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User perceptions about the adoption and use of ethanol fuel and cookstoves in Maputo, Mozambique

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ABSTRACT

Ethanol has been proposed as a clean cooking fuel to reduce the use of charcoal in urban and peri-urban households in sub-Saharan Africa (SSA). This could have the twin benefits of reduced impacts on human health and deforestation. The aim of this study is to better understand the barriers to the uptake of ethanol stove technologies by eliciting users' perception, adoption, and use patterns of ethanol stoves. The study was undertaken in Maputo, a city that was the focus of the first large-scale commercial ethanol stove project in Africa. A mixed-methods approach was adopted using both quantitative ($N = 341$ household interviews) and qualitative methods (5 focus group discussions, expert interviews). Ethanol stoves are currently used by about 17% of the surveyed households, while approximately 12% had discontinued its use and 71% never used it. While a large proportion of ethanol users compared the stove favourably against charcoal in terms of cooking time, convenience, cleanliness, and easiness to use, ethanol use seems to have diminished compared to charcoal. Ethanol seems to have replaced other clean cooking technologies such as electricity or LPG rather than charcoal. High ethanol fuel prices combined with low fuel quality and accessibility, as well as stove malfunctions due to poor design influenced many ethanol stove adopters to quit it. For the effective uptake of ethanol, it will be necessary to address the factors that tend to discourage its use, particularly its high initial and operational cost, poor fuel quality, unreliable fuel supply, and poor stove design. Although clean cooking fuels might not be attractive to users due to affordability and failure to meet user preferences, awareness raising campaigns that target potential users should emphasise the associated health and safety benefits of clean cooking fuels.

Introduction

Charcoal is a very important cooking fuel in most of the large urban areas of Africa as it is relatively cheap, reliable, convenient and accessible (BTG, 2010). These characteristics make charcoal an appealing fuel, particularly to the urban poor, as it can be purchased in small volumes and requires very limited investment to buy charcoal stoves. For example, charcoal use is very high in Mozambique, with about 87% of the households in Maputo and Matola, 85% of households in Beira city, and as much as 92% of households in Nampula using charcoal as their cooking fuel (Atanassov, Egas, Falcão, Fernandes, & Mahumane, 2012).

The widespread use of charcoal, however, raises concerns over large-scale deforestation (Ellegård, Chidumayo, Malimbwi, Pereira, & Voss, 2001; Atanassov et al., 2012; Baumert et al., 2016; Cuvilas, Jirjis, & Lucas, 2010; Mangue, 2000; Takama et al., 2011). According to Atanassov et al. (2012) charcoal users in Maputo and Matola in Mozambique consume an equivalent of 1.8 million tonnes of wood per year, which approximates to 141,985 ha of destroyed forest annually. Different development and environmental initiatives have attempted to reduce charcoal use, while the government has sought to regulate its use, but with limited success (Baumert et al., 2016; Cuvilas et al., 2010; Neufeldt, Langford, Fuller, Iiyama, & Dobie, 2015; Woolen et al., 2016).

Using biomass energy is not a cause for concern per se, but it becomes an issue when biomass resources are harvested unsustainably and when dirty and inefficient energy conversion technologies are used (Foell, Pachauri, Spreng, & Zerriffi, 2011; Ouedraogo, 2006). Fuelwood is usually combusted in open fires and traditional stoves that have low fuel efficiency and produce high emissions of indoor air pollutants (Ruiz-Mercado, Masera, Zamora, & Smith, 2011; van der Kroon, Brouwer, & van Beukering, 2014). High indoor air pollution has been associated with adverse health impacts (Puzzolo, Bruce, & Stanistreet, 2013; Bailis et al., 2007; Diaz-Chavez, Johnson, Richard, & Chanakya, 2015; Foell et al., 2011; Heltberg, 2004; Lambe, Jürisoo, Wanjiru, &

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Senyangwa, 2015). For example, in 2012, indoor air pollution accounted for about 4.3 million deaths globally and 600,000 deaths in Africa (WHO, 2016). High incidence of respiratory diseases due to indoor air pollution were observed in surveyed households in Mozambican cities such as Nampula (26%), Beira (25%), Maputo (19%), and Matola (19%) (Atanassov et al., 2012). While charcoal is considered a transition fuel from firewood, its indoor air pollution and the associated health impacts are still more notable when compared to clean cooking fuels such as ethanol, LPG and electricity (ClimateCare, 2016; MacCarty, Still, & Ogle, 2010; Practical Action Consulting, 2011; World Bank, 2015).

Ethanol has been promoted as an alternative cooking fuel to fuelwood and charcoal as it can improve household cooking efficiency, as well as has substantial health and environmental benefits (Ohimain, 2012). Ethanol stoves are very efficient and clean compared to other fuels commonly used for cooking, such as fuelwood and charcoal (Takama et al., 2011). Ethanol stoves produce substantially lower indoor air pollution than fuelwood and moderately lower indoor air pollution than charcoal stoves, reducing health impacts at the household level (Bailis, Pennise, Ezzati, Kammen, & Kituyi, 2004; ClimateCare, 2016; Gaia Association, 2014; MacCarty et al., 2010; Practical Action Consulting, 2011; World Bank, 2015). In addition, ethanol stoves are potentially easier and more convenient to use (Practical Action Consulting, 2011), as they do not require much effort in preparing the fire or cleaning after cooking compared to charcoal and fuelwood stoves.

Ethanol has been tested and used in gel and liquid form for household cooking in a number of African countries, although market penetration has generally been quite low (World Bank, 2015). Understanding the needs and behaviour of cookstove users is an important starting point when aiming to promote clean cooking interventions (Lambe et al., 2015; Rehfuess, Puzzolo, Stanistreet, Pope, & Bruce, 2014). Although ethanol has been gaining prominence as a household cooking fuel, due to its relatively lower penetration than other clean cooking alternatives (World Bank, 2015), there are significant gaps regarding its adoption, use and impact.

This aim of this study is to contribute to the current knowledge around the adoption of clean cooking stove technologies in sub-Saharan Africa (SSA), and particularly ethanol. This paper captures the perceptions, adoption and use patterns of stoves in Maputo, Mozambique, across three study groups (a) ethanol stove users, (b) ethanol stove quitters, and (c) households that never adopted ethanol stoves. The city experienced an extensive promotion of ethanol stoves from 2008 (with gelfuel under brand Chama Azul) and from 2010 to present (with liquid ethanol fuel under the brand name NDZiLO).

Both quantitative and qualitative research approaches are necessary for the analysis of energy technology adoption and use patterns (IEA and the World Bank, 2015; Kowsari & Zerriffi, 2011). Thus in this study we use a mixed-methods approach that combines quantitative and qualitative information collected through household survey, focus group discussions (FGDs), and expert interviews. Quantitative data obtained from the household survey are complemented with insights from the qualitative analysis of FGDs and expert interviews. The hypotheses underlying this study are that:

- There is no significant difference in the socioeconomic characteristics of adopters and non-adopters of ethanol stoves;
- Socioeconomic characteristics do not significantly influence the adoption of ethanol stoves.

Methodology describes the study sites and the data collection and analysis methods (Study site–Data collection). Results outlines the main results focusing on preferences regarding stove/fuel use and sourcing (Stove and fuel use, sourcing and preferences for cooking), cooking patterns (Food consumption and cooking patterns), reasons behind ethanol stove adoption (Ethanol stove adoption and use), socioeconomic characteristics of study groups (Socioeconomic differences between study groups) and costs related to stove operation (Differences in fuel consumption and expenditure). Discussion identifies the key implications and research priorities for promoting ethanol stoves in Sub-Sahara Africa.

Methodology

Study site

The study was carried out in Maputo city, the capital city of Mozambique, located in Maputo Province at the south of the country. Maputo City has a population of 1,225,868 people (Instituto Nacional de Estatística, 2014), largely depending on charcoal for domestic cooking energy needs (Introduction). Maputo was the focus of a large programme initiated by Cleanstar, a private company, involving the promotion of ethanol stoves and ethanol fuel as an alternative to charcoal. This involved an extensive promotion of ethanol stoves as a clean alternative to charcoal, with sales effectively starting end of 2012 (United Nations Foundation, 2016). The program resulted in approximately 30,000 ethanol stoves being sold in the larger Maputo area, and between 70,000–140,000 l of ethanol consumed per month (NDZiLO Operations Manager, personal communication, 27 June 2015). At the same time Cleanstar initiated ethanol production in the city of Beira (Central Mozambique) with cassava sourced from smallholder farmers from the north of the country.

However, the ethanol production component of Cleanstar was discontinued in 2013 and its ethanol distribution component was transferred to a company called NDZiLO in June 2013 (NDZiLO Operations Manager, personal communication, 27 June 2015). The re-structuring of Cleanstar meant that there was no ethanol production from cassava any more to supply the ethanol stove users in Maputo. Instead towards the last months before the collapse of Cleanstar they were imports of ethanol from South Africa, which was cheaper but of lower quality. This fuel often caused the underperformance and malfunctions of the canisters (NDZiLO Operations Manager, 27 June 2015, personal communication). Several users reverted to charcoal and LPG instead. However after the collapse of Cleanstar, NDZiLO started importing good quality ethanol fuel from South Africa in an effort to revive the ethanol stove sector.

Despite these issues related to ethanol fuel availability, Maputo still arguably constitutes the largest user-base of ethanol stoves in a major city of Africa. The sale of NDZiLO cookstoves and cooking fuel continues to this date, which makes the city of Maputo a unique opportunity to attempt to understand the social constraints and acceptance of ethanol stoves as an alternative to charcoal as a cooking fuel.

Data collection

The data collection comprised of a household survey, focus group discussions and expert interviews. We undertook an extensive household survey in July 2015 in the city of Maputo. This survey targeted both users and non-users of ethanol stoves. In total, 341 households were selected from the neighbourhoods of Benfica ($N = 72$), Chamaculo ($N = 61$), Hulene ($N = 60$), Mavalane ($N = 69$), Maxaquene ($N = 65$), and Urbanizacao ($N = 14$). These areas were selected as they had experienced extensive adoption of ethanol stoves as identified through expert interviews with management of NDZiLO that spearheaded the adoption campaigns. In addition, these areas were also chosen as to represent households of the predominant socio-economic background in Maputo. We selected participants randomly from a list of all ethanol stove customers provided by Zoe enterprises (holding company of NDZiLO). Through this purposeful sampling we tried to capture dynamics and reasons of ethanol adoption in comparison with other cooking options, rather than provide a baseline study of cooking fuel preferences across the city.

The household survey aimed to capture information on (a) the demographic and socioeconomic background of respondents,[1] (b) use patterns of various cooking stoves and fuels (c) food cooking and consumption patterns, and (d) detailed information on the perceptions of ethanol stoves. The household survey contained mostly closed-ended questions, with some open-ended questions used for eliciting deeper explanations of some key questions (see Supplementary Electronic Material). Survey development was informed from the extensive experience of the authoring team in stove and biofuel research in Africa, including in Maputo. We selected the household survey as the main data collection mechanism given its ability to elicit quantitative information between households in a consistent manner. We tried to minimise recollection uncertainties through the careful selection of questions and coding of possible answers. We reduced to the extent possible non-sampling errors through careful training of enumerators, pre-testing of the survey and triangulations of findings with qualitative techniques (see below) (Waha, Zipf, Kurukulasuriya, & Hassan, 2016).

Household survey data was supplemented with qualitative semi-structured interviews with key participants in the ethanol and charcoal urban value chain. This included 48 charcoal vendors and senior personnel that was involved in Cleanstar's operations. In addition, we undertook Focus Group Discussions (FGDs) with ethanol users (both current and past users). FGDs can allow for an in-depth understanding of user perceptions (Bender & Ewbank, 1994) and are considered an essential tool for understanding consumer behaviour (Folch-Lyon & Trost, 1981). FGDs have been used in the past to understand household energy choices in Mozambique (Risseeuw, 2012). They were used in this study to enrich the findings of the household survey by eliciting additional information through the interaction of ethanol stove users.

We used a revealed preference FGD design. The selection of participants was based on a list of all ethanol stove customers provided by Zoe enterprises (holding company of NDZiLO). Potential participants were identified through the list and were first called by local assistants who briefed them about the study and the planned meeting. Potential participants were then requested to indicate their availability for the FGDs with each selecting any day from Monday to Friday.

In total we performed five FGDs in July 2015, each with about 8–10 people. Participants in the group discussions were both men and women above the age of 20, with most being in the “46 years and above” category.

Data analysis

Handling and analysis of the quantitative data was done in Microsoft Excel and R, version 3.2.2 (R Core Team, 2015). Data was initially analysed through descriptive statistics namely frequencies, means, and proportions. The ANOVA and the Tukey's HSD post-hoc tests were used to test for the significance of differences in various socio-economic variables between the three study groups, i.e. (a) ethanol stove adopters, (b) ethanol stove quitters and (c) those that never adopted ethanol stove. ANOVA can test the null hypotheses that the means for three or more groups are equal (Field, 2009). However, while the ANOVA can show that there are differences between groups, it does not clearly show which factors are responsible for this difference. Hence we use the Tukey's HSD post-hoc tests to show which groups are different from each other.

When assessing the adoption of ethanol fuel and cookstoves, understanding the overall socio-economic characteristics of the households is important (Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2017; Rehfuess et al., 2014). Income is a widely used indicator of household poverty and economic welfare. However as a mono-dimensional measure it has received wide criticism within the academic community, especially when used to indicate poverty levels (e.g. Alkire & Foster, 2011). There has been an increasing proliferation of academic literature on poverty measures using not only monetary indicators/metrics (e.g. USD/day) (Alkire & Foster, 2011). For the purpose of this paper we adopt the Multidimensional Poverty Index (MPI), which is a high-resolution lens on poverty (Alkire et al., 2015; Alkire & Foster, 2011; Alkire & Santos, 2011; Mudombi et al., 2016). Essentially the MPI is a composite indicator comprising of 18 individual indicators across three major categories, i.e. health, education and living standards (Alkire & Foster, 2011). For more information on the derivation of the MPI see the Supplementary Electronic Material.

The household Food Consumption Score (FCS) was used to understand the types of food consumed within a household (and its frequency), as a proxy for nutrition/food security. The FCS is a standardised metric developed by the Food and Nutrition Technical Assistance (FANTA) projects as a measure of dietary diversity and a proxy for food security (FANTA, 2006; Hoddinott and Yohannes, 2002; Mudombi et al., 2016). Respondents were asked for the number of times in the seven days prior to the survey that a particular type of food was consumed by the members of the household, and also the number of the days that particular type of food was prepared at home. We used the FCS as one of the nutrition indicator in the MPI (see also Mudombi et al., 2016). Detailed information about the calculation of the FCS is included in the Supplementary Electronic Material.

Qualitative content analysis techniques were used to analyse the FGDs data. FGDs were transcribed and the text was analysed by first classifying it into categories with similar meanings and themes (Hsieh & Shannon, 2005). This information from the FGDs gave an in-depth understanding of perceptions and usage of the ethanol cookstove and fuel.

Overall the presentation of results in Results broadly focuses on the quantitative data from the household survey and the charcoal vendors. These results are complemented where needed by insights gained through the qualitative analysis of expert interviews and FGDs. Unless stated otherwise, all results in Results come from the household survey.

Results

Stove and fuel use, sourcing and preferences for cooking

Most households (96.19%) used charcoal for cooking, of which (29.9%) used it exclusively, with the remainder using it in combination with one or more other fuels (Fig. 1). Other common fuels were electricity (32.8%), LPG gas (22.9%), ethanol (17.0%) and firewood (12.0%) but in all cases, almost always in combination with charcoal. None of the households indicated that they used kerosene fuel for cooking.

Fig. 2 shows that the charcoal stove was preferred by the greatest proportion of households (about 54%), followed by LPG stove (23%), electrical stove (10%), ethanol stove (10%), and firewood stove (3%). Interestingly, at the same time a relatively bigger proportion of household (by about 37% of households) indicated the charcoal stoves as their least preferred stove, followed by electrical stoves (31%), firewood stoves (14%), ethanol stoves (13%), and LPG stoves (5%). The reasons for stove preferences as elicited from the household survey and the FGDs were highly variable between stove types (Table 1).

In terms of fuel switching, a relatively small percentage of households (14%) indicated that they had changed their main cooking fuel to a new fuel in the past 5 years. Fuels that experienced a net gain in users are charcoal and LPG. About 31% of the households that changed their main fuel had abandoned charcoal as their main; however, 56% of the households adopted charcoal as their main cooking fuel. This is also the case with LPG, as about 15% of those households abandoned LPG, while 23% adopted LPG, thus representing net gains in users.

[1] It has been suggested that it is important to obtain the demographic characteristics of households, including the people who stay at the household and the average number of people cooked for on a regular basis (Hemstock, 2005, 2007).

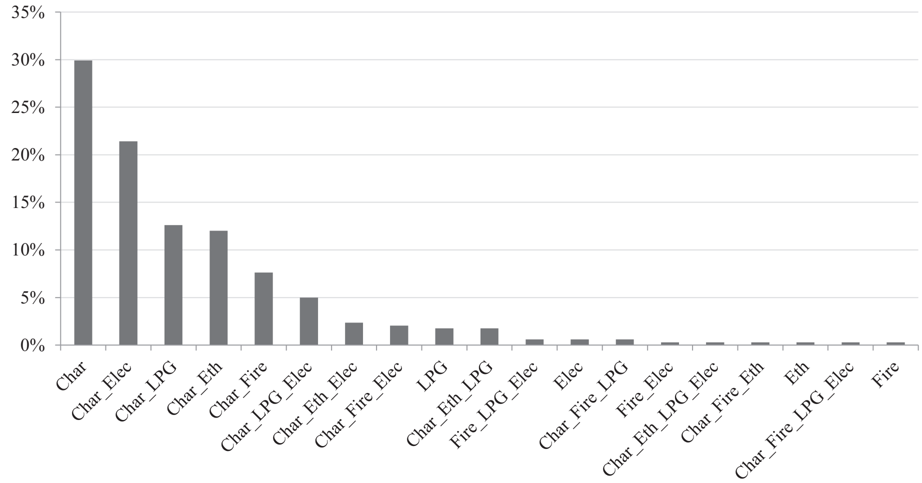


Fig. 1. Household cooking fuel combinations Note: Char = Charcoal; Fire = Firewood; Elec = Electricity; Eth = Ethanol.

Fuels that registered a net loss of users as the main cooking fuel were electricity, firewood, ethanol, and kerosene. Electricity was abandoned as a main fuel in 25% of the households and was adopted as the main fuel in 13% of the households, firewood was abandoned in 15% and was adopted in 2%, ethanol was abandoned in 10% and was adopted in 6%, and kerosene was abandoned in 4% and adopted by 0% as the main fuel.

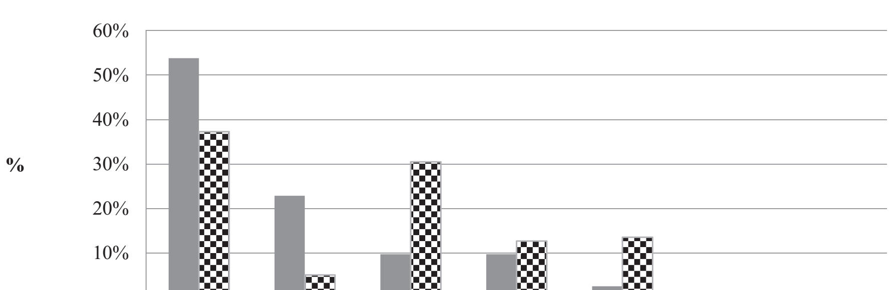
As discussed in Introduction, access to cooking fuel, both in terms of availability and time to access it, is an important factor affecting its adoption and/or usage. The household survey suggest that there was no specific main source for firewood, as almost equal proportions of households accessed it from the municipal market, roadside sellers, home sellers, and own collection. Charcoal was mainly sourced from home sellers, municipal market, and roadside sellers. Electricity tokens/vouchers and ethanol were mainly bought at designated shops in the market place while LPG was mainly bought at fuel stations. A dedicated question in the household survey identified that the average time to source the fuel (i.e. going from the household to the purchase/collection point and back) varied considerably between fuels, with firewood taking the longest (about 47 min), followed by ethanol (30 min), LPG (25 min) and charcoal (24 min).

When it comes to the areas of origin of the charcoal, expert interviews with charcoal sellers found that the charcoal supplied in Maputo city came from the neighbouring Gaza and Inhambane provinces, most specifically from the districts of Chicualacuala, Vilanculos, Chokwe, Mabalane, Caia, Massingir, Macia, Guija, and Ximondzo. All of these are over 150 km and some as far as 600 km from Maputo, showing the considerable extent of the charcoal supply chain.

Food consumption and cooking patterns

The functionality of each type of stove was further evaluated by asking household survey respondents the main stoves used for various types of food prepared and consumed at home (Fig. 3). Generally speaking, most households predominately used the charcoal stove to cook most types of food. For example, the fraction of household using predominately charcoal stoves to cook food was: maize flour (61.9%); rice (74.5%); bread/wheat/other cereals (1.2%); tubers (43.4%); peanut/beans/peas (77.7%); fish (62.8%); livestock meat (36.4%); poultry meat (61.0%); eggs (32.4%); milk/dairy products (5.9%); and vegetables (76.0%). The LPG stove was used as the predominant stove as follows: maize flour (4.4%); rice (12.9%); bread/wheat/other cereals (0.3%); tubers (9.1%); peanut/beans/peas (4.1%); fish (10.6%); livestock meat (5.0%); poultry meat (11.4%); eggs (13.6%); milk/ dairy products (2.3%); and vegetables (6.5%). Electricity and ethanol stoves were mostly used for food that takes short time to be cooked. For instance, the electricity and ethanol stove was predominately used by 15.9% and 8.3% of households to cook eggs.

The household survey also inquired approximate cooking time for various types of food using the predominant stoves (Table 2). While this information provides an added lens on the fact that stoves using modern fuels tend to be faster, it is important to note that some stoves like ethanol stoves are not commonly used to cook many types of food. Thus some of these results are based on the experience of the respondents and are possibly uncertain. In any case, LPG and ethanol stoves seem to relatively have the shortest cooking times compared to other stoves.



	Charcoal Stove	LPG Stove	Electric Stove	Ethanol Stove	Firewood Stove	Joint Stove	Improved Charcoal Stove
Favorite	53.81%	22.88%	9.75%	9.75%	2.54%	0.42%	0.42%
Less Prefered	37.29%	5.08%	30.51%	12.71%	13.56%		

Fig. 2. Household stove preferences.

Table 1
Reasons behind stove preference reasons elicited the survey and FGDs.

Stove	Reasons for being preferred	Reasons for not being preferred
Firewood stove	- More economic - Cooks faster	- Takes time to illuminate - Makes cookware dirty - Very dirty and smoky - Causes a smoky smell to food
Charcoal stove	- Safer - Easy for cooking - More economic - Does not make cookware dirty - Produces less smoke - Faster to cook - More flexible and cheap - Has an insurance for future use - Secure - Best for foods that take longer time - More comfortable -Versatile (i.e. can be used for many cooking activities) - Effective - Easy access - Easier to use - Used to it.	- Makes the cookware and hands dirty - Burns the pots - Less flexible shaft - Relatively less fast - Can affect the flavor of the food - More expensive - Takes time and difficult to illuminate especially during rainy days - Not economic - Slow to cook.
Improved charcoal stove	- Very good	NA
LPG stove	- Very good	- Difficult to handle and safety issues - Slow - Expensive (particularly the fuel tanks)
Electrical Stove	- Not dirty - Faster - More economic - Cheaper than charcoal - More convenient - Simple to use.	- Time consuming - Delay in food steaming - High cost of energy - Uses a lot of energy - Safety issues and fear of electrocution.
Ethanol stove	- Fast and more comfortable - Does not make the cookware dirty - Economical - Future use (backup) - Very easy to use	- More expensive - Worsens the sinusitis - Smelly - Slow - Not economical - Price has been increasing - Flame is very intense - Stove tanks get corroded - Small burners - Safety issues (one respondent indicated that she saw someone being burnt by the stove)
Joint (LPG and electricity) stove	- Quick	NA
Kerosene Stove	NA	- Smelly

The above was corroborated by FGD participants who further indicated that they liked to use the ethanol stove for food that takes a short time to cook such as eggs, rice, soup, tea, curries (chicken or fish and crushed peanut) as well as for heating food and water for bathing. Most of the respondents did not like cooking beans on ethanol stoves because it was quite expensive (i.e. requires between 2 and 5 l of ethanol fuel to fully cook the beans).

Ethanol stove adoption and use

About 29% of the households reported that they have (or previously had) an ethanol stove. Of these, about 54% still used the stove, 4% indicated they only use it at times, and about 42% were no longer using the stove. Thus, considering the total household survey sample, the adoption profile[2] is as follows: current adopters (17%), quitters (12%), and non-adopters (71%).

The survey respondents (those who knew or had used the stoves) were also asked about the reasons why they preferred the ethanol stove to the charcoal stove. The most frequent reason was that ethanol stoves are faster to light (fire-up) and cook than charcoal stoves (68%). Less prevalent but still important reasons include that ethanol stoves produce less smoke than charcoal stoves (21%), that ethanol stoves are more economic than charcoal stoves (7%), and that ethanol stoves are better than charcoal stoves (4%).

FGD participants highlighted the convenience of using the ethanol stove (i.e. the stove is easy to use, takes a shorter time to start and put off, it can be used anywhere and in all seasons) as the main reason that prompted them to buy an ethanol stove. Examples of some quotes[3] include P5.29 *"It is safe and fast and can be used anytime"* and P3.15 *"Ethanol stove can be used on rainy and windy days, any time and in every part of the house (living room, kitchen)"*. Another important aspect was social exposure i.e. awareness of the stove (P 3.13 *"When I saw the stove I got interested because I heard that it wasn't dangerous for kids and it could be used indoors without smoke"*). The participants highlighted that a good marketing strategy had been used by NDZiLO to promote usage of the stove. Peer influence (e.g. from the neighbours) also influenced some households to adopt the stove because it was trendy. Other reasons include economic aspects, safety (P3.17 "*It is not dangerous even*

[2] The usage of the terms adopters, quitters (adopters who discontinued), and non-adopters in this article are in reference to the adoption of ethanol cooking fuel and the cookstove.

[3] P5.29 represents participant number 29 in focus group discussion number 5. Same coding applies to other participant highlights.

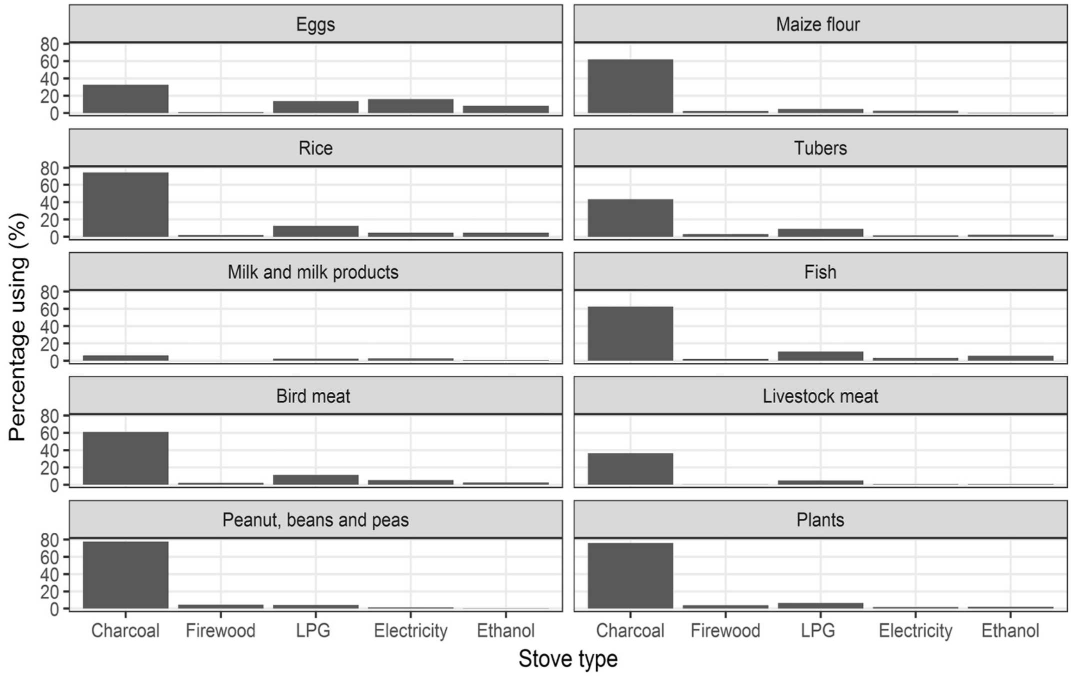


Fig. 3. Types of food cooked by each type of stove.

kids can use it without any problem"), health (e.g. lack of smoke or indoor air pollution), and lower environmental impact (i.e. low effect on pollution and forest degradation).

On the other hand, the main reasons for quitting using the ethanol stove include being expensive, lack of accessibility to fuel, and that stoves broke down (Table 3). These challenges were also highlighted in the FGDs. For example, FGD participants did not like the high ethanol price, as it was pointed out that the price had continued to increase within the 18 months before the FGDs. Moreover, the quality of ethanol deteriorated in the period around the collapse of Cleanstar[4,5] (see also Study site), to the extent of producing bad smell during cooking. In addition, the lack of after-sales services was a challenge. For example, users could not replace the clogged filters, which reduced the intensity of the fire thereby slowing down cooking, while the rusting of tanks resulted in fuel waste. Other challenges raised in FGDs included that the fuel tank design made the fuel filling process cumbersome, as well as that the wide space between the flame and the cooking pot resulted in energy loss. In relation to the above, some participants expressed the following when justifying their decision to reduce the frequency of using the ethanol stove:

- P4.24 *"I used to use the stove during the whole day but now I am no longer using it every time because of the lack of ethanol"*
- P3.16 *"I used to use it every day but now only four times per week because the tank is rusted and it wastes ethanol"*
- P4.21 *"After the shortage of fuel, the intensity of flames were no longer the same, now I use the electricity stove"*.

From the main household survey, it seems that all respondents that did not have an ethanol stove, had heard about it. The main sources of information were television (61%), friends/family (17%), promotions (10%), shops (6%), and the marketplace (5%). About 53% of the respondents that did not have the ethanol stove indicated that they would like to buy the stove, 41% did not want to buy it, and 6% were unsure.

The reasons that were highlighted by the respondents for not using the ethanol stove are presented in Table 4. A number of reasons were highlighted, however the most common reason was that both the stove and the fuel were expensive, followed by the stove was expensive (i.e. the initial cost), then the bad reputation of the stove, and the stove not being appropriate to the needs of the household.

Socioeconomic differences between study groups

The interplay between various socio-economic attributes determines whether a household is energy poor or not. Energy poverty is an important component of the general poverty, which is viewed as having multiple dimensions (Data analysis). Therefore, in order to understand energy access and poverty it was critical to explore deprivation across various socio-economic indicators and how it relates to the adoption of ethanol cookstoves (Fig. 4). In general, the lowest deprivation scores were observed for assets, access to electricity, nutrition, housing, and child school attendance. Just 5% (or less) of households in each adoption category were deprived across these indicators. The highest deprivations for most households were observed for clean cooking fuel, improved drinking water, and improved sanitation.

[4] Expert interviews suggested that (a) the differential in fuel price between ethanol and charcoal, and (b) the decrease in quality, can be both attributed to the closure of the Cleanstar ethanol production facility in Beira. NDZiLO was forced to import ethanol from South Africa in the period between the ceasation of ethanol production in Beira and the collapse of the company. Even though this imported ethanol was cheaper than the Cleanstar ethanol, it was still more expensive than charcoal. However this imported ethanol had poorer quality, which was responsible for destroying the stove canisters, the supply was infrequent and with delays. The combination of high prices and low quality was a key reason for several adopters to quit the use of the ethanol stove.

[5] Expert interviews with senior members involved in Cleanstar's operations suggest that ethanol production (similar to the entire Cleanstar operations) ceased due to a series of reasons. These include among others (a) overextended and unviable ethanol supply chain (i.e. cassava production in northern Mozambique, ethanol distillation in Beira, central Mozambique, and final consumption in Maputo, southern Mozambique), (b) optimistic expectations about the quantity and quality of cassava production from smallholders, which affected feedstock supply; (c) investor withdrawal early in the project phase, (d) social unrest in Beira area in autumn 2014, (e) high VAT prices that further lowered economic viability of the end-product (CEO Cleanstar, personal communication, 24 August 2016; Founder Cleanstar, personal communication, 14 October 2015; NDZilo, personal communication, 25 June 2015)

Table 2
Average cooking duration for different stoves and types of food.

Food	Cooking duration (min)				
	Ethanol	LPG	Firewood	Charcoal	Electricity
Maize flour	25	36	45	45	57
Rice	26	28	33	32	30
Tubers	27	32	36	37	55
Peanut, beans, peas	55	93	108	103	102
Fish	31	35	46	42	36
Livestock meat	68	52	60	70	75
Poultry meat	28	34	28	39	37
Eggs	6	6	10	6	5
Milk/Dairy products	7	9	–	11	8
Vegetables	74	65	96	93	95

The percentage of households that were classified as multidimensionally poor in the adoption groups were as follows: adopters (5%), quitters (12%), and non-adopters (19%) (Table 5). In terms of poverty levels, the lower the MPI value, the less poverty there is. Thus adopters had the lowest poverty followed by quitters, then non-adopters.

We tested for differences among the different indicators between adoption groups, however, significant differences were only observed for access to improved sanitation and bicycle ownership. In terms of improved sanitation, quitters had significantly better access to improved sanitation compared to both adopters and non-adopters. When it comes to bicycle ownership there were significantly more non-adopters than adopters who owned bicycles. The significance of these factors warrants further investigation to understand how they relate to cooking fuel access.

When it comes to nutrition, adopters had a significantly higher average FCS of 67.9 than non-adopters who had an FCS of 61.3, which implies a more diverse diet and higher food security. Furthermore, while many differences were observed in terms of the number of days the various foods were prepared at home, the only significant difference was observed in the consumption of tubers (see Supplementary Electronic Material, Table A4). Adopters prepared tubers at home at an average of 1.9 days per week, which was significantly higher than for non-adopters who prepared tubers (1.2 days per week), and quitters (1.1 days per week).

Differences in fuel consumption and expenditure

Differences in the use (number of days per week) of other fuels (namely firewood, charcoal, electricity, and LPG) were also assessed between the different groups (Table 6). Significant differences were observed between adopters and non-adopters in the use of firewood and electricity. Non-adopters used firewood on average 0.57 days per week, which was significantly higher than adopters (0.02 days per week). Non-adopters used electricity on average 2 days per week, which was significantly higher than adopters (0.78 days per week). What is interesting to note is that charcoal use within households remains very similar as most households used charcoal in conjunction with other cooking options (Fig. 1).

Table 3
Reasons for discontinuing the use of ethanol stoves.

Reason	Percentage
Expensive (economic reasons)	47.4%
Broke down (already does not work)	12.3%
The fuel is not accessible	12.3%
Have another stove that works better	5.3%
Disappointed with the product	5.3%
Not suitable for the size of pots	3.5%
Gave to another household	3.5%
Slow	3.5%
Does not have sufficient cooking heads	1.8%
Stolen	1.8%
Had borrowed the stove	1.8%
Safety considerations because of children in household	1.8%

Table 4
Reasons for not using the ethanol stove.

Reason	Percentage
Both the stove and the fuel are expensive	30.2%
The stove is expensive	9.8%
Bad reputation	8.5%
Not appropriate to the needs of the household	8.5%
The fuel is expensive	6.8%
The stove is not trusted	6.8%
Not interested in the stove	5.1%
Has another stove	4.7%
Lack of information and experience	3.8%
The stove model/design is not good (e.g. the fuel evaporates)	3.8%
Difficult to access the fuel	2.6%
Safety considerations	2.1%
The fuel smells and affects the taste of the food	1.7%
Respondent is not the decision-maker in purchasing stoves	0.4%

Comparing the average monthly expenditure[6] on each fuel by the three groups shows that there were no significant differences between them (Table 7). In terms of firewood, ethanol stove adopters had the lowest average monthly fuel expenditure, while non-adopters had the highest. In terms of charcoal, ethanol adopters had the lowest expenditure while quitters had the highest. In terms of LPG, quitters had the lowest expenditure while non-adopters had the highest. The expenditure on electricity is based on calculations[7] that were derived from the number of days per month that each household indicated that they used electricity for cooking. These monthly electricity estimates show that non-adopters had the lowest expenditure, while quitters had the highest.

Overall, adopters spent on average (including electricity estimates) USD 35.38 per month on cooking fuel(s), which was significantly higher than non-adopters and quitters who spent on average USD 26.81 and USD 27.13 per month, respectively (Fig. 5). Since, electricity expenditures for cooking are our own estimates, we conducted further analysis of the differences in average monthly expenditure by excluding electricity estimates, i.e. in each adoption category we excluded those who used electricity for cooking. Results suggest that adopters had an average monthly cooking fuel expenditure of USD 35.44, which was again significantly higher than that of both non-adopters and quitters who had average monthly expenditures of USD 28.12 and USD 26.21 respectively.

To have an in-depth understanding of the cost differences between fuels, prices per usable megajoule (MJ) were calculated for each fuel (Table 8). From these calculations it becomes evident that ethanol cooking fuel is much more expensive (per usable MJ) than any other cooking fuel.

Discussion

Findings confirm many previous studies that identified woodfuels as the principle fuel in Maputo (Brouwer & Falcão, 2004; Cuvilas et al., 2010; Mangue, 2000; Takama et al., 2011). Our results show that

[6] Average monthly expenditures were calculated as averages only for households in a group who were using a particular fuel i.e. for each fuel, non-users of that particular fuel were excluded in deriving the average.

[7] It was difficult to get the household average electricity consumption for cooking in Maputo. In deriving the estimates of the electricity expenditure per month, the average household electricity consumption per day for cooking was derived from (Atanassov et al., 2012). The household survey for this study provided the number of days per week and the number of times per day, electricity was used for cooking by each household. The household electricity tariff used for this period is the old prepaid tariff of 3.18 Mt/kWh (Caldeira, 2015). N.B. The electricity tariffs were increased in November 2015, after the survey that is why the old tariff was used.

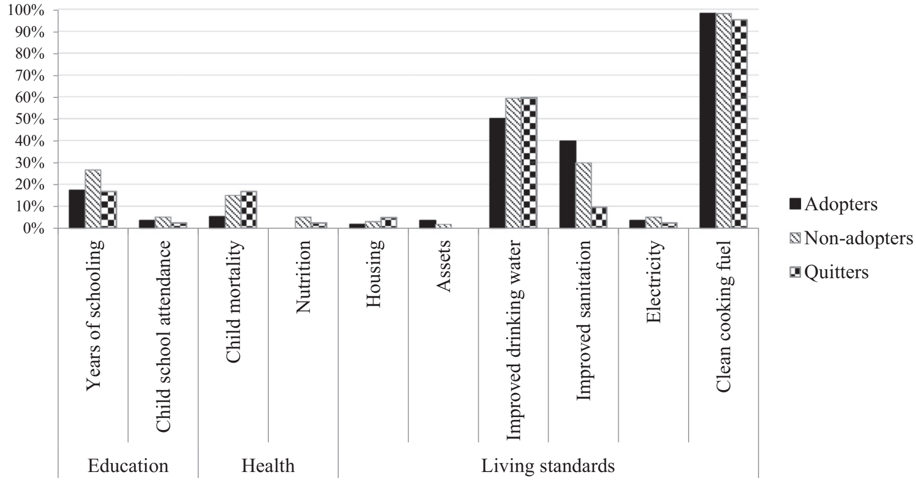


Fig. 4. Deprivation in variation socio-economic indicators.

charcoal absolutely dominates cooking fuel preferences, with firewood being a relatively less used fuel. This differs from studies in Malawi where in urban areas, the percentage usage of firewood (41.9%) and charcoal (44.6%) was almost equal (Gamula et al., 2013; National Statistical Office, 2012), but concurs with studies from Dar es Salam where there is a well-documented shift from firewood to charcoal (Ellegård et al., 2001).

Though the current study did not perform a survey of fuel preference across all of Maputo, it implies that that there has been a major switch from fuelwood to charcoal as the preferred fuel. For example, BTG 1990 (quoted in Mangue, 2000) found that residents in informal settlements in Maputo preferred firewood (59.6%) to charcoal (17.3%) for cooking, while residents in the "cement city" region preferred electricity (54.7%) to firewood (39.5%) and charcoal (1.6%). By 2004, Brouwer and Falcão (2004) found that 11.7% of households used exclusively charcoal, and 70% used charcoal in combination with one or more other fuel. Some of the reasons that could have contributed to this marked switch from firewood to charcoal could due to the increased availability of charcoal considering its extensive supply network (Woolen et al., 2016), and its better cooking attributes when compared to firewood.

It is also interesting to note that paraffin (kerosene) use has dropped substantially over this period, with almost zero use in the (relatively poor) areas of Maputo where our study was undertaken. Our study further confirms this trend towards the gradual dominance of charcoal as the most commonly used cooking fuel in Maputo, with our data confirming that this switch is still ongoing. There is a limited transition to electricity or LPG, fuels that are typically referred to as modern fuels.

In this respect, ethanol supplements charcoal for cooking, rather than completely replacing it (Stove and fuel use, sourcing and preferences for cooking). Ethanol is a desirable fuel for quick heating activities such as boiling water for tea or boiling eggs, but is perceived as a far too expensive option for long and slow cooking, such as boiling beans. This suggests that it is more likely that ethanol is, in fact, replacing other quick sources of heat such as electricity or LPG, rather than charcoal.

Charcoal still remains an important fuel compared to ethanol, even when households have other stove options (Stove and fuel use, sourcing and preferences for cooking). This concurs other studies in Sub-Sahara Africa that households tend to use multiple fuels and stoves to meet their cooking energy needs (Mekonnen, Gebreegziabher, Kassie, & Kölin, 2009; Ruiz-Mercado & Masera, 2015), which is in line with the fuel stacking theory (Kowsari & Zerriffi, 2011; Masera, Saatkamp, & Kammen, 2000).

In the literature, charcoal is generally considered as a transitional fuel - that it is a stepping stone to modern fuels such as LPG and electricity (Neufeldt et al., 2015). What makes it transitional is firstly the fact that it is processed to enhance its features when compared to firewood. For example, from users' perspective compared to firewood it has a higher energy density, produces less smoke, is convenient to use, burns for a long time with minimal maintenance and leaves relatively low soot on the pots (Stove and fuel use, sourcing and preferences for cooking). Secondly, charcoal is purchased rather than collected, moving the user into a cash-based economy. Purchased charcoal quantity can be aligned to a household's available cash (Neufeldt et al., 2015), as it can be purchased in very small quantities making it suitable for the low income groups who cannot afford purchasing large sacks (Ellegård et al., 2001). However, poor households might end up paying disproportionately higher prices for cooking fuel as they are "forced" to purchase the fuels in smaller quantities (Kambewa, 2007). This pricing differential is evident in Maputo and means that small volumes of charcoal sell for almost twice the cost of 70 kg charcoal sacks (Differences in fuel consumption and expenditure). Similarly, ethanol is also more expensive when purchased in small volumes (e.g. 1 l compared to 5 l bottles). If ethanol is to become an effective pro-poor fuel, then it needs to compete effectively in the small volumes market, as this tends to be the way the poor purchase cooking fuel (see below).

Although there is some evidence across Africa that better-off households are moving up the energy ladder to electricity (e.g. Nyembe, 2011), there is also extensive evidence that many African cities (including Maputo) are in effect becoming stuck with charcoal as the major fuel, despite alternatives being available that are potentially cheaper (de Fátima, Authur, Zahran, & Bucini, 2010; Olang, Esteban, & Gasparatos, 2018). Indeed, while a large number of respondents in the current study had access to electricity, many were not using it as their primary cooking fuel (Stove and fuel use, sourcing and preferences for cooking). Understanding why consumers stick to charcoal may help

Table 5
Differences in poverty levels between adopters, quitters, and non-adopters of the ethanol stove.

	Multidimensionally poor households	Intensity of poverty	Headcount ratio	MPI
Adopters	5%	0.400	0.064	0.026
Non-adopters	19%	0.425	0.184	0.078
Quitters	12%	0.377	0.125	0.047
Average	16%	0.419	0.159	0.066

Table 6
Differences in fuel consumption.

	Adopters	Non-adopters	Quitters	Significance of differences: Adopters vs non-adopters	Adopters vs quitters	Quitters vs non-adopters
Firewood (days used/week)	0.02	0.57	0.29	**	n.s	n.s
Charcoal (days used/week)	5.95	6.18	5.83	n.s	n.s	n.s
Electricity (days used/week)	0.78	2.00	1.83	**	n.s	n.s
LPG (days used/week)	0.83	1.53	1.51	n.s	n.s	n.s

Significance level: *** = 0.01, ** = 0.05, * = 0.1, n.s = not significant.

Table 7
Differences in expenditure on various fuels.

	Expenditure (US$)			Significance of differences		
	Adopters	Non-adopters	Quitters	Adopters vs non-adopters	Adopters vs quitters	Quitters vs non-adopters
Ethanol	13.63	0	0			
Firewood	1.19	7.55	5.08	n.s	n.s	n.s
Charcoal	20.46	21.68	24.42	n.s	n.s	n.s
LPG	14.90	15.83	12.69	n.s	n.s	n.s
Electricity (estimate)	3.38	2.50	3.43	n.s	n.s	n.s
Total monthly energy costs	35.38	26.81	27.13	***	***	n.s
Total monthly energy costs (excl. electricity users and costs)	35.44	28.12	26.21	***	**	n.s

Significance level: *** = 0.01, ** = 0.05, * = 0.1, n.s = not significant.
Note: The exchange rate used for August 2015 is 1US$ = 37 MT/US$ (United Nations, 2015).

better understand why there is an overall slow uptake of ethanol (or electricity) as a cooking fuel, despite the relatively initial rapid uptake of ethanol stoves.

Generally speaking, respondents perceived ethanol to be expensive (Stove and fuel use, sourcing and preferences for cooking, Ethanol stove adoption and use). Although detailed stove trials were not conducted in this study to determine fuel use for typical meal preparation, simple cooking time recollection (Food consumption and cooking patterns) and stove efficiency calculations indicate that ethanol was more expensive than any other commonly used fuel in terms of cost per unit useful energy (Differences in fuel consumption and expenditure). Despite the uncertainties in calculations,[8] it seems clear that ethanol is an expensive cooking fuel, especially for long slow cooking (Food consumption and cooking patterns–Ethanol stove adoption and use).

Current ethanol prices in Maputo are close to three times higher than those in Brazil and USA. In order, to be competitive with charcoal (purchased as 70 kg bags), ethanol would need to sell for 0.47 USD/l. For ethanol to be competitive with charcoal purchased in small quantities, it would need to sell at 0.90 USD/l. If such lower ethanol prices were to be achieved in Maputo it may radically change ethanol use dynamics. However until then the high cost of ethanol is a serious hindrance for its widespread adoption for cooking. In a similar study, Lambe et al. (2015) highlight that the poorly developed ethanol supply chain in Addis Ababa, Ethiopia resulted in prohibitively high ethanol prices, which made the fuel out of reach for lower-income users. High ethanol prices have also been partly attributed to its demand as a transport fuel, and its competition with other agricultural/industrial activities (Puzzolo et al., 2013).

In our study, the discontinuation of Cleanstar's ethanol production and supply chain based on cassava from smallholders led in the few months before the collapse of the entire company to the importation of more expensive, but poorer quality ethanol from South Africa. The lack of a local and cheap supply of good quality ethanol was clearly a constraint to the widespread use of ethanol stoves in Maputo, and the sustained use after collapse. Towards this end economic incentives will be necessary to ethanol producers and users, if ethanol is to become a competitive fuel for cooking. For instance, it was pointed out that ethanol had a high Value Added Tax (VAT) in the order of 16–17%, which was never waived and eventually reduced its economic competitiveness with other cooking fuels (Founder of Cleanstar, personal communication, 14 October 2015). Thus issues of subsidies on household ethanol fuel use would need to be considered seriously as there is potentially social (as well as environmental) justification for lowering the cost of ethanol cooking fuel.

Apart from pricing, stove design is another critical issue that merits attention. Barnes, Openshaw, Smith, and van der Plas (1994) called for the better interaction and feedback between stove designers, producers, and users. Respondents highlighted important design problems such as the fact that the fuel tank design makes fuel filling process cumbersome, that the fuel tank gets rusted easily, and that the wide space between the flame and the cooking pot results in energy wastage (Ethanol stove adoption and use).

A shortcoming of the present study is that data was mainly based on reported information on fuel purchasing, use quantities, and cooking time. This information tends to be subjective, especially for long recollection periods. Future studies can integrate both the reported information by the respondents, as well as performing actual long-term monitoring of the various aspects of the household cooking system.

A second important area that merits further study relates to comparing the performance of different cooking fuels on land use change (incl. deforestation), water use, and GHG/air pollutant emissions throughout their entire lifecycle. Moreover, it is critical to understand the environmental benefits of switching from charcoal to ethanol. Already major concerns have been raised over the contribution of charcoal use to deforestation in Mozambique (Introduction). Although direct links between charcoal, deforestation and loss of ecosystem services are sometimes difficult to determine (Woolen et al., 2016), and despite some studies suggesting that not all charcoal use is unsustainable (Mwampamba, Ghilardi, Sander, & Chaix, 2013), this increased reliance on charcoal remains a concern from an environmental perspective. In fact, environmental benefits such as reduction on deforestation and GHG emissions were major justifications of the funding received by Cleanstar from investors and donors (Founder of Cleanstar, 2015, personal communication, 14 October 2015).

[8] Standardised fuel efficiency tests can be a poor predictor of actual fuel usage (Hager & Morawick, 2013). Further, calculations of usable energy costs tend to be highly sensitive to fuel use efficiency assumption.

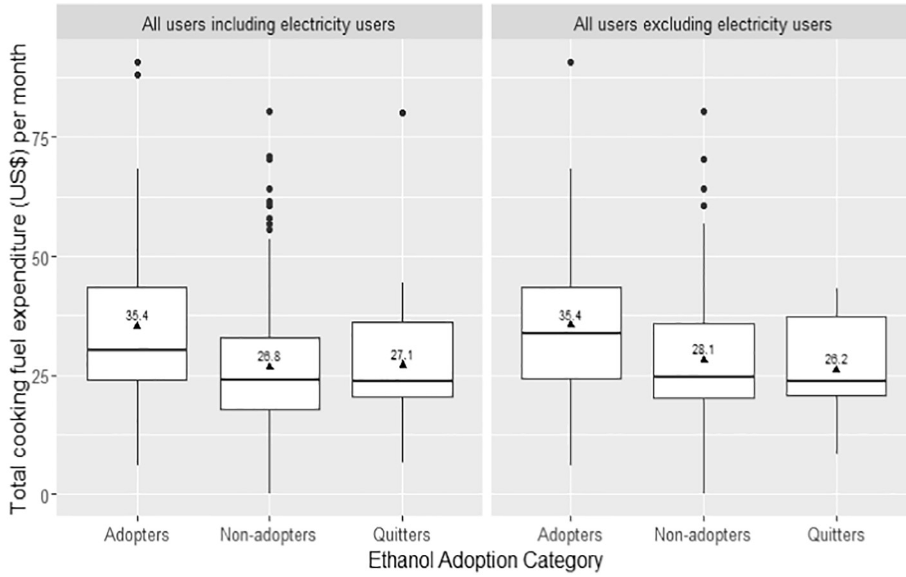


Fig. 5. Average total cooking fuel monthly expenditure (with and without electricity users) Note: Values inside the boxplot represent the average monthly expenditure per household in each ethanol adoption category.

Although the use of ethanol may well be having a positive impact on reducing deforestation based on the assumption that 1 l of ethanol will replace about 2.5 kg of charcoal (based on studies carried by Cleanstar), considering current penetration of ethanol stoves/fuel in Maputo (Study site), this could offset 2500–5000 t of fuelwood use per year. However, it is important to base future estimates of environmental co-benefits based on realistic stove/fuel use scenarios of urban households.

Finally, it is worth noting that health and environmental concerns did not come up strongly as drivers of ethanol stove adoption. This is despite the well-documented evidence that cooking with modern fuels can have substantial environmental and health benefits (e.g. Rosenthal, Quinn, Grieshop, Pillarisetti, & Glass, 2018). Future ethanol promotion efforts, apart from focusing on the price, can further raise awareness of these other positive benefits of ethanol. Possibly this can catalyse a larger uptake of ethanol cookstoves in urban contexts of Africa.

Conclusion

The current study on ethanol stove uptake in Maputo found that about 17% of the households were currently using the ethanol stove (adopters), 12% had discontinued its use (quitters), while 71% never adopted it. Users reported several positive attributes related to the use of ethanol stoves/fuel such as being fast, convenient, clean, economical, and easy to use. On the other hand, several reasons that reduced the desirability of ethanol stove/fuel came up, primarily related to cost. Fuel prices, together with lack of accessibility to fuel and the fact that stoves were prone to break down, were the main reason for quitting the ethanol stove. Furthermore, ethanol stoves failed to fully meet the expectations of some users (especially those that quitted) in terms of pot sizes that could be used and the number of burners available on the stove/s.

It would seem that while user perceptions to ethanol-based cooking are relatively positive, its wide scale uptake seems unlikely under

Table 8
Fuel efficiency, useful energy, and price per unit.

Fuel		Energy content of fuel (MJ/kg or MJ/l)	Efficiency of stove (%)	Useful energy (MJ/unit)	Price (USD/Kg or USc/L	Price (USD) per MJ
Firewood*¥		15	10%	1.50		
Charcoal*¥	70 kg	29	25%	7.25	31.00	4.28
	850 g	29	25%	7.25	45.00	6.21
	500 g	29	25%	7.25	60.00	8.28
Kerosene#€	l	35.3	42%	14.83	86.00	5.80
LPG*£	Kg	45.2	55%	24.86	130.00	5.23
Electricity kWh@Ω	Social	3.6	60%	2.16	3.22	1.49
	0 to 300	3.6	60%	2.16	7.53	3.49
	301 to 500	3.6	60%	2.16	10.63	4.92
	>500	3.6	60%	2.16	11.17	5.17
	Prepaid	3.6	60%	2.16	9.58	4.43
Ethanol*β	1 l	20	55%	11.00	180.72	16.43
	2 l	20	55%	11.00	150.60	13.69
	5 l	20	55%	11.00	132.53	12.05

Source for quantities and prices.
* From survey,# from key informants, @ from web site of electricity authority.
Source for energy content and mean stove efficiency.
¥ (Smith et al., 2000; Ravindranath & Ramakrishna, 1997; Bhattacharya & Abdul Salam, 2002; Jetter et al., 2012)
€ (Ravindranath & Ramakrishna, 1997; Bhattacharya & Abdul Salam, 2002).
£ Ravindranath & Ramakrishna, 1997; Bhattacharya & Abdul Salam, 2002; Berkley Air Monitoring Group, 2012).
Ω (spiral plate) (Hager & Morawick, 2013).
β (Lloyd & Visagie, 2007; MacCarty et al., 2010).

current cost structures and fuel supply issues. The discontinuation of Cleanstar production facility resulted in the importation of expensive and poor quality fuel in the few months prior to Cleanstar collapse, which has undoubtedly contributed to some of the negative perceptions on ethanol stoves. While eventually the price and quality of imported ethanol improved (still more expensive than charcoal though), past negative experiences seem to have affected negatively perceptions about the product.

Our assessment implies that the rate of charcoal use continues to grow in the areas studied in Maputo. This is despite alternative fuels such as LPG, ethanol, and electricity being available (and in the case of electricity potentially cheaper). Given that the population is growing fast and that the proportional use of charcoal is increasing, the demand for charcoal will most likely continue to increase. As a consequence, there will be increasing pressure for wood from the indigenous forests, increasing the risk of deforestation.

Though some modern fuels can be potentially cheaper than charcoal, it seems that switching to these fuels does not happen spontaneously. There are complex social and economic factors that determine fuel preferences and use. The drivers that determine the switch from transitional fuels to modern fuels are clearly complex and still poorly understood. The key factors for favouring charcoal as a fuel over modern fuels are that charcoal is perceived as (a) a security (i.e. backup) measure, (b) an insurance for future use, (c) a more flexible and cheap fuel, (d) a fuel best for foods that take longer time, (e) a versatile fuel (i.e. can be used for many cooking activities), (f) a fuel easier to access, (g) a fuel easier to use, and (h) a fuel with which users are accustomed to.

For the effective uptake of ethanol fuel, it will be necessary to address the various factors that discourage its use, particularly high costs, low quality and unreliable supply. In addition, the design and quality of the ethanol stoves should also be improved (e.g. the tendency for rusted tanks). As health and environmental issues did not feature as drivers of stove adoption (despite being well-documented), advertising campaigns and awareness raising about such benefits could contribute to improved adoption. Thus, while ethanol (and modern cooking fuels in general) might not be attractive to users due to unaffordability and failure to meet certain preferences, co-benefits related to health, safety and the environment issues might influence ethanol adoption.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2018.03.004.

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