children originates from the combustion of solid fuels by other homes leading to exposure when visiting neighbours, and through general ambient air pollution in the local community. With more widespread use of clean, low emission fuels, the neighbouring and wider community sources of exposure would be diminished.

In comparing the results for these modelled health impacts with the projected market development for this project, it should be noted that as health (deaths, DALYs) projections are not available separately for urban and rural population, nor by type of fuel use (or socio-economic group as a proxy), it is not possible to exactly model the market growth proposed.

The impacts are estimated over a period of 10 years, between 2010 and 2020, with adoption calculated for the following two scenarios:

4. **Scenario 1 (AGECC Universal Clean Energy Access):** At the rate required to meet the target for universal access to clean, modern household energy by 2030 that has been proposed by the UN Secretary General's Advisory Group on Energy and Climate Change (AGECC)[15]. Thus, over the first 10 years of this period, the rate of adoption among current solid fuel using homes is set at that needed to halve the current proportion of households reliant on traditional solid fuels and stoves. For this scenario, a constant yearly adoption rate has been assumed.

5. **Scenario 2: 17% adoption at 10 years:** This scenario examines health impacts of adoption at a rate required to achieve 17% adoption by 2020, this being the level seen after the first ten years of the projections based on an ethanol price of 35 cents/litre[16] and 20 year adoption. The year-on-year rates of adoption are based on the same curve as proposed for the market development at this price over 20 years, but only the first 10 years are used here.

[15] The AGECC targets for universal energy access by 2030 form a key part of the UN International Year of Sustainable Energy for All (2012).

[16] This is a conservative estimate of predicted price of ethanol based on several variables including the cost of feedstock's and co-products and taking into consideration the fact that there is currently no large-scale micro-distillery operation in Madagascar. For further information on the calculation of this figure please refer to: Madagascar: Ethanol as a Household Fuel: Approach for Market, Financial and Economic Analysis – March 2011

The risk reductions for ALRI and COPD are those reported in the CRA (GBD project)[17], while those for IHD are drawn from a prior scenario analysis for India[18] (Table 14.2). As coal is not used in Madagascar as a household fuel, lung cancer is not included.

Table 14.2: The risk reductions for ALRI and COPD as reported in the CRA (GBD project)

Disease	Age group	Relative risk	
		Males	Females
Pneumonia	Children < 5 years	2.3	2.3
COPD	Adults 30 and older	1.8	3.2
IHD	Adults 30 and older	1.073	1.21

Data on current and projected population and disease mortality and incidence for Madagascar over the period 2010 to 2020 have been obtained from WHO. Population numbers use the medium variant assumptions, avoiding extreme assumptions about mortality, birthrate, and other determinants of population projections. The current % of the population relying on solid fuels (wood, charcoal, other biomass), is taken from the WHO household energy database19. The business as usual figures are based on current trends in switching to cleaner stoves and fuels. Based on figures in Wilkinson et al [2010][18], which were also consistent with trends in the HDI [Human Development Index], a 'natural' transition to clean fuels and stoves of 1% of households per year is assumed. The number of households is determined from data on urban and rural household size, drawn from UN population statistics, as applied by Hutton et al in a cost-benefit analysis case study for household energy interventions20, with additional adjustment for increasing urbanization over time. Results describing the averted deaths for child ALRI, COPD and IHD are reported here, for the two 10-year scenarios described above.

14.3. Results for child ALRI

14.3.1. Scenario 1: Adoption rate on track to meet AGECC target

The adoption of clean fuels and stoves to meet the AGECC target in 2030, would involve households adoption of ethanol stoves at a rate of some 225,000 per year (constant rate of adoption), for the 10-year period to 2020 (Table 14.3(a)). This illustrates the fractions of the population who remain without clean stoves under 'business as usual' (Column 1) and with Scenario 1 adoption (Column 2), for the period 2010 – 2019.

[17] Smith KR et al. (2004). Indoor air pollution from household use of solid fuels. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. M. Ezzati. Geneva, World Health Organisation.
[18] Wilkinson P et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet. 2009 Dec 5;374(9705):1917-29. Epub 2009 Nov 26.
[19] See: http://www.who.int/indoorair/health_impacts/he_database/en/index.html .
[20] Hutton G et al: Evaluation of the costs and benefits of household energy and health interventions at global and regional levels. *World Health Organization* 2006

Table 14.3 (a) Fractions of the population without clean stoves under 'business as usual' (Column 1) and with Scenario 1 adoption (Column 2), for 2010 – 2019.

Year	Demography		'Business as usual' given current trends in switching to cleaner stoves/fuels		Situation with Scenario 1 (AGECC) adoption of clean (ethanol) stoves	
	Madagascar population	Total number of households (HH)	(1) Population fraction without clean stoves	Population exposed without clean stoves	Clean stoves adopted	(2) Population fraction without clean stoves
2010	21,313,000	3,989,222	0.99	21,121,183	225,873	0.94
2011	21,885,470	4,097,496	0.98	21,471,616	225,873	0.87
2012	22,457,940	4,205,828	0.97	21,812,928	225,873	0.81
2013	23,030,410	4,314,218	0.96	22,145,266	225,873	0.75
2014	23,602,880	4,422,668	0.95	22,468,777	225,873	0.70
2015	24,175,350	4,531,176	0.94	22,783,603	225,873	0.64
2016	24,778,396	4,645,777	0.93	23,118,413	225,873	0.59
2017	25,381,442	4,760,456	0.92	23,444,248	225,873	0.54
2018	25,984,488	4,875,210	0.91	23,761,255	225,873	0.50
2019	26,587,534	4,990,042	0.91	24,069,577	225,873	0.45

Impact on child pneumonia

The impact of the programme on ALRI in children under 5 years, would be to avert just over 9,000 deaths over the 10 years, and just over 300,000 DALYs, Table 14.3 (b). The health benefits increase each year as the cumulative total of clean stove grows, so that in 2019, a total of 1,600 deaths 56,000 DALYs would be prevented. For the whole 10-year period, the averted burden amounts to just under 10% of the national total ALRI deaths and about 10% of DALYs, but almost 17% for both deaths and DALYs in 2019.

Table 14.3 (b): Impact of Scenario 1 on child ALRI, 2010-1019

	Deaths			DALYs		
Year	Total ALRI projected	Averted each year	Cumulative averted	Total ALRI projected	Averted each year	Cumulative averted
2010	12,056	172	172	418,049	5,981	5,981
2011	11,759	345	517	408,865	11,989	17,971
2012	11,472	515	1,032	399,031	17,901	35,872
2013	11,190	682	1,714	388,045	23,653	59,525
2014	10,911	847	2,561	378,406	29,377	88,902
2015	10,637	1,010	3,571	368,916	35,021	123,923
2016	10,346	1,166	4,737	358,822	40,440	164,363
2017	10,061	1,319	6,056	348,941	45,748	210,110
2018	9,782	1,469	7,525	339,272	50,951	261,061
2019	9,509	1,616	9,141	329,814	56,054	317,115
Total	**107,721**	**9,141**	**9,141**	**3,738,160**	**317,115**	**317,115**

Impacts on chronic obstructive pulmonary disease (COPD)

For COPD in adults over 30 years of age, the impact of the programme would be to avert just over 3,100 deaths over the 10 years, and just over 38,000 DALYs, Table 14.3 (c). In 2019, the benefits are 650 deaths and 7,900 DALYs prevented. For the whole 10-year period, the averted burden amounts to just under 10% of the national total COPD deaths and about 8.5% of DALYs, but almost 16% in 2019.

It should be noted that – unlike child ALRI – the prevention of COPD morbidity and mortality would not be realised immediately: as the disease has a long 'latent period' (the time between exposure and onset of the disease process) of 10-20 years, this same time period will need to elapse before the majority of these benefits are actually seen. A useful way to view this is that the health benefits for people receiving the clean fuel interventions during this period are 'banked', and will be realised in the future.

Table 14.3 (c): Impact of Scenario 1 on adult chronic obstructive pulmonary disease (COPD) 2010-2019

Year	Deaths			DALYs		
	Total COPD projected	Averted each year	Cumulative averted	Total COPD projected	Averted each year	Cumulative averted
2010	3,198	44	44	39,466	541	541
2011	3,282	92	136	40,550	1,135	1,677
2012	3,367	144	280	41,619	1,777	3,453
2013	3,452	200	479	42,686	2,467	5,920
2014	3,543	260	739	43,756	3,210	9,130
2015	3,636	325	1,064	44,793	4,004	13,134
2016	3,751	397	1,461	46,102	4,877	18,011
2017	3,866	474	1,935	47,395	5,814	23,824
2018	3,981	558	2,493	48,679	6,819	30,644
2019	4,100	648	3,141	50,000	7,905	38,549
Total	**36,177**	**3,141**	**3,141**	**445,046**	**38,549**	**38,549**

Impacts on ischaemic heart disease (IHD)

For IHD in adults over 30 years of age, the impact of the programme would be to avert just under 3,000 deaths over the 10 years, and almost 30,000 DALYs, Table 14.3 (d). In 2019, the benefits are 540 deaths and 5,500 DALYs prevented. For the whole 10-year period, the averted burden amounts to just under 3% of the national total IHD deaths and DALYs, but almost 5% in 2019. As with COPD, the prevention of IHD morbidity and mortality would not be realised immediately, but somewhat more rapidly than COPD as reductions in risk factors generally show major impacts on IHD risk after a period of around five years.

Table 14.3 (d): Impact of Scenario 1 on adult ischaemic heart disease (IHD) 2010-2019

Year	Deaths			DALYs		
	Total IHD projected	Averted each year	Cumulative averted	Total IHD projected	Averted each year	Cumulative averted
2010	9,120	51	51	92,779	505	505
2011	9,350	103	153	95,154	1,027	1,532
2012	9,577	156	309	97,489	1,558	3,091
2013	9,800	210	519	99,773	2,097	5,188
2014	9,989	263	782	101,864	2,638	7,826
2015	10,175	317	1,099	103,866	3,181	11,007
2016	10,421	373	1,472	106,489	3,746	14,753
2017	10,664	429	1,901	109,058	4,318	19,071
2018	10,904	486	2,387	111,576	4,895	23,966
2019	11,140	543	2,930	114,043	5,478	29,444
Total	**101,140**	**2,930**	**2,930**	**1,032,090**	**29,444**	**29,444**

14.3.2. Scenario 2: Adoption at rate to meet 17% of solid fuel users in 10 years

Table 14.4 (a) illustrates the fractions of the population who remain without clean stoves under 'business as usual' (Column 1) and with Scenario 2 adoption (Column 2), for the period 2010 – 2019.

Table 14.4 (a) Fractions of the population without clean stoves under 'business as usual' (Column 1) and with Scenario 2 adoption (Column 2), for 2010 – 2019.

Year	Demography		'Business as usual' given current trends in switching to cleaner stoves/fuels		Situation with Scenario 2 (35 cents) adoption of clean (ethanol) stoves	
	Madagascar Population	Total number of Households (HH)	(1) Population fraction without clean stoves	Population exposed without clean stoves	Clean stoves adopted	(2) Population fraction without clean stoves
2010	21,313,000	3,989,222	0.99	21,121,183	57,193	0.98
2011	21,885,470	4,097,496	0.98	21,471,616	18,517	0.96
2012	22,457,940	4,205,828	0.97	21,812,928	23,744	0.95
2013	23,030,410	4,314,218	0.96	22,145,266	29,989	0.93
2014	23,602,880	4,422,668	0.95	22,468,777	37,187	0.92
2015	24,175,350	4,531,176	0.94	22,783,603	45,119	0.90
2016	24,778,396	4,645,777	0.93	23,118,413	53,374	0.88
2017	25,381,442	4,760,456	0.92	23,444,248	61,353	0.86
2018	25,984,488	4,875,210	0.91	23,761,255	68,340	0.83
2019	26,587,534	4,990,042	0.91	24,069,577	73,633	0.81

Impacts on childhood pneumonia

The impacts of this adoption scenario on ALRI deaths and DALYs in children under 5 years are shown in Table 14.4 (b). The programme impact would be to avert just over 1,300 deaths over the 10 years, and just over 45,000 DALYs. In 2019, the benefits are 250 deaths and 8,900 DALYs prevented. For the whole 10-year period, the averted burden amounts to around 1% of the national total ALRI deaths and DALYs, but nearly 3% in 2019.

Table 14.4 (b): Impact of Scenario 2 on child ALRI, for the period 2010 - 2019

Year	Deaths			DALYs		
	Total ALRI projected	Averted each year	Cumulative averted	Total ALRI projected	Averted each year	Cumulative averted
2010	12,056	41	41	418,049	1,410	1,410
2011	11,759	53	93	408,865	1,828	3,238
2012	11,472	67	161	399,031	2,341	5,580
2013	11,190	85	246	388,045	2,956	8,536
2014	10,911	107	352	378,406	3,700	12,236
2015	10,637	132	484	368,916	4,570	16,807
2016	10,346	160	644	358,822	5,543	22,350
2017	10,061	191	835	348,941	6,614	28,964
2018	9,782	224	1,058	339,272	7,754	36,717
2019	9,509	257	1,316	329,814	8,921	45,639
Total	**107,721**	**1,316**	**1,316**	**3,738,160**	**45,639**	**45,639**

Impacts on COPD

For COPD in adults over 30 years of age, the impact of the programme would be to avert some 460 deaths over the 10 years, and just over 5,600 DALYs, Table 14.4 (c). In 2019, the benefits are 105 deaths and 1,280 DALYs prevented. For the whole 10-year period, the averted burden amounts to just over 1% of the national total COPD deaths and of DALYs, but about 2.5% in 2019. As for Scenario 1, these averted deaths and DALYs have effectively been banked as future benefits.

Table 14.4 (c): Impact of Scenario 2 on adult chronic obstructive pulmonary disease (COPD), for the period 2010 - 2019

Year	Deaths			DALYs		
	Total COPD projected	Averted each year	Cumulative averted	Total COPD projected	Averted each year	Cumulative averted
2010	3,198	10	10	39,466	128	128
2011	3,282	14	24	40,550	174	302
2012	3,367	19	43	41,619	234	536
2013	3,452	25	69	42,686	311	847
2014	3,543	33	102	43,756	409	1,256
2015	3,636	43	145	44,793	530	1,786
2016	3,751	55	200	46,102	679	2,464
2017	3,866	70	270	47,395	855	3,319
2018	3,981	86	356	48,679	1,057	4,377
2019	4,100	105	461	50,000	1,283	5,660
Total	**36,177**	**461**	**461**	**445,046**	**5,660**	**5,660**

Impacts on IHD

For IHD in adults over 30 years of age, the impact of the programme would be to avert just under 500 deaths over the 10 years, and almost 5,000 DALYs, Table 14.4 (d). By 2019, the benefits are 106 deaths and 1,070 DALYs prevented. For the whole 10-year period, the averted burden amounts to about 0.5% of the national total IHD deaths and of DALYs, but about 1% in 2019. These benefits would be realised in the future, starting from some 5 years after the interventions were introduced.

Table 14.4 (d): Impact of Scenario 2 on adult ischaemic heart disease (IHD), for the period 2010 – 2019

	Deaths			DALYs		
Year	Total IHD projected	Averted each year	Cumulative averted	Total IHD projected	Averted each year	Cumulative averted
2010	9,120	12	12	92,779	121	121
2011	9,350	16	28	95,154	163	285
2012	9,577	22	50	97,489	217	502
2013	9,800	29	79	99,773	286	788
2014	9,989	37	116	101,864	370	1,158
2015	10,175	47	163	103,866	472	1,631
2016	10,421	59	222	106,489	596	2,227
2017	10,664	73	295	109,058	739	2,966
2018	10,904	89	385	111,576	899	3,865
2019	11,140	106	491	114,043	1,071	4,936
Total	**101,140**	**491**	**491**	**1,032,090**	**4,936**	**4,936**

14.4. Discussion of the modelled health impacts

These two scenario models for the period 2010 to 2019 give some impression of the health benefits that would result from very substantial reductions in IAP exposure with clean fuels. The first, based on the ambitious AGECC target for 2030, emphasises the very large impact that elimination of exposure to household air pollution can be expected to have, particularly for childhood pneumonia and COPD. Ethanol can contribute to achieving this target, but does not need to be seen as the only option: other clean fuels and advanced biomass burning stoves (e.g. fan-assisted gasifiers) also hold the promise of delivering very low emissions of health damaging pollutants. The second scenario, based on projections for market growth for ethanol cooking only, still offers valuable benefits that can be seen to increase over time with growth in the total number of clean stoves in use.

In interpreting these estimated health benefits, however, it is important to keep in mind the multiple sources of imprecision in estimates of all of the parameters that contribute to the models, and the various assumptions that have been made.

In summary, the more ambitious Scenario 1 (AGECC target) would, in the year 2019, lead to the prevention of around 17%, 16% and 5% respectively of total national deaths and DALY's for child ALRI, adult COPD and IHD. Scenario 2, based on market growth with an ethanol price of 35 cents/litre, would in the year 2019, result in prevention of around 3%, 2.5% and 1% respectively of total national deaths and DALY's for child ALRI, adult COPD and IHD. This does however also assume that all homes in this market projection are using solid fuels at the start of the period. Note that homes switching from LPG to ethanol would not gain any health benefit through reduction of indoor air pollution.

It was previously mentioned that the exposure-response functions required to predict the health benefits given the measured exposure reductions observed for ethanol in this study, are not yet available. For this reason, large (>90% reductions) that accord with the available evidence on risk of exposure have been used for the modelling thus far. Preliminary results from the RESPIRE study in Guatemala indicate that a 50% reduction in exposure resulted in an approximate 15-20% reduction in pneumonia incidence[21]. This compares with the 56% reduction in risk used in the CRA and the current modelling, derived from studies that report a comparison of solid fuel use with clean fuel or other indictors of very low or absent exposure, and from which a pooled odds ratio of 2.3 was obtained. The implications of this are that the health impacts of ethanol stoves in Madagascar, if based on exposure reduction in the current study, would be around one-third of those reported for Scenario 2, above (the figures for Scenario 1 assume clean stoves, however achieved). We have argued above, however, that with widespread use of clean fuels, adequate supply and affordability, the exposure reductions with ethanol should in practice, and over time, be larger than those observed in the current study.

Based on the more limited evidence on the impact of the improved wood stove in Vatomandry, a similar effect could be expected, that is, around one third of the modelled health impacts. Unlike ethanol, however, which burns very cleanly and has low emissions of pollutants, the wood stoves achieve exposure reductions mainly by venting the smoke outside of the home. One important consequence of this is that we would not expect community outdoor levels of air pollution to be reduced, and consequently, reductions in personal exposures will never be as great as should be achievable with a low emission stove such as the ethanol Cleancook. For household continuing to use biomass, attention should be focused now on low emission stoves, such as those using fans and/or gasification.

Not included in these estimates of deaths and DALY's averted are other health outcomes which have not yet been formally included in the CRA, but for which there is growing evidence of a link with IAP exposure. These outcomes include low birth weight, TB, cataract, and possibly also lung cancer where biomass fuel is used (as opposed to coal which is already confirmed and included). The update of the CRA/GBD project will be published later in 2011, and will provide evidence summaries and risk estimates for any additional health outcomes that can in future be included in burden of disease assessment for IAP.

Finally, other health issues which were included in the study, notably burns/scalds, and symptoms of eye irritation, headache, etc., are also not formally included in these calculations as suitable summary estimates of risk (in the case of burns) or impact on health (eye irritation, headache) are not available. The importance of these outcomes for health and quality of life should however also be taken into consideration in assessing the benefits of the Ethanol (and other) interventions.

[21] Smith KR et al. Impact of a chimney wood stove on risk of pneumonia in children aged less than 18 months in rural Guatemala: results from a randomized controlled trial Epidemiology 2006;17:S45 (Abstract)

15. Conclusion and next steps

15.1. Conclusions

This study clearly demonstrated that the ethanol stove is an attractive alternative to solid household fuels in Madagascar. The Cleancook ethanol stove performed well, substantially reducing household concentrations of the health-damaging fine particles ($PM_{2.5}$) and carbon monoxide (CO). In Ambositra, personal (predicted) PM2.5 exposure was reduced to around 50 µg/m3, still above the World Health Organization guideline levels (10 µg/m3 for annual $PM_{2.5}$), but encouraging nonetheless (the data did not permit reliable prediction of $PM_{2.5}$ exposure in Vatomandry). It was also appealing to Malagasy cooks: almost all who received the stove used it and deemed it an improvement over their existing stove. This led cooks to use the stove, which in turn resulted in varying reductions in levels of exposures between sites (larger reductions in the highland community) and women and children (larger reductions seen in the women).

The link between reduced exposures and health improvements is becoming increasingly well documented, and some specific health impacts have been modeled for the Malagasy context showing that widespread adoption of clean cookstoves (including ethanol) would have a substantial impact on mortality and illness in Madagascar from conditions such as childhood pneumonia and chronic obstructive pulmonary disease (COPD). The study also directly measured impacts on common symptoms of eye irritation and headaches in mothers, and also burns in both mother and children. In comparison with the control group, the Ethanol stoves were found to substantially reduce risk of all of these outcomes for the mothers, although effects on child burns were non-significant.

Another key lesson from this study is that the design of the ethanol stove matters, as do factors associated with obtaining the fuel – access and price. Initially, the complexity of choosing an appropriate and safe stove was underestimated by the implementing partners. Fortunately, the team was able to recover from this oversight, but a repeat of this mistake in the program design and scale-up phase would have more dire consequences. Furthermore survey findings indicating that some households curtailed their use of the ethanol stove because the fuel was hard to obtain and/or too expensive suggest that the fuel supply chain issue also requires careful planning and monitoring.

This study also suggests that the locally produced Fatana Pipa wood stove, used only in the Vatomandry site, is also a promising stove, although it cannot compare with the performance of the liquid fuel ethanol stove, primarily because it relies on venting smoke outside the home rather than reducing emissions. Although it is not an aspirational stove and some cooks had concerns about its size and safety, most households that received it felt that it was better than their existing options. The stove also showed reductions in adult eye irritation and headache symptoms, and burns in both adults and children. Since it is clear that universal access to ethanol or other clean fuels (e.g. LPG) cannot be achieved immediately, this improved woodstove with a chimney could provide an interim solution to families in poorer/rural areas, where people do not have the resources to buy modern liquid or gaseous fuel.

The charcoal stove tested in this study performed poorly in respect of kitchen air pollution and personal exposure measures, and cannot be relied upon to deliver any health benefits to the Malagasy population. Despite this, there was evidence of reductions in eye irritation and headache in Vatomandry, in comparison with the control group. Nevertheless, given the clear finding that neither kitchen IAP nor personal exposure were reduced, it is recommended that this stove is not considered for any further investment. If charcoal is expected to continue being an important household cooking fuel, it will be important to identify and further assess alternative charcoal stoves that have superior performance to those used in the current study.

In this study, the group of homes that received only the awareness-raising intervention did not show any consistent improved outcomes over the control group. However, the authors recommend that this finding be interpreted in the context of the resources invested in the awareness-raising campaign for this project, which can at best be characterized as modest. This finding should not result in the exclusion of behaviour change communications and support for the introduction of improved stoves – indeed, an educational component should always accompany introduction of new fuels and cooking technologies. Instead we recommend that the participant perceptions gathered through this study could be used to inform future awareness-raising or social marketing efforts.

15.2. Scientific and Technical Next Steps

The technical scope of this assessment was more rigorous than has been the norm among cookstove programs. The primary goal of this assessment was to inform programmatic investment decisions; however, a secondary consequence is that this study breaks significant new scientific ground as well. To our knowledge, these results represent the most comprehensive household level assessment of the impacts of ethanol on indoor air quality and personal exposure, as well as the first time the impacts of such personal exposure reductions on childhood pneumonia and other health outcomes (COPD, IHD) have been modeled for an African context. As a result, the authors recommend that the key results be submitted for publication in a peer-reviewed journal.

Further from a scientific perspective, this study's success in isolating and measuring a significant and sustained effect from an improved cookstove intervention on personal exposure justifies a more detailed evaluation of the pathway from which health benefits could be derived. This should include more detailed assessment of exposure, including personal particulates (for which new, small scale monitors are under development), and biomarkers. Biomarkers can include both (i) measures of exposure such as COHb and urine metabolites of wood smoke, and (ii) markers of the disease process, for example, oxidative stress. Once larger scale sustained use of ethanol stoves is established, this would provide the opportunity to conduct studies of impacts on priority health outcomes, including child pneumonia, adverse pregnancy outcomes and the development of adult respiratory disease. We recommend that any such further investigations be conducted on study populations in the highland areas where background levels were higher and more consistent.

Should further work be done in Vatomandry, or similar settings the notably lower exposure levels and better ventilation observed would suggest that any future studies in this type of setting need larger numbers with repeated monitoring to overcome the imprecision created by the day to day variation in these factors.

15.3. Programmatic Next Steps

One of the clear and consistent findings of the qualitative surveys done for this study was the prevalence of a secondary fuel and/or stove in many homes both at Baseline and in the post-intervention rounds. This finding is not surprising, as similar patterns of fuel mixing have been documented in other parts of Africa. (Consequently, it is very important to view the total energy needs of the household, including for cooking (food and other tasks such as preparing animal feed, etc), heating and lighting, and not the cooking requirements in isolation.) This secondary fuel use must have an impact on indoor air quality and personal exposure, and it may explain certain trends in the data, but currently the authors can only speculate on the details of these effects. Therefore one recommendation for next steps is to undertake a further study of total household energy usage using temperature sensors that can provide an objective record of daily stove use.

The primary goal of this study was to inform investment decisions for the Government of Madagascar, the World Bank, and other stakeholders with regards to improved cookstoves. In particular, the Component A mandate was to assess the potential impacts on health and well-being of ethanol cookstoves; in parallel, Component B looked at the feasibility of the ethanol supply chain. Consequently the results presented here must be interpreted as demonstrating the efficacy of a potential intervention, which cannot substitute for an assessment of true effectiveness once the program has been designed and implemented. We recommend that these subsequent assessments focus on access to and adoption of ethanol stoves including effectiveness of supply chains, financing, behavior change support, etc.

The Fatana Pipa wood stove performed well but to be effective as an intervention, the design and installation challenges of this stove and its chimney would need to be addressed. We would also recommend that it be subject to rigorous laboratory testing to understand the mechanisms behind its high performance and perhaps optimize those advantages. A broader testing of other wood stoves available in Madagascar may also identify a better product. It is also recommended that the suitability and affordability of alternative, cleaner burning biomass stoves (for example those using fans and/or gasification) be assessed in the context of Madagascar.