Sustainable Cities and Society 55 (2020) 102039

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Insights into household fuel use in Kenyan communities

A Osano[a], J Maghanga[b], C.F Munyeza[c], B Chaka[a], W Olal[a], P.B.C Forbes[c,*]

[a] Department of Mathematics and Physical Sciences, Maasai Mara University, P.O. Box 861-20500, Narok, Kenya
[b] School of Science and Informatics, Taita Taveta University, P.O. Box 635-80300, Voi, Kenya
[c] Department of Chemistry, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria 0002, South Africa

ARTICLE INFO

Keywords:
Domestic fuel use
Solid fuels
Domestic combustion
Indoor air pollution
Three-stone stove
Charcoal stove

ABSTRACT

Clean household fuel use is a cornerstone of the development of sustainable cities, in order to minimise household combustion emissions in communities and the negative air quality and human health impacts associated with this. In developing countries, factors determining fuel use are multi-faceted and complex. A survey was thus conducted to better understand the current household fuel usage profile in four regions of Kenya; namely Bomet, Voi, Mombasa and Narok. The fuel use parameters investigated covered bio-data and economic status, dwelling type, fuel choice and usage, combustion devices and ventilation in kitchens. The fuel type usage was distributed between firewood (25 %), charcoal (24 %), kerosene (24 %) and liquefied petroleum gas (LPG) (23 %). Three-stone stoves were still predominant in rural communities, whilst cleaner devices burning kerosene and LPG were used more widely in urban Mombasa. With the exception of Voi, there were more chimneys in urban dwellings than in the rural homes, even though brick houses were the most popular dwelling type overall (52 %). The results of this study will provide a useful basis for decision making regarding potential future clean energy intervention strategies in Kenya in order to promote sustainable development.

1. Introduction

Household air pollution arising from the use of solid fuels for cooking and heating purposes is the eighth leading global risk factor contributing to disease in developing communities (State of Global Air, 2018). Global Burden of Disease studies have also estimated that the exposure to smoke from household air pollution is responsible for approximately 3.5 million premature deaths worldwide and various health issues such as cancer and cardiovascular diseases (Bonjour et al., 2013; HosgoodIII et al., 2013; State of Global Air, 2018; Suter et al., 2018). Moreover, there is evidence that exposure to air pollution is associated with adverse pregnancy outcomes such as low birth weight, pre-term births and still births (Abusalah et al., 2012; Patelarou & Kelly, 2014; Pope et al., 2010). Firewood, animal dung, crop waste and coal are examples of solid fuels which are dominant in rural communities of developing African countries, where open fires and simple stoves are used for residential activities. Due to the fact that roughly half of the world's population relies on solid fuels (Adkins, Tyler, Wang, Siriri, & Modi, 2010), there is growing public concern over emissions of air pollutants from inefficient combustion thereof, which significantly contributes to both indoor and ambient air quality (Sharma, Ravindra, Kaur, Prinja, & Mor, 2019). An example of these airborne pollutants are polycyclic aromatic hydrocarbons (PAHs), which are ubiquitous by-products of incomplete combustion of carbonaceous and organic matter such as charcoal, wood, gas, tobacco and diesel (Szulejko, Kim, Brown, & Bae, 2014). PAHs usually persist in the environment and have a negative impact on human health due to their well-known potential carcinogenic and mutagenic properties. PAHs contain two or more fused benzene rings and they are produced from domestic, industrial processes and vehicular combustion processes.

Systematic measurements of $PM_{2.5}$ in households using solid fuels around the world are not well documented. Quantitative estimations of the contribution of household fuel burning to atmospheric particulate matter levels are difficult to obtain, because emission factors vary greatly with wood type, combustion equipment and operating conditions (Martins & da Graça, 2018; Munyeza, Rohwer, & Forbes, 2019; Roden et al., 2009; Vicente & Alves, 2018). Bonjour et al (2013) developed a multi-level model to allow for the estimation of household solid fuel use for cooking purposes over the period 1980–2010 (Bonjour et al., 2013). However, statistics on household fuel use require updated field surveys, particularly from poor and vulnerable populations, in order to validate modeled results (Duan et al., 2014). Most previous surveys worldwide have focused on fuel use over short time periods, making it difficult to identify changing temporal trends, such as progress towards the establishment of sustainable cities based on clean fuel usage.

* Corresponding author.
E-mail address: patricia.forbes@up.ac.za (P.B.C. Forbes).

https://doi.org/10.1016/j.scs.2020.102039
Received 7 June 2019; Received in revised form 10 January 2020; Accepted 11 January 2020

There is a scarcity of reported information on current household fuel patterns for cooking and space heating purposes across the African continent. A recent study using household fuel data from a Demographic and Health Survey found that 66 % of sampled sub-Saharan households rely on biomass for cooking whilst only 25 % have access to electricity (Makonese, Ifegbesan, & Rampedi, 2018). In Kenya, which is one of the few African countries enjoying high growth rates with a positive impact on the income level of its citizens, an estimated 82 % of households still use traditional cooking fuels every day (Rahnema, Sanchez, & Giordano, 2017).

Several field testing surveys in Kenya have evaluated the general performance and usability of biomass cook stoves (Adkins et al., 2010; Lozier et al., 2016; Muindi, Kimani-Murage, Egondi, Rocklov, & Ng, 2016; Pilishvili et al., 2016; Tigabu, 2017). These studies mainly focused on the effectiveness of new improved combustion cook stoves in reducing household air pollution and their acceptability in some Kenyan societies. However, in practice, not all urban and rural households have access to these improved stoves. The choice of fuel and combustion device is expected to vary between provinces and also between rural and urban communities due to the influence of multiple factors. This study aimed to investigate these current factors and their impact on communities in order to facilitate progress towards increasing clean fuel and sustainable resource use.

In this study, we report on the fuel use patterns among urban and rural communities in four different counties in Kenya, namely Narok, Voi, Mombasa and Bomet. Possible influencing factors were explored such as geographical location, economic level (occupation and monthly income), type of dwelling, and fuel(s) and combustion device(s) used. The resulting data on household fuel use for domestic purposes is useful for comparison to and evaluation of previous estimations, and contributes to meeting the research gap on current solid fuel use in the World Health Organization (WHO) database. Additionally, the results are useful for domestic comprehensive risk analyses and burden of disease studies. Importantly, such information can motivate for further sampling campaigns and development of household air pollution control strategies for clean energy interventions, thereby improving quality of life, reducing human health impacts, and promoting environmentally sustainable development.

2. Research methodology

2.1. Background to the survey

Kenya is composed of 42 communities who live in varied climatic conditions, with different fuel consumption behaviors. In identifying suitable regions for sampling, the factors considered were: climatic conditions, cultural issues, dominant tree species present, economic status, fuel wood consumption patterns, and prevalence of burning of charcoal, respectively. The country was partitioned into two broad regions namely the coastal region of Kenya, a part of the country which is at sea level and mainland Kenya, representing areas which are above sea level and are inland. For each of the two regions, two counties were selected according to similarities and differences based primarily on: altitude, types of fuels used, climatic conditions, cultural practices and beliefs, and combustion devices used.

Urban and rural communities in each county were identified, namely Narok and Bomet counties which are located inland in the Rift Valley area where the climate is warm and temperate, and Mombasa and Voi counties in the coastal area of Kenya which have a tropical climate (Fig. 1).

In determining suitable sampling sites, variability in settlement areas which would lead to different fuel consumption behaviors was considered. In urban areas, the choice of sampling sites was based on level of income in order to cover both middle and low level income earners. A total of 106 questionnaires were administered as detailed in Table 1.

2.2. Survey methodology

Variability of about 10 km^2 between any two respondents was considered to avoid similarities hence sampling was purposive and randomized. Questionnaires were administered during September and October 2017 by means of face to face interviews, which lasted between 10 and 20 min. Respondents were requested to fill in their bio-data; income status; settlement types; fuel wood use; types, volumes, and cost of fuels used; and combustion devices employed, as detailed in the questionnaire (refer to Appendix (in Supplementary material)). In terms of fuel consumption, amounts were estimated by respondents, based on the fact that fuel is purchased on a mass basis. Respondents were also asked to give their perceptions and preferences regarding fuel sources and sustainability thereof. Data analysis and presentation was carried out using descriptive statistics (Microsoft Excel).

3. Results and discussion

3.1. Bio-data and economic status

The use of a particular type of cooking fuel is usually seen as a proxy for socioeconomic status in most African countries. This is also supported by the energy ladder theory which states that as incomes rise, households tend to substitute traditional solid biomass cooking fuels with those that are cleaner, more efficient, and more expensive (Schlag & Zuzarte, 2008). However, in the case of Kenya, a correlation between income and fuel switching is not always observed (refer to Table S1 in the Supplementary material), as it is also driven heavily by fuel availability in each region and other factors.

Out of the total population sampled in this survey, 80 % of the respondents were self- employed. In the urban areas of Kenya, half the population lives below the poverty line while a third of the rural population is generally poor (Kwach, 2018). In terms of earnings, in this study it was found that 53 % of households were earning below Ksh 10,000 (~100 USD) per month. The majority of respondents were female (84 %), which may be attributed to cultural issues especially in the rural areas, where it is a common practice for men not to go into the kitchen. Traditionally, women and children are responsible for the preparation of meals and in some cases the collection of firewood. Consequently, women and children typically suffer the most from indoor air pollution and burns, with young children being particularly susceptible to diseases that result in premature deaths and lung problems (Rahnema, Sanchez, & Giordano, 2017). In terms of age, 69 % of the respondents were between 21–40 yrs, while 20 % were 41–60 yrs, 6 % were below 20 yrs and 6 % were above 61 yrs. Most respondents were married (79 %), whilst the family size ranged widely from less than three (35 %), between 4–6 (38 %), to more than 6 members (27 %).

3.2. Types of dwellings

A total of 106 households were sampled. There were three types of dwellings found in the sampling regions namely; brick houses, informal shelters and traditional houses. Brick houses were the most prevalent dwelling type found in all the regions (67 %) followed by traditional dwellings (21 %) and then informal houses (12 %). Details regarding the presence of a dedicated kitchen in the dwellings as well as ventilation details are described under section 3.5.

3.2.1. Brick houses

In the urban areas, the highest number of brick houses was found in Narok (52 %), whilst the least was found in Voi and Mombasa (45 %) (Fig. 2). Brick houses, for the purposes of this study, comprised of stone, concrete or brick-built structures roofed with brick tiles or corrugated iron sheeting (Fig. 3a). Of the four regions, Narok is a highly agricultural area, where commercial farming like wheat production is

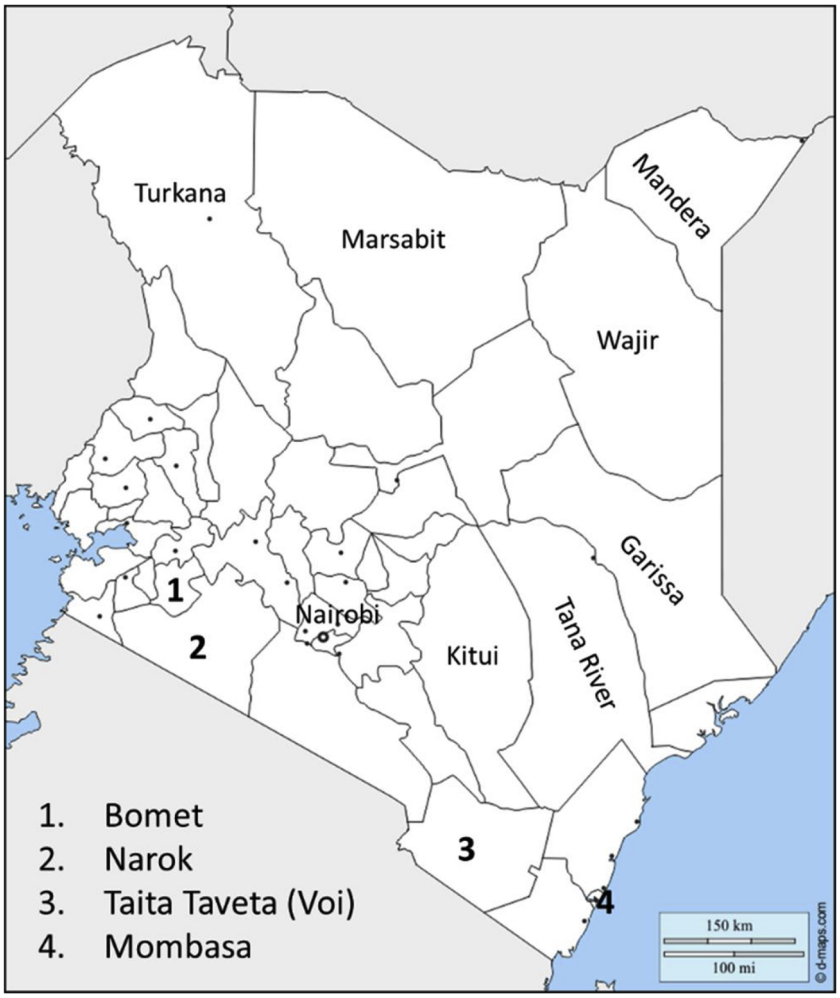

Fig. 1. Map of Kenya showing the four sampling regions (Source: a blank map was downloaded online (https://d-maps.com/) which was modified by the authors).

practiced, as compared to the rest of the study areas. Voi lies on an arid and semi-arid land (ASAL) area with most economic activities being small scale enterprises, hence the income level is low on average compared to the other sampled regions. In the rural areas, Voi had the highest number of brick houses (45 %) while Narok had the least (5 %). Bomet, Mombasa and Narok had more brick houses in the urban than rural areas, whilst Voi had the same number of brick houses in both rural and urban areas.

3.2.2. Informal shelters

Informal shelters were classified as those houses with iron sheeted walls and roofs or mud walled structures with iron sheet roofs (Fig. 3b). This kind of informal housing was highest in Narok (52 %) and lowest in Bomet (4 %). The community living in Narok is mainly Maasai who are pastoralists, which could be the reason for the high number of informal dwellings as compared to the other regions. The Maasai people still follow a traditional semi-nomadic lifestyle and observe their age old customs. Interestingly, no informal shelters were found in the urban areas of all the four regions. The displayed pattern could be a result of the urban redevelopment programs such as the Kenya Informal Settlements Improvement Project (KISIP, 2014). This programme was intensified by the Ministry of Lands, Housing and Urban Development, which eventually resulted in forced evictions and demolition of informal settlements in Kenya (Miyandazi, 2015). Voi and Mombasa had the same proportion of informal shelters.

3.2.3. Traditional houses

Traditional houses were classified as mud walled structures with thatched roofs or steel roof tops. The Maasai people traditionally rely on local, readily available materials and indigenous technology to construct their own traditional houses known as the Maasai Manyattas. As illustrated in Fig. 4, the structural framework of Manyattas is made

Table 1
Distribution of questionnaires completed in the four sampling regions in both rural and urban households and related climatic information. Source of climatic data: https://en.climate-data.org/africa/kenya.

Region number	Region name	Total number of households	Number of rural households	Number of urban households	Average annual temperature (°C)	Average annual rainfall (mm)
1	Bomet	24	11	13	17.5	1247
2	Voi (Taita Taveta)	20	10	10	23.3	616
3	Mombasa	20	10	10	26.7	1196
4	Narok	42	20	22	17.1	771

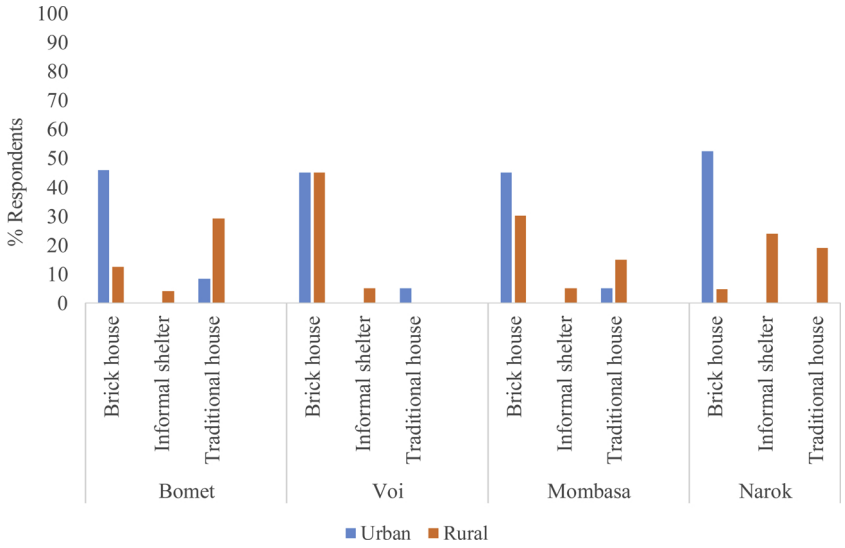

Fig. 2. Types of dwellings in urban and rural areas of the sampling regions.

up of timber poles fixed directly into the ground and interwoven with a lattice of smaller branches of wattle, which is then plastered with a mix of mud, sticks, grass, cow dung, and ash. In Bomet, the highest number of traditional houses (29 %) was recorded, whilst the lowest was found in Voi and Mombasa respectively (5 %). In the rural areas, Bomet had the highest number of traditional houses followed by Narok, Mombasa then Voi. In the urban areas, Bomet had the highest number followed by Mombasa and Voi, whilst they were not found in Narok.

3.3. Fuel use

3.3.1. Types of fuels used

It was found that over the four regions, 25 %, 24 %, 24 % and 23 % of Kenyan households relied on firewood, charcoal, kerosene, and LPG for cooking, respectively (Fig. 5). Only 4 % of the population used other types of fuels such as cow dung, biogas and sawdust. In terms of the urban-rural difference in regional household fuel use patterns, it was observed that urban residents used slightly more clean and non-solid fuels for cooking, such as LPG and kerosene. In rural households, firewood was still the predominant fuel used with only 25 % of the respondents reporting use of LPG.

The fuel use pattern is known to vary dramatically among different regions due to many factors such as household income, fuel accessibility and cost, as well as household cooking habits (Duan et al., 2014; Makonese et al., 2018). Fig. 6 shows how different regions preferred different fuel types. Charcoal appeared to be the most popular fuel in all the four regions, with saw dust being the least preferred fuel. Interestingly, the proportion of households who relied on firewood was lower for the Mombasa and Voi regions compared to Bomet and Narok. This is because these regions lie in the coastal area of Kenya which is mostly humid throughout the year resulting in a lack of dry firewood. For this reason, an increased use of sawdust, charcoal and kerosene was observed in these coastal communities.

3.3.2. Amount of fuel used daily in the studied communities

Most households were found to consume less than 2 kg/day of fuel, with a few exceptions of more than 3 kg/day. This could be attributed to the large number of fuel regimes being used at the same time. Charcoal was found to be consumed more in urban areas (Table 2) with the highest consumption of 3.0 kg/day in Voi and lowest of 0.8 kg/day in Narok compared to rural areas which ranged from 1.3 kg/day in Mombasa to 0.2 kg/day in Voi. No use of biogas was reported by any respondent.

Firewood use was more dominant in rural communities, as previously mentioned, with the highest usage of 6.8 kg/day in rural Bomet and lowest of 2.3 kg/day in rural Voi, compared to 1.5 kg/day in urban Bomet. This could be attributed to the fact that the kitchens in these types of rental dwellings in urban areas are typically not designed for

Fig. 3. A typical brick house (a) and informal shelters (b) in the study areas.

Fig. 4. Typical traditional houses in the study area, **a–b** shows traditional houses with iron sheet roofing, **c–d** shows Maasai Manyattas traditional homes and the ventilation holes in the walls thereof whilst **e** shows a traditional house with thatched roofing.

firewood use. LPG use was overall less than the other fuels, although it was used more in urban areas, with the highest consumption of 0.2 kg/day in urban Mombasa.

3.3.3. Fuel expenditure

Daily expenditure on fuels by communities varied widely (Table 3). Of the four regions, Bomet urban and rural communities had the highest number of respondents who chose their fuel based on its low cost. Such choices are highly related to household income and abundance of the fuel which impacts on its cost, as evidenced by the small amount spent daily on fuel. Bomet was also declared one of the poorest counties in Kenya based on a 2015 GDP per capita of 282 USD (Kwach, 2018).

3.3.4. Sources of fuels

The majority of the respondents in rural areas obtained their fuels

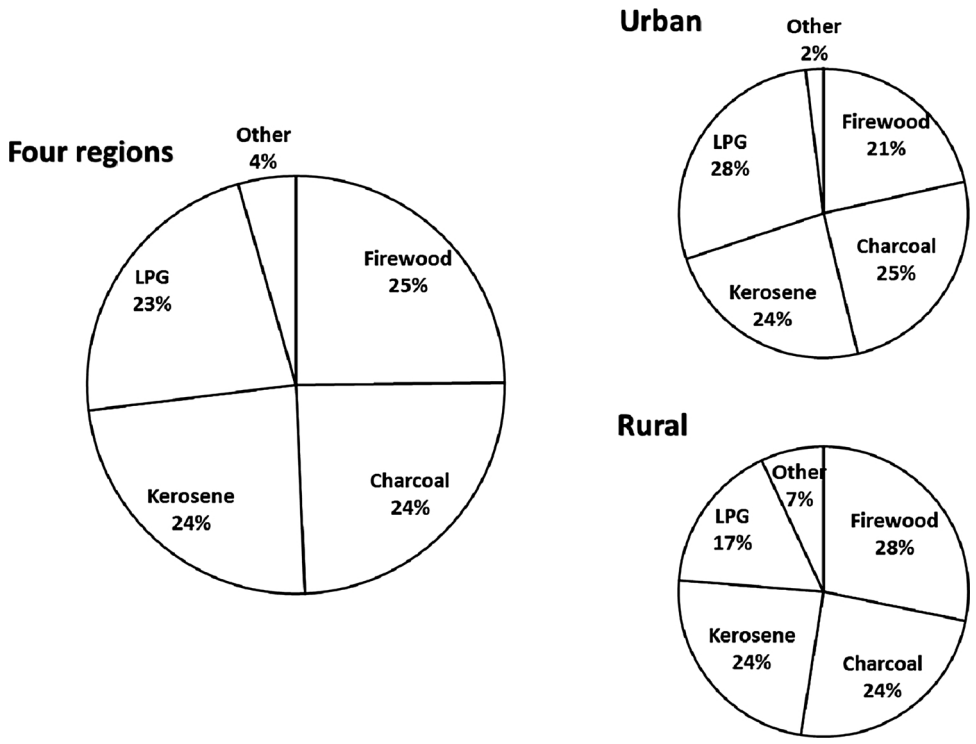

Fig. 5. Average household fuel use patterns over the four selected regions, in rural and urban areas.

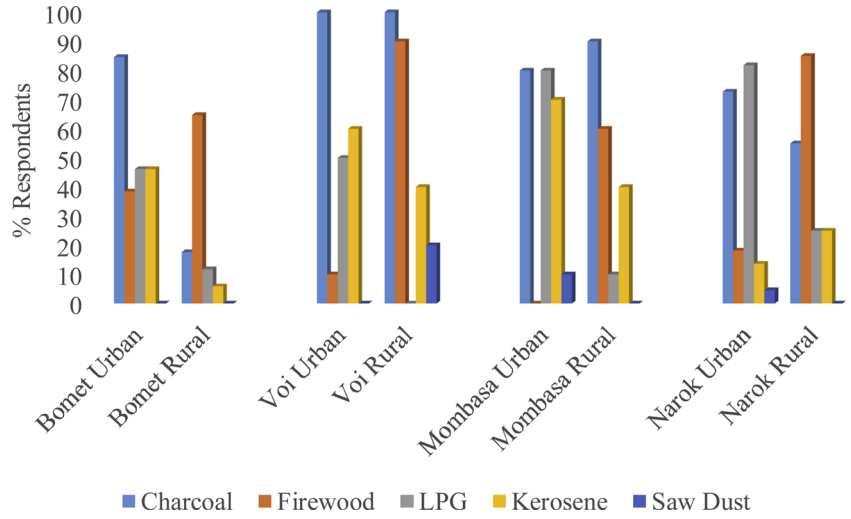

Fig. 6. Types of fuels used per region.

through self-collection (70 % in Mombasa and 60 % in Narok and Voi) (Fig. 7), whilst this was considerably less in urban areas (5–20%). Purchasing from informal vendors was highest in rural Voi (90 %) and lowest in rural Bomet (45 %). Those in urban areas obtained their fuel from shops (100 % of rural Mombasa respondents). Informal vendor supply was the highest at urban Voi (100 %) and lowest in urban Mombasa (30 %). Rural areas recorded correspondingly low responses regarding purchasing of fuel from shops, with the highest of 40 % in rural Mombasa and none in Bomet rural. This could be attributed to their heavy reliance on firewood and charcoal which are obtained locally as well as less dependence on LPG which is obtained from shops.

3.3.5. Frequency of fuel collection

Most households collected their fuels on a monthly basis, especially in the urban areas (80 % in urban Mombasa) (Fig. 8). This could be attributed to the availability of income based on monthly earnings. Weekly fuel collections were most common in rural Mombasa (50 % of respondents). Daily fuel collections had the highest response of 54 % in urban Bomet and none in both rural Voi and urban Mombasa. In a few counties, especially Narok and Bomet, some households would collect fuel two to three months in advance.

3.3.6. Factors influencing the choice of fuel used

The choice of which kind of fuel households used depended primarily on availability and ease of use factors. The importance of availability varied between 55 and 90 %, while ease of use ranged between 60 and 90 % (Fig. 9). This factor was likely linked to the primary combustion devices which were most accessible to many households; namely a charcoal stove called a Jiko and a three-stone stove. The importance of cost ranged from 10 to 46 %. This could be attributed to the fact that most people access firewood and charcoal for free or very cheaply, as they are near the source or they make it themselves, respectively. The least important factor considered was that of cultural issues, which was 0 % for almost all the regions except in rural Narok and Bomet (20 % and 9 % respectively). This could be attributed to strong cultural beliefs still being practiced by both the Maasai and Kalenjin communities living in each of these regions, respectively. No seasonality in terms of fuel use was noted by respondents, as all but one household used their chosen fuel(s) throughout the year.

Table 3
Daily expenditure on fuels in KSh. (KSh. 100 ≈ $1 USD).

	Charcoal	Firewood	LPG	Kerosene	Sawdust
Bomet Urban	27	5	10	8	0
Bomet Rural	12	28	6	5	0
Voi Urban	69	0	27	13	0
Voi Rural	6	8	0	4	2
Mombasa Urban	37	0	29	24	0
Mombasa Rural	23	1	4	11	0
Narok Urban	15	0	23	2	0
Narok Rural	5	2	5	3	0

3.4. Combustion devices (cook stoves)

In order to address health and environmentally related challenges resulting from traditional cooking practices in Kenya, most development efforts have been focusing on improved solid fuel combustion devices. Additionally, a recent survey has reviewed the experience in Kenya regarding the promotion of improved solid fuel cook stoves (Tigabu, 2017). The survey showed that the main focus has been on

Table 2
Estimated quantity of fuel used on a daily basis in each community studied.

	Amount of fuel used per day				
	Charcoal (kg)	Firewood (kg)	LPG (kg)	Kerosene (L)	Sawdust (kg)
Bomet Urban	1.0	1.5	0.1	0.1	0.0
Bomet Rural	0.5	6.8	< 0.1	0.1	0.0
Voi Urban	3.0	1.4	0.2	0.2	0.0
Voi Rural	0.2	2.3	0.0	0.1	0.1
Mombasa Urban	1.4	0.1	0.2	0.4	0.0
Mombasa Rural	1.3	4.6	< 0.1	0.2	0.0
Narok Urban	0.8	0.1	0.2	0.0	0.0
Narok Rural	0.5	2.4	< 0.1	< 0.1	0.0

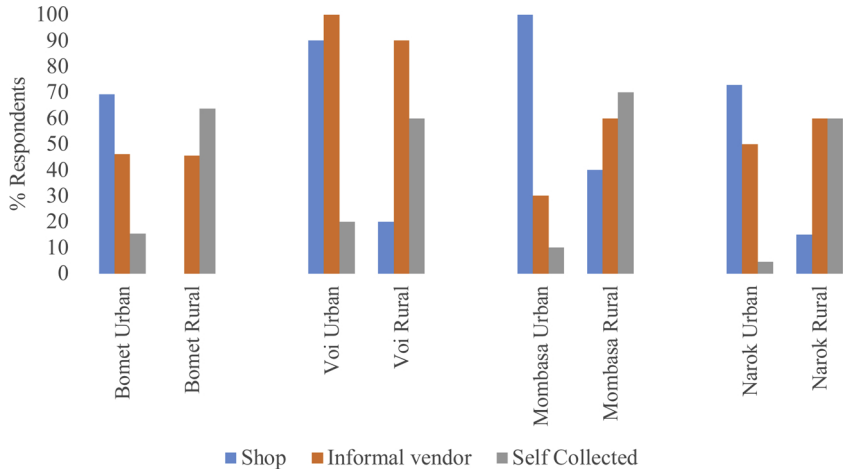

Fig. 7. Sources of fuels used by households in urban and rural communities in the study regions.

increasing production and distribution of improved cook stoves, overlooking the fact that some of the disseminated combustion devices are used less regularly or are even abandoned.

Traditional cook stoves, specifically the Jiko charcoal stove and wood burning three-stone stove, are popular in rural areas (Fig. 10). Personal and kitchen level concentrations of particulate matter < 2.5 μm and carbon monoxide (CO) measured during the use of these traditional and improved cooking devices have been documented in literature (Lozier et al., 2016; Pilishvili et al., 2016; Raiyani et al., 1993). With regards to levels of smoke and toxic emissions (such as PAHs), most findings illustrated that traditional biomass stoves resulted in more household air pollution compared to improved cook stoves (Adkins et al., 2010; Gachanja & Worsfold, 1993). Field measurements and estimations of gaseous and particle pollutant emissions from cooking processes in high population countries such as China and India also reported higher emissions from their traditional biomass stoves which use wood or cattle dung as fuel (Chen et al., 2016; Raiyani et al., 1993). Households using modern LPG or kerosene stoves had the lowest levels of indoor pollution since the stoves have been confirmed to be fuel efficient. Intensified research to design and disseminate clean fuel stoves which are cost-effective is still needed. Therefore, our study examined the current combustion devices being used in the four regions of interest and noted that most households still use traditional combustion devices, which indicates the need for more effective intervention strategies.

The combustion devices used in a particular Kenyan county depended on the type of fuels used. Most of the households in urban areas used a Jiko (charcoal stove) as a combustion device due to the fact that any household using charcoal requires a Jiko (Fig. 11). The highest Jiko use recorded was in urban Voi (100 %), while the least was 62 % in urban Bomet. Rural communities recorded slightly lower rates of Jiko use, with the highest for both rural Voi and Mombasa (90 %) and the lowest in rural Bomet (27 %).

Unsurprisingly, the rural areas dominated in the use of three-stone combustion devices which could be attributed to their high use of firewood. This is because three-stone stoves are cheap and are easy to obtain and assemble compared to other combustion devices. As for rural areas of Narok, the semi-nomadic Maasai rely mostly on the three-stone stove as these are easily discarded when they migrate. However, a few exceptions indicated that other forms of combustion devices, such as improved Jikos which use firewood, are being used by some households. Rural Bomet households recorded the highest use of the three-stone stove (91 %), while only 30 % of rural Voi respondents used it, as they used primarily improved firewood Jikos.

Use of kerosene stoves was higher in urban than rural areas, with the highest use rate of 70 % in urban Mombasa. This could be attributed to the fact that in Mombasa there are fewer choices of fuel while kerosene is cheaper than in other places. In rural areas this kind of combustion device was not widely used (highest in rural Mombasa (50 %) and lowest in rural Narok (0 %)).

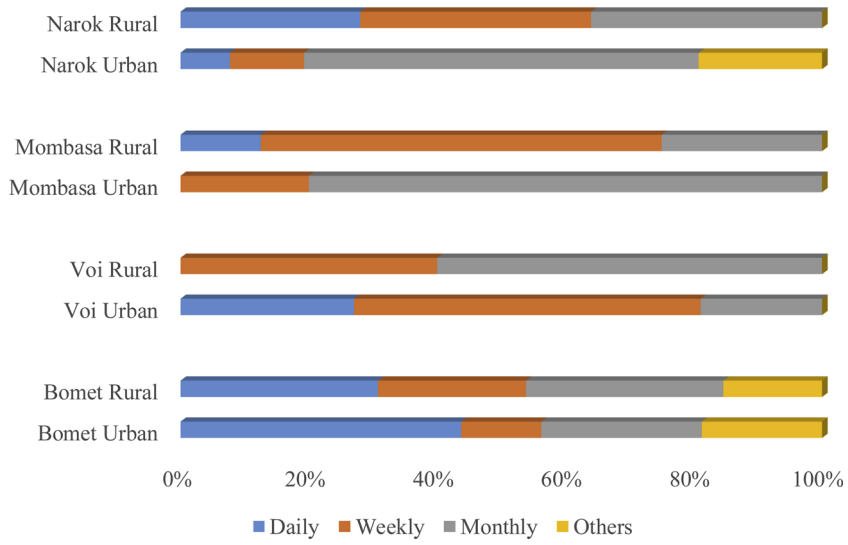

Fig. 8. Frequency of fuel collection by different communities in the study regions.

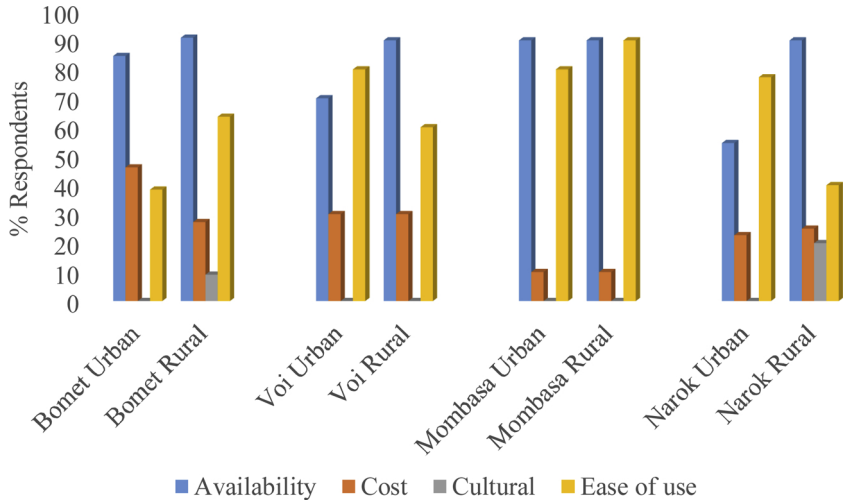

Fig. 9. Reasons given for the choice of fuel used by households in the study regions.

Gas cookers dominated in urban areas with the highest use rate in urban Narok (82 %), which could be attributed to LPG availability, affordability and its convenience in use. Very low or no usage of LPG was found in rural areas with the highest usage in rural Bomet (18 %). This could be a result of low levels of income in these rural communities and inaccessibility of LPG supply.

3.5. Combustion area within dwellings

The nature of the combustion area in the households studied was inspected and analyzed for its potential impact on indoor air quality (and related human health effects) and to some extent the combustion efficiency of various stoves (Fig. 12). A number of parameters were investigated, such as existence or absence of a dedicated kitchen, whether the combustion area was temporary or permanent, the presence or absence of ventilation in the form of windows and chimneys, and the general space available for combustion activities. These parameters provide valuable information when quantitative indoor air pollution studies are performed as the exposure of residents to potentially harmful pollutants such as PAHs and particulate matter generated during combustion is directly influenced by ventilation of homes. Good ventilation allows for dilution of emitted pollutants and efficient removal thereof, and also provides sufficient oxygen for efficient combustion. Poor insulation on the other hand, may increase the need for combustion for space heating purposes during the winter season, particularly in colder regions.

In this study, the number of windows in kitchens was higher in the Narok and Bomet regions which was consistent with the fact that firewood was their main choice of fuel, and would require good ventilation for efficient burning. With the exception of Voi, there were more chimneys in urban dwellings than in the rural homes. The existence of chimneys could be attributed to financial factors with most households in the rural areas not being able to afford a chimney structure.

3.6. Perceived negative aspects of fuel types

The evaluation of the perceived negative aspects of the different fuel types is shown in Fig. 13. The negative effect of the type of fuel used

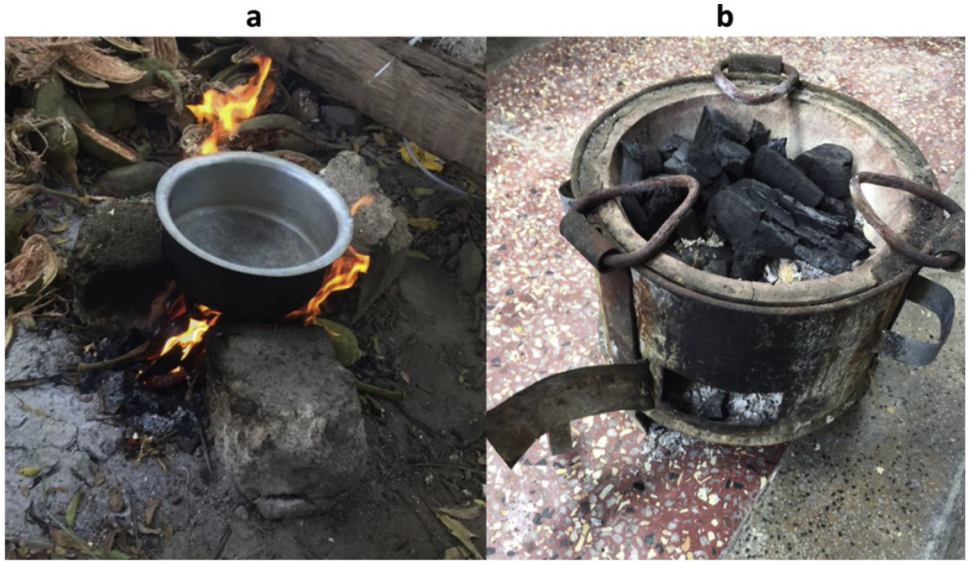

Fig. 10. Typical traditional combustion devices in use in Kenya are the wood burning three-stone stove (a) and a Jiko which uses charcoal fuel (b).

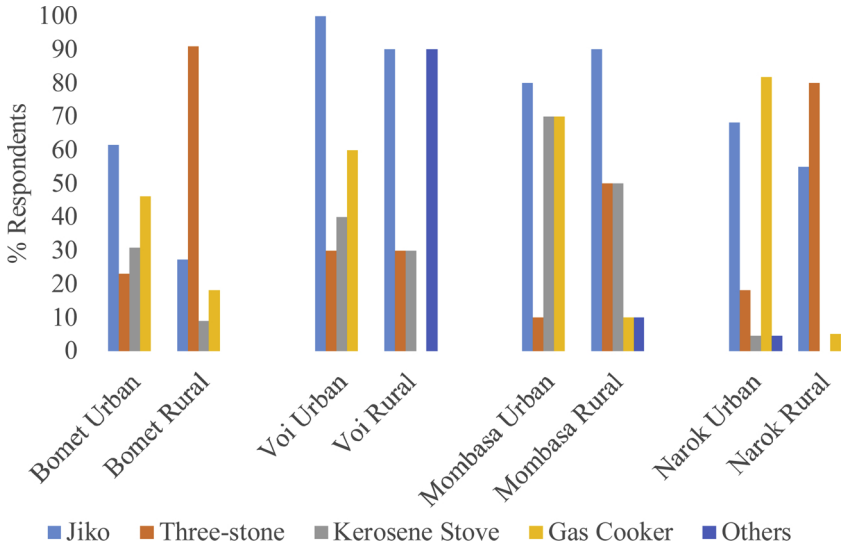

Fig. 11. Types of fuel cook stoves used in urban and rural areas of the four study regions.

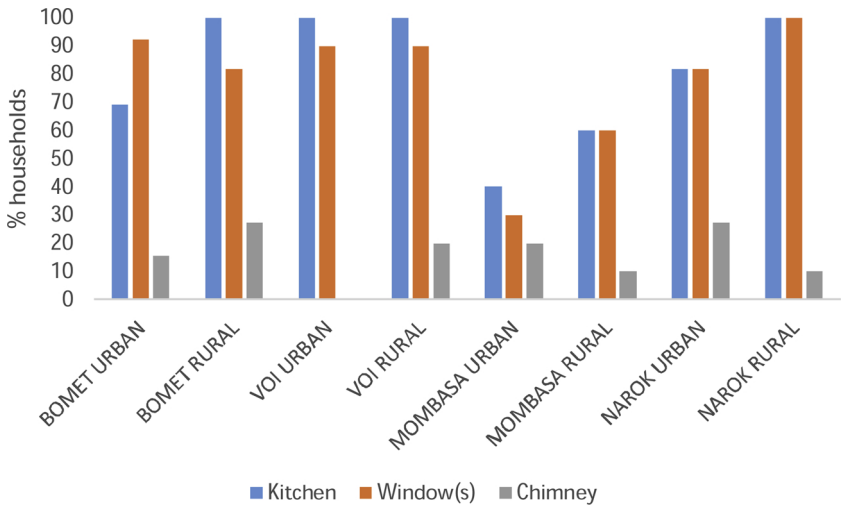

Fig. 12. Percentage of households in each urban and rural area which had kitchens, kitchens with window(s) and kitchens with chimneys respectively.

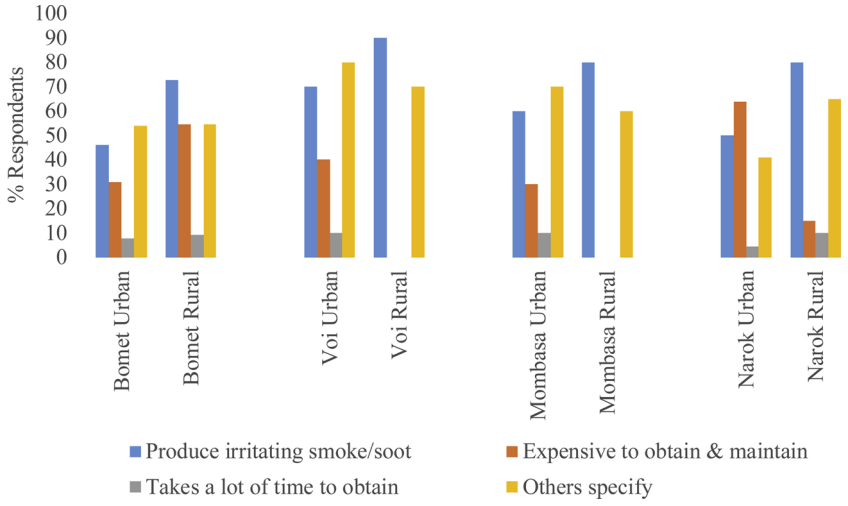

Fig. 13. Perceived negative aspects related to fuel types in the four surveyed regions.

which was evident in almost all households was the production of irritating smoke/soot, particularly in rural communities (90 % of respondents in rural Voi reported this). Urban areas recorded lower negative effects in this regard, where firewood is used less.

The other negative aspects mentioned by respondents were: large amounts of firewood required for complete cooking; causes coughing; risky with children (LPG); and dangerous when used with closed doors (charcoal). Others aspects were deforestation (with respect to firewood and charcoal) and difficulty in lighting when wet (charcoal and firewood). Expense of fuels was more of a problem in urban than rural areas. The time that it takes to obtain the fuel was not found to be a significant negative aspect.

4. Conclusions

The field survey provided firsthand data for household fuel use analysis, including perceptions of respondents in this regard. Household fuel use varied among the four regions, and differed between rural and urban areas. Overall, the most widely used fuel type was firewood (25 %) followed closely by charcoal (24 %), kerosene (24 %) and LPG (23 %). It was found that availability and ease of use of fuel were the key determinants regarding the fuel type utilized, whilst the perceived negative aspects related to fuels were found to be primarily the production of irritating smoke/soot; associated health matters; danger in use; and high costs.

The results of this study provide a useful basis for decision making regarding future intervention strategies in Kenya to reduce household combustion emissions and thereby to enhance air quality and improve human health. Education of communities regarding the benefits of clean fuel use as well as improved indoor air quality will invariably be key factors in achieving environmentally sustainable development.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

Funding provided by the National Research Foundation of South Africa and National Research Fund of Kenya (NRF), grant number 105807) through joint collaboration between the University of Pretoria South Africa and Maasai Mara University Kenya is gratefully acknowledged. Many thanks to Maasai Mara University and Taita Taveta University for facilitating the questionnaire survey activities. Mr. Abdallah Marjan of Maasai Mara University and Ms Grace Kalaghe of Pwani University are thanked for their assistance with the questionnaire administration.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2020.102039.

References

Abusalah, A., Gavana, M., Haidich, A.-B., Smyrnakis, E., Papadakis, N., Papanikolaou, A., et al. (2012). Low birth weight and prenatal exposure to indoor pollution from tobacco smoke and wood fuel smoke: A matched case–Control study in Gaza strip. *Maternal and Child Health Journal, 16*(8), 1718–1727.

Adkins, E., Tyler, E., Wang, J., Siriri, D., & Modi, V. (2010). Field testing and survey evaluation of household biomass cook stoves in rural sub-Saharan Africa. *Energy for Sustainable Development, 14*(3), 172–185.

Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., ... Smith, K. R. (2013). Solid fuel use for household cooking: Country and regional estimates for 1980–2010. *Environmental Health Perspectives, 121*(7), 784–790.

Chen, Y., Shen, G., Liu, W., Du, W., Su, S., Duan, Y., ... Xing, B. (2016). Field measurement and estimate of gaseous and particle pollutant emissions from cooking and space heating processes in rural households, northern China. *Atmospheric Environment, 125*, 265–271.

Duan, X., Jiang, Y., Wang, B., Zhao, X., Shen, G., Cao, S., ... Wang, L. (2014). Household fuel use for cooking and heating in China: Results from the first Chinese Environmental Exposure-Related Human Activity Patterns Survey (CEERHAPS). *Applied Energy, 136*, 692–703.

Gachanja, A., & Worsfold, P. (1993). Monitoring of polycyclic aromatic hydrocarbon emissions from biomass combustion in Kenya using liquid chromatography with fluorescence detection. *The Science of the Total Environment, 138*(1–3), 77–89.

HosgoodIII, H. D., Chapman, R. S., He, X., Hu, W., Tian, L., Liu, L. Z., ... Lan, Q. (2013). History of lung disease and risk of lung cancer in a population with high household fuel combustion exposures in rural China. *Lung cancer, 81*(3), 343–346.

Kwach, J. (2018). *Lists of counties in Kenya by population, size, wealth and performance.* https://www.tuko.co.ke/262119-lists-counties-kenya-by-population-size-wealth-performance.html#262119.

Lozier, M. J., Sircar, K., Christensen, B., Pillarisetti, A., Pennise, D., Bruce, N., ... Farrar, J. L. (2016). Use of temperature sensors to determine exclusivity of improved stove use and associated household air pollution reductions in Kenya. *Environmental Science & Technology, 50*(8), 4564–4571.

Makonese, T., Ifegbesan, A. P., & Rampedi, I. T. (2018). Household cooking fuel use patterns and determinants across southern Africa: Evidence from the demographic and health survey data. *Energy and Environment, 29*(1), 29–48.

Martins, N. R., & da Graça, G. C. (2018). Impact of PM2. 5 in indoor urban environments: A review. *Sustainable Cities and Society, 42*, 259–275.

Miyandazi, V. (2015). *Forced evictions and demolition of informal settlements in Kenya*.

Muindi, K., Kimani-Murage, E., Egondi, T., Rocklov, J., & Ng, N. (2016). Household air pollution: Sources and exposure levels to fine particulate matter in Nairobi slums. *Toxics, 4*(3), 12.

Munyeza, C. F., Rohwer, E. R., & Forbes, P. B. (2019). A review of monitoring of airborne polycyclic aromatic hydrocarbons: An African perspective. *Trends in Environmental Analytical Chemistry,* e00070.

Patelarou, E., & Kelly, F. J. (2014). Indoor exposure and adverse birth outcomes related to fetal growth, miscarriage and prematurity—A systematic review. *International Journal of Environmental Research and Public Health, 11*(6), 5904–5933.

Pilishvili, T., Loo, J. D., Schrag, S., Stanistreet, D., Christensen, B., Yip, F., ... Bruce, N. (2016). Effectiveness of six improved cookstoves in reducing household air pollution and their acceptability in rural Western Kenya. *PloS One, 11*(11), e0165529.

Pope, D. P., Mishra, V., Thompson, L., Siddiqui, A. R., Rehfuess, E. A., Weber, M., et al. (2010). Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. *Epidemiologic Reviews, 32*(1), 70–81.

Rahnema, A., Sanchez, F., & Giordano, P. (2017). *Alternative cooking fuels in Kenya: How can household decision-making Be impacted? IESE Business School Working Paper No. 1177-E.* SSRNhttps://ssrn.com/abstract=3102883.

Raiyani, C., Shah, S., Desai, N., Venkaiah, K., Patel, J., Parikh, D., et al. (1993). Characterization and problems of indoor pollution due to cooking stove smoke. *Atmospheric Environment Part A General Topics, 27*(11), 1643–1655.

Roden, C. A., Bond, T. C., Conway, S., Pinel, A. B. O., MacCarty, N., & Still, D. (2009). Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. *Atmospheric Environment, 43*(6), 1170–1181.

Schlag, N., & Zuzarte, F. (2008). *Market barriers to clean cooking fuels in sub-Saharan Africa: A review of literature.* Stockholm: Stockholm Environment Institute.

State of Global Air. Available online: https://www.stateofglobalair.org/ (Accessed 7 August 2018) 2018.

Sharma, D., Ravindra, K., Kaur, M., Prinja, S., & Mor, S. (2019). Cost evaluation of different household fuels and identification of the barriers for the choice of clean cooking fuels in India. *Sustainable Cities and Society, 52*, 101825.

Suter, M. K., Karr, C. J., John-Stewart, G. C., Gómez, L. A., Moraa, H., Nyatika, D., ... Ghodsian, N. (2018). Implications of combined exposure to household air pollution and HIV on neurocognition in children. *International Journal of Environmental Research and Public Health, 15*(1), 163.

Szulejko, J. E., Kim, K.-H., Brown, R. J., & Bae, M.-S. (2014). Review of progress in solvent-extraction techniques for the determination of polyaromatic hydrocarbons as airborne pollutants. *TrAC Trends in Analytical Chemistry, 61*, 40–48.

Tigabu, A. (2017). Factors associated with sustained use of improved solid fuel cookstoves: A case study from Kenya. *Energy for Sustainable Development, 41*, 81–87.

Vicente, E., & Alves, C. (2018). An overview of particulate emissions from residential biomass combustion. *Atmospheric Research, 199*, 159–185.