



RESEARCH ARTICLE

REVISED **“We threw away the stones”: a mixed method evaluation of a simple cookstove intervention in Malawi**

[version 2; peer review: 2 approved]

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### Abstract

**Background:** Air pollution exposure is responsible for a substantial burden of respiratory disease globally. Household air pollution from cooking using biomass is a major contributor to overall exposure in rural low-income settings. Previous research in Malawi has revealed how precarity and food insecurity shape individuals' daily experiences, contributing to perceptions of health. Aiming to avoid a mismatch between research intervention and local context, we introduced a simple cookstove intervention in rural Malawi, analysing change in fine particulate matter (PM<sub>2.5</sub>) exposures, and community perceptions.

**Methods:** Following a period of baseline ethnographic research, we distributed *'chitetezo mbaula'*, locally-made cookstoves, to all households (n=300) in a rural Malawian village. Evaluation incorporated village-wide participant observation and concurrent exposure monitoring using portable PM<sub>2.5</sub> monitors at baseline and follow-up (three months post-intervention). Qualitative data were thematically analysed. Quantitative analysis of exposure data included pre-post intervention comparisons, with datapoints divided into periods of combustion activity (almost exclusively cooking) and non-combustion periods. Findings were integrated at the interpretation stage, using a convergent design mode of synthesis.

**Results:** Individual exposure monitoring pre- and post-cookstove intervention involved a sample of 18 participants (15 female; mean age 43). Post-intervention PM<sub>2.5</sub> exposures (median 9.9µg/m<sup>3</sup> [interquartile range: 2.2–46.5]) were not significantly different to pre-intervention (11.8µg/m<sup>3</sup> [3.8–44.4]); p=0.71. On analysis by activity, background exposures were found to be reduced post-intervention (from 8.2µg/m<sup>3</sup> [2.5–22.0] to 4.6µg/m<sup>3</sup> [1.0–12.6]; p=0.01). Stoves were well-liked and widely used by residents as substitutes for previous cooking methods (mainly three-stone fires). Commonly cited benefits

### Open Peer Review

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1. **Marc Jeuland** , Duke University, Durham, USA

2. **Deborah Stanistreet**, Royal College of Surgeons in Ireland, Dublin, Ireland

Any reports and responses or comments on the article can be found at the end of the article.

related to fuel saving and shorter cooking times.

**Conclusions:** The cookstove intervention had no impact on cooking-related PM<sub>2.5</sub> exposures. A significant reduction in background exposures may relate to reduced smouldering emissions. Uptake and continued use of the stoves was high amongst community members, who preferred using the stoves to cooking over open fires.

### Keywords

Air pollution, particulate matter, PM2.5, improved stove, intervention, low- and middle-income countries



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**REVISED Amendments from Version 1**

Overall, the paper has been reviewed and changes made in line with reviewer comments, to improve the focus on the qualitative ethnographic findings, and prevent any overstatement of the significance of the quantitative (air quality monitoring) results. More specific changes have also been made in response to reviewer comments. Changes are outlined below:

In the abstract and throughout the paper, use of the word 'baseline' has been reviewed. To eliminate confusion, the word is now only used to indicate the pre-intervention phase. In referring to non-combustion exposures, the word 'background' exposures now used for clarity.

In the introduction, the word 'persisting' has been replaced with 'persistent', as suggested.

Also in the introduction, the following sentence has been rewritten in line with reviewer comments: '*Centring local perspectives in this way, as well as constituting arguably the 'right' approach to global health problems, can optimise the suitability and sustainability of any subsequent solutions*'

Text has been added under the 'Study setting and population' section to provide more information on the setting and environment, including cooking practices in the village, as suggested by the reviewer. Extra text in the 'Study design and intervention' section and 'Data collection' strengthens this aim.

Also under 'Study design and intervention' section and 'Data collection' subheadings, extra text clarifies timescales of the study, which were previously confused.

Boxplots (Figure 4, Figure 5a & Figure 5b) have been updated to plots using corrected values to improve the quality of the figures. Relevant analytic methods have been updated under 'Data analysis'. Quantitative results have been updated slightly to reflect the more accurate re-analysis of the data.

Qualitative data have been added to the results in response to reviewer's comments, and elements of the discussion revised in keeping with this.

**Any further responses from the reviewers can be found at the end of the article**

## Introduction

Air pollution – and fine particulate matter (PM<sub>2.5</sub>) in particular – is a widely recognised risk factor for cardiorespiratory and wider systemic disease, and the interactions between airborne particulates and climate change also have repercussions for health<sup>1-3</sup>. In Malawi, which is largely rural, air pollution is a persistent problem, stemming mainly from domestic cooking: Malawian households cook on average three times per day, using biomass fuel (usually firewood) on three stone fires<sup>4</sup>.

Recent ethnographic work on 'smoke' in the Malawian setting highlighted the ways in which local experiences and values – often very different from those of western researchers – can shape locally-relevant priorities for intervention, and contextualised approaches<sup>4</sup>. By centring local perspectives, we can make interventions more context-appropriate, which often also brings benefits in terms of long-term sustainability. For health research which ostensibly aims to improve the lives of people in LMICs, prioritising participants' perspectives – rather than those of researchers – is also arguably best practice<sup>5-7</sup>.

In rural Malawi, where experiences of precarity, scarcity and food insecurity are common, these contextual realities often take precedence over externally proposed agendas such as ours. In a recent study exploring Malawian communities' perceptions of health within a trial of advanced cookstoves<sup>8</sup>, participants linked good health primarily to food security<sup>9</sup>. Thus the research imperative in such contexts should be for cleaner air solutions which avoid amplifying existing daily challenges for residents, as well as appropriately addressing shared concerns. In considering options for cleaner cooking in LMICs such as Malawi, economic affordability for the majority is a key consideration<sup>10-13</sup>. Whilst initial costs of clean stoves are important here, also relevant are costs of ongoing fuel purchase, and maintenance and repair costs of any newly introduced technologies<sup>14-17</sup>.

Perceptions of the benefits of new technologies are also context specific. Studies set in various LMIC settings have cited flexibility, in terms of fuel use or place of cooking<sup>18,19</sup>, and ability to cook quickly or for large numbers of people<sup>12,20,21</sup> as important considerations. Whilst cleaner burning biomass-fuelled cookstoves have been largely rejected by health researchers due to suboptimal emission reductions, features such as more efficient fuel use are themselves highly valued by local populations, with consequent potential environmental impacts conferring additional advantage<sup>22</sup>. Thus, while individual household interventions will not be sufficient to achieve clinically impactful reductions in PM<sub>2.5</sub><sup>23,24</sup> there may be wider benefits to adoption of locally relevant cleaner stove types in low-income settings such as Malawi. This could represent a useful interim step on the way to the much-needed provision of clean fuels at scale<sup>25</sup>.

Following an extended period of ethnographic and monitoring groundwork in a village in Malawi<sup>4</sup>, we provided locally made clay wood-burning stoves to every household. Realist evaluation aimed to assess residents' views of the cookstoves as well as any changes in personal PM<sub>2.5</sub> exposures three months after cookstove distribution.

## Methods

### Ethical considerations

The study was approved and sponsored by the LSTM Research Ethics Committee (20-022). In-country ethical approval was granted by the College of Medicine Research Ethics Committee (COMREC) in Blantyre (P.06/20/3069). Informed consent processed were completed for all participants involved in air quality monitoring. For other village residents, an extended process of community consent and introduction was undertaken, with engagement throughout the project ensuring continued consent for participation<sup>1</sup>.

### Study setting and population

The study was set in a rural village of approximately 300 households in Southern Malawi: the site of previous ethnographic and baseline monitoring work<sup>4</sup>. Residents were all subsistence farmers, and economic insecurity was common. Most income came from ad hoc piece work or self-employment

in small businesses. Cooking, mainly carried out by female household members, constituted the main source of  $PM_{2.5}$  exposure in this setting<sup>26</sup>. Across the village, most cooking was done on three-stone fires, using collected firewood for fuel. Households frequently owned a charcoal cookstove but, as their use required the purchase of charcoal, these were only used on specific occasions, such as when heavy rain prevented the use of three stone fires<sup>4</sup>. In addition, a few houses in the village – two, to our knowledge – had donated firewood cookstoves (or *chitetezo mbaula*, meaning ‘protecting stove’). Residents of these households used the stoves as well as three stone fires, and residents’ views on their benefits were mixed. Further contextual details are as previously reported<sup>4</sup>.

All households in the village were involved in the participant observation work and the intervention, and in qualitative elements of the evaluation. For exposure monitoring, consenting adult participants were recruited with an aim of achieving a broadly representative sample of village residents, including both men and women, members of different household sizes and structures, and varied cooking needs. These participants had to be resident in the village and habitually spending six or more days per week in the village setting. Children (aged under 18) were not included.

### Study design and intervention

This was a before-after study. Following a period of extended participant observation around the village and individual baseline exposure monitoring in a total of 23 residents (between February and March 2020), all households in the village were given a locally produced firewood cookstove. These moulded, natural-draught cookstoves made of clay were the same as to those already present in a few households, provided by government or non-governmental organization initiatives<sup>27</sup>, and recently piloted in rural Malawi in advance of a large cookstove trial<sup>28</sup>.

The cookstoves were introduced to key local representatives (including the chief and a local health surveillance assistant)

at a small village meeting, with explanations of their use and some expected benefits, before distribution – without cost – to households, in December 2020.

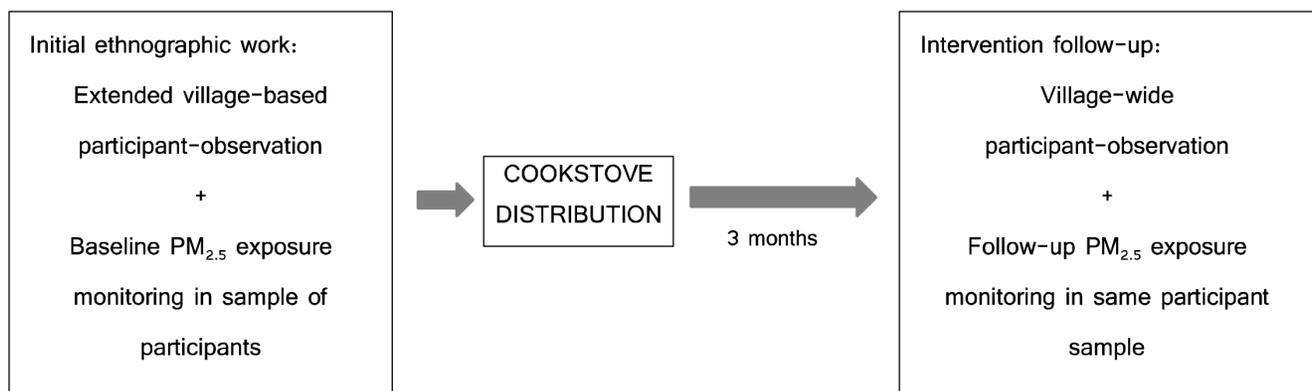
Three months after their initial introduction, researchers (PhD research candidate, SS, and research assistant, HS) returned to the village and continued participant observations around the village, extending between March and May 2021. The originally sampled 23 residents were approached again for involvement in repeat  $PM_{2.5}$  exposure monitoring (taking place March-April 2021) during the same evaluation period. These methods are depicted in [Figure 1](#) below.

### Data collection

**Quantitative data collection.** The original sample of 23 participants who took part in air pollution exposure monitoring were asked to each spend a further period of 48 hours carrying personal air quality monitors to assess post-intervention  $PM_{2.5}$  exposures. PurpleAir PA-II-SD laser particle counting devices (Purple Air, UT, USA) were used, as in the pre-intervention phase, again with 20Ah portable power banks (Anker Innovations, Changsha, China), and carried in specially designed waist bags. The devices took  $PM_{2.5}$  readings at two-minute intervals throughout the monitoring period.

As in the baseline study<sup>26</sup>, on monitor collection, memory cards were removed and the data used to create simple line graphs on a laptop, which were then viewed together, by the participant and researcher, and used as a basis for activity recall. This technique (developed on the basis of earlier work using monitoring alongside participant observations), allowed for division of all traces into ‘background’ periods of no identified exposure, and periods of ‘activity’ (where a specific source of combustion was identified). Further information was gathered around each identified episode of cooking, including bath-water warming or fire/stove use for heating, place of cooking, stove or device, and fuel used<sup>29</sup>.

**Qualitative data collection.** Participant observations were carried out by the doctoral researcher (SS) and Malawian research



**Figure 1.** Visual depiction of study flow and combination of methods.

assistant (HS), together with a local fieldworker: a village resident, and centred around cooking activity. As researchers and village residents were familiar with each other, following the initial period of ethnographic participant observation, observations were now spread around the village without the prior focus on a small number of individual households. Researchers visited the village on most days each week over a period of 10 weeks (during the same time period as the second set of exposure monitoring), spending time in all areas of the village over this observation period. Participant observation at this stage involved less active involvement by researchers in daily activities and more passive observation and discussion. Observations were mainly focused around evidence of stoves, fires, food, and fuel use.

Discussions, particularly in the post-intervention period, were often based around cooking and related activities (also including food preparation, starting of the fire or cookstove, and washing of dishes), partly because families were most often engaged in these activities when spending time around the household. Discussions were in reality more unstructured, participant-led conversations, and mainly concerned cooking and stove use, although other related topics were incorporated as was felt relevant by participants and researchers. Ad hoc conversations were held with any willing community members who were present at the time of our visits (although care and attention was always given to ethical issues including questions of confidentiality). In view of the social nature of the village setting, these conversations at times involved several women: either from an extended family group, or a group of village residents. At other times conversations were held with individual men and women. Conversations usually took place at residents' homes, almost always outside houses, in yards or verandas. Contemporaneous field notes were made during this fieldwork, integrating discussion content and observations.

The study was designed such that pre- and post-intervention monitoring took place during similar months over successive years. Both exposure monitoring periods and the period of post-intervention observation fell during the rainy season in Malawi (which is between between November and April each year).

#### Data analysis

**Analysis of  $PM_{2.5}$  exposure data.** Descriptive comparisons of proportion of recorded time (datapoints) spent cooking, and specific cooking features (place, device and fuel used) before and after stove introduction were produced. Exposures before and after introduction of the stoves were compared using median and interquartile range values. All exposure datapoints were first divided into 'activity' or 'background', categories using matched time-activity data, and medians and interquartile ranges before and after intervention introduction were then compared for both 'background' and 'activity' subcategories. For boxplots, corrected  $PM_{2.5}$  values were used: values were log transformed after adding 0.1 to allow log transformation of zero values. For statistical comparisons of

pre- and post-intervention exposures, median exposures for each participant (pre- vs post-intervention) were compared using a Wilcoxon signed-rank test. A non-parametric test was chosen as the data did not consistently show a normal distribution<sup>30</sup>. Data were analysed using R<sup>31</sup>, and the package ggplot2<sup>32</sup> was used to create plots.

**Analysis of participant observation data.** Fieldnotes were jointly reviewed and reflected on by SS and HS with input from the local fieldworker, and tentative themes iteratively developed through these discussions. Content of the notes was entered onto QSR NVivo V.12 (released in March 2020) for formal coding (SS) and review (HS). The combination of participant observations with personal monitoring allows a number of benefits including triangulation – avoiding a reliance on 'self-report' by participants – and introducing insights into how interventions work within social contexts<sup>33</sup>: particularly important in the case an intervention centred so firmly in the domestic sphere.

The combination of qualitative and quantitative enquiry, with each applied as appropriate, was used here as it allows for a fuller exploration of outcomes, particularly important for complex interventions with social elements<sup>34,35</sup>. Rather than separate but parallel applications and analysis, an integrated synthesis was used, allowing for more in-depth findings than when either single methodology is used alone. Qualitative and quantitative data collection were undertaken concurrently by the same research team, with integration happening at the interpretation stage: the so-called 'Convergent Design' model of mixed method study design<sup>36</sup>.

#### Results post-intervention

Between February 2020 and April 2021, 18 participants (15 female; mean age 43, standard deviation 14.2) completed the study with matching pre- and post-intervention traces (February – March 2020, and March – April 2021 respectively). The predominance of women in the sample reflected the majority female nature of cooking in the village. Three participants were lost from the full pre-intervention monitoring set (originally 23 participants) due to participants moving away from village (N=2) and participant death (N=1), and problems with monitors and batteries left only 18 with matching traces. The overall pre- and post-intervention dataset incorporated 1563 hours monitoring time (of which 788 hours post-intervention). In the pre-intervention dataset, trace lengths ranged from 23.3 to 58.5 hours (median 43.1; IQR 39.3 – 49.2). Post-intervention traces ranged between 24.1 and 53.9 hours (median 48.6; IQR 40.7 – 49.1). Traces shorter than 48H were due to battery faults.

Of the total recorded period (pre- and post-intervention), 351 hours (22.5%) constituted 'activity', of which 92% was cooking (including bathwater warming) activity. Other non-cooking activities included exposure to others' fires or stoves (such as when socialising at a neighbour's household) and burning grass on farmland. A larger proportion of the total post-intervention

monitoring period constituted combustion activity compared with pre-intervention (30% post- vs. 23% pre-intervention). Further details are available on Harvard Dataverse<sup>29</sup>.

### Cooking characteristics

In the baseline dataset, a majority of time spent cooking (across the dataset) employed three stone fires, with the remaining less than 20% of the time spent using charcoal or firewood stoves. After introduction of the firewood cookstoves to all households, over 95% of the overall cooking time was spent using the new stoves, with consequent reductions in use of three stone fires and charcoal stoves, now together constituting less than 5% of total cooking time<sup>29</sup> (Figure 2).

There were significant differences in fuel use in the before and after phases, with maize cobs widely used (in all but three households) post-intervention (Figure 3). This was linked to the timing of the harvest: whilst pre- and post-intervention periods occurred at a similar time of year, the post-intervention phase coincided with the immediate post-harvest period such that maize cobs were freely available in the village and tended to be used as fuel in preference to other available fuel types such as wood and charcoal<sup>29</sup>. Qualitative observations revealed how this change in fuel use also explained the increase in ‘combustion hours’ in the post-intervention dataset, with the inefficient burning of maize cobs extending cooking time, compared with firewood use.

### PM<sub>2.5</sub> concentrations before and after cookstove introduction

Median overall PM<sub>2.5</sub> concentrations pre- and post-intervention were not significantly different: pre- and post-intervention medians and interquartile ranges (IQR) 11.8 µg/m<sup>3</sup> (IQR: 3.8 – 44.4) and 9.9 µg/m<sup>3</sup> (IQR: 2.2 – 46.5) respectively (corrected

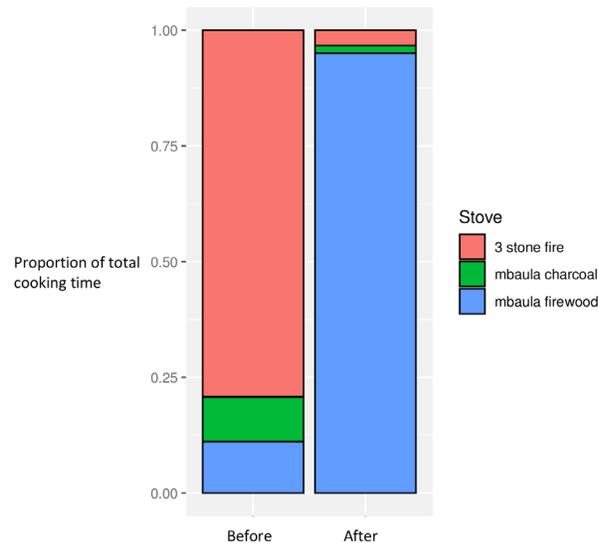
data shown in Figure 4, with dotted line to denote the WHO-recommended 24-hour upper limit (PM<sub>2.5</sub> concentration 15µg/m<sup>3</sup>)<sup>37</sup>. Comparison of pre- and post-intervention medians grouped by participant number confirmed no significant difference between these concentrations (Wilcoxon V=95; p=0.70).

Matching activity data to traces, we found that median and interquartile range values during cooking activity before and after cookstove introduction were not significantly different (median and IQR for cooking-related concentrations pre- and post-intervention 79.4 µg/m<sup>3</sup> (IQR: 21.5 – 397.0) and 80.6 µg/m<sup>3</sup> (IQR: 36.3 – 307.4) respectively; V=86; p=1.00. Median and IQR concentrations were above WHO-recommended 24-hour upper limits throughout (corrected data shown in Figure 5a).

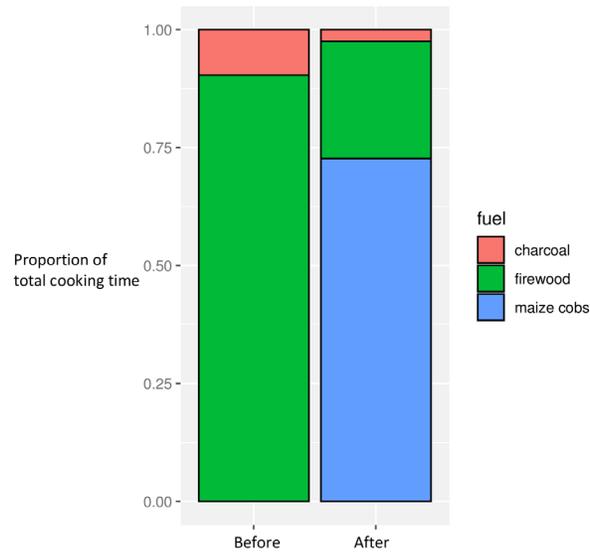
During periods of no identified combustion activity (‘background’), there was a statistically significant reduction in median PM<sub>2.5</sub> concentrations after the introduction of stoves, from 8.5 µg/m<sup>3</sup> (IQR: 3.0 – 21.4) to 4.6 µg/m<sup>3</sup> (IQR: 1.0 – 12.7); V=123; p=0.03. This reduction brought more of the values below the WHO limits (corrected data shown in Figure 5b).

### Qualitative findings

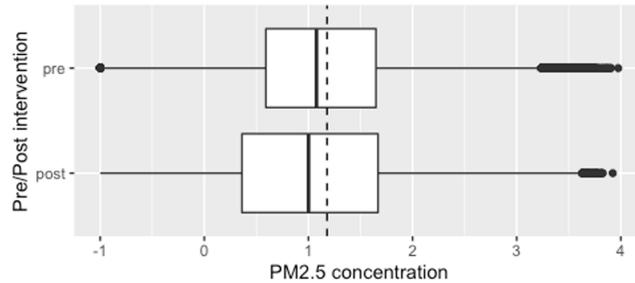
**Cookstove use:** Observations throughout the village supported the finding from the monitoring sample of high cookstove uptake rates. On walking through the village, we frequently found people cooking on the cookstoves and there was good evidence of cookstove use at households we passed. Almost all the cookstoves were blackened with cooking smoke, and they were often covered in maize meal flour, suggesting habitual use. Notably, where previously three stones were to be seen in and around almost every household, and often smouldering in the background before or after formal cooking episodes,



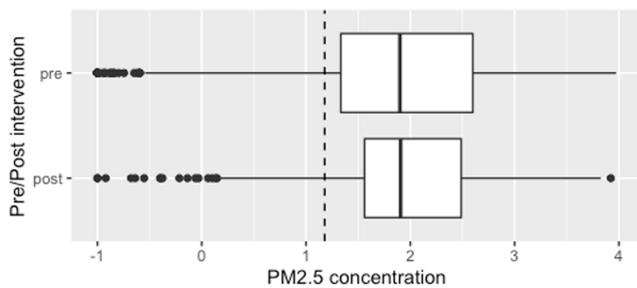
**Figure 2.** Proportion of overall cooking time by stove use, before and after intervention introduction.



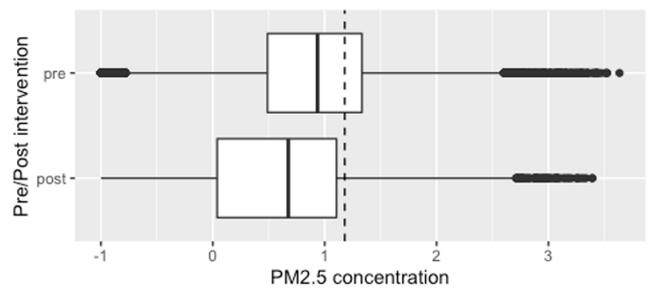
**Figure 3.** Proportion of overall cooking time by fuel use, before and after intervention introduction.



**Figure 4.** Box plot depicting corrected overall median PM<sub>2.5</sub> exposures before and after cookstove introduction, with PM<sub>2.5</sub> concentrations plotted on a log scale. Dotted line indicates WHO-recommended 24-hour upper limit (PM<sub>2.5</sub> concentration 15µg/m<sup>3</sup>).



**Figure 5a.** Box plot depicting corrected cooking-related median PM<sub>2.5</sub> exposures before and after cookstove introduction, with PM<sub>2.5</sub> concentrations plotted on a log scale. Dotted line indicates WHO-recommended 24-hour upper limit (PM<sub>2.5</sub> concentration 15µg/m<sup>3</sup>).



**Figure 5b.** Box plot depicting corrected background median PM<sub>2.5</sub> exposures before and after cookstove introduction, with PM<sub>2.5</sub> concentrations plotted on a log scale. Dotted line indicates WHO-recommended 24-hour upper limit (PM<sub>2.5</sub> concentration 15µg/m<sup>3</sup>).

these were now much less frequently seen. In some cases, the stones or bricks were seen to be discarded outside the yard. This was confirmed when raised in discussion with household members who, when asked where their three stone fires were, responded, “*palibe (there are none), we threw them away*”.

This finding, while frequent, was not universal, however. In discussion, a few residents mentioned using fires concurrently with their stoves if cooking had to be done quickly. In two households, women reported children (who were unused to the new stoves) using fires for cooking, and some women said that the stoves could not be used for very large amounts of food (for example when making “*thobwa*”, a fermented maize drink, and for cooking during special occasions such as weddings and funerals), although others’ accounts asserted the opposite view, confirming their use of the new stoves for these purposes.

One reason for not using the new stoves which was raised during several discussions was that firewood was sometimes in low supply. This related to the season, where there was little firewood to be found on the ground and this was sometimes damp or wet. In this situation, some residents bought small bags of charcoal, using this on charcoal stoves for the necessary household cooking. The purchase of firewood was uncommon as this was sold in large bundles which required a larger amount of money, as compared with small bags of charcoal.

**Perceived benefits of cookstoves:** In response to questions around why participants liked and used the new cookstoves, there were a range of responses, of which the most common was that the stoves saved firewood. Participants used the same fuel as they would have used on their three stone fires – maize cobs (and at times maize stalks) as well as wood – and many claimed that their stoves “*uses less maize cobs or firewood than three stone fire*”. The stoves were thus felt to be cost saving. A field-note made during a conversation with a resident, which – when raised – resonated with many others, read:

*“(Female participant explained that) it saves firewood, so saves money too. Sometimes she has to buy firewood, money goes further when using (a firewood cookstove)”.*

Variations on this, which were also commonly stated, were that the fire in the stoves was shielded by the wind, and that the stove “*keeps the heat*”, thus allowing for ongoing cooking or bathwater warming, without the continuing use of fuel.

The second most commonly noted benefit of the stoves was faster cooking time (“*imafulumira*”), with some also noting the stove heating up more quickly than the time taken by a fire.

*“Our relish is now cooked in 10 minutes – previously, with a three stone fire, it would take until after 12”*

Fewer residents raised the issue of smoke in discussing benefits. When asked specifically about smoke levels, opinions were split, with some feeling that the stoves produced more smoke, but others feeling that fires were worse. When discussing smoke levels, many people talked about fuel:

*“with wood, the firewood stove is better, even if using maize cobs, although with these there’s more smoke than with wood”*

*“Wet wood is smoky at first, then it dries and is better – there’s no difference between the stove and three stone fire. I would still use the firewood stove with wet wood”*

It was noted that the benefit of not having to tend to the fire in the stove as much as a three stone fire (as it was protected from the wind) and being able to move the stove inside or outside, allowed them a degree of control over their smoke exposures while cooking. This was supported by a quantitative finding of more cooking taking place outdoors in the post-intervention phase than pre-intervention<sup>29</sup>.

**Perceived disadvantages of cookstoves:** The main issue raised with the cookstoves was that of breakage. We observed a number of stoves which had cracks in the sides already, although in most cases these stoves continued to be used. The cracks rarely prohibited the use of stoves but did mean that these participants refrained from using very large pots on the stoves, out of caution, and from moving them to different places.

We came across a few stoves in which, over time, cracks had progressed to significant breakage (and a piece of the stove was completely displaced). In one of these cases, the resident had bound wire around the cookstove rim to hold it together, allowing her to continue to use the stove. In other cases, the stoves could no longer be used and were discarded, with residents in these households having reverted to the use of three stone fires. When asked about replacing the broken stoves, residents were positive, with most stating that they would pay between 1000 and 2000MK (approximately 1.20 – 2.50 USD): approximately the market price of the stoves. The extract from a conversation below illustrates many residents’ thoughts on replacing the stoves:

*“Me: Would you buy another? How much would you spend?”*

*Female resident: Yes. 1000, 1500, 2000 kwacha. “Anthu azolowera” (people have now become used to the stoves)”*

The main concern for most was that the stoves were not available for sale in the area, and that transport to the nearest market where they could be purchased would make their replacement unaffordable.

## Discussion

Three to five months after the introduction of locally made clay stoves in the village, the new stoves were being used in most households, and for most of the cooking and bathwater warming activity. In the sample of participants involved in personal exposure monitoring, there was no change in PM<sub>2.5</sub> exposures with the introduction of the new stoves, although ‘background’ exposures – in the absence of specific combustion activity – were lower post-intervention. Qualitative data revealed a widespread approval of the stoves amongst residents, with the main reason stated being their more efficient use of fuel. Cracking of the stoves with use was a key issue raised, and is a relatively commonly reported issue with these basic stoves, often

related to quality of clay or manufacturing processes<sup>38,39</sup>, although residents seemed keen to replace the stoves, should they be available for sale.

The widespread use of the new stoves was apparent in both the time-activity data collected alongside air quality monitoring, and in participant observation data, with both sources clearly indicating a replacement of previous cooking methods with the new stoves. This is notable, given the prevalence of ‘stacking’ (combined use of multiple cooking modalities, old and new, rather than replacement) following the introduction of ‘improved’ cooking technologies<sup>40–43</sup>. This relates to the reasons for continued use of traditional stoves, which vary but include limitations of newly introduced technologies, need for concurrent cooking on multiple stoves, and fuel access and cost, as well as (less commonly) different context-specific cooking needs<sup>40,41,43,44</sup>. Participants in this study raised some of these issues, namely that of using multiple devices concurrently, although when asked they stated that they would use two stoves if they were available. Issues with fuel access were also sometimes raised, in keeping with previous findings around resource limitations in this setting<sup>4</sup>.

In spite of the widespread cookstove use amongst the cohort, there was no difference in individuals’ PM<sub>2.5</sub> exposures, either overall or during cooking periods, after introduction of the stoves. This is perhaps unsurprising given the lack of clear evidence of exposure reduction with these basic cookstove types, compared with traditional cooking fires<sup>45</sup>. Participants’ observations of faster cooking time and less need to tend the fire when cooking on the new stoves signpost the potential for reductions in personal emissions on a larger scale – although this was not seen in our small sample of participants. Our finding of reductions in ‘background’ exposure (during non-cooking time) could reflect a previously reported greater reduction in smouldering emissions<sup>46</sup>. This possibility is supported by the fact that frequent observations of household fires being left to smoulder in the pre-intervention period were greatly reduced in the post-intervention period when most of the fires were replaced by the more-efficiently burning cookstoves. Given the decrease further below WHO-recommended thresholds, this may be an encouraging direction of change from traditional stoves.

These outcomes could be framed in terms of implementation science frameworks such as the RE-AIM framework<sup>47,48</sup> with statements relating to the high levels of ‘adoption’ and ‘reach’, poorer ‘effectiveness’ outcomes – judged in terms of researcher plans to reduce air pollution – and thoughts around ensuring ‘maintenance’ of the intervention in the longer term. This approach, with assessments made only in respect to researchers’ predetermined aims and outcomes, was not the aim of the study however. Our ethnographic work allowed insights into participants’ lived experiences, enriching the evaluation and helping us to understand its value from a range of perspectives.

In qualitative discussions, residents’ main comments on the new stoves related not to ‘smoke’, but to perceived reductions in fuel use compared with three stone fires which they replaced,

reflecting improvements in burning efficiency. This efficiency benefit is reported in the literature, although improvements with basic stoves tend to be modest compared with more advanced cookstoves<sup>45,49,50</sup>. The positive reception to the stoves seen in our study echo community responses to the introduction of the Jambar (another simple biomass stove with efficiency benefits) in rural Senegal<sup>51,52</sup>. Researchers Jeuland et al. note that “reducing firewood and charcoal consumption are important objectives in themselves – both from environmental and poverty alleviation perspectives”<sup>22</sup>. This is particularly relevant in a setting such as rural Malawi in which many residents’ lives are shaped by severe economic scarcity, and where access to food, and fuel on which to cook daily meals, are prime concerns<sup>4</sup>.

Researchers conducting the trial in Senegal and others have noted that participants’ willingness to pay for new stoves was high despite their initial free provision, and that their widespread provision to all community members positively influenced their uptake<sup>16,52</sup>. Findings of the current study agree with this, in that positive reports of the stoves were far more forthcoming after their introduction across the village than before the intervention from the few households which owned the stoves<sup>4</sup>. This village-level approach is also important in view of the shared nature of air pollution, with widespread uptake of cleaner technologies required to accrue air quality benefits<sup>53,54</sup>.

Strengths of our study lie in the combined use of qualitative observations and quantitative data collection to allow a real-time evaluation of the intervention – delivered on a whole-village level – in its intended context, and activity matched exposure data. We acknowledge that our study had limitations, namely the small sample of participants involved in the quantitative ‘air quality monitoring’ component, and the slight difference in timing of pre- and post-intervention phases resulting in the widespread use of maize cobs as fuel in the post-intervention phase. Outcomes of air quality monitoring were broadly in keeping with expectations however, adding evidence around potential reductions in exposures during the ‘smouldering’ phase. These findings should be further explored with larger scale monitoring studies, using techniques such as those we have employed to decouple cooking- and non-cooking related exposures.

In conclusion, whilst there were no cooking-associated reductions in PM<sub>2.5</sub> exposure after introduction of the cookstoves, the stoves were welcomed and widely used by residents across the village. Residents valued the efficiency and fast cooking of these stoves, as well as additional benefits such as a reduced need to tend the fire and the possibility of moving the site of cooking.

Whilst significant improvements in air quality will require a more comprehensive approach<sup>24,55,56</sup>, accessible cooking solutions such as these stoves with the potential to meet communities’ immediate needs represent a valued interim alternative to cooking on open fires. Scale up of production and distribution to allow more households to replace their stoves once broken, or even schemes to support local production, are required to allow more communities access to these simple technologies.

**Data availability****Underlying data**

Harvard Dataverse: Comparative pre-post PM2.5 data, <https://doi.org/10.7910/DVN/PNYOTX><sup>29</sup>.

This project contains the following underlying data:

- ppSet2.Raqm files.Rdata
- ppSetT.Raqm files.Rdata

**Extended data**

Harvard Dataverse: Comparative pre-post PM2.5 data, <https://doi.org/10.7910/DVN/PNYOTX>.

This project contains the following extended data:

- MM paper Supplement.docx

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

**Reflexivity statement**

The following reflexivity statement details key elements of the research partnership, conduct and reporting of the work presented above, in the hope that transparency with regard to transnational research practices will lay a foundation for more equitable ways of conducting collaborative research across the academic system.

<b>Study conceptualization</b>	<p><b>1. How does this study address local research and policy priorities?</b></p> <p>Air pollution is a global health priority. Malawi is a low-income country with high levels of air pollution and consequent morbidity. Cooking using solid fuels is thought to be a key contributor to airborne pollutant exposure in rural populations. Our interventional study – informed by an in-depth ethnographic account of air pollution (or ‘smoke’) in the setting – involved the introduction of a locally made cookstove in an effort to reduce individuals’ exposures while also considering residents’ other priorities relating to their health and wellbeing.</p>
	<p><b>2. How were local researchers involved in study design?</b></p> <p>The research assistant (HS) for this study is a local social scientist based in Malawi with previous experience doing research in this area. He was involved with study design and data collection and ensured that approaches and methods were context-appropriate throughout. The fieldworker (DM) is a resident in the village in which the study is based and contributed perspectives in study design and implementation as well as optimising linkages with the community throughout the wider study.</p>
<b>Research management</b>	<p><b>3. How has funding been used to support the local research team(s)?</b></p> <p>Part of the research funding was used to provide salaries for local researchers – as above – and staff involved in the broader research grant including research governance and grants management.</p>
<b>Data acquisition and analysis</b>	<p><b>4. How are research staff who conducted data collection acknowledged?</b></p> <p>The research assistant and fieldworker worked with the main researcher on data collection, and the research assistant also supported data management activities. Both are authors of this paper with their specific contributions acknowledged appropriately.</p>
	<p><b>5. How have members of the research partnership been provided with access to study data?</b></p> <p>Study data is archived at Malawi Liverpool Wellcome Trust. Local researchers have direct access to the data.</p>
	<p><b>6. How were data used to develop analytical skills within the partnership?</b></p> <p>The PhD researcher (SS) supported the research assistant in quantitative data management as well as analysis of quantitative and qualitative data, helping to develop these skills further.</p>
<b>Data interpretation</b>	<p><b>7. How have research partners collaborated in interpreting study data?</b></p> <p>Data interpretation involved discussions around analytical decisions and methods, which incorporated various members of the team (based in Malawi and the UK)</p>
<b>Drafting and revising for intellectual content</b>	<p><b>8. How were research partners supported to develop writing skills?</b></p> <p>The lead author of this paper is a doctoral candidate. She led in writing the paper, with reflective input and advice from all partners.</p>
	<p><b>9. How will research products be shared to address local needs?</b></p> <p>Preliminary findings have been shared within the village at dissemination events. Earlier quantitative data have been presented at local research dissemination conferences and within the research institution (MLW), and these forms of sharing will continue with the present data. This manuscript will be made available to the wider global scientific community for discussion and development of the findings.</p>

<b>Authorship</b>	<p><b>10. How is the leadership, contribution and ownership of this work by LMIC researchers recognised within the authorship?</b></p> <p>Please refer to the section on “Authors’ contribution” in the manuscript. Each author’s role is described including researchers from LMICs.</p>
	<p><b>11. How have early career researchers across the partnership been included within the authorship team?</b></p> <p>Please refer to question 8 above regarding leadership of the project. The study also incorporated a junior researcher in the LMIC setting as research assistant and a local fieldworker who had not previously had any research involvement, all included as authors.</p>
	<p><b>12. How has gender balance been addressed within the authorship?</b></p> <p>The research lead (whose doctoral work is represented here) is female, as are 3/7 of the authors, with representation from both local LMIC and HIC settings. Contributions to the study are acknowledged in the “Authors’ contribution” section of the manuscript</p>
<b>Training</b>	<p><b>13. How has the project contributed to training of LMIC researchers?</b></p> <p>The research assistant (HS) has been involved in the research process throughout, developing key skills, and has been supported in successfully applying for a Masters’ scholarship in Global Health research. Involvement of the local fieldworker (DM) constituted her first experience of research participation. Both have significantly contributed to the project and are recognised accordingly in the authorship. These experiences will lay the foundation for further academic career development.</p>
<b>Infrastructure</b>	<p><b>14. How has the project contributed to improvements in local infrastructure?</b></p> <p>Whilst this is a small scale study, the project team have strived to support constructive engagement between the village community and the research institution throughout. Stoves were provided to all households as part of the study and links have been made with the local provider to enable residents to purchase replacement stoves in the future. Work is also underway to create a nursery/health centre in the village to express thanks to residents for their involvement and to provide continuity of employment for the local fieldworker. With reference to question 3 above, research governance, ethics and grant management systems of the local implementing partner (MLW) were supported through this grant.</p>
<b>Governance</b>	<p><b>15. What safeguarding procedures were used to protect local study participants and researchers?</b></p> <p>The local ethics body and LSTM research ethics committee reviewed and approved the study protocol ensuring that both participants and researchers are protected throughout the study. Among other considerations, participants provided informed consent prior to their participation and, specifically, a named safeguarding lead (SS) was in place throughout, with various avenues of contact for participants to report any concerns, and structures for appropriate referral of any such reports.</p>

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# Open Peer Review

Current Peer Review Status:  

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## Version 2

Reviewer Report 18 March 2022

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**Marc Jeuland** 

Sanford School of Public Policy, Duke Global Health Institute, Duke University, Durham, NC, USA

Thank you for the revisions made in response to my comments. I found them to be responsive and on point.

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental health, energy access, economics

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

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## Version 1

Reviewer Report 09 March 2022

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**Deborah Stanistreet**

Department of Epidemiology and Public Health Medicine, Royal College of Surgeons in Ireland, Dublin, Ireland

There is a dearth of mixed methods papers in the HAP field that integrate quantitative findings with the qualitative data that explores the perspectives of the cookstove user and this is a well

written and interesting paper that addresses just that issue.

The Mbaula is indeed a cheap 'improved' cookstove in Malawi, one of the only improved stoves that communities can afford. Many communities have benefited from acquiring one over the three stone fire for a number of reasons, but for a number of reasons, the ability of the stove to reduce emissions had varied between studies. From our (soon to be published) scoping review it is also the only improved cookstove on the market which is cheap enough and accessible to the poorest populations in Malawi and therefore exploring community perceptions alongside HAP reduction is very useful.

This particular study found no significant difference in PM2.5 levels between the three stone fire and the Mbaula, but it may be worth also examining the evidence regarding whether the Mbaula can reduce HAP in a laboratory setting through the Clean Cookstoves Catalogue and to discuss some of the differences in performance between laboratory and field setting use and how this might be addressed.

<http://catalog.cleancookstoves.org/stoves/385>

Of particular interest is the discussion about the community views of the stoves and how this can potentially impact uptake and sustained use, as historically, there has been a greater focus on the technical aspects of the stove with less emphasis given to community preference. Might it be feasible to recommend the adoption of other behaviours that would reduce HAP alongside the Mbaula such as improved ventilation, facilities to dry wood, etc. as a means of reducing emissions further?

**Is the work clearly and accurately presented and does it cite the current literature?**

Yes

**Is the study design appropriate and is the work technically sound?**

Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**

Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**

Yes

**Are all the source data underlying the results available to ensure full reproducibility?**

Yes

**Are the conclusions drawn adequately supported by the results?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** public health

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 16 Mar 2022

**Sepeedeh Saleh**, Liverpool School of Tropical Medicine, Liverpool, UK

Many thanks to Dr Stanistreet for this review and the interesting and very relevant comments. We eagerly anticipate reading the upcoming scoping review mentioned, and we agree with the suggestion of the need for further evidence around the stove's performance in different environments, in view of its wide accessibility in very low-income settings.

We are grateful for the comments on the possibility of other 'behavioural' elements influencing overall exposures. A paper describing details of individual exposures in the village (pre-intervention), which provides evidence on the roles of fuel type and ventilation in shaping exposures, is currently under review, and we look forward to contributing further to these ongoing discussions around determinants of exposure in the rural African setting.

**Competing Interests:** No competing interests.

Reviewer Report 07 March 2022

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**Marc Jeuland** 

Sanford School of Public Policy, Duke Global Health Institute, Duke University, Durham, NC, USA

**Review of "We threw away the stones": a mixed method evaluation of a simple cookstove intervention in Malawi'**

### Summary

This is an interesting mixed methods study that explores adoption and use of simple biomass improved cookstoves in a rural village in Malawi. The authors conducted ethnographic research alongside measurement of exposures and time spent cooking to obtain richer insights on fuel and stove use practices and perceptions. The real strength of the study, in my opinion, is the ethnographic work, and I feel that the exposure results are somewhat overemphasized given the lack of a theoretical basis for expecting much exposure reduction. In trying to explain the exposure results (or lack thereof) the authors mostly speculate, without really nailing things down. More general and specific comments follow below.

### General comments

I generally like this paper and the point it is making, but I think that the central role afforded to exposure actually detracts. It seems like the paper is almost apologetic about the lack of significant improvements in exposure. In so doing, it ironically elevates that issue and puts it on an equal footing with the more interesting ethnographic aspects and insights. I would urge the authors to re-equilibrate the discussion to be more consistent with their points about livelihoods.

*Introduction, the sentence:*

- “Centring local perspectives in this way, as well as constituting arguably the ‘right’ approach to global health problems, can optimise the suitability and sustainability of any subsequent solutions”. This phrase is needlessly ambiguous. First, I am not sure what the authors mean by the “right” approach. I also think “optimize the suitability and sustainability” is too strong a phrase. Just centering local perspectives does not guarantee optimizing these rather difficult objectives. Moreover, local perspectives can actually be in direct conflict with sustainability, if we are considering environmental sustainability, for example.

*Study setting:*

- I appreciate that the paper reference previous studies in this particular location, but a reader of this article would like to know a bit about the site without having to refer to those prior studies. What are the main economic livelihoods activities in this location? Are there particularities of cooking and fuel collection activities there that are worth highlighting? Etc. This is especially valuable for understanding the context and broader implications of this research.

*Study design and intervention:*

- “Although they were known about by many in the village, few households already owned one of these firewood cookstoves.” This is a very important sentence, that raises many questions. If known about, why didn’t more households have these stoves? What had been the experiences with the stoves? Surely this would influence how people responded to the intervention. I noted that the authors discuss this point a bit on p.9 when emphasizing the importance of a “village-level” approach, but more background and discussion would be helpful about prior experiences and impressions.

*Data collection:*

- It would be useful to understand seasonal aspects of data collection. I gather from the manuscript that the pre- and post-intervention observations were 3 months apart. Were these in significantly different seasons? Also, what was the season for the the ten week period of observations, and how does this relate to behaviors and insights obtained? (Note that this comes up on p.6 as an explanation for changed fuel use, but a reader wants to know such details much earlier).

*Results:*

- Can the authors explain more why “combustion hours” increased post intervention? (p.5). Is this likely related to the intervention or due to some other time-varying phenomenon that was correlated with the intervention?
- Figure 4 and the statement about medians pre and post intervention do not seem to match. Am I misreading the plot?
- Did any households purchase firewood (not just charcoal)? My experience in Malawi tells me that this can be common in some areas, especially in the rainy season when firewood is wet. More details would be helpful here, including more explanation of the observation on p.7 that “This related to the season, where there was little firewood to be found on the ground

and this was sometimes damp or wet.”

- The authors say “Fewer residents raised the issue of smoke in discussing benefits, indicating what this may not have been a priority.” First of all, the sentence is not grammatically correct. But more importantly, isn’t the more logical explanation that this basic stove does not really reduce emissions? Concluding that this is not a priority is a stretch.
- How should we interpret the reduction in “baseline” exposures? (there is speculation of less smouldering, but this seems unlikely to me unless it was observed – in any case, evidence is not presented that this is the key mechanism at work). Also, throughout, I find the term baseline confusing, because it suggests pre-intervention, but the authors instead mean background exposures. I suggest just saying “background” exposures. Is the change due to seasonality – since dust and ambient pollution could be lower in the post-intervention period? Or could it be about different time use patterns due to season (more time in the fields, where air is cleaner)?
- Findings of significant breakage just a few months after intervention are concerning, but the authors don’t really reflect much on this issue and how villagers were thinking about it.

*Discussion:*

- “Four to six months”. I thought the observations began after 3 months. Or should it be 4 months?
- “Residents valued the efficiency and fast cooking of these stoves – responding to key local priorities – and these factors as well as less need to tend the fire and the possibility of moving the site of cooking also hold the potential for small reductions in population-level exposure.” The second part of this sentence goes too far, given the results of the study. And again, it almost devalues the first part of the sentence, apologizing for the lack of exposure improvements.

**Specific comments**

*Introduction:*

- “In Malawi, which is largely rural, air pollution is a persisting problem”. Do you mean “persistent”?
- “Thus, while individual household interventions will not be sufficient to achieve clinically impactful reductions in PM2.5 there may be benefits to community-level adoption of locally relevant cleaner stove types in low-income settings such as Malawi.” Is the “community-level” qualifier needed here? Wouldn’t there even perhaps be benefits from individual adoption? (e.g., fuel and time savings)

*Data Collection:*

- “Discussions were often based around cooking activities, partly because this was the activity families were most often engaged in when spending time around the household.” It would be nice to define “cooking activities”. In particular, I find it hard to believe that cooking was the activity with the most time spent, unless cooking is defined rather broadly to include cleaning, firewood collection and preparation, etc. Some more precision here would be helpful. Cooking hours themselves are likely significant, but rarely the dominant form of time use in settings such as this one.

*Discussion:*

- “Researchers conducting the trial in Senegal and others have noted that participants’

willingness to pay for new stoves was high despite their initial free provision, and that their widespread provision to all community members positively their uptake". There's a word missing in the latter part of the sentence.

**Is the work clearly and accurately presented and does it cite the current literature?**

Yes

**Is the study design appropriate and is the work technically sound?**

Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**

Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**

Partly

**Are all the source data underlying the results available to ensure full reproducibility?**

Yes

**Are the conclusions drawn adequately supported by the results?**

Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental health, energy access, economics

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.**

Author Response 15 Mar 2022

**Sepeedeh Saleh**, Liverpool School of Tropical Medicine, Liverpool, UK

Dear Prof Jeuland

Many thanks for your review of this paper, which has now been revised in response to the comments.

We have reproduced and addressed individual comments below (reviewer comments in italics).

*Introduction, the sentence:*

- *"Centring local perspectives in this way, as well as constituting arguably the 'right' approach to global health problems, can optimise the suitability and sustainability of any subsequent solutions". This phrase is needlessly ambiguous. First, I am not sure what the authors mean by the "right" approach. I also think "optimize the suitability and*

*sustainability" is too strong a phrase. Just centering local perspectives does not guarantee optimizing these rather difficult objectives. Moreover, local perspectives can actually be in direct conflict with sustainability, if we are considering environmental sustainability, for example.*

Thank you for this comment. The section in question has now been rewritten to improve the clarity and accuracy of the message.

*Study setting:*

- o I appreciate that the paper reference previous studies in this particular location, but a reader of this article would like to know a bit about the site without having to refer to those prior studies. What are the main economic livelihoods activities in this location? Are there particularities of cooking and fuel collection activities there that are worth highlighting? Etc. This is especially valuable for understanding the context and broader implications of this research.*

Thank you for noting this. Appropriate detail has now been added in the text under 'Study setting and population'.

*Study design and intervention:*

- o "Although they were known about by many in the village, few households already owned one of these firewood cookstoves." This is a very important sentence, that raises many questions. If known about, why didn't more households have these stoves? What had been the experiences with the stoves? Surely this would influence how people responded to the intervention. I noted that the authors discuss this point a bit on p.9 when emphasizing the importance of a "village-level" approach, but more background and discussion would be helpful about prior experiences and impressions.*

Many thanks, Prof Jeuland, for pointing this out. Relevant information has been added in the text. The key issue here is that we came across only two households which had these (donated) cookstoves so there was little scope for wider discussion of residents' experiences with these.

*Data collection:*

- o It would be useful to understand seasonal aspects of data collection. I gather from the manuscript that the pre- and post-intervention observations were 3 months apart. Were these in significantly different seasons? Also, what was the season for the ten week period of observations, and how does this relate to behaviors and insights obtained? (Note that this comes up on p.6 as an explanation for changed fuel use, but a reader wants to know such details much earlier).*

Thank you for picking up this valuable area of discussion. There was a lack of clarity in the paper as it was written, in relation to study timescales. This has now been revised (under the 'Study design and intervention' and 'Data collection' sections). The pre-intervention and post-intervention data collection periods actually took place during similar months over successive years. Most seasonal aspects should therefore be comparable between the two periods. A key difference here relates to the timing of the harvest, which fell during the

post-intervention monitoring period (but not during the pre-intervention period of monitoring). This had repercussions on fuel use, as described in the paper.

*Results:*

- *Can the authors explain more why “combustion hours” increased post intervention? (p.5). Is this likely related to the intervention or due to some other time-varying phenomenon that was correlated with the intervention?*

Thank you for raising this question. Our extended period of qualitative observation gave us insights into the likely reason for this, linked to the burning of maize cobs as fuel, which was inefficient and therefore extended cooking times, in comparison to firewood. This had been added to the text (under 'Cooking characteristics').

- *Figure 4 and the statement about medians pre and post intervention do not seem to match. Am I misreading the plot?*

We are grateful for this astute observation. The data as presented in figure 4 reflected the original values with some zero values removed by the system, due to the log scale. This was the cause of the incoherent figure. All three box plots have now been replaced, with the use of corrected values to ensure the full data are presented. The text in the relevant sections has also been revised to reflect this.

- *Did any households purchase firewood (not just charcoal)? My experience in Malawi tells me that this can be common in some areas, especially in the rainy season when firewood is wet. More details would be helpful here, including more explanation of the observation on p.7 that “This related to the season, where there was little firewood to be found on the ground and this was sometimes damp or wet.”*

Thank you for this observation. More information on fuel purchase has now been added, under 'Study setting and population', as well as the section described above. In relation to the specific question raised, we observed that village residents rarely bought firewood (this tended to be done only if households came across more money than they usually had access to) – mainly due to the costs of purchasing (large) bundles of firewood. Charcoal – being more commonly sold in small bags – was the more usual purchased fuel of choice where firewood was not freely available.

- *The authors say “Fewer residents raised the issue of smoke in discussing benefits, indicating what this may not have been a priority.” First of all, the sentence is not grammatically correct. But more importantly, isn't the more logical explanation that this basic stove does not really reduce emissions? Concluding that this is not a priority is a stretch.*

Many thanks for noting this. The relevant sentence has been rewritten to better reflect the subsequent discussion around residents' perceptions on the stoves and smoke levels.

- *How should we interpret the reduction in “baseline” exposures? (there is speculation of less smouldering, but this seems unlikely to me unless it was observed 10/21 & 13/21 – in any*

*case, evidence is not presented that this is the key mechanism at work). Also, throughout, I find the term baseline confusing, because it suggests pre-intervention, but the authors instead mean background exposures. I suggest just saying "background" exposures. Is the change due to seasonality – since dust and ambient pollution could be lower in the post-intervention period? Or could it be about different time use patterns due to season (more time in the fields, where air is cleaner)?*

We are grateful, Prof Jeuland, for your raising of this question and for noting the confusion around the use of the word 'baseline'. The use of 'baseline' has been reviewed throughout the paper, and changes made, in line with reviewer suggestions, to avoid confusion.

Regarding the question of the reduction in background exposures, the suggestion of smouldering is a proposed cause, but one supported by our extended observations in the field, both over a period of nine months before any intervention and following the introduction of the stoves. We regularly witnessed (and experienced) fires smouldering for periods of time following one cooking episode, and between episodes of cooking or bathwater warming, while household members served food, ate, and relaxed in the yard or veranda. During our time in and around households after the intervention, we noted that this was barely ever the case with cookstoves, and thus could be a likely mechanism for the reduced background exposures post-intervention. These details have been added to the manuscript in the relevant sections.

As discussed above, there were few seasonal differences between the pre- and post-intervention periods, as these periods covered similar months, both in the second half of the rainy season.

- *Findings of significant breakage just a few months after intervention are concerning, but the authors don't really reflect much on this issue and how villagers were thinking about it.*

Thank you for this point. Whilst the cracks in most cases did not constitute 'significant breakage' (most cracks were cosmetic, as described in the text, not interfering with cooking function), we agree that this had potential repercussions for intervention sustainability. This could be compounded by the issue of the stoves not being sold in or close to the village, and subsequent added costs of accessing new stoves. Unfortunately, these ongoing issues were too expansive to include in the current paper, whose scope was already felt to be quite broad. We agree that sustainability of this intervention over time will be an important subject to assess in future publications.

*Discussion:*

- *"Four to six months". I thought the observations began after 3 months. Or should it be 4 months?*

Many thanks again for noting the confusion with regard to timescales in this paper. The 'Study design and intervention' and 'Data collection' sections have been revised to clarify these issues, as has this sentence.

- *"Residents valued the efficiency and fast cooking of these stoves – responding to key local*

*priorities – and these factors as well as less need to tend the fire and the possibility of moving the site of cooking also hold the potential for small reductions in population-level exposure.” The second part of this sentence goes too far, given the results of the study. And again, it almost devalues the first part of the sentence, apologizing for the lack of exposure improvements.*

We are grateful for this comment and agree with your point, Prof Jeuland. The sentence in question has been altered accordingly.

### **Specific comments**

#### *Introduction:*

- *“In Malawi, which is largely rural, air pollution is a persisting problem”. Do you mean “persistent”?*

Thank you for this suggestion. The word has been changed to ‘persistent’.

- *“Thus, while individual household interventions will not be sufficient to achieve clinically impactful reductions in PM2.5 there may be benefits to community-level adoption of locally relevant cleaner stove types in low-income settings such as Malawi.” Is the “community-level” qualifier needed here? Wouldn’t there even perhaps be benefits from individual adoption? (e.g., fuel and time savings)*

Thanks again for this comment, with which we agree. We have removed the qualifier and slightly altered the sentence to reflect this point.

#### *Data Collection:*

- *“Discussions were often based around cooking activities, partly because this was the activity families were most often engaged in when spending time around the household.” It would be nice to define “cooking activities”. In particular, I find it hard to believe that cooking was the activity with the most time spent, unless cooking is defined rather broadly to include cleaning, firewood collection and preparation, etc. Some more precision here would be helpful. Cooking hours themselves are likely significant, but rarely the dominant form of time use in settings such as this one.*

We are grateful for this interesting observation. Our meaning here was that, in the post-intervention period, during which we mostly spent time and around households, the activities we observed (and at times took part in) around the household were largely related to cooking. This is in contrast to wider daily activities such as working on farms, bringing water from the well, and going to the shops, which took place away from the household. We also agree that the phrase ‘cooking and related activities’ better reflects our meaning here. We have revised the text to better explain this.

#### *Discussion:*

- *“Researchers conducting the trial in Senegal and others have noted that participants’ willingness to pay for new stoves was high despite their initial free provision, and that their widespread provision to all community members positively their uptake”. There’s a word missing in the latter part of the sentence.*

Many thanks for noting this omission. The missing word has now been added.

Once again, we thank you for your appreciation of the paper content and for the thorough and insightful review, which has much improved the paper.

Kind regards

Dr Sepeedeh Saleh MBChB, MPH, MFPH, DTMH, Wellcome Trust Clinical PhD Fellow,  
on behalf of the 'PAMODZI' project team

**Competing Interests:** No competing interests.

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