The Pollutant Exposure Impact of Solar Lighting:

Results from a pilot experiment in rural Kenya

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Introduction

A small study was carried out in Busia County, Kenya, to quantify changes in exposure to fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) associated with introducing solar lamps into households using kerosene lamps as their primary lighting source.

Popularity and sales of solar lighting have been increasing rapidly in developing countries, particularly in sub-Saharan Africa and South Asia. It has been suggested that solar lighting devices may provide a near-term alternative to polluting kerosene lamps, and other forms of fuel-based lighting, in areas with limited access to electricity. Whether there are health benefits to families using solar lamps rather than kerosene lamps has not been scientifically investigated. Evidence has been increasing, however, that uses of kerosene lighting and cooking devices in households are associated with serious health effects, particularly involving the lungs, but possibly also the eyes and to unborn babies. Evidence also suggests that these effects are caused by exposure to the pollutants emitted by the kerosene devices when they are operated.

The level of pollution to which an individual is exposed is often used as an indicator of health risk. The size of exposure changes is a critical input in the design of any health study intended to directly measure health impacts. Such health-focused studies typically require large sample sizes. Any exposure reductions resulting from the removal of kerosene sources would provide a first approximation of whether kerosene lamps contribute to baseline health impacts, and the possible benefits were they to be removed. This input on exposure changes was what the present study was intended to obtain, as well as to confirm the acceptability of the solar lamps as kerosene lamp replacements.

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Existing Evidence

Although there are still few epidemiologic studies of the health impacts of household kerosene use for lighting and cooking, the existing evidence is strongly suggestive. A growing body of evidence from developing countries has associated household kerosene use with adverse health outcomes – including tuberculosis, low birth weight, neonatal death, and pneumonia. There is also evidence that these effects are due to the exposure to the smoke emitted from these devices. This has led the World Health Organization to recommend discontinuing household kerosene use, while calling for additional studies to strengthen the evidence base.

Exposures to pollutants emitted from kerosene lamps and their associated health risks are not well characterized. We know that the smoke emitted by lamps commonly found in African homes contains large quantities of fine particulate matter ($PM_{2.5}$), probably the most important pollutant indicator of health risks. From measurements of how quickly $PM_{2.5}$ is emitted from a kerosene lamp, it has been estimated that a single lamp used inside a typical room can easily exceed World Health Organization Guideline Concentrations (WHO AQGs). The existing scientific evidence for lighting exposure, however, consists of estimates from laboratory experiments or measurements in selected rooms of homes. These studies are important and useful, but do not necessarily reflect the extent to which kerosene lamps contribute to *exposure* – the level of pollution directly experienced by the user. This added level of detail is important for determining whether lamps meaningfully contribute to exposure, given the other pollutant sources affecting a person. Moreover, no study has determined how exposure or air quality changes when solar lamps are introduced into households.

This Report

The first part of this report focuses on describing household demographics and results from questionnaires on self-reported health symptoms.

Part two focuses on the use of kerosene lamps and how this changed after the three solar lamps were provided to each household.

The third part looks at pollutant concentrations in rooms of the house and how those changed after solar lamps were introduced.

The fourth section looks at how exposure to two members of the house, an adult and a school pupil, changed after solar lamps were introduced.

Methods

The study employed a paired "before-and-after" design in which data were collected in the households before and after the introduction of solar lamps ("baseline" and "follow-up", respectively).

As we were particularly interested in the impact of solar lamps on school pupils who use kerosene for studying, households were recruited from a secondary school, located a few miles from the city of Busia, Kenya. With the co-operation of the school, 20 pupils (and their households) were selected from among the senior students in the school (Forms 3 and 4).
All participating households were required to use kerosene lamps as their main form of lighting and to have a kitchen building separate from the main living area.

Once baseline procedures had been completed, the family was provided at no charge with 3 SunKing Eco solar lamps and given instruction in their proper use. Kerosene lamps were not removed and no attempt was made to enforce their use or the disuse of kerosene lamps, or to maintain the working status of any lamps. Households had solar lamps for 3-4 weeks before field staff returned to perform follow-up procedures, including pollutant measurements.

Exposure Characterization

Several methods were used measure exposure characteristics of enrolled households before and after the introduction of solar lamps.

Questionnaires

Questionnaires were administered separately to the head of household, the school pupil lamp user and the adult lamp user (in almost all cases a female household member involved in the cooking, often the pupil's mother). These questionnaires obtained information on household circumstances, including means of cooking and lighting. They also inquired about health-related symptoms experienced by the lamp users.

Use of Kerosene and Solar Lamps (usage)

Lamp usage shows when and how long each lamp in a house was operated. Usage was measured by monitoring the temperatures of kerosene lamps and the voltages of the light emitting diode (LED) inside the solar lamps.

This approach does not measure pollutants, but it does provide information that complements pollutant measurements. Unlike pollutant monitors that can only be deployed for several days, usage monitors can be used to collect data for several weeks, providing a lot of information for confident estimation of the length of time kerosene lamps are used each day, and then whether reductions in kerosene lamp use correspond to increased use of the solar lamps (displacement). Also, usage serves as a check on whether reductions in pollutant levels correspond to reductions in the use of kerosene lamps (pollutant attribution).

Room Concentrations

The concentrations of health-damaging pollutants were measured inside selected rooms of each house. These types of measurement are often called measurements of indoor air quality. Monitors for measuring particles that penetrate the deep lung ($PM_{2.5}$) and carbon monoxide (CO) were placed at baseline and follow-up in the main living area, the school pupil's bedroom, and the kitchen--for a span of four days.

This approach measures pollutant levels in the rooms, but may still not reflect the true exposure of a person. This is because people do not typically spend all their time in a single room, but move through various environments which may or may not have monitors in them. Like usage measurements, room concentrations provide an idea of the extent of source attribution, since most pollution-generating sources affecting the room air are known in advance. Room concentrations are also easily compared to existing health benchmarks, such as the World Health Organization's Air Quality Guidelines (WHO AQGs).

Personal Exposure Concentrations (Exposure)

Monitors for health-damaging air pollutants were worn by 2 individuals living in each home. This type of measurement is often referred to as 'personal exposure', or sometimes just 'exposure'. At baseline and follow-up, two lamp users in each house wore a vest containing light-weight, unobtrusive $PM_{2.5}$ and CO monitors for a period of two days.

Personal monitoring provides a better estimate of true exposure than does room concentrations because the monitoring devices move with the wearer, and are thus affected by any pollutant source encountered. Changes in an individual's exposure are then recorded, whether a source is known or not.

Results

Household Characteristics

The median household size was 6 people, including 5 kerosene lamp users. All 20 households used cooking fires with biomass (19) or charcoal (1) as their primary cooking fuel. Of the 20 homes, 12 exclusively used kerosene for lighting; the other 8 reported use also of the light of the wood fire, cell phone lights or rechargeable battery lights. Lamps were used for reading, studying, cooking, and other work.

All houses had a separate private pit latrine and a separate kitchen building, where cooking was done with an open fire. None of the houses were connected to the electric grid and all used kerosene as their main lighting source, although supplementary sources were sometimes used. No household used solar lamps or candles.

Kerosene Lamp Usage

The extent to which solar lamps reduce exposure is predicated on them displacing use of kerosene lamps. Therefore, monitoring of both lamp types is important for demonstrating that the solar lamps were not only used, but that they also displaced polluting kerosene devices.

Lamp usage monitors showed two peak usage time periods each day: a large peak in the evening (maximal at around 7:00 pm) and a smaller peak in the morning (maximal at around 6:00 am). These trends were consistent from measurements during baseline (kerosene lamps only) and follow-up.

Solar lamps were used heavily, and their introduction to homes was associated with a 90% displacement of baseline kerosene lamp use. Average usage of the solar lamps at follow-up was about 4-5 hours per solar lamp, or 12-14 hours per household across all three solar lamps. While some continuing kerosene lamp use was detected, it accounted for less than 10% of total lighting hours in the average home. Homes that had only two kerosene lamps at baseline increased their overall lamp use time after the three solar lamps were received, suggesting that some unmet lighting needs existed at baseline.

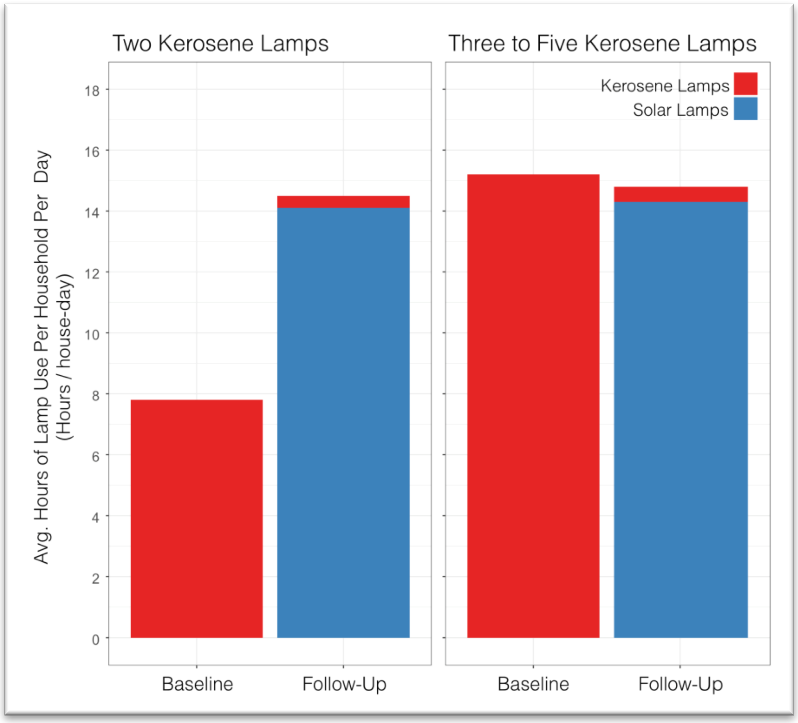

Figure 1. Average hours of lamp use per household per day by study phase, based on the number of kerosene lamps at baseline. Colors correspond to the hours of lighting contributed by kerosene and solar lamps. Each home received three solar lamps after the baseline phase, regardless of the number of kerosene lamps at baseline.

Room Concentrations

One indication of whether exposure reductions resulted from solar lamps is if the concentration of pollutants decreased in rooms where kerosene lamps were used.

At baseline, room concentrations were high, with average $PM_{2.5}$ levels exceeding the WHO guideline by a factor of at least six. Kitchens had the highest concentrations, followed by the pupils' rooms, and main living areas. High levels in the kitchens are not surprising, since all houses reported use of solid fuels for cooking, and because kitchens were unvented. Solid fuel stoves emit $PM_{2.5}$ and CO at a much faster rate than kerosene lamps.

Comparing baseline and follow-up $PM_{2.5}$ concentrations in the three rooms showed a mean reduction of 79% in the pupils' rooms and 61% in the main living rooms, but little change in kitchen concentrations. Reductions in the pupil's room and main living areas were highly statistically significant, meaning that there is confidence that reduction was not likely to be due to chance. The average indoor $PM_{2.5}$ levels in the main living areas and pupils' bedrooms at follow-up were near levels that would be expected in the absence of strong indoor sources of smoke. Little effect on kitchen levels was likely due to several factors: that the stove is a far more dominant source of $PM_{2.5}$, not all houses used kerosene lamps in their kitchens, and, in at least one case, families prohibited solar lamps from being used in the kitchen.

CO concentrations were low in terms of recognized health standards, regardless of study phase, and were unlikely to have been greatly influenced by the change to using solar lamps. This is consistent with the fact that kerosene lamps have been shown to produce relatively little CO. Monitoring of CO was not carried out in kitchens.

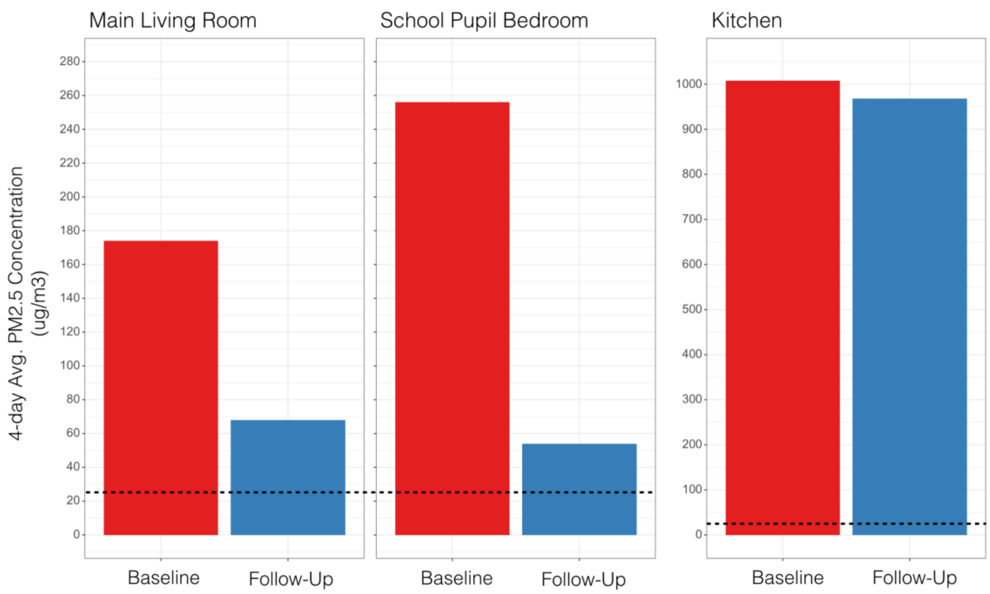

Figure 2. Average $PM_{2.5}$ concentrations (4-days) in the main living rooms, school pupil's bedrooms, and kitchens before (baseline) and after (follow-up) receiving three solar lamps. Note the difference in scales between the kitchen and other rooms. The dashed line corresponds to the WHO Air Quality Guideline level of 25 μg/m^3, which is considered a "safe" level of exposure.

Personal Exposure Concentrations

Concentrations of $PM_{2.5}$ exposure at baseline were at least five times greater than WHO guideline levels. Adults experienced exposure levels that were 60% greater than school pupils, which was likely because of their greater involvement in cooking with solid fuel stoves.

Personal monitoring of $PM_{2.5}$ showed an average 24-hour reduction in exposure of 73% between baseline and follow-up for school pupils, and a 50% reduction for adults. The levels of exposure experienced by pupils at follow-up were very close to what would be expected from outdoor air alone (ambient levels). The average exposure of pupils was close to the WHO guideline level, but many participants exceeded it. Adult exposures at follow-up were four times above the WHO guideline level, despite their reduction in exposure.

The difference in baseline and follow-up exposure levels experienced by adults and pupils highlights the strong influence of non-lighting pollutant sources, specifically solid fuel cooking stoves.

Personal CO monitoring showed average reductions of 16% and 33% for school pupils and adults, respectively. However, like micro-environmental measurements, both baseline and follow-up concentrations were well below recommended health guideline levels.

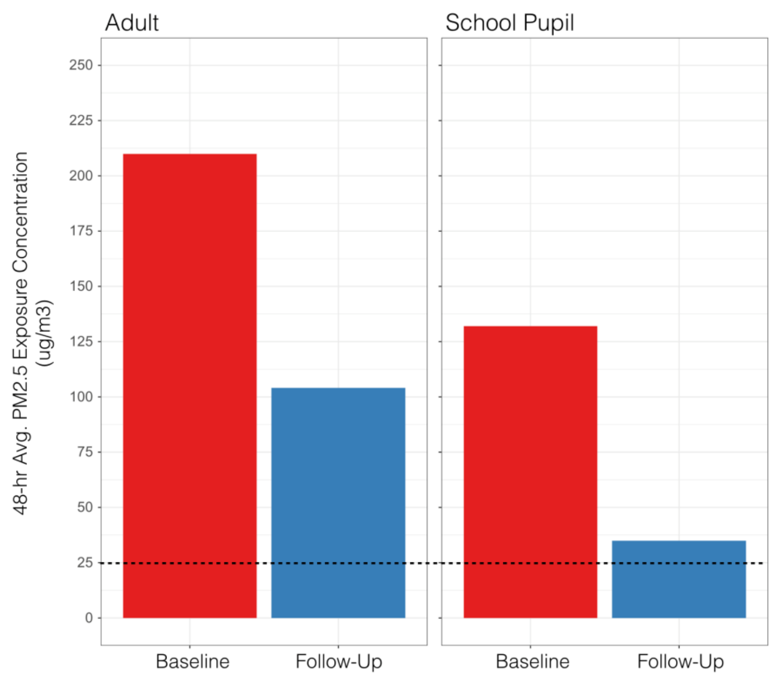

Figure 3. Two-day average $PM_{2.5}$ personal exposure concentrations for adults and school pupils, before and after the receiving three solar lamps. The dashed line corresponds to the WHO Air Quality Guideline level of 25 $\mu g/m^3$, which is considered a "safe" level of exposure.

Discussion

As far as we are aware, this is the first field-based study of personal exposures to $PM_{2.5}$ from kerosene lamps, and the first to estimate the extent to which such exposures can be reduced by provision of solar lamps.

The longer-term objective of this study is to research the question of whether introducing solar lamps into kerosene-lamp using homes could bring health benefits. To inform the design of such a study, particularly to decide on the appropriate number of participants, information on the extent to which solar lamps can reduce exposure to $PM_{2.5}$ is needed. This study has provided this information, and suggests that kerosene-related exposures are of such a magnitude that potentially their sustained removal from homes could yield health benefits.

Another important objective of this study was to determine whether solar lamps would be sufficiently accepted by family members that they would displace kerosene lamp use. This is a critical factor on which exposure reduction is heavily predicated. The results from usage sensors provided good evidence that provision of three solar lamps was sufficient to displace over 90% of kerosene lamp use in participating households. While this is short of the ideal 100% displacement, evidence from our exposure measurements suggests that three solar lamps ensured that the school pupils, at least, would have a solar lamp when doing their homework in the evenings.

A third objective of this study was to test the usefulness of some basic symptom questions. We did not expect to be able to detect with statistical confidence any changes in health status associated with the change from kerosene to solar lamps. However, we found a complete remission of symptoms reported at baseline. This complete elimination of ocular and respiratory symptoms is difficult to interpret, as removal of a single cause of common symptoms usually would not eliminate those symptoms entirely. It is possible that the reported symptom reductions were, at least in part, a manifestation of the so-called "Hawthorne effect", in which knowledge of the investigation and assumptions about what the investigators hoped to see influenced symptom reporting. Any study to follow this should include more objective measures of health status, less susceptible to a Hawthorne effect.

In interpreting the results of this small study, there are several important considerations. This study provided evidence of solar lamp-related exposure benefits among kerosene-dependent homes of Busia County, Kenya and does not necessarily reflect all community contexts. Personal exposure measurements among adults indicated, for example, that addressing other sources of exposure in the home, particularly the cooking stove, is critically important in achieving "safe" air quality levels for all family members. In this study, the fact that rural Kenyan houses typically separate their kitchens from other living spaces likely resulted in kerosene lamps playing a more pronounced influence on some family member's daily exposure. This might not have been the case if kitchens had been combined with, or in the same building as, sleeping areas. This illustrates the fact that results obtained in one setting do not necessarily apply in other settings.

As a critical household energy service need, the high displacement measured here is encouraging for the household energy sector as a whole, but merits further examination to determine whether these exposure reductions and use trends are sustained. Ideally, demonstration of long term and sustained exposure reductions should be one objective of any study that follows this one.

This study has shown (i) that kerosene lamp use in Busia county, Kenya, is associated with substantial measureable exposure to $PM_{2.5}$, both in adult and school pupil lamp users, (ii) these exposures are of such a magnitude that they have high potential to cause adverse health effects, and (iii) provision of at least 3 solar lamps per household provides a potentially effective means of reducing exposures and likely mitigating some health impacts of household air pollution. However, achieving "healthy" exposure levels for all family members would also require addressing additional sources of exposure related to household energy, particularly solid fuel cooking stoves.

In conclusion, we believe that the results of this study provide *prima facie* evidence of likely health harm from kerosene lamp use in at least some contexts, and benefits of providing solar lamps to displace kerosene lamp use.