DOTTORATO DI RICERCA IN
"Gestione Sostenibile delle Risorse Agrarie, Forestali e Alimentari "

CICLO IXXX

Settore Scientifico Disciplinare AGR/09

ENVIRONMENTAL AND ECONOMIC BENEFITS DUE TO SUBSTITUTION OF TRADITIONAL COOK STOVES IN MOZAMBIQUE

Coordinatore:
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Anni 2014/2016

UNIVERSITÀ DEGLI STUDI FIRENZE

Scuola di dottorato di Agraria

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Abstract

The use of solid biomass as cooking fuel is still predominant in developing countries. Indeed, around half of the world population relies on woody fuels to meet household energy needs using traditional and inefficient technologies. The use of biomass on a such vast scale has several negative effects on environment and human health. The substitution of traditional cooking devices with more efficient technologies is one of the most valuable options to reduce wood fuel demand with significant benefits for environment and biomass end users. These benefits regard the reduction of climate impact related to cooking activities, the decrease of anthropic pressure on forests, economic saving for the beneficiary households and the reduction of health pollutant emissions. Many efficient stove programmes have been implemented since the 1970s whose main target was to reduce the impact of biomass use on human health. In the last years, the mitigation potential of GHG emissions have become the predominant objective of stove projects. This is because after the adoption of the Kyoto protocol such programmes can claim access to carbon market as additional source of finance to overcome economic constraints which had limited success of many cookstove projects. This study analyses two cookstove carbon projects which are being implemented in Mozambique, one targeting the substitution of traditional charcoal stoves in Maputo and Pemba urban areas and the other the substitution of the traditional three-stone fire in Gilè natural reserve area. The aim is to assess environmental and social benefits related to these projects integrating laboratory and field data, assessing as well the entire woodfuel supply chains. Laboratory tests aim to provide an assessment of both traditional and improved stove efficiencies and emissions of GHG and other pollutants. Field tests provide real data on fuel consumption during baseline and project scenario, on efficient stove adoption and penetration among households, as well as on population perception of social and environmental benefits related to efficient cookstove usage.

Laboratory tests show that efficient stoves, independently of the fuel used, have a better thermal efficiency and lower specific fuel consumption and firepower. This is particularly evident for thermal efficiency which increases from 15% to 33% in the case of wood stoves and from 21% to 38% for charcoal stoves. The increase in CO2 emission factors in g/MJ of efficient stoves (49% for wood and 52% for charcoal efficient stoves) is also a sign of improved combustion efficiency which lead to a reduction of product of incomplete combustion which are dangerous both for environment and human health.

The number of families involved in the Maputo/Pemba programme in September 2016 were 11,479, expected to rise to 19,888 by the end of 2017. 4.000 household will be involved in the Gilè programme starting from May 2017. Field data analysis shows that the use of CH2200 allows to significantly reduce charcoal consumption. Mean daily fuel reduction per household was 1.71 kg/day/hh during the first year and 1.46 kg/day/hh for the second year of project activity. As a result, GHG emission reduction achieved by March 2016 was 27,618 tons of CO_2 equivalents. The programme is estimated to reduce 362,594 tons of CO_2 equivalent by the end of 7th year of project activity. The methodology used to estimate emission reduction with the purpose of claiming carbon credit emission does not envisage the emission related to charcoal life cycle. Including such emission, the project could save up to 529,698 tons of CO2 eq., overall 46% higher. The calculation of potential emission reduction for Gilè programme is based on the baseline fuel consumption and the differences in stove thermal efficiencies calculated during laboratory tests. This is estimated to be 48,070 tons CO_2 eq. Contribution to climate change is not only limited to GHG emissions but it is also related to other climate pollutants emitted as result of incomplete combustion. The use of efficient cooking technologies has the potential to reduce such pollutants. For Maputo/Pemba programme this reduction is estimated to be 17,872 tons CO_2 eq. and 23,555 tons CO_2 eq. for the Gilè project. It is not in the scope of this study to assess direct effect of air pollution on human health, however, the use of efficient cookstove has the potential to

reduce exposure to such pollutants. For instance, Rocket Works stove reduces emission of fine particulate matter (PM1) up to 86% and CH2200 stove up to 57%.

In Maputo and Pemba households use a substantial part of their budget to purchase charcoal. During the first year of project, thanks to the use of efficient stoves, families saved up to 116 US dollars. Such high saving allows them to payback the investment sustained to buy the stove in only 25 days.

Charcoal production is one of the main causes of deforestation and land degradation, the reduction of charcoal demand achievable through Maputo/Pemba project activities have the potential to save up to 2,003 hectares of Miombo forests. In Gilè area the impact of cooking activities is estimated to be low, since only a small part of households cut trees for the purpose of wood harvesting. However, it is estimated that around 90 hectares can be saved with this project.

This study is part of a wider research carried out by the GESAAF department of the University of Florence in collaboration with CarbonSink, a spinoff of the same university. Further research will be conducted in the following years on cookstove performance, efficiency drop over years and durability of project technologies. Furthermore, it has been planned to update laboratory equipment to include other substances in the pollutant analysis. Moreover, it is under study a monitoring campaign to assess household exposure to health damaging emissions.

Keywords: Climate Change, Efficient Cookstoves, Climate Finance, Health Damaging Pollutants, Deforestation.

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1 Introduction

1.1 Use of biomass as cooking fuel

Human beings and fire have interacted for more than two million years. Vegetal biomass has always been one of the primary sources of energy for warmth, light and cooking. Approximately half of the world population currently relies on solid biomass (such as wood charcoal and dung), in spite of the increasing use of fossil fuels starting with the Industrial Revolution (Fullerton, Bruce, e Gordon 2008). The areas in which the use of solid biomass is still predominant are concentrated in developing countries where access to fossil fuels and efficient cooking and heating technologies is limited (Bonjour et al. 2013). In Asia and Sub Saharan Africa, biomass provides around 70% of household energy demand (Ndiema, Mpendazoe, e Williams 1998). In rural areas, over 90% of the population is estimated to rely on biomass for their energy needs (Agenbroad et al. 2011).

The use of biomass on a such vast scale has a negative effect on global climate change. Although biomasses are generally neutral to carbon cycle, it is the actual demand of wood and charcoal one of the key drivers of deforestation in developing countries since they are not harvested in a sustainable way causing important losses of carbon stocks.

However, the environmental effects of biomass use for energy production are not only a result of deforestation but also of its combustion. Energy production from solid biomass in households takes place mostly in traditional and inefficient devices. The first combustion system ever used by humans and still the most common one, especially in rural areas, is the three-stone open fire (Smith et al. 2000) (Figure 1). In urban areas, where wood is not commonly available, the most common cooking/heating device is the charcoal traditional stove (Figure 2). These two systems are particularly inefficient due to heat dispersion and incomplete combustion, especially the three-stone open fire.

Figure 1: Traditional three-stone fire

Figure 2: Traditional Charcoal Stove

Inefficient biomass combustion leads to incomplete combustion products and emissions in the environment of powerful GHG and Black Carbon (Agenbroad et al. 2011; P. Smith et al. 2007).

Emissions do not only affect global environment. These substances, along with poor ventilation are a major cause of adverse health effects. The WHO estimates that over 4 million people per year die prematurely because of indoor air pollution caused by biomass burning («WHO | Household air pollution and health» 2016).

1.2 Biomass definition

Biomass can be defined as organic materials derived from living organisms such as plant matter and manure, that have not become fossilized and are used as fuel (American Heritage® Dictionary).

Biomasses provide around 15% of primary energy use worldwide. 75% of this energy is used in developing countries where it is used to meet the household heating demand. The most common biomass is wood, with a consumption of 1.86 billion of m^3 (FAOSTAT 2016) per year. As previously underlined, wood consumption and its derived products are manly concentrated in Africa, Asia and South America (Figure 3).

Africa alone accounts for 35% of the world wood fuel consumption (in the form of firewood and charcoal), particularly in Sub Saharan Africa where more than 75% of the population uses biomass as main fuel. 85% of the wood is used to meet household cooking requirements (WEET 2000).

Wood is often used directly as fuel in combustion devices, particularly in rural areas where it is abundant, however, it is often transformed in charcoal to facilitate transport to areas far from wood supply basin (forested areas). This is particularly common in Africa (Figure 4), where the rapid growth of urban areas has increased the fuel demand. Once charcoal is produced through pyrolysis, it is transported to the city and commercialized.

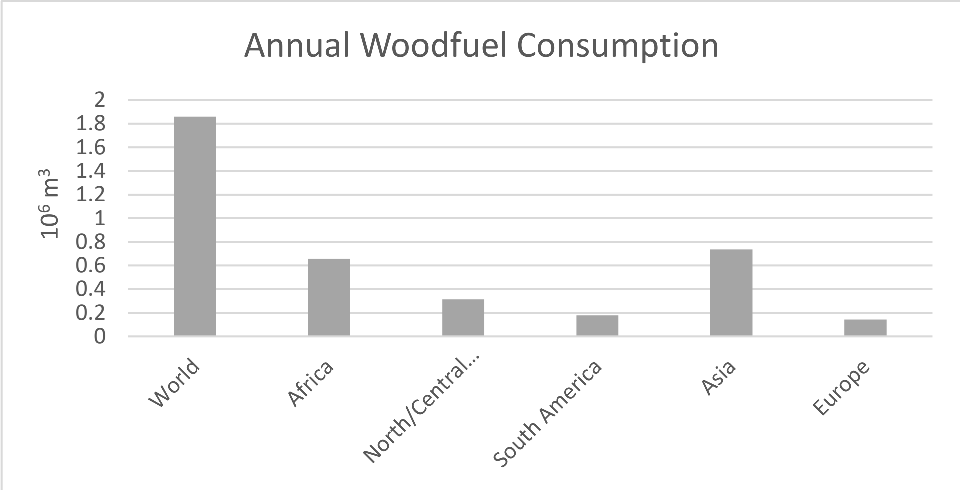


Figure 3: World wood fuel consumption (FAOSTAT, 2016)

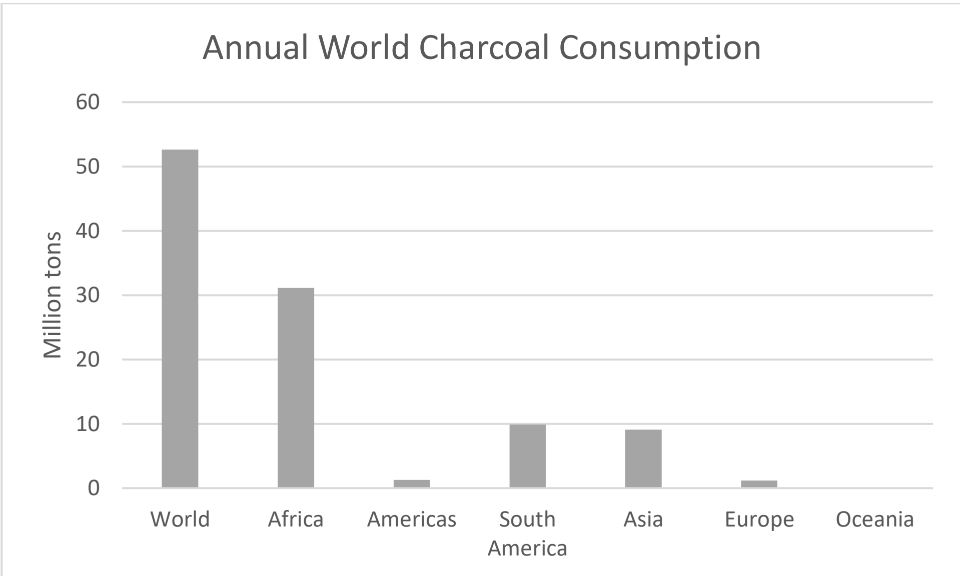


Figure 4: World charcoal consumption (FAOSTAT, 2016)

1.3 Impact of biomass use

Biomass fuel is a renewable source of energy and therefore, potentially neutral to the carbon cycle. This is true when biomass is harvested sustainably, which means that carbon emissions due to biomass combustion are balanced by the absorptive capacity of the plants. For instance, biomass from forest is a sustainable source of energy if the harvesting rate does not exceed the forest regeneration rate. In developed countries, this concept is well known and the sustainable management of forests is applied, being often mandatory by national laws. In developing countries instead, where the majority of biomass fuel is produced and consumed, sustainable management of forests and natural resource protection is generally poor and biomass harvest is often one of the main causes of deforestation and land degradation.

This is particularly evident in Africa, where the increasing demand of biomass fuel due to the economic growth is putting under pressure natural resources and forested areas. Several studies assess the impact of fuel consumption on African forests and they show that wood collection and charcoal production, along with agricultural expansion, are the main drivers of land degradation (up to 45%) and deforestation (Hosonuma et al. 2012; Girard et al. 2002; Kammen e Lew 2005).

However, it is necessary to make a distinction between woodfire and charcoal and therefore between fuel used in urban and rural contexts. While impact of firewood harvesting can be considered limited, implications of charcoal production represent an increasing threat to forests in the majority of Sub-Saharan nations. Charcoal is the main source of cooking energy in urban contexts and its demand is constantly increasing as a consequence of population growth (Figure 5). 1% increase in urban population is estimated to result in 15% increase in charcoal production (Mwampamba 2007). These represent a serious threat to forest resources, since charcoal production processes are particularly inefficient and require large quantities of wood (in the ration 6 Kg of wood per kg of charcoal). Generally, charcoal consumers use around 4/6 times more fuel than woodfire consumers. Moreover, charcoal is usually made from wood of slow growing species that are particularly vulnerable to overexploitation (Chidumayo 1991).

We mentioned before that biomass harvesting in Africa is generally not renewable, contributing to global climate change. Indeed, carbon dioxide released in the atmosphere by biomass combustion is not balanced by the plant absorbing capacity. Deforestation rate shows that plant growing rate is systematically overcome by wood fuel harvesting. Moreover, deforestation and land degradation causes the loss of large amounts of carbon stoked in the soil, increasing the effect of biomass use on climate.

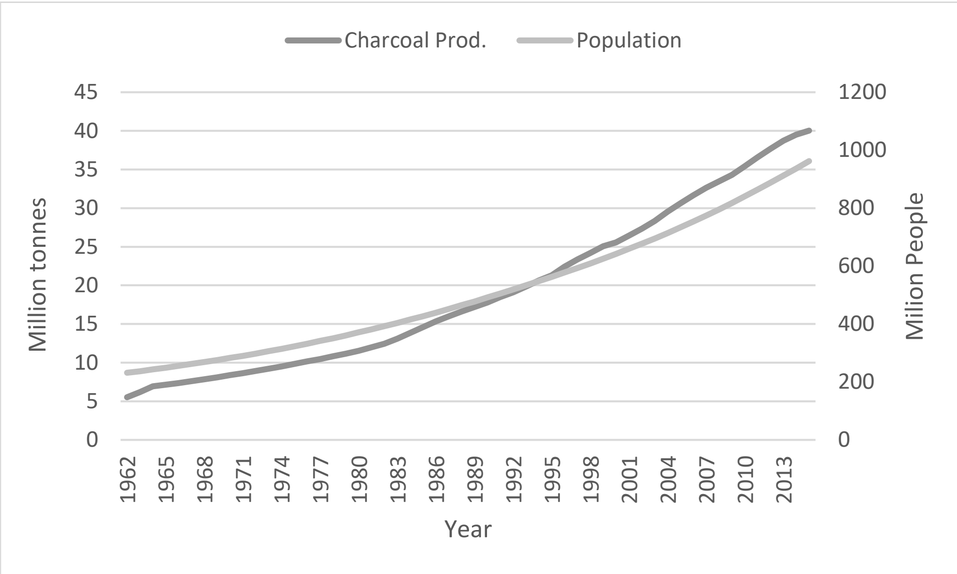


Figure 5: Charcoal Production and Population of Sub Saharan Africa (FAOSTAT, 2016)

The contribution of biomass use to anthropogenic climate change is estimated in a range between 1-3 % (Haines et al. 2009). Although this contribution may seem limited, it is also unnecessary since this source of energy is potentially sustainable and has been identified as one of the possible substitutes of fossil fuels responsible for climate change.

However, contribution of wood fuel use on global warming is not limited to combustion of not renewable biomass. It is often assumed that biomass combustion is "climate neutral" when it is collected in a sustainable way. This assumption relies on the fact that CO_2 emitted during combustion is recycled by plants in a short period, before it can influence the climate change process. This implies a perfect combustion of wood fuels, which produces only CO_2, H_2O and ash. However, simple cooking devices such as the three stone fire and traditional charcoal stove do not only emit carbon dioxide. They convert fuel in other products as a result of incomplete combustion (PICs) mainly because of poor oxidation. Many of these products have a higher global warming potential than CO_2. Among them greenhouse gasses such as nitrous oxides (N_2O), methane (CH_4), and other air pollutants such as carbon monoxide (CO), volatile organic compounds (VOCs, particularly non-methane hydrocarbons) and black carbon/organic carbon particles. Methane and nitrous oxides are usually accounted when estimating the climate impact of biomass combustion. Even if the quantity of these gasses generated during combustion is limited if compared to CO_2 emissions, their impact is relevant due to their high global warming potential (GWP) (Table 1). The mechanism leading to the formation of these gasses during combustion is not well understood and it varies depending on fuel and cooking device characteristics (Ndiema, Mpendazoe, e Williams 1998). Calculation of these gas emissions relies on direct measurements and emission factors from the IPCC (IPCC 2006).

Carbon monoxide emissions from traditional wood stoves could represent as much as 10-15 % of CO_2 emissions (MacCarty et al. 2008) and even more for charcoal stoves, as a result of oxygen deficit. CO has a small direct GWP but it leads to indirect radiative effects such as an increase in CH_4 lifetime and O_3 formation (Fuglestvedt, Isaksen, e Wang 1996). CO impact is often neglected because of the difficulty in accurately calculating these effects.

Black carbon (BC) and organic carbon (OC) are emitted in the form of fine particulate matter (PM $\leq$ 2.5 µm) and consist of carbonaceous materials originated during combustion. Their characteristics have both the potential to reduce (OC) and increase global warming (BC). However, it is estimated a clear preponderance of its warming effects. Residential biomass burning contributes for 60 to 80% of Asian and African emissions of BC. It has several effects on the climate systems related to the absorption potential and the scattering of sunlight and it also influences the properties of ice and liquid clouds and the reduction of albedo effect caused by deposition on snow and ice (Bond et al. 2013). It has been estimated that emissions of black carbon may be the second biggest contributor to global warming, after carbon dioxide emissions (Ramanathan e Carmichael 2008). Reduction of BC emissions through efficient combustion can represent a huge boost to rapidly reduce the current global warming. Indeed, BC has a short life span in the atmosphere compared to other GHGs (around two weeks) and therefore climate system response to its concentration could be particularly fast.

Volatile Organic Compounds which include non-methane hydrocarbons (NMHC) have a small direct impact on global warming due to their short atmospheric life span too. However, VOCs influence climate through the production of organic aerosols and their involvement in photochemistry, such as production of O_3 in the presence of NO_x and light (IPCC 2007). This effect is difficult to estimate and is largely dependent on the properties of the VOC considered. VOCs emission, particularly in the form of NMCH, is the result of fuel incomplete combustion.

Dinitrogen Monoxide (N_2O) is a powerful greenhouse gas, with a direct GWP of 298 kg CO_2 eq. over a 100-year period. It originates during high temperature combustion as a result of complete oxidation of the nitrogen contained in wood fuel (Bai et al. 2013). Combustion temperature in biomass devices is usually low (< 800 °C), hence N_2O emission could be considered negligible and not dependent on combustion device technology. However, giving the high GWB of this gas, it is necessary to consider these emissions when assessing the impact of wood fuel use on climate change.

Table 1: Global warming potential (100-year CO2 equivalent)

Emission	Global warming potential, 100-year CO2 equivalent	Reference
CO_2	1	IPCC, 2013
CO	1.9	IPCC, 2013
CH_4	25	IPCC, 2013
N_2O	298	IPCC, 2013
Black Carbon	658	IPCC, 2013
Organic Carbon	-66	IPCC, 2013
VOCs	14	Edwards and Smith, 2002

In addition to their impact on global warming, products of incomplete combustion have a damaging effect on human health (Haines et al. 2009). When analysing the effects of carbon monoxide, nitrous oxides, VOCs and Hydrocarbons, particles with diameters below 10 microns (PM10), and particularly those less than 2.5 microns in diameter (PM2.5) which can penetrate deeply into the lungs, an enormous burner of disease is uncovered. The 24-h mean particulate matter levels set in the WHO guidelines for air quality are 50μg/m3 for PM10 and 25μg/m3 for PM2, but in the developing world the peak indoor concentration of PM10 often exceeds 2000 μg/m3 (Regalado et al. 2006) (Figure 6). Continuous exposure to indoor air pollution caused by PICs is linked to several diseases: respiratory tract infections, exacerbations of inflammatory lung conditions, cardiac events, stroke, eye disease, tuberculosis (TB), low birthweight and cancer among others (Bruce, Perez-Padilla, e Albalak 2000). Children and women are the most affected by indoor air pollution and it is estimated to cause around 4 million deaths yearly, mainly located in developing countries (Lelieveld et al. 2015).

The increasing demand and distant supply basins have caused an increase in the costs sustained by the families for obtaining charcoal. In urban slums, where the majority of households survive with less than 2 dollars per day, fuel purchase represents a relevant part of the family budget, subtracting resources from other activities. On the other hand, wood is free of charge in rural environments, but anyway its collection requires a relevant amount of time, particularly when harvesting areas are far from dwellings. However, wood has recently become a tradable fuel in rural areas as well, after regulation has been implemented by many local authorities in an attempt to reduce pressure on forests and control wood harvest (e.g. Ethiopia).

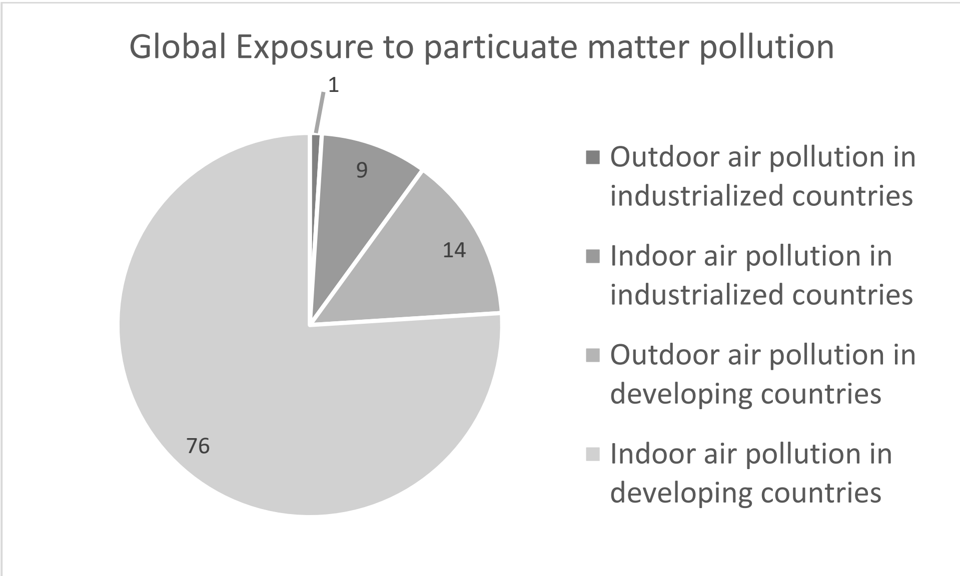


Figure 6: Global exposure to particulate matter.

1.4 Efficient cookstoves

The use of improved cooking devices can be among the most valuable options to mitigate impact related to biomass fuel use in developing countries. An improved stove is designed to reduce fuel consumption and harmful emissions due to increased thermal efficiency (Barnes et al. 1993). The majority of these stoves operate using the natural convention or chimney effect, which is created by confining fire in a combustion chamber, which reduces heat dispersion driving energy to a specific target (Jetter e Kariher 2009). Figure 7 shows an example of a simple combustion chamber for an improved cooking stove, isolated with Rockwool to reduce heat dispersion, while Figure 8 shows the chimney effect principle.

Figure 7: Example of improved cook stove combustion chamber

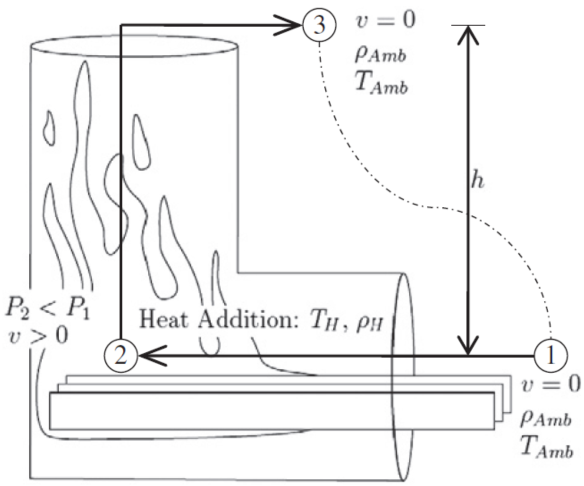


Figure 8: Chimney effect

There are a variety of efficient cookstoves designed for a variety of wood fuels. They can be grouped in two main categories: locally made (artisan or semi industrial) and industrially produced (Figure 9).

Figure 9: Examples of efficient stoves. From top left to bottom right: locally made wood, locally made charcoal, industrial wood and industrial charcoal stoves

Locally made stoves are usually easy to produce and cheaper than industrial stoves but they are also less efficient. On the contrary, industrial stoves are more expensive but more elaborated, durable and efficient. Potential benefits of using efficient cooking stoves are related to health, fuel saving, GHG emission reduction and time and cost efficiency. International protocol for laboratory and on field tests have been developed to assess the performance of these stoves. («CDM: Energy efficiency measures in thermal applications of non-renewable biomass --- Version 8.0» 2016; «Global Alliance for Clean Cookstoves» 2016)

Figure 10 and Figure 11 show the comparison of thermal efficiency and some pollutant emissions between traditional and improved stoves for different wood fuels. For all fuels, new cooking technologies show an increased efficiency and decrease of pollutants.

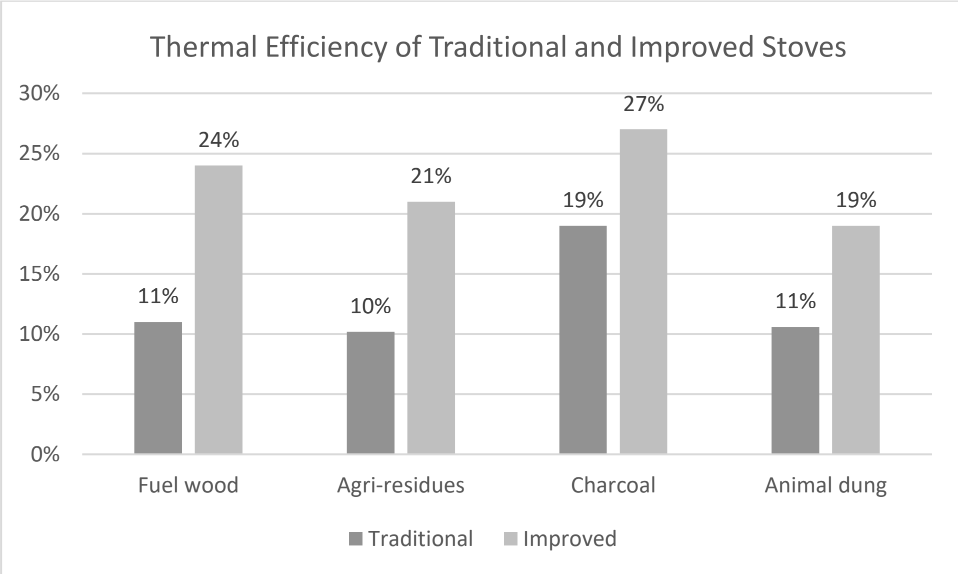


Figure 10: Thermal efficiency of traditional and improved cook stoves (Bhattacharya e Abdul Salam 2002)

Table 2: Efficiency and emission factor values for traditional and improved stoves (Bhattacharya e Abdul Salam 2002)

Biomass type	HHV (MJ kg−1)	Thermal Efficiency		Emission factor (g kg−1 of fuel burned)					
				CH4		N2O		CO	
		TS[b]	IS[b]	TS[b]	IS[b]	TS[b]	IS[b]	TS[b]	IS[b]
Fuel wood	16.55	11	24	8.6	6.76	0.06	0.08	107	31
Agri-residues	16.5	10.2	21	300a	2.18	4 a	4 a	48	75
Charcoal	30.75	19	27	7.8	200 a	1 a	1 a	477	246
Animal dung	13.3	10.6	19	300 a	300 a	4 a	4 a	50	39

a) Unit—kg TJ−1.

b) **TS**=Traditional Stove; **TS**= Improved Stove

1.5 Efficient cookstoves distribution

For almost four decades, improved cooking stoves have been promoted and distributed in Africa, South America and Asia in order to reduce wood fuel use and to improve quality of life (Berrueta, Edwards, e Masera 2008). Although prior attempts to introduce efficient cook stoves date back to the 50s in India, only in the late 70s cooking stove programmes started to be systematically implemented. During that period, scientific research helped increase awareness about air pollution caused by woodfuel burning and induced human diseases. A successful initiative was the Chinese National Improved Stove Project (K. R. Smith et al. 1993). In ten years (1982-1992), around 129 million efficient stoves were introduced in the rural areas of the country, reaching around 50% of households.

However, the Chinese programme remains an isolated case since similar initiatives in other developing countries were not so successful. Indeed, authority support and economic situation allowed the use of a bottom up approach (small pilots to scale up) with a small contribution from the government (around 15% of stove price) and the adoption of an extensive monitoring plan to revise programme design and assess its results («The Past, Present, and Future of Improved Cookstove Initiatives» 2016).

During the same period in Africa very little results were obtained by efficient stove distribution projects. The reasons behind this are multiple. In rural areas wood is generally free, therefore there is no willingness to purchase new stoves. Instead, in areas where the population must buy the fuel (e.g. charcoal) families cannot afford the cost of new cooking stoves.

NGOs and international donors have promoted distribution of stoves free of charge in an attempt to increase the use of improved cook stoves. However, the lack of economic resources and authority support largely limited the benefits to small local pilots. The possibility of scaling up stove programmes and of creating local markets was limited by the fact that people need to change their cooking habits and also because they do not get sufficiently involved in keeping a regular maintenance of the stoves that they have received for free.

These various past experiences have provided new project developers with knowledge and tools for improved implementation. Although in Africa stoves do not sell as easy as a cell phone, knowledge and appeal of efficient cook stoves are increasing, mainly because of the adoption of new approaches (Figure 9) based on an efficient distribution and marketing strategy, increase of industrial production and training of local manufacturers (Kees e Feldmann 2011). Apart from this, new initiatives include a cost for the families, although greatly subsided (e.g. 3 dollars for 20 dollars stove cost).

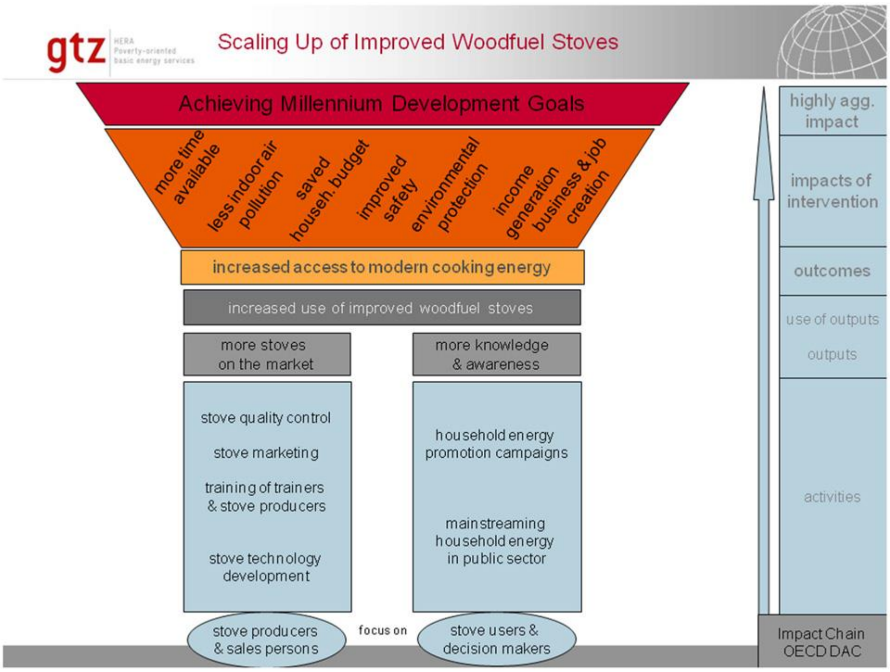


Figure 11: The GTZ HERA Approach for scaling up stove projects

1.6 Carbon Finance and improved cooking stove programmes

For many years, the main drivers of improved cookstoves dissemination have been the reduction of biomass impact on human health and forest protection.

In the last ten years, the mitigation potential of GHG emissions have become the predominant objective of stove projects.

After the adoption of the Kyoto Protocol, international community agreed that Climate Change is one of the main issues that humans have to face in the next century. Temperature increase must stay below 2°C to avoid irreversible effects on world climate systems. As a result, initiatives and projects which work to reduce GHGs emissions have been strongly encouraged and supported financially by measures such as the "Carbon Finance". The creation of stove markets requires funds and time. The lack of funds and the limited duration of many projects significantly reduce the success of scaling up. Carbon Finance is providing new fundamental resources to stove initiatives and it is drastically changing the clean stove sector.

Climate Finance is changing the traditional donor support approach, increasing the average duration of the projects (4 years on average), supporting the creation of self-sustained markets, subsidising stove prices and encouraging commercial initiatives for stove production (Figure 12). Moreover, Climate Finance revenues attract interest of the private sector which is now joining no profit organizations into implementing cooking stove projects.

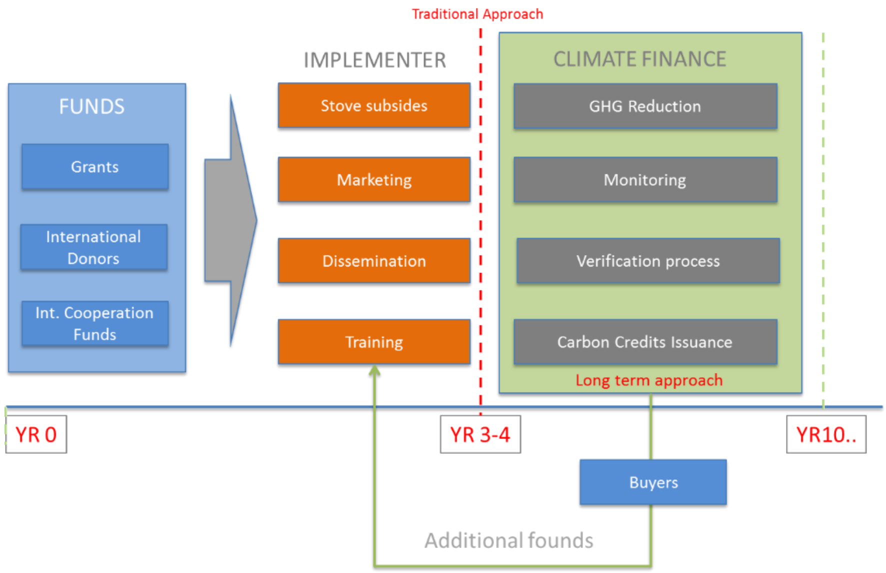


Figure 12: Climate Finance approach (courtesy of CarbonSink)

Climate Finance is based on the commercialisation of Carbon Credits on the international markets. Carbon Credits are tradable units which represent a tone of CO_2 equivalent not emitted or absorbed from the atmosphere. Carbon Credits are used to comply with mandatory emission reduction schemes (eg: EU-ETS) or for voluntary emission reduction initiatives.

Carbon Credits are certified in compliance with internationally recognized standards. They can be sold only after the emission reduction/absorption has been achieved, making of climate finance a result based mechanism.

The Clean Development Mechanism is the carbon credit standard approved by the United Nations as one of the flexible mechanisms of the Kyoto Protocol. It allows developed countries to buy Carbon Credits generated in developing countries to cover part of their mandatory emission reduction in a cost-effective way (based on the fact that GHG emissions have a global effect and does not matter where they occur). It also provides financial resources and sustainable technology transfer to developing countries. Primary demand for CDM credits the EU's Emissions Trading Scheme and from European governments.

Many entities (individuals, private and public organizations) acquire Carbon Credits to reduce their emissions even if they are not required. A voluntary Carbon Market has been developed to trade voluntary Carbon Credits (VERs). The most popular are the Gold Standard (GS) and the Voluntary Carbon Standards (VCS). Each standard, either for regulated or voluntary market, has a defined set of procedures and methodologies to quantify emission reduction and certify Carbon Credits which guarantee that GHG reductions have effectively happened and that Carbon Credits are sold only one time. The voluntary market is much smaller than compliance markets, with 101 million tons of CO_2 equivalent traded in 2012, versus a total of 10.7 billion $MtCO_2$ eq. traded in global carbon markets (Lambe et al. 2015). This difference is not so great in the efficient stove sector (Figure 13), since voluntary markets are particularly suitable for small-scale decentralized projects such as stove dissemination. Consequently, the volume of Carbon Credits from cooking stoves transacted in the voluntary carbon market in 2015 was 3.8 MtCO2eq, with a value of 15.2 M USD (Hamilton et al. 2013). Carbon Finance started to become incredibly popular in the stove sector in 2012, when the request of registration showed a rapid increase. Under the CDM registered stove projects per year increased from less than 15 in 2011 to more than 45 in 2012, with more than 250 project registered in 2016 («UNEP DTU CDM/JI Pipeline Analysis and Database» 2016).

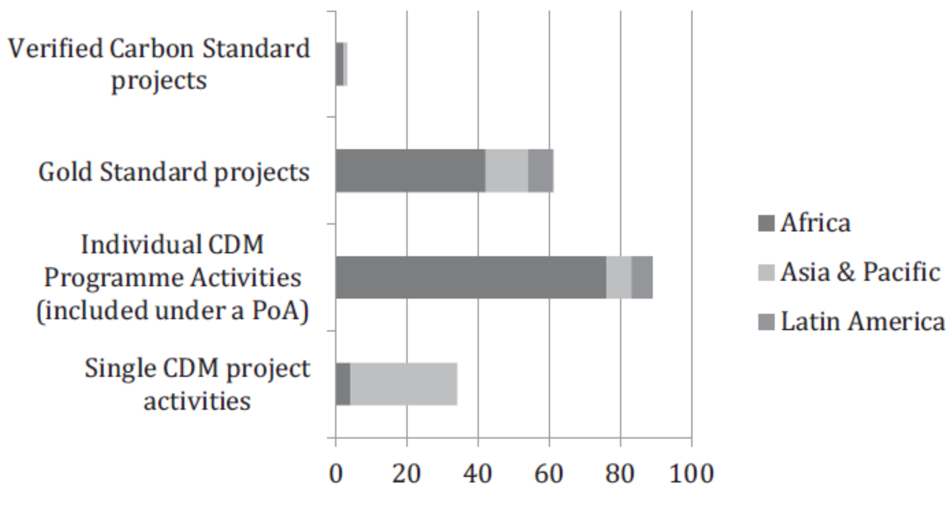


Figure 13: Total cookstove projects registered under carbon standards in early 2013 (Lambe et al. 2015).

These numbers suggest that Carbon Finance is perceived as a benefit for cooking stove projects in several ways:

- It attracts new players and encourages the development of the stove market (e.g.: international producers of high quality stoves) and makes available additional funds from private sector.
- It provides additional economic resources from Carbon Credits.
- It requires an extensive monitoring of the project which can help to assess the effectiveness of implemented strategies (e.g.: adoption rate, dissemination and marketing, stove durability) and eventually allows an ongoing correction.

1.7 Woodfuel consumption in Mozambique

Similarly to most of the Sub-Saharan African Countries, the majority of the population in Mozambique relies on the use of woodfuel to meet their primary energy needs.

The country is located in Southeast Africa bordered by the Indian Ocean to the east, Tanzania to the north, Malawi Zambia and Zimbabwe to the west, Swaziland and South Africa to the southwest (Figure 14). The country has an estimated population of 26.6 million people («The World Factbook — Central Intelligence Agency» 2016a). Mozambique is divided into 11 provinces and 129 districts. The capital city is Maputo (1.8 million ab. In 2008), located in the south.

Mozambique was a Portuguese colony. The country gained its independence in 1975 after ten years of independence war (1964-1974).

From 1977 to 1992 the country was devastated by a violent civil war which has left the country in a catastrophic social and economic situation.

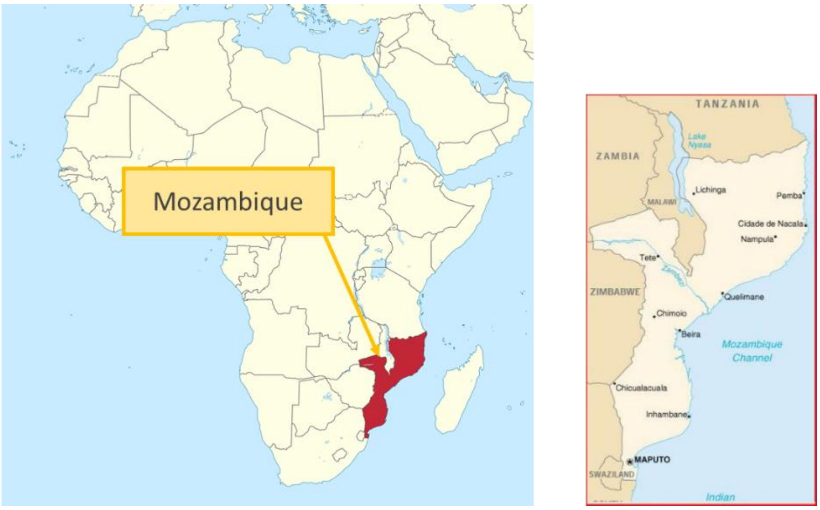


Figure 14:Mozambique Map

After the war, Mozambique had impressive economic growth rates (Figure 14). Despite the encouraging development progress made in recent years, poverty is still widespread and Mozambique is one of the world's poorest countries. Mozambique's Human Development Index for 2014 is 0.416, positioning it at 180 out of 188 («Human Development Reports» 2016). According to the World Bank data, the percentage of Mozambicans living below the national poverty line was 54% in 2008. Although this ratio decreased from 70% in 1997, 67% of population live with less than 1.90 US$/day («Poverty and Equity Database World DataBank» 2016).

In line with other developing countries, household energy production in Mozambique mainly relies on traditional biomass fuels (in the form of wood and charcoal). Access to other sources of energy is limited by low household incomes and electrification rate which is among the lowest in the world. National Grid serves only 36% of the country population, 27 % in rural areas («The World Factbook — Central Intelligence Agency» 2016b).

In Maputo, charcoal is used as cooking fuel by 75% of the population which is manly located in city slums. This is the general rule for all urban centres of the country. In rural communities, traditional biomass use (in the form of wood) covers up to 90% of energy needs (Brouwer e Falcão 2004).

Mozambique is one of the four African countries with large forested areas (Hosonuma et al. 2012) which are the main source of woodfuel and charcoal. Consequently, wood fuel harvesting represents one of the main drivers of deforestation and land degradation in the country. According to World Bank data, in the period 1990-2015 Mozambique lost 12% of its forests. Forest covered area has decreased from 55% of total country area in 1990 (433,780 km^2) to 48% in 2015 (379,400 km^2). The yearly average forest lost is around 2,175,500 ha («World Development Indicators - World DataBank» 2016). Woodfuel harvesting, particularly for charcoal production, is estimated to contribute up to 20% to biomass loss in the country (Ryan, Berry, e Joshi 2014). Charcoal consumption has been estimated around 5 billion tons/year, with 700.000 tons in the city of Maputo Alone (Falcão 2008). Charcoal is produced by artisanal methods resulting in a low production efficiency (around 6 kg of wood per kg of charcoal) and in a huge demand of wood. Hence, wood used in charcoal production comes mainly from not renewable and illegal harvesting and it is the main driver of land degradation in Mozambique and the second cause of deforestation after agriculture (Hosonuma et al. 2012). An analysis of charcoal supply chains in Maputo shows that production basins are constantly distancing from the city because of vegetation lost. In the late 1980s the vegetation was completely removed in an area of 60 km around the city. In 1993 forested areas were located within a radius of 60–100 km which increased to 150–200 km in 1997. Currently, Maputo is using charcoal and firewood produced in areas 600-km far from the city (Cuvilas, Jirjis, e Lucas 2010).

As previously underlined, deforestation and land degradation patterns show that the majority of woodfuels used in cooking activities come from not renewable harvesting. The loss of carbon stock in forested areas as a consequence of not renewable exploitation is a major source of greenhouse gas emissions. Although recent data on Mozambique GHG emissions are not available (the las national GHG inventory dates back to 1994), around half of the country emissions comes from deforestation and land degradation of which around 20% are from woodfuel harvesting («UNFCCC Greenhouse Gas Inventory Data - Detailed data by Party» 2016). Global warming contribution of woodfuel use in cooking activities is not limited to loss of biomass in forest areas. Inefficient charcoal production, which is a major source of Methane emissions, and inefficient combustion in traditional devices contribute to global warming.

In terms of health, the consequences of using inefficient cooking devices are severe health effects. In Mozambique, where the majority of population relies on the use of woodfuels in traditional inefficient devices, incidence of disease related to biomass burning pollution is estimated to be high, particularly among children and women. Biomass users show more respiratory disease and eye discomfort which are reasonably linked to the higher exposition to particulate matter and other pollutant (Ellegård 1997).

Provision of woodfuel is a relevant expense for households, both in terms of time and money. For many charcoal users, resources dedicated to fuel purchasing are a relevant part of their family budget. Mozambique is experimenting a continuous increase of charcoal prices, particularly in big urban areas, which is jeopardizing capacity of households to provide an adequate quantity of fuel for meeting their cooking needs. Prices are expected to rise further, following the increase in the demand and recession of supply basins.

1.8 Efficient Stoves in Mozambique

The dissemination of efficient cooking systems in Mozambique has the potential to significantly reduce the issues related to the use of woodfuel. Indeed, the high share of population relying on traditional biomass devices could create an important market for efficient cooking stoves. Benefits related to use of cooking devices could encourage clean development and access to energy at household level, meeting the millennium sustainable goals (Figure 15).

Goals 4/5/6 are related to indoor air quality improvement.

Goals 1/2 are related to a reduction in temporal and economical resources dedicated to fuel harvesting or acquisition.

Goal 8 is related to the development of an improved cook stove market (often trans/national).

Goal 7 is related to the reduction of pressure on forest areas and decrease of GHG emissions.

Figure 15: Millennium Development Sustainable Goals

Despite potential for improved stove dissemination, very few initiatives have been successfully developed in Mozambique. The main barriers to develop an organic strategy to substitute traditional cooking devises are the lack of funds and of a policy framework, particularly during the civil war. As underlined in paragraph 1.5, in order to scale up and spread stove activities, it is necessary to create a local self-sustained market, through incentives to prices, monitoring and a valid marketing and dissemination strategy which have to be sustained in time. All this is missing in Mozambique.

In the last decades, the success of stove projects in many African countries has been based on the contribution of "Climate Finance" as additional source of funding for encouraging and scaling up stove initiatives. In Mozambique potential of Carbon Finance has been poorly exploited. Despite the potential for Carbon Credits generation from clean cookstoves in the country, which is estimated between 8 and 12 million tons of CO_2 eq. (UNEP DTU PARTNERSHIP

2016), only recently several stove projects have been registered under voluntary and regulated carbon standards for Carbon Credits emissions to have access to Climate Finance.

This trend follows the general low appeal Mozambique has for Carbon Finance projects. However, the country has a huge potential for climate mitigation projects which aim to generate Carbon Credits, particularly in the sectors of forestry, energy efficiency and renewable energy.

Mozambique has just recently joined the Forest Carbon Partnership Facility (FCPF) to support a strategy to reduce GHG emission in the country and to facilitate the implementation of carbon projects. The FCPF is a World Bank Programme, founded with the support of governments and other entities, which aims at reducing emissions from deforestation and forest degradation, forest carbon stock conservation, the sustainable management of forests, and the enhancement of forest carbon stocks in developing countries (activities commonly referred to as REDD+). The FCPF is based on two funding mechanisms: the Readiness Fund, which supports countries in developing a REDD+ strategy and the Carbon Fund, a result based mechanism which will be used to buy Carbon Credits generated within REDD+ programmes.

At present, FCPF is assisting Mozambique in the preparation of its National REDD+ Strategy with its Readiness Found, which will be implemented from 2016. Dissemination of efficient cooking stoves are included in Mozambique REDD+ programme, since targeting woodfuel demand is one of the actions proposed to reduce deforestation and land degradation in the country. This could represent an important opportunity to develop a widespread programme for efficient cookstoves in the country. The readiness found can be used to finale pilot projects, implement a valid dissemination and marketing strategy and encourage creation of local markets and production. The Carbon Found can create a stable “market” for Carbon Credits, reducing uncertainties related to Carbon Finance and providing resources to support stove distribution for a period long enough to create a stable demand for efficient stoves.

To date, only three cookstoves programmes in the country are eligible to generate Carbon Credits thus make use of Carbon Finance as additional source of revenues. The Maputo Ethanol Cookstove project was the first to be registered in 2013 under the UNFCCC to generate credits for the regulated market. It was developed by Cleanstar Mozambique aiming to facilitate a transition from inefficient conventional non-renewable biomass stoves by disseminating up to 30,000 clean burning and highly efficient cooking stoves to households in the urban area of Maputo. The emission reduction expected during the project "crediting period" of 7 years was up to 270,000 tCO2. However, no credits have been yet issued from the project. Indeed, the UNFCCC project database shows that no issuance requests nor monitoring report have been summited and therefore it is not possible to verify the success of the project in terms of actual emission reduction, stove dissemination and benefits related to the project.

In late 2014, a collaboration between the Italian company CarbonSink Group (spinoff of the University of Florence), the NGO AVSI and with the financial support of Cloros, an efficient charcoal stove project was launched in Maputo. The project aimed to distribute around 5,000 Environfit CH2200 in the district of Chamanculo C and to generate Carbon Credits for the voluntary market. The project included 3 VPAs (micro scale Projects with a limit of 10,000 tons CO_2 eq emission reduction) and was registered in 2015 under the *Gold Standard Programme of Activities (PoA) "GS1247 Improved Kitchen Regimes Multi-Country PoA".* The first Carbon Credits were issued in 2015 with a second insurance in November 2016.

Figure 16: Environfit CH2200 Charcoal Stove

The project was intended as a pilot to establish efficient charcoal cookstove activities in Maputo. Furthermore, the collaboration between AVIS and CarbonSink led to the registration of the first CDM Programme of Activities (PoA) in Mozambique, which is currently the only Cookstove PoA registered in the country. The PoA was intended as an opportunity to scale up stove activities in the country and generate Carbon Credits for the regulated market. Currently, three CPAs (Component Programme of Activities) have been included in the programme, two in Maputo and one in Pemba. Distribution is currently ongoing and foresees around 14,000 stoves in Maputo and 6,500 in Pemba. Monitoring activities, to be submitted to the CDM, have been carried out in November 2016 while first credit issuance is expected in June 2017. The Nording Environment Finance Corporation (NEFCO) has signed an agreement with AVSI and CarbonSink to purchase the credits generated within the 3 CPAs. NEFCO is a company which invests in result based climate finance with the aim to provide Carbon Credits to its founders, the Nordic Governments, supporting them in meeting their emission reduction targets.

Other initiatives are currently under development in the country and are seeking for climate finance support to increase their chances of success and sustainability. However, nowadays only the beforementioned projects are known to the author as climate finance stove projects.

2 Subject of the Thesis

For many years, health and reduction of deforestation and land degradation have been the main drivers for improved cooking programmes. Recently, Climate Finance arose as a key resource to encourage distribution of efficient cooking devices, particularly in countries where their penetration has been limited. Moreover, Climate Finance could help to overcome economic barriers which have impeded the creation of markets for efficient stoves.

As previously underlined, Climate Finance is a result based mechanism, since issuance and commercialization of Carbon Credits is possible only after emission reduction has been monitored, assessed and certified by Carbon Standards. The detailed and constant monitoring of stove Carbon Projects gives access to data that has not been possible to obtain with such detail from previous projects. These amounts of data regarding social and environmental factors represent an opportunity to assess and compare the real benefits of these projects. Furthermore, they provide not only a measure of project success but also material to support policy makers and encourage project developers.

Field tests and surveys are critical to assess real impacts related to instruction of efficient stove such as fuel consumption, GHG and other pollutant emissions, fuel cost etc. However, laboratory tests are often necessary to have a clear picture on efficiency and emissions patterns of cooking technologies, since they are conducted in a controlled manner and provides data with low variability. The advantages of integration between field and laboratory data is particularly evident during the selection of the stove model to be adopted, which is a key "success factor", to achieve adequate levels of fuel reduction compared to the baseline situation (traditional stove). The stove has to be, efficient, durable, cheap and accepted by households. For instance, laboratory test on both traditional and improved stoves can provide essential data on cooking technologies efficiency that when integrated with field data on baseline fuel consumption they are fundamental to assess "Ex Ante" GHG reduction potential. Furthermore, they can provide a benchmark for fuel reduction potential during the project activities.

There is a flourishing literature on benefits related to efficient cooking technologies. Many studies evaluate potential emission reduction (GHG and other pollutants) based on laboratory analysis of different stove models and fuels. Many others provide analysis of field data on social or environmental benefits. However, at the knowledge of the writer, very few studies provide a comprehensive analysis of these benefits. Many studies are focused only on one particular benefit related to efficient stove, with predominance on health diseases and indoor air pollution. Many others are focused on either field or laboratory data.

This study follows the new approach in cookstove literature which aims to assess benefits related to efficient cookstove projects integrating laboratory and field data, assessing as well the entire woodfuel supply chain. Laboratory tests aim to provide an assessment of both traditional and improved stove efficiencies and emissions of GHG and other pollutants. Field tests provide real data on fuel consumption during baseline and project scenario, on efficient stove adoption and penetration among households, as well as on population perception of social and environmental benefits related to efficient cookstove usage.

Since stove projects analysed in this study have the primary target to reduce GHG emissions and generate Carbon Credits, the methodologies used to assess GHG emission reduction, which are issued by Carbon Standards and have to be followed in order to claim Carbon Credits sustenance, are developed with a conservative approach. Hence, not all the emissions caused by fuel harvesting, production and use are taken into consideration.

This study also provides a comparison of emission reduction calculated with these methodologies and an estimation of the whole potential emissions of wood supply chain not included in these methodologies.

Giving the potential to implement improved cooking programme in developing countries and the range of benefits related to these programmes, these aspects need to be carefully investigated, especially because they are highly dependent on location and technology used. In Mozambique, a country where economic and social conditions have limited the implementation of this type of projects, literature can provide essential information on developing technologies and their social penetration, which may help assure the success of new projects.

3 Materials and Methods

The work presented in this thesis is the result of a collaboration between GESAAF department of the University of Florence and CarbonSink, a spinoff of the same university which is specialized in the implementation of GHG mitigation projects. The research is focused on assessing the benefits related to two cookstove programmes located in Mozambique, for which GESAAF provides technical and scientific assistance to CarbonSink.

The first programme involves the distribution of the charcoal efficient stove CH 2200 by EnvironFit in Maputo and Pemba areas. The programme, as described in paragraph 1.8, was firstly conceived as a small pilot for the voluntary carbon market with the Gold Standard Foundation, implemented on field by the Italian NGO AVSI Foundation. Stove distribution lasted from January to May 2014 with 4,451 stove distributed in the neighbourhood of C Chamachulo C. The project was then scaled up and registered under the UNFCCC CDM Scheme for the regulated Carbon Market. Stove distribution started in January 2015 in Pemba and several neighbourhoods of Maputo (Figure 17) and is currently undergoing. The number of stoves to be distributed by summer 2017 are 20,000 with 5,499 stove already in use.

The second programme is part of the project "Strengthening of financial sustainability and biodiversity of Gilé National Reserve – Mozambique", founded by European Union EROPAID Programme. The project involves the distribution of 4,000 efficient wood stoves in the buffer area of the Gilè Natural Reserve. The Project developer is the Italian NGO COSV along with CarbonSink and the technical support of the University of Florence. It aims to reduce anthropic pressure on one of the last Natural Miombo forests in Mozambique. Furthermore, a study to assess charcoal consumption in Pebane, a urban centre nearby the reserve, has been included in the project since charcoal production is thought to be one of the main drivers of deforestation in the area. The project is in its starting phase. Assessment of wood and charcoal consumption was concluded in October 2016. Stove distribution is expected to start in 2017.

Figure 17: CDM Distribution Area Maputo

The collaboration between GESAAF and Carbon Sink aimed to assess stove efficiency (both traditional and improved stoves) in laboratory, design survey campaigns and collect on field data regarding fuel consumption and provide an assessment of potential benefits related to these projects. The result of this collaboration is the object of this thesis.

3.1 Laboratory assessment of cooking technologies

The stove testing laboratory (Figure 18) was designed to quantify emissions from stoves by collecting exhaust through a sampling hood. Furthermore, stove efficiencies where assessed by measuring the quantity of emissions and fuel necessary to complete a cooking tasks.

Figure 18: Sampling hood and gas analysis system

3.1.1 Sampling Hood

The hood collection method was chosen since it easily allows to dilute and cool stove exhausts with ambient air, which is necessary for measuring emission and reduce complexity of equation used in this study. The hood is placed on a case equipped with several shelves to adjust the distance between the top of the stove and the hood which have to be at least 1 meter to avoid interferences with combustion. Moreover, the cage reduces the possibility of exhaust dispersion in the environment. Details on hood design and dimensions are presented in Figure 19. The hood is collected to a centrifugal blower trough a duct which has a 13-cm diameter.

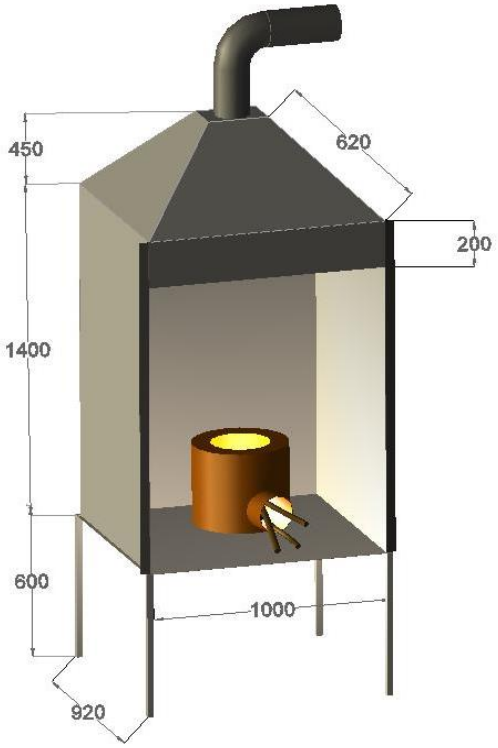


Figure 19: Sampling Hood

3.1.2 Sampling scheme

The laboratory was designed to measure emissions produced during combustion in cook stoves. The stove is placed under a hood which collects the emissions and air from the laboratory environment. The flow rate, temperature and pressure in the duct are measured with a hot wire anemometer (model Velocical Plus, figure 20 N°2). A fraction of the flow is sucked by a vacuum pump through the two sample ports to the sensors.

A computer is connected to the sensors to measure concentration of substances in real-time. Figure 20 shows a scheme of the sampling lines. The two sampling ports are located in the horizontal section of the duct. One is dedicated to particulate matter sampling from the exhaust flow while the other one is for collection of gaseous substances. Tubes are made in stale steel to avoid deposition of particulate and other substances. Furthermore, a series of mixing baffles have been placed at the beginning of the duct horizontal section to further avoid deposition of solid substances after the turn. The design of the baffles is presented in figure 21.

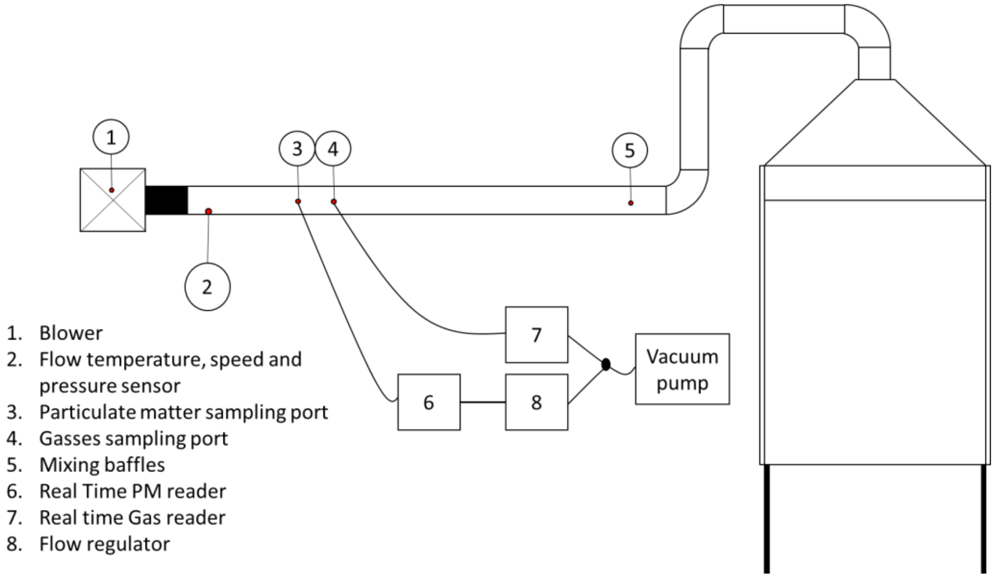


Figure 20: Sampling line scheme

Figure 21: Mixing Baffles

Sampling of any substances containing particles from a flow of gasses requires particular care. For instance, if the sampling velocity at the point of sampling is less than the fluid velocity, then all the particles, especially the smaller size particles, will not enter the sampling tube. If the velocity is more, then more particles will enter the tube. Ideally, the flow of the sample through the sampling probe should be at the same velocity and direction of flue gas at that point, the so called Isokinetic Sampling. Furthermore, to avoid interference of turbulence on sampling, good practice indicates that probe should be 8 duct-diameters downstream of the mixing baffles and 2 duct diameters upstream of the blower (Hinds 1982).

The sampling probe (Figure 22) was placed 1.50 meters downstream the mixing baffles and 0.5 meters upstream the blower. Sampling velocity is regulated to match exhaust one through a flow regulator placed between the probe and the vacuum pump. The following formula was used to set the flow regulator:

$$Q_s = V_e * \pi \left(\frac{d_s}{2}\right)^2 * \frac{60}{1000}$$

Where:

Q_s = Flow rate of sampling probe in l/m

V_e = Velocity of exhaust in the duct in m/s

d_s = Diameter of the nozzle at the end of the sampling probe in mm

The diameter of the nozzle is 6.5 mm.

Figure 22: Sampling probe for particulate matter

3.1.3 Sampling Sensors

The sensors used in this study target the following combustion substances:

Particulate Matter, Carbon Dioxide (CO_2), Methane (CH_4), Carbon Monoxide (CO), Volatile Organic Compounds (VOCs), Nitic Oxides (NO), Nitrogen Dioxide (NO_2). All the sensors are from Alphasense except Methane sensor which is from ClairAir.

Particulate Matter: As mentioned, particulate matter is sampled thought a separate sampling line. The sensor is placed in a airproof box connected to the probe upstream and to the flow regulator and the vacuum pump downstream. The sensor is an Alphasense OPC-N2 (Figure 23) which measures PM_1, $PM_{2.5}$ and PM_{10}. The OPC-N2 is optical particle counters which measures the light scattered by individual particles carried in a sample air stream through a laser beam. These measurements are used to determine the particle size (related to the intensity of light scattered via a calibration based on Mie scattering theory) and particle number concentration. Differently to other OPCs the N2 does not employ air-pumps or particulate filters to draw air to the sensor. Instead, it uses a micro fan to direct the sampling air to the scattering chamber, reducing maintenance. The sensor has an SPI output which is connected to an USB adapter and then to a PC to read data with the OPC-N2 software.

Figure 23: The OPC-N2 Particulate Matter Sensor

Carbon Dioxide: Carbon Dioxide sensor is a Not Dispersive Infrared sensor, models Alphasense IRC-A1. The sensor consists of an infrared source, optical cavity, dual channel detector and internal thermistor. The sensor as a measuring range which stamps from 0 to 5,000 ppm (Part per Million) of CO_2. The sensor comes with a supporting circuit for measuring the signals from the IRC-A1 sensor, converting and linearizing it into CO2 concentration and supplying an output as USB. The USB port is then connected to a PC to read CO_2 concentration in real-time. The USB port is also used to supply power to the sensor.

Electrochemical gas sensors: Carbon Monoxide, Nitic Oxides and Nitrogen Dioxide are electrochemical gas sensors from A4 (4-electrode) Alphasense Family. The sensor consists of an electrochemical cell that generates a current that is linearly proportional to volume of the target gas. The 4 electrodes have the following function:

- The working electrode responds to the target gas, either oxidising or reducing the gas, creating a current flow that is proportional to the gas concentration. This current must be supplied to the sensor through the counter electrode.
- The reference electrode is used by the potentiation circuit to maintain a fixed potential at the working electrode.

- The counter electrode completes the circuit with the working electrode, reducing some chemical species (normally oxygen) if the working electrode is oxidising, or oxidising if the working electrode is reducing the target gas.
- The Auxiliary electrode corrects for zero currents. It buried within the sensor and has the same catalyst structure as the working electrode. It is not in contact with the sampled gas and any background current arising from solid electrode processes or from electrochemistry involving the electrolyte will be measured on both the WE and the AE

Volatile Organic Compounds Sensor: The VOCs sensor is a PID-AH2 measure volatile organic compounds by photoionization detection (Figure 24). Test gas is presented to the membrane filter at the top of the photoionization cell and freely diffuses into and out of the underlying chamber formed by the filter, housing walls, and a UV lamp window. The lamp emits photons of high energy UV light, transmitted through the window. Photoionization occurs in the chamber when a photon is adsorbed by the molecule, generating two electrically charged ions. An electric field, generated between the cathode and anode electrodes, attracts ions. The resulting current, which is proportional to the concentration of the VOC, is measured and used to determine the gas concentration. PID is calibrated using isobutylene, all the others VOCs are reported to isobutylene eq.

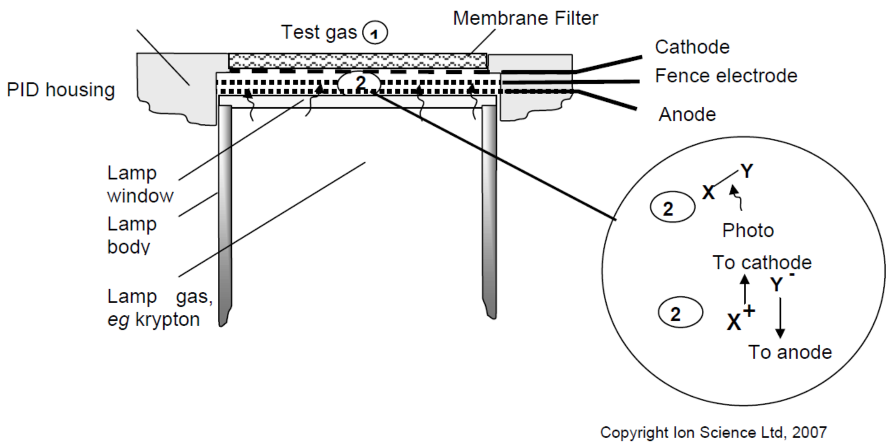


Figure 24: PID Sensor working scheme

Methane: Methane sensor is Clairair's standard non-dispersive infrared gas sensors which works similarly to CO_2 sensor. It is provided with a OEM 4-20mA transmitter that controls the sensor and provides a linear 4-20mA output. The sensor is calibrated measure methane in a range 0-5%.

The electrochemical and the PID sensor are mounted on a Alphasense AFE Board (Figure 25). The board is powered at 6.5 VDC and it provides two outputs for each of the three electrochemical sensors (Working and Auxiliary electrodes) and one output for the PID Sensor. Furthermore, the board has a PT1000 Platinum Resistance Temperature Detector (RTD), to read temperature in the sensor box. All output from AFE are buffered as DC signals.

Figure 25: AFE Board

Output from AFE Board and from OEM (after the OEM 4-20ma current is transform in voltage with a resistor) are converted to digital signal with a standard A/D 16-bit converter. The converter was then connected to an Arduino Micro and thought the Arduino USB output to the PC.

Since Arduino outputs for each of the red channels is in Volts, a software was designed to transform output into gas concentration. Thereafter, gas concentration was logged in to a CSV file. The following formula was used to calculate gas concertation for the 3 electrochemical sensor:

- $ppm_i = \frac{[(WE_i - WEz_i) - (AE_i - AEz_i)}{S_i}$

Where

ppm_i = Concentration in part per million of the Gas i

WE_i = Working Electrode reading for the gas i in mV

WEz_i = Working Electrode zero current for the gas i in mV

AE_i = Auxiliary Electrode reading for the gas i in mV

AEz_i = Auxiliary Electrode zero current for the gas i in mV

S_i = Sensitivity of the sensor i in mV/ppm

Values of Zero current and sensitivity are from Alphasense calibration sheet and are presented in the following table:

Table 3: Electrodes zero current and sensitivities for electrochemical sensors in mV

Sensor	**NO_2**	**CO**	**NO**
Working e. zero	391	396	313
Aux e. zero	396	316	311
Sensitivity	319	289	386

VOCs, Methane and PT1000 temperature readings are from a single channel. Following the formulas used to transform Voltage in gas concentration:

$$ppm_{voc} = \frac{(V_{pid} - V_z)}{S_{pid}}$$

Where

ppm_{voc}= VOCs concetration in ppm isobutylene eq.

V_{pid} = Voltage output prom PID channel

V_z = PID zero current (46.8 mV)

S_{pid} = PID sensitivity (47.9 mV/ppm)

$$ppm_{CH4} = \frac{V_{CH4}}{S_{CH4}}$$

Where

ppm_{CH4}= CH_4 concertation in ppm

V_{CH4} = Voltage output prom CH_4 channel

S_{CH4} = CH_4 sensitivity (13.9 mV/ppm)

$$T° = T°_{off} + \frac{(V_{pt1000} - V_{off})}{S_{PT1000}}$$

Where

$T°$= Temperature inside the sensor box in Celsius

T_{off} = Ambient Temperature in Celsius

V_{PT1000} = Voltage output from PT1000 channel

V_{off} = Voltage output at ambient temperature

S_{PT1000} = PT1000 sensitivity (1 mV/°C)

3.2 Stove Testing Protocol

The need for standardized protocols to test and compare stoves in laboratory controlled conditions was conceived in the early 1980s, when the first studies to assess performance of traditional and efficient stoves were developed. In 1985 Volunteers in Technical Assistance (VITA) provided the first guidelines for cookstove testing, called the Water Boling Test (WBT). The WBT is a standardized set of procedures that assesses stove performance while completing a cooking task (boiling and simmering water) to investigate the heat transfer and combustion efficiency of the stove. The last version of the WBT (4.2.3) was developed in 2009 with the contribution of The Global Alliance for Clean Cookstoves, an initiative of the UN Foundation, which aims to support adoption and spreading of efficient cookstove solution.

The (WBT) simulates a relatively simple cooking process: boiling and stimming a standard pot of water. The primary target of the WBT is to measure stove efficiency, hence how much of the combustion heat is transferred to the pot by a specific cooking device. WTB can provide useful information regarding stove specific fuel consumption and potential saving, technology assessment before field implementation and improvement of stove design. However, it is a standardized test protocol, designed to reduce variability in a controlled laboratory environment. Hence, it cannot be fully representative of the on-field condition and of the actual cooking habits.

The WBT consists of three phases:

- ***Cold-start high-power phase***: the test begins with the stove at room temperature and uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot.

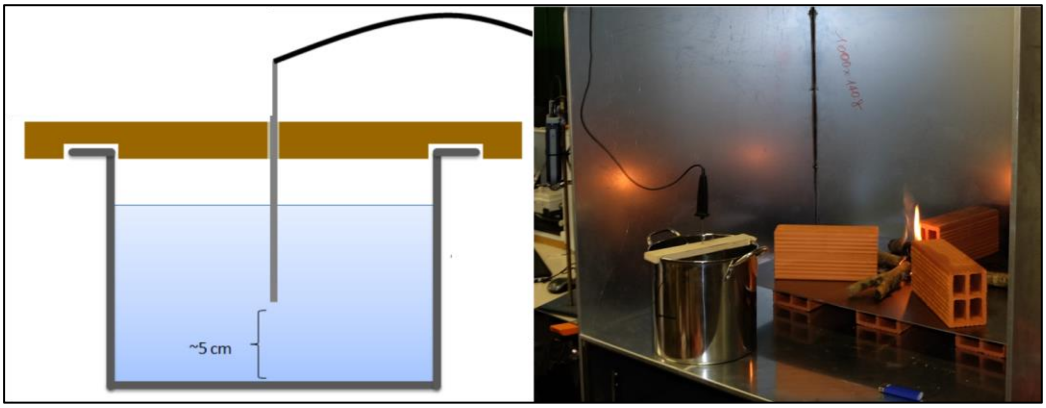
- The ***hot-start high-power phase*** is conducted after the first phase while the stove is still hot. Again, the tester uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot.
- The ***simmer phase*** provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

The hot-start high-power phase is necessary to identify differences in efficiency for stoves with high thermal mass (E.g. ceramic stoves). Preliminary tests showed that there are no differences for the stoves tested because of their limited thermal mass. Hence, this phase was omitted in this study since tested stoves do not have a relevant thermal mass. Each stove was tested three times to assess variability and reduce errors induced by the tester.

The pots used to conduct the WBT were a standard 8 l light aluminium pots which are similar to the one used in the project areas. Before the test the pot was filled with 5 litres of room temperature water. Empty and full pots where weighed before the test started.

Ambient condition (temperature, humidity and pressure) and background concentration of measured gasses were recorded as well.

A Deltahom HD2107.1 digital thermometer, provided with a PT100 probe was used to measure water temperature in the pot. The probe was placed in to the water 5cm over the pot bottom (Figure26).



The fuel bundles used in each phase the test were weighed (around 5 kg for wood and 1 kg for charcoal) along with lighting materials. The lighting material for wood consists of 150 grams of wood kindling plus two firelighter tabs (16 grams) made of wood and a paraffin. Charcoal was lighted only with the two firelighter tabs. Below a description of the testing procedure used for the C*old-start high-power and the simmer phase.*

C*old-start high-power phase* starts with the lighting procedure, which lasts five minutes. During this time, emissions were recorded with the pot off the stove. Once the fire caught, the pot was placed on the stove and the timer started and starting time recorded. The initial water temperature was recorded to confirm that it does not vary from ambient temperature. Water temperature, emissions, hood flows and temperature were continuously measured and registered on a CSV File. No lids were used during the tests, since this may increase the variability of the WBT results, making it harder to compare results from different tests.

Water was rapidly brought to boiling temperature (at a predetermined local boiling point). If necessary, fuel was added to keep the fire at a high burning rate.

When the water reached local boiling temperature (as shown by the digital thermometer) the following steps were done:

- Time and temperature were recorded

- For wood stoves: all wood from the stove was removed and flames extinguished (flames were extinguished by placing wood in a box saturated with CO_2). All charcoal unburned in the stove and at the end of the wood was placed in a separate container and weighed. The unburned wood removed from the stove together with the remaining wood from the bundle was weighed.
- For Charcoal stoves: The stove was weighed empty before test start and then again at the end of the cold start phase without removing the remaining charcoal.

Finally, the pot with the hot water was weighed.

The simmer phase starts rapidly after the high-power phase. It was designed to "test the ability of the stove to shift into a low power phase following a high-power phase in order to simmer water for 45 minutes using a minimal amount of fuel" (The WBT version 4.2.3)

Before placing the pot on the stove along with the hot water from the previous phase, water temperature and pot weigh were recorded.

For wood stoves, the unburned fuel was placed in the stove and lighting procedure was repeated as in the previous phase. When necessary, fuel was added from a second bundle of fuel.

For Charcoal stoves, the weight of the stove loaded with fuel remaining from the cold start high power phase was weighed. Hence, was not necessary to repeat the lighting procedure.

The lighting procedure used for steaming phase of wood stove is not representative of real cooking since fire is not extinguished and pots are usually left on the stove. However, when testing wood stove efficiency, it is necessary to weight wood and charcoal which have to be removed separately from the stove. This is not necessary for charcoal stoves. To make steaming phase similar to real cooking, kindling weight was not included in fuel consumption material and emissions were not recorded during lighting phase.

Furthermore, the pot was placed on the stove soon after the flame caught to avoid excessive temperature drop.

The timer was started soon after the pot was placed on the stove. The steaming phase requires 45 minutes. During this time the fire is maintained at a level that keeps the water temperature as close as possible to 3 degrees below the boiling point. The test is invalid if the temperature in the pot drops more than 6°C below the local boiling temperature.

After 45 minutes, water temperature, weight of the pot and fuel used were measured following the procedure described in the previous phase. At this point the test was over and real time emission registration interrupted.

3.3 Stove Tested

Few pre-tests were performed on each type of stove, as indicated in the WBT protocol to become used to stove characteristics. Each stove was then tested three times to assess variance induced by tester or ambient conditions (such as humidity and temperature).

Laboratory tests were conducted on the cooking technology used in the project areas. For each project, both traditional stoves (or baseline stove) and efficient stoves (project stove) were assessed.

Maputo/Pemba Project stoves

Up to 95% of families in urban areas of Maputo and Pemba rely on inefficient traditional charcoal stoves for cooking their food (Figure 26) (Brouwer e Falcão 2004). The model tested was a single fire stove.

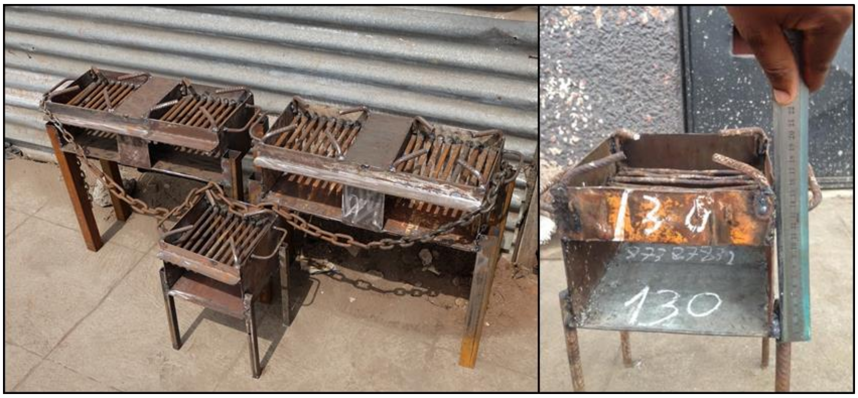


Figure 26: Traditional charcoal stove (one and two fire models)

The efficient cook stoves model distributed in the project areas is an Envirofit CH-2200 Charcoal cook stove (Figure 16). The iron combustion chamber is insulated for the outlet protection layer with rock wool which avoids lateral heat dispersion. Air flows to the charcoal through a regulable air inlet placed in the bottom of the stove.

Gilè project

The Gilè project is under development in the buffer area of Gilè natural reserve. The cooking system used by the majority of the households is the three-stone fire. This cooking system, which is and the most basic and popular one in Sub-Sharan rural areas, has been replaced in laboratory with 3 bricks. The project aims to substitute this inefficient cooking system with The Rocket Works Zama wood stove, starting in spring 2017. The stove is designed to be portable, small and durable and it is made of high quality, heat resistant stainless steel. This stove was tested and compared to the baseline stove (3 stone) to assess potential emission reduction and fuel saving (Figure 27).

Figure 27: Three stone and rocket works cooking systems

3.4 Stove metrics

The metrics measured to characterize stoves during laboratory tests can be summarized in three categories:

- *Stove characteristics*
- *Efficiency and performance measures*
- *Emission measures*

These measures are the most common used to assess and compare stoves. Following a brief description of metrics for each category. The majority of these metrics are described in the WBP protocol.

1. Stove characteristics

- *Burning Rate:* A measure of the average grams of wood burned per minute during the test. This shows which stove consumes more fuel.
- *Firepower:* Firepower is a measure of how quickly fuel was burning, reported in Watts (Joules per second).

2. Efficiency

- *Time to Boil* – The time it takes for the pot to reach boiling temperature from the starting temperature.

- *Thermal Efficiency* – Thermal efficiency is a measure of the fraction of heat produced by the fuel that is directly transferred to the water in the pot. The remaining energy is lost in the environment. In this way, a higher thermal efficiency indicates a greater ability to transfer the heat to the pot.

- *Specific Fuel Consumption* – This is a measure of the amount of fuel required to boil (or simmer) 1 litre of water. It is calculated by the equivalent dry fuel used minus the energy in the remaining charcoal, divided by the litres of water remaining at the end of the test.

3. Emission metrics

- Emission metrics regards emissions of all pollutant recorded during the test phases. Gasses are reported both as concentration (ppm) and also as mass on an equivalent dry basis.

- *Average Concentration* – This metrics measures average concentration of a gas (ppm) during cold start, seaming phases and the whole test.

- *Emissions per MJ of fuel burned* –This metric reports the Emission Factor per MJ of fuel burned.

- *Emissions per task and total emissions* – total emissions (in grams) during a single phase and during the whole test.

- *Emissions per weight of fuel burned* – This is also reported although this metrics is highly dependent on fuel characteristics, and therefore there is less comparability between different stoves.

3.4.1 Preliminary measurements

Local Boiling Point. The local boiling point is the temperature at which the water pressure equals the atmospheric pressure. Once reached the boiling point water temperature no longer rises and water evaporates. At 1 bar (e seal level pressure) water boils at 100 °C. However, this temperature is variable.

To determinate local boiling point in the laboratory, an empiric method was used, placing the pot with 5 litres of water on a gas stove. Water temperature was bringing to boil condition (visually checked) and the thermos-probe was placed in to the water. Water temperatures were logged for 10 minutes (logging time 1 second) and recorded values averaged, since water temperature oscillates around boiling point during the process.

3.4.2 Fuel selection and characteristics

Because of logistic constraints it was not possible to transport a large amount of fuel from the project areas. Charcoal used in Maputo and Pemba is usually produced with hard wood from Miombo tropical dry forests and occasionally from mangroves. However, fuel used in laboratory tests was selected to be as similar as possible to fuels used in the project areas. In order to do so, a comparison of humidity and heating values was made between a small sample of charcoal brought from Maputo and one that is commonly used in Italy.

Wood used in Gilè also comes from Miombo forests. In this case, the most similar species in Italy is the "Fraxinus ornus" and it is easily found in Florence. Sampled wood was small round sticks with a diameter between 2 and 4 centimetres.

Fuel was tested for moisture content and calorific value. Calorific Value was measured with a semi-automated bomb calorimeter (model IKA C200) which provides indications of the **Higher Heating Value (HHV)** of the fuel samples. HHV is the amount of heat released by a fuel once it is combusted and the products have returned to ambient temperature of 25°C, which takes into account the latent heat of vaporization of water in the combustion products. Before performing the tests with the calorimeter, the fuel was oven dried since fuel humidity would have reduced HHV (part of the heat would have been used to evaporate humidity). Three samples were tested for each fuel and then averaged to calculate the HHV.

The Lower heating value (LHV) was derived from the HHV. It is the energy that can be extracted from the combustion of the fuel (dried) if combustion products are cooled but the water produced by the reaction of fuel hydrogen with water stays in the gas phase and its latent heat is not extracted. The WBT indicates that for wood fuels (charcoal and wood), vapour latent heat is around 1.32 MJ/kg which is the difference between LHW and HHV. This value has been calculated as follows: 6% off wood dry mass is hydrogen (60 g) which reacts to form 540 g of water whose latent heat of vaporization is roughly 1.32 MJ (since vapor latent heat of water is 2.5 MJ/kg).

The fuel moisture content (MC) measures the quantity of water contained in the fuel. In charcoal this quantity is be very low (around 1-2%) while fresh wood may contain more than 50% water mass (wet basis). In this work the fuel moisture content is accounted as percentage of the wet mass of the wood. Moisture content of fuels were calculated in the following way: three small samples (300 grams for wood 100 grams for charcoal) were randomly selected from the fuel supplies. The samples were weighed and then placed in an oven at 103 °C. Samples were left in the oven for 10 hours and then weighed every two hours until the mass stopped decreasing. At this point it can be assumed that all the water in the fuel evaporates and the weight of the dry fuel is recorded. Moisture content is then calculated with the following formula:

$$MC = \frac{m_{fuel,wet} - m_{fuel,dry}}{m_{fuel,wet}}$$

3.4.3 Parameters which are calculated during the tests

Equivalent Dry fuel consumed is the amount of dry fuel that was burned which accounts for the energy that was needed to remove the moisture in the fuel. For wood fuels, it also accounts for the amount of charcoal remaining unburned and removed from the stove at the end of the test. It was calculated as follows:

$$f_{cd} = f_{dry} - f_{H2O} - f_{char}$$

Where f_{dry} is the dry fuel consumed, calculated as follows

$f_{dry} = f_{cm}(1 - MC)$ and f_{cm} is the wet fuel consumed during the test.

$\boldsymbol{f_{H2O}}$ is the fraction of fuel needed to evaporate the water contained in wet fuel and it is equal to the mass of water in fuel multiplied by change in enthalpy of water, divided by the LHV of the fuel. It is calculated as follows:

$$f_{H2O} = \frac{\Delta E_{H2O}}{LHV}$$

Where

$$\Delta E_{H2O,} = m_{H2O}(C_p(T_b - T_{fuel}) + \Delta h_{H2O})$$

and

$m_{H2O} = f_{cm} * MC$

C_p = The specific heat capacity of liquid water (4.2 kJ/kg*k)

Δh_{H2O}= The specific enthalpy of vaporization (2,260 kJ/kg)

T_b = Local boiling point and T_{fuel} is temperature of fuel which can be assumed equal to ambient temperature.

$\boldsymbol{f_{char}}$ is the energy of the char which remains unburned at the end of the test. It is calculated only in case wood fuel is used and it is equal to the mass of the char multiplied by the char LHV and then divided by the fuel LHV of the wood therefore:

$$f_{char} = \frac{m_{char} * LHV_{char}}{LHV}$$

The heating value of the char is assumed to be 29.800 MJ/kg (IPCC 2006).

Thermal efficiency is a ratio of the energy released by the fuel used to heat and evaporate the water. It is the most relevant indicator used to define stove characteristics and fuel consumption during high power phase. When comparing thermal efficiency of baseline and project stove it is possible to define potential fuel saving. It is calculated as follows:

$$h_c = \frac{\Delta E_{H2O,heat} + \Delta E_{H2O,ev}}{E_{relased}}$$

Where $\Delta E_{H2O,heat}$ is the energy required to heat the water which is calculated as the mass of water times specific heat capacity times change in temperature:

$$\Delta E_{H2O,heat} = m_{H2O} * C_p * \Delta T$$

The mass of the water is calculated as the weight of the pot with water minus the weight of the empty pot at the beginning of the test

$\Delta E_{H2O,ev}$ is the energy needed to evaporate the water and it is equal to the mass of water evaporated multiplied by the specific enthalpy of water:

$$\Delta E_{H2O,ev} = w_{cv} * \Delta h_{H2O}$$

w_{cv} is the quantity of water which evaporates and it is calculated as the difference of the water in the pot at the beginning and at the end of the test.

Low Power Specific Fuel Consumption is the energy consumed per litre of water simmered per minute. This metric is used to assess the efficiency of the stove during steaming phase. According to the WBT, efficiency should not be used to assess the amount of energy used during steaming phase. Stimming phase reflects the ability of the stove to keep water at stand temperature close to the boiling point using a minimum amount of fuel and does not reward steam generation. Thermal efficiency positively accounts for the generation of steam; therefore, it is not a good indicator for this phase. Instead, The Low Power Specific Fuel Consumption could be used to evaluate low power stove performance. It is calculated as the amount of equivalent dry fuel consumed time the LHV of the fuel, normalized for the mass of water at the end of the phase and the steaming time.

$$SC_{lp} = \frac{f_{sd} * LHV}{w_{sr} * \Delta t_s * 1000}$$

Where w_{sr} is the amount of water at the end of the test and Δt_s is the steaming time in minutes.

Burning Rate measures the amount of fuel burned per minute and it is measured by dividing the amount of dry fuel burned by the time required to complete the phase.

Firepower is the fuel energy consumed to boil/steam the water divided by the time to boil/steam. It tells the average power output of the stove (in Watts) and it is calculated as follows:

$$FP = \frac{f_{cd} * LHV}{\Delta t_c * 60}$$

3.4.4 Emission Metrics

All the gasses measured in laboratory tests are expressed in part per million (ppm). This is a dimensionless unit which evaluates the concentration of targeted gases in exhaust flow. Emission analysis performed in this study uses both concentration (eg: average ppm concentration per phase) and mass metrics (eg: g per MJ of fuel). To calculate mass metrics, it is necessary to transform gas concentration to dry mass using the ideal gas law. This step was not necessary for particulate matter emission metrics since they are already recorded in µg/m^3.

Average Concentration was calculated by averaging real time measures which were logged every 1 second.

To calculate dry mass from concentration in ppm the following formula, derived from the ideal gas law, was used:

Total Emissions is the total amount of gas/substance emitted during the test. It is calculated as the average concentration transformed in dry mass for each phase. To calculate dry mass from concentration a formula derived from the ideal gas law was used:

$$C_i\left[\frac{g}{m^3}\right] = \frac{C_{i,ppm} * MW_i * P_{atm} * 10^{-6}}{R * (T_d + 273.15)}$$

Where $C_{i,ppm}$ is the concentration of the gas calculated as the difference between average concentration measured and background concentration in ppm, MW_i is the molecular weight of the gas I and P_{atm} is the atmospheric pressure in kPa. R is the gas constant value (which is equal to 0.00831 kPa*m^3/mol*k) and T_d is the average exhaust temperature.

The total emission for the gas is then calculated as follows:

$$TE_i = C_i\left[\frac{g}{m^3}\right] * V_{tot}$$

Where V_{tot} is the total exhaust flow during the test.

Emissions per task are calculated from the previous formula substituting the flow of each phase to total flow.

Emissions per MJ of fuel burned are emissions in mass reported to one MJ (on a net calorific base). This metric is calculated both for high power and steaming phase. When it refers to the entire WBT it represents the Emission Factor for a gas for a given cooking technology and fuel. It is calculated as follows

$$EF_i = \frac{TE_i}{f_{cd}LHV}$$

3.4.5 Comparison between the stoves and statistical analysis

As previously underlined, three full Water Boling Tests have been performed for each stove. This is necessary to assess variability induced by tester or ambient conditions. The performance metrics presented in this study are the average of the three test results. Furthermore, for each indicator the Standard Deviation and Coefficient of Variation are presented.

Traditional stoves and improved stoves were compared to assess differences in fuel consumption and pollutant emissions. This analysis was performed comparing the metrics of the stoves, evaluating differences and performing a t-student test. To conclude the stove metric comparison, all the four-stove analysed where compared to analyse which stove has better performance for each indicator.

3.5 Field data collection

Laboratory tests are a simplification of cooking tasks and they cannot be fully representative of real cooking conditions. In order to evaluate benefits related to efficient stoves, it is necessary to collect field data to verify how traditional and improved cookstoves work under real conditions.

The most important indicator of on-field stove performance regards the assessment of fuel consumption both in a baseline situation and periodically during project scenario. This assessment is particularly important for projects which claim Carbon Credits issuance, since the real differences between baseline and project fuel consumption (fuel savings) are the starting point to calculate GHG emission reductions and are generally required by carbon standards.

Although necessary, field data provides a full picture of cookstove project benefits only when integrated and compared with laboratory metrics. This is because the collection of data on field, particularly regarding emission factors is often difficult because of technology and variability constraints.

3.5.1 Maputo and Pemba programme field data collection

The Maputo and Pemba cookstove programme started in early 2014. Since the programme aims to request Carbon Credits for both the regulated and the voluntary market, a monitoring campaign was programmed to assess both, baseline and project field situation. The monitoring campaign consists in a quantitative and a qualitative survey for both baseline and project scenario.

The first qualitative survey was conducted in the project area in 2013. It was designed to assess traditional cooking technologies used and to assess the cooking habits of 537 families. Households were asked to provide information about:

- Main type of cooking stove used
- Localization of cooking devices (outdoor-indoor)
- Number of household members
- Daily use of the cooking stove (Frequency)
- Average expense per household for the purchase of charcoal (Meticais)

In 2015 and 2016 two further qualitative surveys were conducted. The main goal was to assess the usage rate of project stove and therefore calculate drop off rates, assuming that a certain number of end users fall back to the baseline technology. In 2015 the usage survey was conducted only on the pilot Gold Standard Project (sample size was 100 households located within the project area) while in 2016 two usage surveys were necessary. This is because the different vintage of the stoves distributed and therefore the necessity to calculate different drop off rates. Furthermore, during the usage surveys, households were asked to respond to some questions related to health effect of cooking activities. An example of the usage survey is presented in ANNEX I. Furthermore, during 2014 and 2015 a market research on charcoal and stove prices was conducted among 90 charcoal and 5 stove vendors. Each vendor was asked to indicate the most common charcoal quantities ("bundles") they are selling. After this, six samples for each indicated quantity were measured. For example, if the vendor sells charcoal usually in bags which cost either 10 or 20 Mozambican Metical (MZM), then totally six samples for the bags of 10 MZM and totally six samples for the bags of 20 MZM were measured. Later, the mean of the six measurements were calculated to find out the mean correlation between the price and the kilograms separately for each quantity the specific vendor is selling.

Project and baseline KPT.

The Kitchen Performance Test (KPT), similarly to the WBT, was developed by the alliance for clean cookstoves to provide a standardized procedure to assess fuel consumption in baseline and project scenarios on the field. The KTP is the most reliable test to measure daily fuel consumption and potential saving due to the use of improved stoves but it is also difficult to perform since it implies intrusion in private life.

The protocol used in this study focuses on the household level instead of stove level. This is because some households were provided with more than one stove.

The KPT was conducted by local surveyors trained and managed by the GIZ-EDEV programme. The KPT can be done in two ways: testing the same family using the traditional stove and after a period of 3-6 month of improved stove use or (paired-sample) or testing families which use traditional stove and another group of family which use improved stove (cross-sectional).

Data for this study come from a cross-sectional KPT survey. This is because of the particular condition on the field. For instance, families often move their residence or address or change their willingness to participate to a second KPT. Furthermore, a cross sectional study allows to assess families during long periods of time (E.g.: second year KPT).

For baseline survey and KPT, families where randomly selected within the project area. For project KPTs and surveys household were selected from the stove database which includes all the participants to the project. The database includes:

- Household ID number
- Selling date
- Model of the stove
- Unique Stove ID
- The total number of stoves installed per household
- Name, address and telephone number of all stove end users where possible
- GPS location of the end user's household where possible
- Mode of use: commercial/domestic

This information has been collected in paper format and entered to the electronic database by AVSI Foundation. The sample size for the baseline survey was 90 households and 35 for the 2015 and 2016 KPT (gold standard project). For the CDM project KPT, sample size was 53 families.

The KPT measures fuel consumption for over three full days, requiring daily household visits for four days. The fuel used by each household was weighed every day. A short introduction survey was administered to gather the basic data of each household and to instruct the participants not to modify their typical cooking habits. A short survey was done every day to record information about stove/fuel usage, the number and type of meals prepared, the number of people for which the meals were prepared.

In addition to fuel consumption (Kg/hh/day), also Kg of fuel per standard adult (STA) were defined. Standard adults can be calculated in this way:

Table 4:Table 4: "Standard adult" equivalence factors, FAO Guidelines for fuel consumption surveys.

Gender and age	Fraction of standard adult
Child: 0-14 years	0.5
Female: over 14 years	0.8
Male: 15-59 years	1
Male: over 59 years	0.8

To encourage participation of the families to the KPT, a reward was offered. Furthermore, during the first day the families where provided with a bunch of pre-weighed fuel (around 9kg) to avoid that additional unweight charcoal was bought and used.

Average charcoal consumption per each household was calculated averaging fuel consumption during the three-day test. Outliers were eliminated from the daily measurement and later on from the family averages. The daily charcoal consumption per household is the average value of mean consumption for each family. The following formula was used to estimate if the sample size was adequate for a required confidence interval of 90/10:

$$n \geq \left(\frac{S_y}{\bar{y}} * \frac{t_{0.90,\mathrm{n}-1}}{0.1}\right)^2$$

Where S_y and $\bar{y}$ are the standard deviation and the mean of the sample, $t_{0.90,\mathrm{n}-1}$ is the critical value for the t Student distribution and 0.1 is the required precision.

Fuel reduction is then caudated as the difference between the baseline and the projects daily fuel consumption per household as measured in the KPTs.

To verify if the means difference was significate with a 90-confidence interval a t test was performed on the two samples (baseline and project KPT data).

3.5.2 Gilè Programme field data collection

The Gilè cookstove programme started in March 2016. In October 2016, the first assessment of the baseline situation was concluded. This baseline monitoring aimed to evaluate cooking technologies used, cooking habits, fuel consumption and fuel harvesting techniques and distances. The baseline survey was conducted within a sample of 120 families randomly selected in the project area (Figure 28).

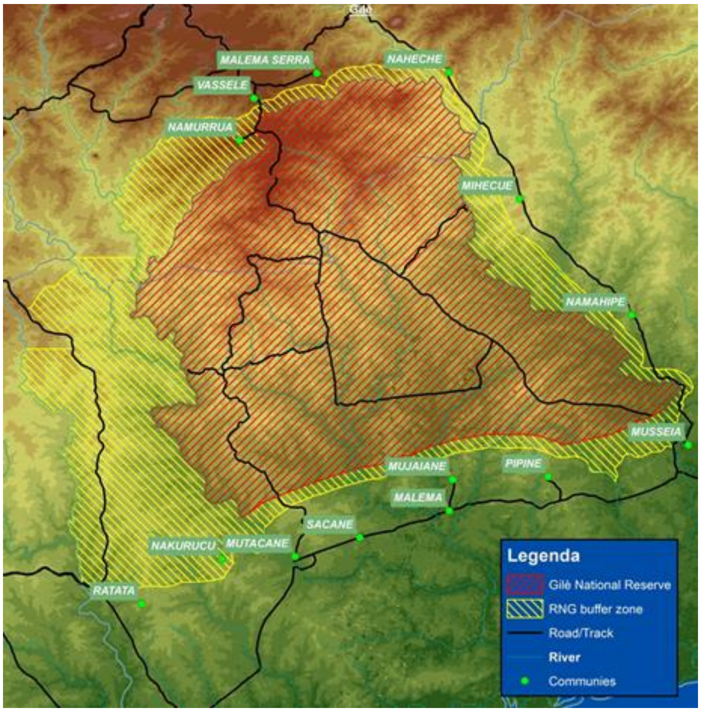


Figure 28: Gilè project area

The survey was digitalized and data automatically saved in to an online database. This reduced collection errors and allowed a real-time control of collected information. Furthermore, the use of the tablet allows to Geo-referencing households with the on-board GPS sensor. A scale was used to assess daily fuel consumption with the following procedure: when present during the interview, fuel bundles where weighed and the households were asked to estimate for how long the bundle would have lasted.

Additionally, five households were asked to participate in a three-day fuel consumption assessment. Results were then used to assess consistency of the baseline survey responses since they may include errors of fuel consumption calculation related to subjective evaluation of the households on fuel bundle duration.

As we mentioned before, during baseline survey a survey campaign was conducted also in the urban area of Pebane, which is one of the administrative centre close to the project area. Differently to Maputo, Pebane surrounding areas are reach in wood resources, therefore it is logically to suppose that not all households use charcoal. The main goal of the survey was to identify the share of household using wood and areas where it is more popular than charcoal. Furthermore, 10 families using charcoal were involved in a three-day fuel assessment to evaluate differences respect to Maputo on consumption and charcoal price and provide a first set of data useful to plan and develop future cookstove projects within the REDD+ pilot programme.

3.6 Assessment of Benefits Related to the Projects

The benefit related to the programmes analysed in this study regard reduction of greenhouse gas emission, health damaging pollutants, pressure on forested areas (Deforestation and land degradation) and economic expenses dedicated to fuel purchase.

3.6.1 GHG Emission reduction calculation Maputo/Pemba

As previously underlined, the programme was registered under voluntary and regulated Carbon Standard. This implies that a methodology recognised by the standards was used to assess emission reduction and claim Carbon Credits insurance. The following formula was used to calculate emission reduction due to project activity in a given year (or monitoring period)

$$ER_y = N_{p,y} * U_{p,y} * P_{p,b,y} * NCV_{b,\,fuel} * (f_{NRB,b,y} * (EF_{fuel,\,CO2} + EF_{fuel,\,nonCO2}))$$

$N_{p,y}$ is the cumulative number of days a family was included in the database for the monitored period. The number of families instead of the number of stoves is used because KPT was conducted on a family basis (some families bought more than one stove). $U_{p,y}$ is the usage rate, as calculated through the usage survey. $P_{p,b,y}$ is the amount of fuel saved fuel calculated as per difference before baseline and project KPT average fuel consumption.

$NCV_{b, fuel,}$ is the Net calorific value of the fuel (in case of dry fuel it is equal to the LHV).

$f_{NRB,b, y}$ is the fraction of biomass that can be established as non-renewable biomass. In this case a default country specific value of 0.91, available on the CDM website, was used («CDM: Default values of fraction of non-renewable biomass» 2017).

$EF_{fuel, CO2} + EF_{fuel, nonCO2}$ are the emission factors (tCO2/TJ) for the fuel. The case of charcoal emission factors is particularly complicated since they should include emission arising all along the charcoal supply chain (forest cutting, charcoal production and combustion) which are often difficult to calculate. Therefore, the methodology allows to use the following simplification: use a conservative wood to charcoal production ratio (from IPCC) and multiply this value by the pertinent EF for wood. The charcoal production ration used is 6 while the emission factor for wood where: for CH_4: 0,3 tCO2eq/TJ and for N_2O: 0,004 tCO2eq/TJ and for CO_2 112 tCO2/TJ. The NCV used for wood is 0.015 TJ/ton (IPCC 2006).

This methodology risks to underestimate GHG emission produced during charcoal life cycle, (e.g. methane emitted during wood carbonization process). This study tries to provide an alternative method to estimate emission reduction per household where these emissions are included. Transports are not included since distances between reduction areas and final consumers are difficult to estimate. The following formula was used to assess emission reduction along the supply chain:

$$ER_{hh} = ER_{com} + ER_{char} + ER_{c,loss}$$

Where ER_{com} is the emission reduction achieved during combustion phase and it is calculated as follows:

$$ER_{hh} = (f_b * NCV * (EF_{CO2,b} + EF_{CH4,b} + EF_{N2O,b})) - (f_p * NCV * (EF_{CO2,p} + EF_{CH4,p} + EF_{N2O,p}))$$

Where f_b and f_p are fuel consumption during baseline and project scenario, NCV is the net calorific value of Charcoal, while fuel emission factors for methane and Carbon dioxide are from laboratory tests for baseline and project technology while N_2O EF is from IPCC (emission factor are reported in CO_2 eq.).

ER_{char} is the emission factor for charcoal production and it is calculated as follows:

$$ER_{char} = (f_b - f_p) * NCV * (EF_{CO2,c} + EF_{CH4,c} + EF_{N2O,c})$$

EF for CH_2 and N_2O for charcoal production are derived from literature values (Pennise et al. 2001). EF for CO_2 is calculated as the difference between the carbon content of wood used in the production process and the carbon content of charcoal output minus the carbon emitted as methane. Charcoalcarbon content is 75% (Pennise et al. 2001).

$ER_{c,loss}$ are the emission caused by the loss of carbon in residual biomass which is left in forest after wood harvesting. Indeed, not all wood is used for charcoal production. Brunches and leaves are left to decay in the forest and therefore their carbon content is transformed in CO_2. It is calculated as follows:

$$ER_{c,loss} = (f_b - f_p) * \rho_{char} * (1 - BEF) * w_{cc} * \frac{44}{12}$$

Where ρ_{char} is the wood to charcoal production ratio , BEF is the biomass expansion ratio used to calculate brunches and leaves not used to produce charcoal and is 1.22 meaning that for each kg of wood collected 0.22 kg of wood are left in the forest. w_{cc} is the wood carbon content which is 0.47 (IPCC, 2007).

This study also reports possible emission arising from loss of carbon contained in belowground biomass. These emissions are reported separately since it is difficult to estimate if all the carbon is transformed in CO_2 or in other substances (e.g. soil organic carbon). Potential emission from belowground biomasses is calculated according IPCC default root to shoot ratio of 0.28 for tropical dry forests.

3.6.2 Calculation of ex ante GHG emission reduction

Assessing emission reduction before project activities have been implemented is fundamental for two reasons:

- It provides an estimation of potential GHG emission reduction achievable with a given efficient stove
- Estimates volumes of Carbon Credits which the project can generate and therefore potential incomes from Carbon Finance
- It provides benchmarks for GHG emission reduction to be used during project activities

The methodology used to assess ex ante emission reduction is based on baseline fuel consumption and the difference in thermal efficiency between the baseline and the project cooking technology. The following formula has been used to calculate ex ante emission reduction:

$$ER_y = N_{p,y} * \left(P_b - {}^{\mu_{hold}}/_{\mu_{new} * P_b}\right) / NCV_{b,\,fuel} * (f_{NRB,b,\,y} * EF_{fuel,\,CO2} + EF_{fuel,\,nonCO2})$$

Where μ_{hold} and μ_{new} are the thermal efficiencies respectively of the baseline and the project stove as calculated in laboratory tests. P_p is the fuel consumption in the baseline scenario. A default value of 1% efficiency lost per year is used for μ_{new} . This formula has been used to assess ex ant emission reduction for both Maputo/Pemba and Gilè programme.

The Gilè project aims to be registered with the Gold Standard, similarly to the Maputo Pilot project. For projects developed in rural contests where the baseline fuel is wood, the GS allows to use a simplified methodology to asses GHG emission reduction (ER). This methodology is based on the Ex ante ER formula. Compared to the standard methodology (used in Maputo), the KTP project fuel consumption is not mandatory. Furthermore, to quantify baseline fuel consumption, default values can be used. Only the survey usage is mandatory to assess baseline fuel and technology used. Often default values underestimate real fuel consumption, therefore they will be compared to results from the baseline survey and, in the case differences are relevant, an extensive KPT will be performed to certify baseline fuel consumption.

Calculation ex ante emission reduction for households using charcoal were also performed for Pebane urban area. Results were presented in terms of potential emission reduction per family, under the assumption that the project technology was the same as the one used in Maputo.

NB: Emission reduction of the entire project refers to a period of 7 years which is equal to the maximum crediting period allowed by Carbon Standards.

3.6.3 Calculation of other climate pollutant emission reduction

As mentioned before, products of incomplete combustion such as VOCs, Carbon Monoxide, Black and Organic Carbon have the potential to contribute to Global Warming. The use of improved cooking devices reduces these emissions thanks to improved efficiency. Following a conservative approach, ER of PICs are reported separately in this study. This is because the GWP value associated with these substance is variable and highly uncertain. This depends on the indirect effect some of these pollutants have on climate, which leads to the formation of other GHGs influencing atmosphere chemistry, or their regional and not global effect or they short lifetime in the atmosphere.

ER of these substances reported in this study is calculated with the following formula. GWPs are form Table 1.

$$ER_{pic} = (f_b * (NCV * \left(EF_{CO,b} + EF_{voc,b}\right) + EF_{BC,b} + EF_{OC,b})) - (f_p * (NCV * (EF_{CO,p} + EF_{voc,p}) + EF_{BC,p} + EF_{OC,p}))$$

Emission factors are from laboratory tests direct measurements except for BC and OC which are calculated as follows:

$$ER_{BC} = EF_{PM1} * F_{BC}$$

EF_{PM1} is the bulk particulate emission factor in g/kg of diameters smaller than one micrometre, intended to separate BC from larger particles such as ash and char and F_{BC} is the fraction of the fine particulate matter that is black carbon and OC is calculated as follows:

$$ER_{OC} = EF_{PM1} * F_{OC}$$

Values for F_{BC} and F_{OC} are presented in the following table

Table 5: Fraction of particulate matter emitted as Organic and Black Carbon (Bond et al. 2013).

Fuel	F_{BC}	F_{OC}
Wood	0.25	0.75
Charcoal	0.5	0.5

3.6.4 Assessment of other benefits related to projects activities

Health damaging pollutants

Products of incomplete combustion cause adverse effects on human health, particularly on women and children which are exposed to cooking stoves emissions. It is not in the scope of this study to assess adverse health effects. However, an assessment of pollutant emission reduction was performed. The calculation of ER for a given pollutant is derived from a combination of its EF, as calculated during laboratory tests, and fuel consumption estimates.

Fuel purchasing costs and savings

Reduction of fuel use and consequent economic savings for households which use charcoal is part of benefit analysis presented in this study. Charcoal costs were assessed during the surveys conducted both in Maputo/Pemba and in Pebane areas. Savings are then calculated multiplying charcoal cost with fuel saving values. Furthermore, a comparison between the cost of traditional charcoal stove and the price at which the CH2200 was sold to the household is provided in the saving/cost analysis.

In Gilè area household were interviewed on time saving benefits related to the reduction of fuel uses. Questions on harvesting area and time spent to collect fuel were included in the baseline survey.

Reduction of deforestation and land degradation

Reduction of impacts on forest areas is calculated in terms of hectares of forest not cut. For the Maputo/Pemba project it has been assumed that wood used in charcoal production is from Miombo forests (Baumert et al. 2016). Hectare of forest saved are calculated with the following formula:

$$FS_t = P_t * \frac{1}{\rho_{char}} * BEF * \frac{CS_m}{w_{cc}}$$

Were FS_t is the forest saved in hectares during the period t, P_t is fuel saved during period t and CS_m is the average carbon stock in Miombo forests per hectares which is equal to 63 tC/ha (Ryan, Williams, e Grace 2011).

The calculation of potential forest saving for Gilè project was calculated based on of the rates of fuel harvested which impacts on deforestation and land degradation. During the baseline survey households where asked to choose among 4 options regarding wood collection:

A: Cutting a tree
B: Cutting a bush
C: Cutting branches from a tree
D: Harvesting without cutting

Only option A is considered to have significant impact on deforestation. Hence, potential fuel saving achievable in the project scenario was multiplied by the rate of households which indicated option A as common methodology for fuel collection.

4 Results

This chapter will present and discuss the results collected both on field and in the laboratory, providing a description of the benefits related to the use of efficient cooking devices shown by the results.

4.1 Stove laboratory tests

The Local Boiling point, which was the first parameter measured, is 99.15 °C. This value is the mean temperature of boiling water recorded during 10 minutes (Figure 29). The lowest and the highest values recorded were 98.8 °C and 99.5 °C respectively, with a standard deviation of 0.134°C.

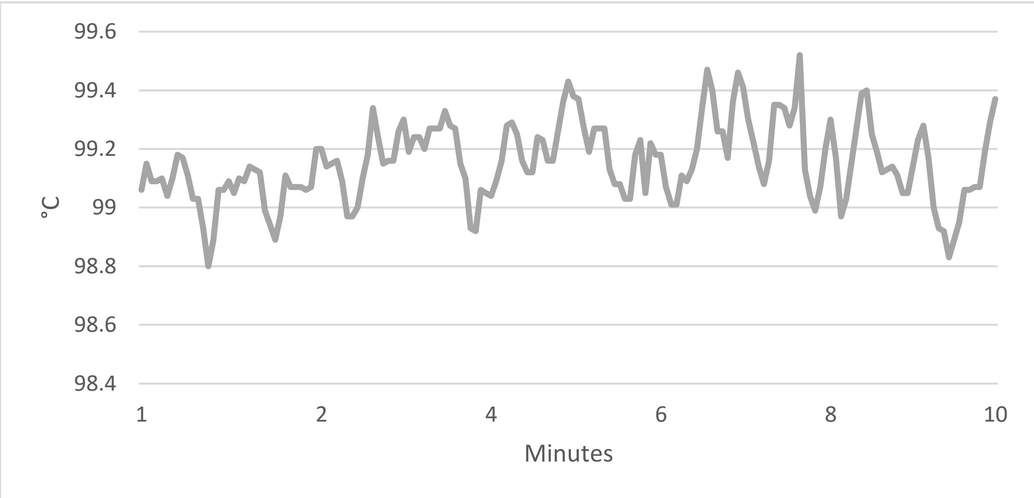


Figure 29: Boling water temperature

The fuel characteristics assessed for the purposes of this study are the heating values and the wet moisture contents. The heating values are presented in the following table.

Table 6: Fuel heating values

FUEL	HHV	LHV
WOOD		
SAMPLE 1	18,970	17,650
SAMPLE 2	18,113	16,793
SAMPLE 3	18,366	17,046
MEAN	18,483	17,163
CHARCOAL		
SAMPLE 1	28,891	27,571
SAMPLE 2	28,746	27,426
SAMPLE 3	28,763	27,443
MEAN	28,800	27,480
Maputo Sample	26,096	24,776

The average HHV of wood, according to the three samples tested in the calorimetric bomb, is 18,483 kJ/kg while the LHV is 17,163. The average HHV and LHV of charcoal are respectively 28,800 kJ/Kg and 27,480 kJ/Kg, which are slightly higher than the ones of the charcoal sample from Maputo (28,100 kJ/Kg and 26,780 kJ/Kg). This difference may be due to the typologies of wood and the production process. However, these differences do not influence the emission metrics calculated in this study. The average moisture content of wood on a wet basis is 13.1 % (Table 7). The moisture content shows that the wood used was well dried, particularly if compared to fresh cut wood which typically has a moisture content around 50%. Use of well dried fuel reduces variability during the tests, but it may not be representative of wood moisture on the field. However, moisture content of wood used in the project area is not known and it must be further investigated.

Moisture content of charcoal is usually very low. The sample of charcoal tested confirms this assumption with a moisture content of 1%. The sample from Maputo has a higher moisture content instead, and this can be attributed to the environmental conditions in which the sample was stored before the test.

Table 7: Fuel moisture contents

FUEL	Moisture content (Wet basis)
WOOD	
SAMPLE 1	11.7%
SAMPLE 2	21.2%
SAMPLE 3	6.2%
MEAN	13.1%
CHARCOAL	
SAMPLE 1	1.0%
Maputo Sample	5.4%

4.1.1 Three-stone fire

The first cooking technology tested was the three-stone fire, which is the baseline cooking system used in Gilè project area. The three stone is the most rudimental and inefficient cooking system and still the most used in rural areas of Mozambique.

The thermal efficiency of three stone fire is estimated to be around 10%, according to the UNFCCC methodology II.G. "Energy efficiency measures in thermal applications of non-renewable biomass"(UNFCCC 2016). However, thermal efficiency measured in laboratory tests is 15%. This difference is mainly due to the fact that laboratory tests are designed to push cooking systems to their best operative performances and are performed in a no wind condition, fire being continuously under supervision (e.g. fire was fed to reach boiling point as fast as possible). Furthermore, the hood blowing system is supposed to lightly increase air flow throughout the fire system and increase stove efficiency.

In any case, these are systematic errors, therefore they do not influence the comparison between stoves (e.g. differences in thermal efficiency).

Table 8: Three stone efficiency metrics

	Unit		MEAN	SD	CoV
Equivalent Dry fuel consumed	**g**	High Power	**777**	**63.7**	**8%**
		Low Power	856	35.1	4%
		TEST	1633	33.7	2%
Thermal efficiency	%		15	1	7%
Low Power Specific Fuel Consumption	g/litre remaining		178	9.8	6%
Burning Rate	g/min	High Power	17.6	6.5	37%
		Low Power	15.5	1.3	8%
		TEST	27.2	0.4	2%
Time to Boil	min		52	18.5	36%
Firepower	watts	High Power	4168	1942.0	47%
		Low Power	4227	356.8	8%
		TEST	4936	954.3	19%

The burning rate and fire power for the high-power phase show a high variability (Table 8). This is because these metrics are time dependents, indeed during the first of the three tests the time to boil was 73 minutes against the 38 and 45 minutes of the second and third tests. However, this did not affect thermal efficiency output which shows very little variability. Hence the test was considered valid. Comparing burning rates and the fire power of high and low -power phases we can see that the stove heat output was kept similar in the two phases.

Emission metrics from the three-stone fire are presented in Table 9.

Table 9: Three stone fire emission metrics

		Units	High Power	Low Power	Δ	TOTAL		
						MEAN	SD	CoV
Average Concentration	CO_2	ppm	1,695	1,681	-1%	1,688	268	16%
	CH_4		1.284	1.700	32%	1.492	1.291	87%
	CO		93.766	76.766	-18%	85.266	13.473	16%
	NO		1.300	0.813	-37%	1.057	0.202	19%
	NO_2		0.629	0.319	-49%	0.474	0.032	7%
	VOCs		18.483	10.570	-43%	14.526	0.502	3%
	PM_1	ug/m3	529	500	-5%	515	69	13%
	$PM_{2.5}$		1091	989	-9%	1040	22	2%
	PM_{10}		1312	1073	-18%	1192	65	5%
Emission Factors	CO_2	g/MJ	82	71	-13%	80	3	4%
	CH_4		0.061	0.047	-24%	0.068	0.019	28%
	CO		2.907	2.134	-27%	2.638	0.196	7%
	NO		0.046	0.023	-49%	0.040	0.008	21%
	NO_2		$1.27*10^{-02}$	$5.94*10^{-03}$	-53%	$1.12*10^{-02}$	$2.98*10^{-03}$	27%
	VOCs		1.303	0.618	-53%	1.176	0.336	29%
	PM_1		$1.70*10^{-02}$	$1.24*10^{-02}$	-27%	$1.85*10^{-02}$	$5.79*10^{-03}$	31%
	$PM_{2.5}$		$3.25*10^{-02}$	$2.41*10^{-02}$	-26%	$3.32*10^{-02}$	$7.53*10^{-03}$	23%
	PM_{10}		$3.78*10^{-02}$	$2.63*10^{-02}$	-30%	$3.63*10^{-02}$	$6.66*10^{-03}$	18%
Total Emissions	CO_2	g	1,111	1,047	-6%	2,158	20	1%
	CH_4		0.840	1.107	32%	1.947	0.480	25%
	CO		39.428	30.426	-23%	69.854	3.496	5%
	NO		0.616	0.345	-44%	0.961	0.208	22%
	NO_2		0.169	0.072	-57%	0.242	0.076	32%
	VOCs		17.321	8.392	-52%	25.713	8.700	34%
	PM_1		0.224	0.171	-24%	0.395	0.151	38%
	$PM_{2.5}$		0.433	0.338	-22%	0.771	0.189	25%
	PM_{10}		0.506	0.367	-28%	0.873	0.162	19%

As expected, Table 9 shows that in general emissions during the high-power phase are higher than during the steaming phase.

4.1.2 Rocket Works

The Rocket Works Zama is the stove chosen to substitute the three-stone fire in the Gilè project area. During the tests the stove shows to be easy to control and efficient due the small combustion chamber which reduces heat dispersion (Figure 30).

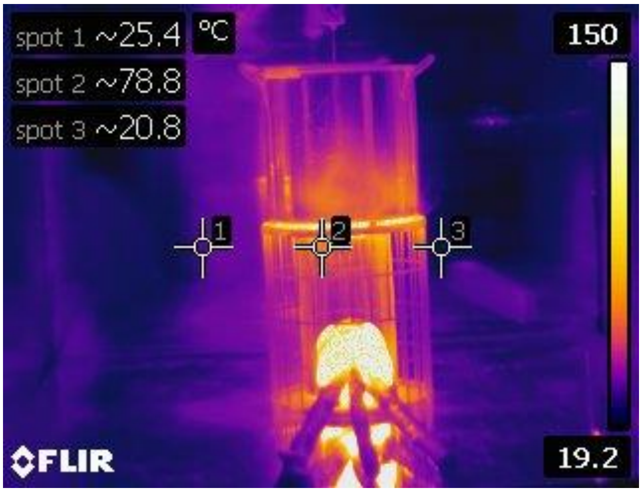


Figure 30: Rocket works picture taken with a thermal camera

The average thermal efficiency is 33% (Table 10). Burning rates and fire powers values are sensibly lower for low-power phase, indicating the stove is capable to stim water even at low fire intensities. All the metrics show very little variation between tests, particularly during the low-power phase, with a COV included in an interval between 1% and 13%, which means that the stove is very little dependent on user induced variability.

Table 10: Rocket works efficiency metrics

	Unit		MEAN	SD	CoV
Equivalent Dry fuel consumed	g	High Power	434	6.2	1%
		Low Power	276	9.8	4%
		TEST	710	11.8	2%
Thermal efficiency	%		33	1	2%
Low Power Specific Fuel Consumption	g/litre remaining		86	4.0	5%
Burning Rate	g/min	High Power	11.3	1.5	13%
		Low Power	6.4	0.4	7%
		TEST	9.1	0.2	2%
Time to Boil	min		40	4.5	11%
Firepower	watts	High Power	3110	433.3	14%
		Low Power	1846	75.0	4%
		TEST	2404	150.2	6%

Some constrains arise regarding durability of the stove due to the light materials and the size of the fuel used which has to be limited to fit combustion chamber, which may represent a problem during real cooking activities. However, these matters have to be further investigated on field.

Emission metrics are presented in following table. A comparison of emission factor values between high and low-power phase shows an increase for all the substances except CO_2 (Table 11). This could be attributed to the process of adding/removing wood during the steaming phase to control water temperature. This process is particularly frequent with this stove and it can alter fire efficiency thus increasing the generation of PICs instead of CO_2.

Table 11: Rocket works emission metrics

		Units	High Power	Low Power	Δ	TOTAL		
						MEAN	SD	CoV
Average Concentration	CO_2	ppm	1,810	951	-47%	1,353	159	12%
	CH_4		0.263	0.300	14%	0.283	0.219	78%
	CO		27.526	29.315	6%	28.477	0.455	2%
	NO		0.458	0.317	-31%	0.383	0.172	45%
	NO_2		0.266	0.310	16%	0.290	0.013	5%
	VOCs		3.802	3.572	-6%	3.680	0.101	3%
	PM_1	ug/m³	75	152	102%	116	8	7%
	$PM_{2.5}$		111	245	120%	182	18	10%
	PM_{10}		119	251	111%	190	19	10%
Emission Factors	CO_2	g/MJ	137	127	-7%	120	19	16%
	CH_4		$2.11*10^{-02}$	$3.19*10^{-02}$	52%	$2.57*10^{-02}$	$6.65*10^{-04}$	3%
	CO		1.319	2.543	93%	1.672	0.181	11%
	NO		0.024	0.052	120%	0.024	0.016	67%
	NO_2		$7.41*10^{-03}$	$1.47*10^{-02}$	99%	$9.35*10^{-03}$	$1.31*10^{-03}$	14%
	VOCs		0.363	0.623	72%	0.441	0.033	8%
	PM_1		$3.21*10^{-03}$	$1.07*10^{-02}$	233%	$5.61*10^{-03}$	$0.74*10^{-03}$	13%
	$PM_{2.5}$		$4.77*10^{-03}$	$1.83*10^{-02}$	284%	$8.80*10^{-03}$	$1.82*10^{-03}$	21%
	PM_{10}		$5.10*10^{-03}$	$1.89*10^{-02}$	271%	$9.17*10^{-03}$	$1.91*10^{-03}$	21%
Total Emissions	CO_2	g	1,020	608	-40%	1,628	223	14%
	CH_4		0.157	0.200	28%	0.357	0.010	3%
	CO		9.831	11.928	21%	21.759	2.067	10%
	NO		0.175	0.138	-21%	0.314	0.191	61%
	NO_2		0.055	0.072	31%	0.127	0.015	12%
	VOCs		2.704	2.912	8%	5.615	0.368	7%
	PM_1		0.024	0.053	124%	0.077	0.009	11%
	$PM_{2.5}$		0.035	0.086	143%	0.122	0.021	18%
	PM_{10}		0.038	0.089	134%	0.126	0.023	18%

4.1.3 Traditional Charcoal stove (Maputo)

The thermal efficiency of the traditional charcoal stove is 21%. This value is thought to be slightly higher than the one of stoves used on the field. Indeed, the majority of stoves used and observed in Maputo and Pemba are old and made of poor quality steel and this may reduce their thermal efficiency. All efficiency metrics show very little variation in the tests (Table 12).

Table 12:Charcoal traditional stove efficiency metrics

	Unit		**MEAN**	**SD**	**CoV**
Equivalent Dry fuel consumed	g	High Power	372	38.7	10%
		Low Power	286	7.0	2%
		TEST	657.7	45.6	7%
Thermal efficiency	%		21	2	10%
Low Power Specific Fuel Consumption	g/litre remaining		112	7.4	7%
Burning Rate	g/min	High Power	11.9	0.6	5%
		Low Power	6.1	0.2	2%
		TEST	10.0	1.0	10%
Time to Boil	min		32	3.1	9%
Firepower	watts	High Power	5439	279.5	5%
		Low Power	2844	67.1	2%
		TEST	4079	144.1	4%

Emission metrics shows that the average concentration and total emissions of CO_2, NO and VOS are lower during the steaming phase (Table 13). Instead, all the other substances show an increase in both concentration and emission.

Table 13: Charcoal traditional stove efficiency metrics

		Units	High Power	Low Power	Δ	TOTAL MEAN	TOTAL SD	TOTAL CoV
Average Concentration	CO_2	ppm	1,810	1,262	-30%	1,491	32	2%
	CH_4		13.000	6.000	-54%	8.927	1.665	19%
	CO		239.802	163.878	-32%	195.622	0.755	0%
	NO		0.518	0.359	-31%	0.425	0.030	7%
	NO_2		0.269	0.098	-64%	0.169	0.013	8%
	VOCs		4.903	3.526	-28%	4.102	0.028	1%
	PM_1	ug/m3	114	26	-77%	63	5	8%
	$PM_{2.5}$		409	62	-85%	207	46	22%
	PM_{10}		677	201	-70%	400	100	25%
Emission Factors	CO_2	g/MJ	78	104	34%	89	2	2%
	CH_4		0.586	0.443	-24%	0.611	0.126	21%
	CO		6.551	8.422	29%	7.572	0.273	4%
	NO		0.015	0.021	40%	0.017	0.001	5%
	NO_2		$4.20*10^{-03}$	$3.07*10^{-03}$	-27%	$3.53*10^{-03}$	$2.38*10^{-04}$	7%
	VOCs		0.269	0.374	39%	0.324	0.013	4%
	PM_1		$2.67*10^{-03}$	$1.16*10^{-03}$	-56%	$2.05*10^{-03}$	$7.56*10^{-05}$	4%
	$PM_{2.5}$		$9.65*10^{-03}$	$2.70*10^{-03}$	-72%	7.64*10-03	$1.56*10^{-03}$	20%
	PM_{10}		$1.60*10^{-02}$	$8.52*10^{-03}$	-47%	$1.55*10^{-02}$	$4.04*10^{-03}$	26%
Total Emissions	CO_2	g	805	832	3%	1,637	112	7%
	CH_4		5.973	4.133	-31%	10.106	1.498	15%
	CO		67.764	68.732	1%	136.497	6.808	5%
	NO		0.157	0.161	3%	0.319	0.045	14%
	NO_2		0.044	0.024	-46%	0.067	0.010	15%
	VOCs		2.768	2.962	7%	5.731	0.268	5%
	PM_1		0.028	0.009	-66%	0.037	0.002	5%
	$PM_{2.5}$		0.098	0.022	-77%	0.120	0.018	15%
	PM_{10}		0.161	0.072	-55%	0.234	0.055	23%

A comparison of the emission factors of the high and low power phases indicates a decrease of combustion efficiency. Indeed, EF of PICs are higher for the simmer phase while there is a decrease of CO_2 Emission factor.

4.1.4 Environfit CH2200 Charcoal stove

The CH2200 stove showed excellent performances during the tests (Table 14) and the average thermal efficiency is 38%. The stove consumed a very little amount of fuel allowing to perform the entire test with none or little amount of additional fuel added. The air inlet regulator allows the tester to easily control thermal output during steaming phase as shown by the little variation of the low-power specific fuel consumption indicator. High-power phase firepower seems to be low and this may be the reason why time to boil is over 51 minutes. This may represent a problem during field uses, particularly for households that prefer fast cooking systems.

Table 14: CH2200 stove efficiency metrics

	Unit		MEAN	SD	CoV
Equivalent Dry fuel consumed	g	High Power	224	11.1	5%
		Low Power	110	4.4	4%
		TEST	334.0	11.8	4%
Thermal efficiency	%		38	1	3%
Low Power Specific Fuel Consumption	g/liter remaining		35	0.3	1%
Burning Rate	g/min	High Power	4.5	0.9	19%
		Low Power	2.4	0.1	2%
		TEST	4.0	0.1	3%
Time to Boil	min		51	10	20%
Firepower	watts	High Power	2076	395.3	19%
		Low Power	1405	255.7	18%
		TEST	1685	144.2	9%

The emission metrics for the CH2200 stove are presented in Table 15. CO_2 average concentrations and emission factors values are in line with a good combustion efficiency. Consequently, emissions of product of incomplete combustion are limited. Generally, average concentrations and total emissions are lower during the steaming phase. Emission factors also shows a decrease during the steaming phase except for methane VOCs and NO_2.

Table 15: CH2200 stove efficiency metrics

		Units	High Power	Low Power	Δ	TOTAL		
						MEAN	**SD**	**CoV**
Average Concentration	CO_2	ppm	1,810	476	-74%	1,182	317	27%
	CH_4		4.500	2.500	-44%	3.559	1.133	32%
	CO		83.104	51.694	-38%	68.329	21.560	32%
	NO		0.182	0.086	-53%	0.137	0.002	2%
	NO_2		0.068	0.088	29%	0.078	0.012	15%
	VOCs		4.517	3.305	-27%	3.947	0.151	4%
	PM_1	ug/m3	71	20	-72%	47	9	19%
	$PM_{2.5}$		218	26	-88%	128	2	1%
	PM_{10}		326	28	-91%	186	17	9%
Emission Factors	CO_2	g/MJ	173	98	-43%	136	19	14%
	CH_4		0.435	0.471	8%	0.546	0.140	26%
	CO		4.947	3.423	-31%	5.951	2.129	36%
	NO		0.012	0.013	13%	0.012	0.000	4%
	NO_2		$2.39*10^{-03}$	$7.38*10^{-03}$	209%	$3.39*10^{-03}$	$8.57*10^{-04}$	25%
	VOCs		0.544	0.915	68%	0.651	0.017	3%
	PM_1		$3.59*10^{-03}$	$2.51*10^{-03}$	-30%	$3.51*10^{-03}$	$3.76*10^{-04}$	11%
	$PM_{2.5}$		$1.12*10^{-02}$	$2.91*10^{-03}$	-74%	$7.89*10^{-03}$	$8.95*10^{-04}$	11%
	PM_{10}		$1.66*10^{-02}$	$3.15*10^{-03}$	-81%	$1.23*10^{-02}$	$2.43*10^{-05}$	0%
Total Emissions	CO_2	g	1,145	298	-74%	1,443	236	16%
	CH_4		2.870	1.635	-43%	4.505	1.217	27%
	CO		32.702	20.579	-37%	53.281	19.334	36%
	NO		0.078	0.036	-53%	0.114	0.008	7%
	NO_2		0.016	0.020	27%	0.036	0.010	27%
	VOCs		3.600	2.635	-27%	6.235	0.382	6%
	PM_1		0.024	0.007	-71%	0.030	0.003	9%
	$PM_{2.5}$		0.074	0.009	-88%	0.083	0.012	14%
	PM_{10}		0.110	0.009	-91%	0.120	0.004	3%

4.1.5 Comparison of traditional and improved woodstoves

The comparative analysis of the efficiency metrics for wood stoves shows that Rocket Works performs much better than the three-stone fire for all the indicators (Table 16). This is particularly evident for thermal efficiency which increases from 15% to 33%, this allows to estimate a potential reduction in fuel use from baseline to project scenario of around 45%. The overall fuel consumption over the test (high and low power phase) more than halved

Table 16: Comparison of three stone and Rocket Works efficiency metrics

	Units	3 Sone	Rocket	Δ	Significance
Equivalent Dry fuel consumed	g	1,633	710	-57%	***
Thermal efficiency	%	15	33	118%	***
Low Power Specific Fuel Consumption	g/liter remaining	178	86	-51%	***
Burning Rate	g/min	27	9	-66%	***
Time to Boil	min	52	40	-24%	NS
Firepower	watts	4,936	2,404	-51%	**

***=significant with 90% interval**
**** =significant with 95% interval**
*****=significant with 99% interval**
NS = not significant

The Low Power Specific Fuel Consumption also halved, confirming an increase of efficiency also in the steaming phase. As a result, the overall fuel consumption for the test (high and low-power phase) of Rocket Works is 57% lower than the one for the three-stone fire. Furthermore, Rocket Works is able to bring water to boiling temperature faster than the three-stone stove even with a reduced firepower. All the metrics confirm that the stove is able to transfer the combustion heat to the pot in a more effective way, reducing heat dispersion which is instead very high for the three-stone fire. Moreover, three-stone fire is much more difficult to control than the Rocket Stove, both during high and low-power phases. As a result, coefficients of variation for the metrics measured over the three tests are higher for the three stone than for the Rocket. The increase in efficiency and reduction of fuel consumption lead to a decrease of average concentration and total emissions for all the substances measured (Table 17).

Table 17: Comparison of three stone and Rocket Works efficiency metrics

		Units	3 Sone	Rocket	Δ	Significance
Average Concentration	CO_2	ppm	1689	1353	-18%	NS
	CH_4		1.477	0.283	-81%	NS
	CO		85.879	28.477	-67%	***
	NO		1.074	0.383	-63%	**
	NO_2		0.485	0.290	-39%	***
	VOCs		14.812	3.680	-75%	***
	PM_1	ug/m3	516	116	-78%	***
	$PM_{2.5}$		1043	182	-83%	***
	PM_{10}		1201	190	-84%	***
Emission Factors	CO_2	g/MJ	80	120	49%	**
	CH_4		$6.8*10^{-02}$	$2.6*10^{-02}$	-62%	**
	CO		2.638	1.672	-37%	***
	NO		$4.0*10^{-02}$	$2.4*10^{-02}$	-41%	NS
	NO_2		$1.12*10^{-02}$	$9.35*10^{-03}$	-17%	NS
	VOCs		1.176	0.441	-62%	**
	PM_1		$1.85*10^{-02}$	$5.61*10^{-03}$	-70%	**
	$PM_{2.5}$		$3.32*10^{-02}$	$8.80*10^{-03}$	-73%	***
	PM_{10}		$3.63*10^{-02}$	$9.17*10^{-03}$	-75%	***
Total Emissions	CO_2	g	2,158	1,628	-25%	**
	CH_4		1.947	0.357	-82%	***
	CO		69.854	21.759	-69%	***
	NO		0.961	0.314	-67%	**
	NO_2		0.242	0.127	-47%	*
	VOCs		25.713	5.615	-78%	**
	PM_1		0.395	0.077	-80%	**
	$PM_{2.5}$		0.771	0.122	-84%	***
	PM_{10}		0.873	0.126	-86%	***

The design of the combustion chamber is intended to a more complete and efficient combustion than the three-stone fire. In line with this, the analysis of emission factor variations (Figure 31) shows that a higher amount of biomass carbon is transformed in CO_2 other than PICs during combustion in the Rocket stove. This reduces significantly the quantity dangerous emissions for health and environment.

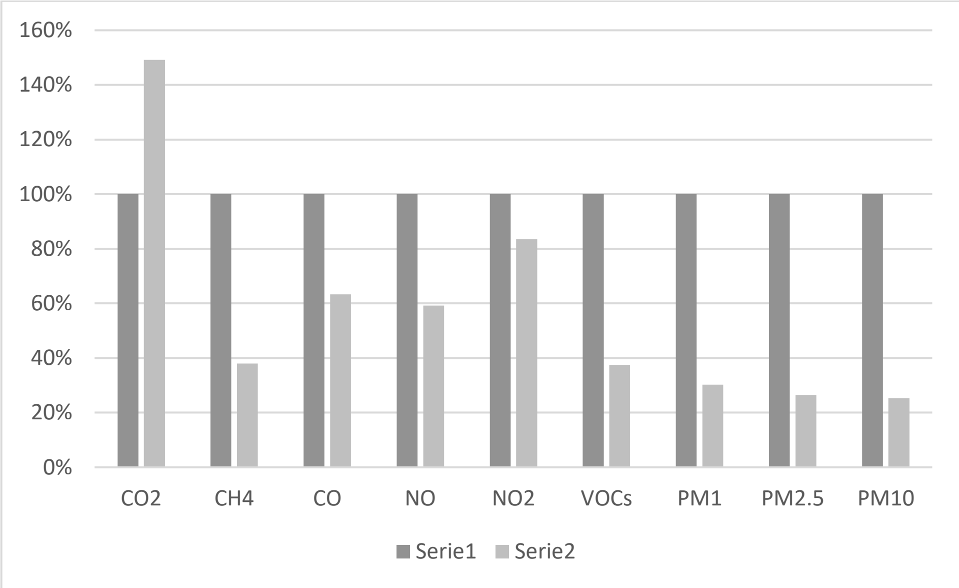


Figure 31: Comparison of Emission Factors of woodstoves (three stone fire used as reference)

The t-test performed on both efficiency and emission metrics shows that the means are significantly different for almost all the variables. Only four indicators from emission metrics and one from efficiency metrics are not significant.

4.1.6 Comparison of traditional and improved charcoal stoves

The tests performed on the CH2200 show that this model has better efficiency indicators than the traditional charcoal stove (Table 18). Thermal efficiency is 84% higher, low-phase and overall fuel consumption shows a decrease of 59% and 49% respectively. In a similar way to Rocket Works, the CH2200 is able to perform the same tasks as the traditional charcoal stove requiring less firepower and at a lower burning rate. However, the CH2200 requires more time to bring water to boiling temperature and this is due to a lower firepower available during the high-power phase, which is 2,076 Watt against the 5,439 Watt for the traditional charcoal stove.

Table 18:Comparison of traditional charcoal stove and CH2200 efficiency metrics

	Units	Charcoal traditional	CH2200	Δ	Significance
Equivalent Dry fuel consumed	g	658	334	-49%	***
Thermal efficiency	%	21	38	84%	***
Low Power Specific Fuel Consumption	g/liter remaining	112	35	-69%	***
Burning Rate	g/min	10	4	-60%	***
Time to Boil	min	32	51	57%	**
Firepower	watts	4,079	1,685	-59%	***

***=significant with 90% interval**
**** =significant with 95% interval**
*****=significant with 99% interval**
NS = not significant

Overall, the traditional charcoal stove seems to emit larger quantities of pollutants as a result of a less efficient combustion. The exhaust analysis shows that average concentrations are higher than in the exhaust of CH2000. Furthermore, the average quantities of pollutants emitted during WBTs is higher compared with the CH2200 tests except for volatile organic compounds (Table 19).

Table 19: Comparison of three stone and Rocket Works efficiency metrics

		Units	Charcoal traditional	CH2200	Δ	Significance
Average Concentration	CO_2	ppm	1491	1182	-21%	NS
	CH_4		8.927	3.559	-60%	***
	CO		195.622	68.329	-65%	***
	NO		0.425	0.137	-68%	***
	NO_2		0.169	0.078	-54%	***
	VOCs		4.102	3.947	-4%	NS
	PM_1	ug/m3	63	47	-25%	*
	$PM_{2.5}$		207	128	-38%	**
	PM_{10}		400	186	-54%	**
Emission Factors	CO_2	g/MJ	89	136	52%	**
	CH_4		0.611	0.546	-11%	NS
	CO		7.572	5.951	-21%	NS
	NO		0.017	0.012	-31%	***
	NO_2		$3.53*10^{-03}$	$3.39*10^{-03}$	-4%	NS
	VOCs		0.324	0.651	101%	***
	PM_1		$2.05*10^{-03}$	$3.51*10^{-03}$	71%	***
	$PM_{2.5}$		$7.64*10^{-03}$	$7.89*10^{-03}$	3%	NS
	PM_{10}		$1.55*10^{-02}$	$1.23*10^{-02}$	-20%	NS
Total Emissions	CO_2	g	1637	1443	-12%	NS
	CH_4		10.106	4.505	-55%	***
	CO		136.497	53.281	-61%	***
	NO		0.319	0.114	-64%	***
	NO_2		0.067	0.036	-47%	**
	VOCs		5.731	6.235	9%	NS
	PM_1		0.037	0.030	-18%	**
	$PM_{2.5}$		0.120	0.083	-31%	**
	PM_{10}		0.234	0.120	-49%	**

The CO_2 emission factor of CH2200 (Figure 32) is 52% higher than the equivalent traditional stove EF. This is in line with the hypothesis of a more complete and efficient combustion of charcoal. However, this does not leads to a reduction of all PICs. Indeed, EF for PM_1 and VOCs are higher while there is very little difference in the EF for $PM_{2.5}$. This may be due to a similar efficiency of combustion even if CH2200 perform better in thermal efficiency metrics.

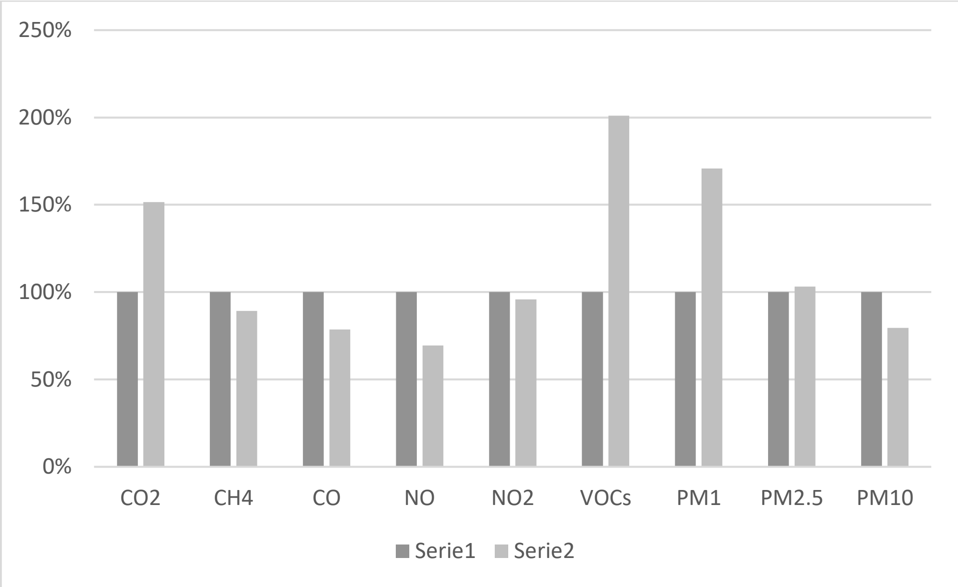


Figure 32: Comparison of Emission Factors of charcoal stoves (traditional charcoal stove used as reference)

The t-test performed on efficiency metrics, shows that the means are significantly different for all the variables. On the contrary, around 30% of mean values of emission indicators are not significant.

4.1.7 Overall comparison of tested stoves

The overall fuel consumption of charcoal stoves is lower than the one of the wood stoves, although charcoal and wood have different calorific values and therefore different thermal output per Kg of fuel. Efficient stoves, independently of the fuel used, have a better thermal efficiency and lower specific fuel consumption and firepower. Time to boil of three stone fire and CH2200 are similar, while the traditional charcoal stove is the faster system to bring water to boiling temperature. The burning rate of the three-stone fire is the highest among the stoves tested with a difference with CH2200 which is over 65%. Overall, the three-stone fire is the system with the worst efficiency performances among the tested stoves (Figure 33).

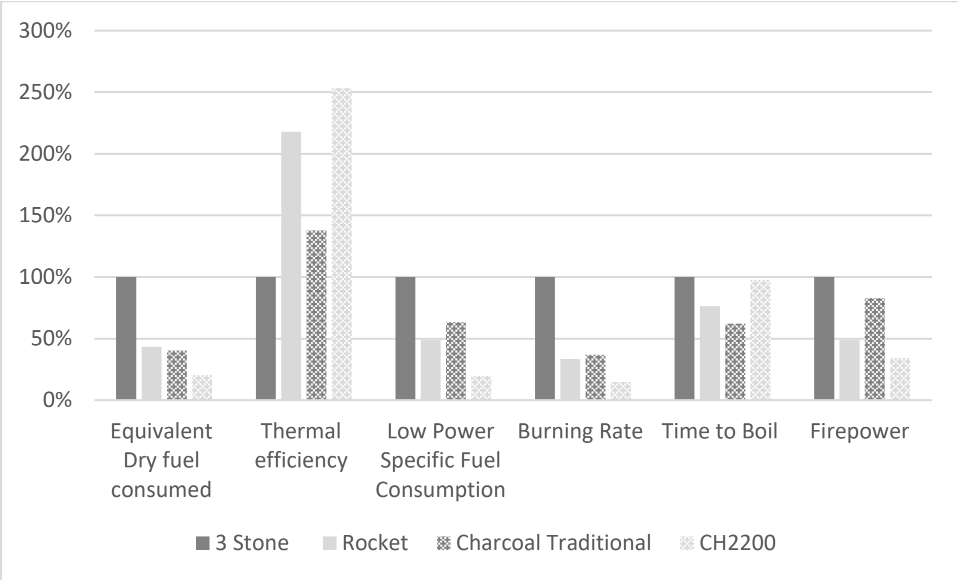


Figure 33: Comparison of efficiency metrics of tested stoves (three stone fire used as reference)

The CO_2 emission factors of efficient stoves (wood and charcoal) are higher than for traditional stoves, as a result of the improved combustion efficiency. Methane and carbon monoxide emission factors of charcoal stoves are much higher than the ones of wood stoves. The three-stone fire is the system which has the highest emission factor for all the other substances. On the contrary, the traditional charcoal stove has the lowest VOCs and fine particulate (PM_1 and $PM_{2.5}$) emission factors (Figure 34).

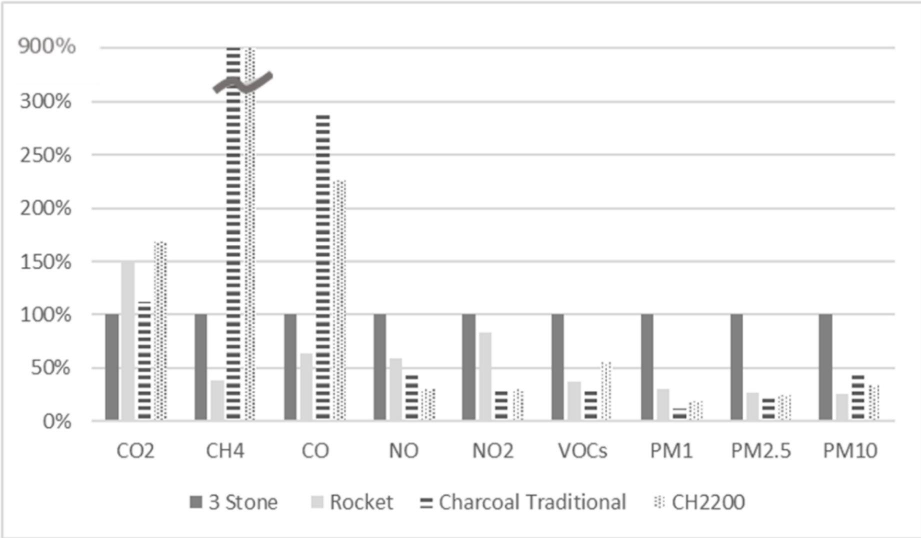


Figure 34: Comparison of emission factors of tested stoves (three stone fire used as reference)

4.2 Field data analysis

The data collected on field was aimed to assess preferred cooking systems in the baseline scenarios, common habits and household response to the implementation of project activates. Furthermore, the quantitative survey was aimed to assess household fuel consumption during both baseline and project scenario.

4.2.1 Maputo/Pemba Programme usage surveys

The first usage survey was conducted in 2014 in Maputo to assess baseline condition prior to start with project activities. Among the 537 surveyed, approximately 95% of the households within the districts of Chamanculo C and Xipamanine cook with traditional charcoal stove, while only 5% of them uses either electric, gas or wood cookstoves.

The traditional charcoal stove can be either a one or a two-fire model. The two fire was used by 58% of interviewed families while the single one was preferred by 37% of the households (Figure 35).

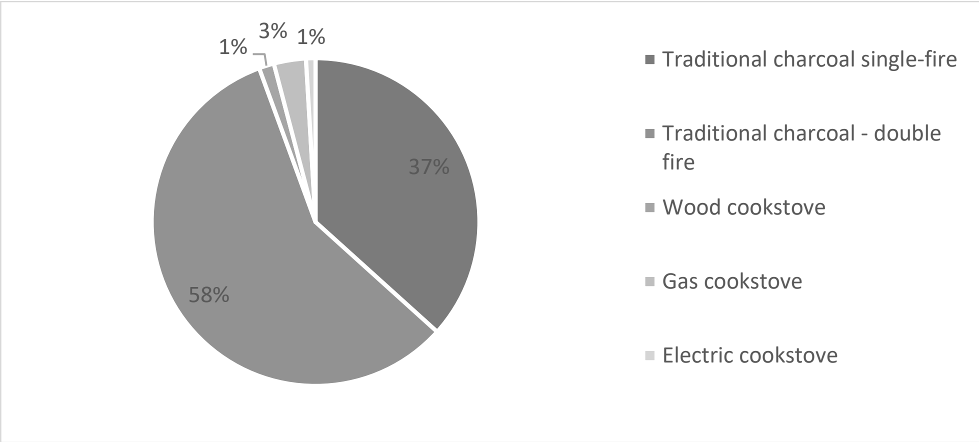


Figure 35: Type of stoves used in the baseline scenario

Households were also asked how many times a day they used the cook stove in order to assess the number of cooking events. The great majority of the families cook twice a day to prepare lunch and dinner (Figure 36). 18% of families use the stove three times (breakfast, lunch and dinner) and 10% only once.

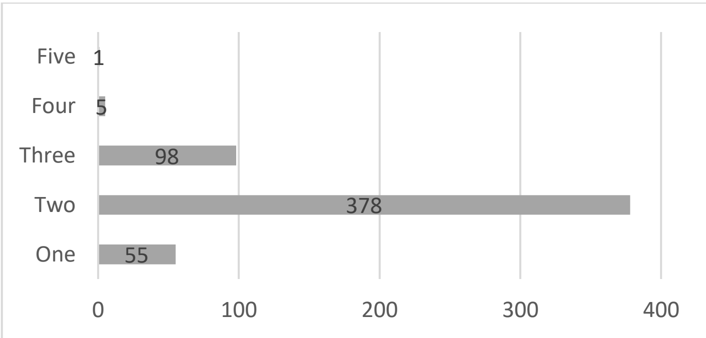


Figure 36: Cooking events

The first project usage survey was conducted during 2015, covering the first period of project activity. The survey was conducted on end users using project technologies for at least 6 moths to explore changes in project scenario over time, such as trends in type of fuels consumed, seasonality, etc. One hundred households were interviewed between 29th October 2014 and

30th March 2015. Within the household sample, the 67% of interviewed beneficiaries had bought one CH2200 stove, while 33% of beneficiaries had bought two stoves. Most of the the families who had bought two stoves (64%) had bought both stoves together, instead 36% had bought the second stove in later phase. All households interviewed declared that they use at least one efficient project stove. 41% of families reported to use also other cooking stoves than the project stove. Additional technologies are used anyhow only as secondary means of cooking during special days, ceremonies or weekends. Gas stoves are the most common additional stoves (17 cases in 41), with three weekly meals cooked on average by each. 13 families declared to use traditional charcoal stoves, respectively 4,2 meals/week on average for the 7 families using traditional single burner stoves, and 2,6 meals/week for families using traditional double burners stoves (Figure 37).

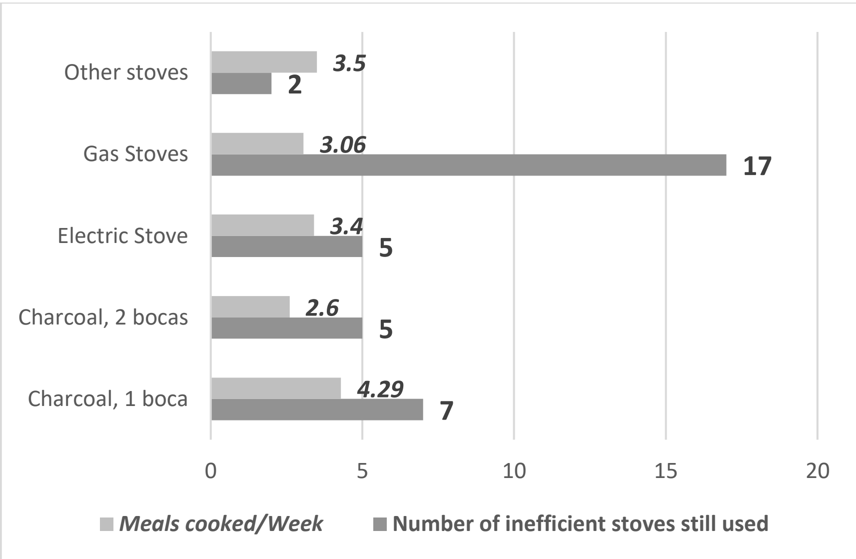


Figure 37: Inefficient stoves still in use and average number of meals cooked every week, by type of stove

94% of the families in the sample are used to cooking at least one meal every day with the project stove/stoves. In average, the sampled families cook 2,16 meals per day (equal to 15,12 meals/week) using the project stoves, with 73% of the interviewed beneficiaries cooking 2 meals per day with the project stoves (equal to 14 meals/week).

Figure 38: Number of meals cooked per day with the CH2200

No seasonal changes of fuel usage were accounted by the survey. Furthermore, the use of cooking stoves for space heating was also very limited, with one participant in 100 who declared to use the cook stove for this purpose in the months of June and July. The re-selling/donating of old stoves to third parties after the purchase of the efficient project stove/stoves was very limited, with only 2 inefficient stoves re-sold to a peer by one family. Promotion of the new efficient stoves to third parties was instead quite high as 69% of participants declared to have promoted the project technology to at least one peer. According to the them, they convinced a total of 212 new people to buy an efficient stove. Based on the above indications, particularly the number of families cooking at least one meal per day with the project stove, the **Usage Rate ($U_{p,y}$)** for the first monitoring period is considered to be of 94%.

The second usage survey involved 100 households. Within the monitoring sample, 76% of interviewed beneficiaries had one project stove, while 24% of beneficiaries had 2 project stoves (36% during the first year). The average age of the stove for the interviewed families is 17 months. Based on the current monitoring result it can be observed that less respondents, 89%, declared to use the project stove in comparison to the first monitoring period during which 100% respondents stated to use the project stove (Table 20). This result indicates that a part of the families returned to use the traditional cooking methods. 79% of the families cook at least one meal every day with the project stove/stoves. This value is lower in comparison with the 94% observed during the first monitoring as well. In average, the sampled families cooked 2.44 meals per day (equal to 17.08 meals/week) using the project stoves which is in line with the frequency observed during the previous monitoring period.

Table 20: Usage rate of the project stoves

	1st monitoring period	2nd monitoring period
Number of CH2200 stove in use	100%	89%
At least one daily meals with CH2200	94%	79%
Average number of daily meals cooked with CH2200	2.16 meals/day	2.44 meals/day

During this survey, a relatively high percentage of families (74%) reported to use also other cooking stoves apart from the CH2200. Additional technologies are used anyhow only as secondary means of cooking during special days, ceremonies or weekends. In average, 1.1 meals/day are cooked by the additional technologies within the families using them. The traditional burner charcoal stoves are the most common additional stoves (30 cases on 74), with seven weekly meals cooked on average by each. This happens particularly with the double burner traditional charcoal stove, probably for the need of cooking more food for a larger number of people during ceremonies and during weekends and celebrations. The use of cooking stoves for space heating was limited, with 3 respondents on 100 who declared using the cookstove for this purpose mostly during the months of May, June and July. Some re-selling/donating of old stoves to third parties after the purchase of the efficient project stove/stoves was observed, with 10 responds stating to have re-sold their old stoves to a peer. This is indicating that the families using the efficient projects stoves are pleased with their new stoves, as they are willing to sell/donate the old traditional stoves. The satisfaction of the respondents with the project stoves is seen also from the promotion of the new efficient stoves to third parties**;** 75% of respondents declared to have promoted the project technology to at least one peer. According to the respondents, they convinced approximately 279 new persons to buy an efficient project stove. Based on the above indications and the summary presented in the Table 18, the **Usage Rate ($U_{p,y}$)** for the second monitoring period is considered to be 79%.

As mentioned before, in 2015 an additional stove program for the regulated carbon market was implemented in Maputo and Pemba. In 2016 a usage survey was conducted among 100 using the project technologies distributed in 2015. The aim was to assess family response, usage rate and differences with families which bought the stove in 2015. Within the household sample, the 68% of beneficiaries had bought one project stove, in line with 2015 usage survey. 25% of families declared to use also other cooking stoves, much less than the 41% of the previous survey. This can be related to the popularity that efficient stoves are gained thanks to the pilot project activities. The percentage of families which respond to use the efficient stove to prepare at least on meal per day is 87%. This value and therefore **Usage Rate ($U_{p,y}$)** of the first monitoring period for the regulated carbon project, is sensibly lower than the usage rate of the first monitoring of the GS pilot project (94%).

The surveys gathered data related to the monthly cost of the fuel sustained by the families as well. During the baseline survey, the monthly average expense for the purchase of charcoal was 682 Meticais, around 23 USD at 2013 exchange rate. After the first year of stove usage, families reported a reduction in charcoal expenses of around 30%. This value was reported higher during the second-year monitoring usage, in line with a reduction of stove efficiency. The survey conducted in 2016 within families using the stove from the regulated program report an average monthly expense of 412 Meticais, in line with the 2015 survey. Table 21 summarizes these results.

Table 21: Average charcoal expenses per household/month

<table>
<tr><th></th><th>2013</th><th>2015</th><th>2016 Vol.</th><th>2016 Reg.</th></tr>
<tr><td>Mean MZN</td><td>682</td><td>471</td><td>513</td><td>412</td></tr>
<tr><td>Exchange Rate MZN/USD</td><td>30</td><td>39</td><td colspan="2">63</td></tr>
<tr><td>Mean USD</td><td>23</td><td>12</td><td>8</td><td>7</td></tr>
<tr><td>SD</td><td>259</td><td>160</td><td>257</td><td>208</td></tr>
<tr><td>COV</td><td>38%</td><td>34%</td><td>50%</td><td>51%</td></tr>
</table>

It is possible to confirm that the introduction of efficient stoves may result in a reduction of economic resources which families dedicate to fuel purchase. However, this results are based on subjective estimation of families and do not consider variations in fuel prices.

Charcoal is usually sold in small plastic bags whose price ranges between 10 and 25 Meticais (based on the size). The most popular size purchased are the 10 MZN and 20 MZN bags. The average price in 2014 was 12.75 MZN/kg (0.42 USD/Kg) which slightly decreased to 12.47 MZN/Kg (0.32 USD/kg) in 2015 (Table 22).

Table 22: Charcoal Prices in Meticais

<table>
<tr><th>Year</th><th>Price (MZN)</th><th>10</th><th>15</th><th>20</th><th>25</th><th>MZN/Kg</th></tr>
<tr><td rowspan="3">2014</td><td>Mean Weight</td><td>0.79</td><td>1.15</td><td>1.49</td><td>2.13</td><td rowspan="3">12.75</td></tr>
<tr><td>SD</td><td>0.20</td><td>0.10</td><td>0.16</td><td>0.24</td></tr>
<tr><td>MZN/Kg</td><td>12.72</td><td>13.06</td><td>13.46</td><td>11.76</td></tr>
<tr><td rowspan="3">2015</td><td>Mean Weight</td><td>0.80</td><td>1.13</td><td>1.58</td><td>2.19</td><td rowspan="3">12.47</td></tr>
<tr><td>SD</td><td>0.16</td><td>0.15</td><td>0.11</td><td>0.18</td></tr>
<tr><td>MZN/Kg</td><td>12.56</td><td>13.23</td><td>12.68</td><td>11.40</td></tr>
</table>

4.2.2 Baseline and Project Kitchen Performance Test

The kitchen performance test was aimed to assess fuel consumption both during baseline and project scenario. The first KPT was concluded in 2014 to assess fuel consumption of 95 households which uses traditional charcoal stoves. The test measures the average fuel consumption during three days. Before proceeding to calculate average fuel consumption, an analysis of the outliers was performed on both the determined daily charcoal consumption per household (kg/day/hh) as well as for the three-day mean daily charcoal consumption of each household (kg/day/hh). When identified, outliers were removed from the dataset (Figure 39).

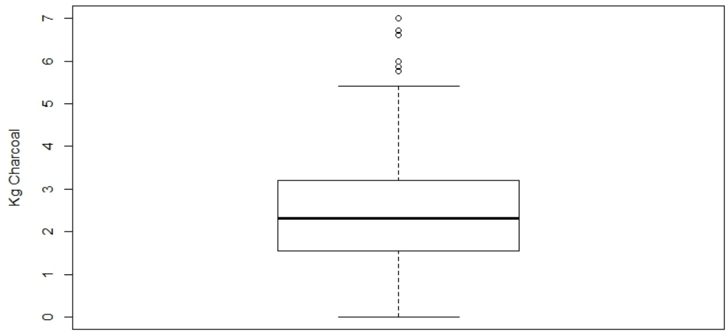


Figure 39: Baseline Dataset Outliers (kg/day/hh)

No outliers were identified in dataset of daily average consumption (over the three days) of the remaining 89 families. The average fuel consumption is 2.35 kg/hh/day (Table 23), with a consumption per standard adult of 0.54 kg/day. The minimum sample size required, as calculated with the formula described in paragraph 3.5.1, is 52 families.

Table 23: Baseline KPT Results

	Fuel Consumption Kg/day/hh	Standard Adults hh
Mean	2.35	4.4
Min	0.46	0.5
Max	5.19	11.1
SD	1.02	2.0
COV	43%	45%
Family N	89	
Min Sample size	52	

The first KPT of the families using project technologies was conducted in 2015, after stoves were on use for at least 6 months. This was necessary to allow families to get used to the new stove. 50 families were involved in the KPT. Figures 40 presents the analysis of the outliers of the three-day consumption dataset.

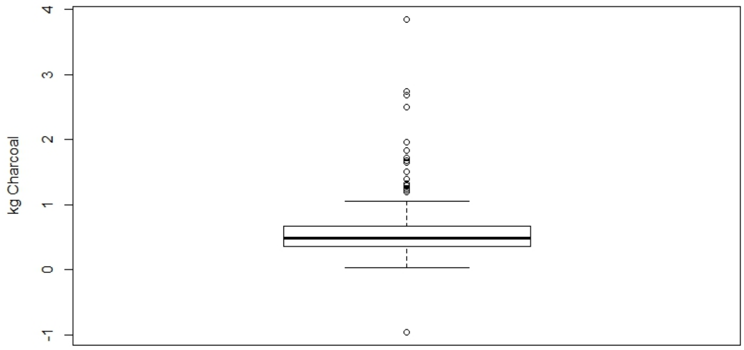


Figure 40: Outlier analysis (kg/day/hh) -daily fuel consumption dataset

The average daily consumption, calculated as the mean of the 33 families remaining after outlier exclusion, was 0.43 kg/day/hh. The minimum sample size required was 14 families (Table 24).

A second project KPT was conducted in 2016, aimed to assess fuel consumption after two years of stove usage. This was necessary to assess loss of stove efficiency due to aging. 35 families were involved, randomly selected from the stove database. Figures 41 presents the analysis of the outliers of the three-days consumptions dataset.

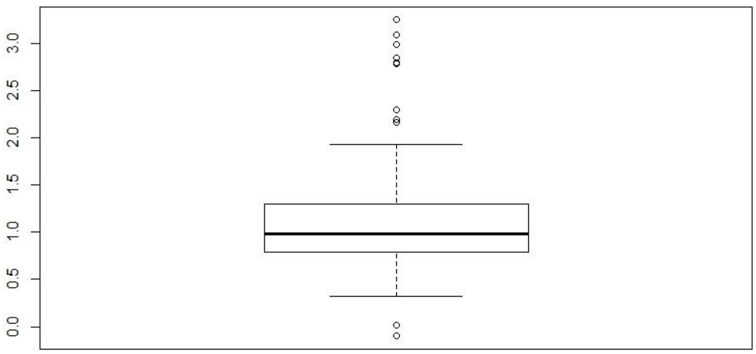


Figure 41: Outlier analysis (kg/day/hh) -daily fuel consumption dataset KPT second year

The mean fuel consumption per household measured during the second year of project activities doubles if compared to the previous KPT monitoring (Table 24). This increase can be related to the reduction in thermal efficiency of the CH2200 after 2 years usage.

Table 24: Project KPT Results

	Project first monitoring KPT		**Project second monitoring KPT**	
	Fuel Consumption kg/day/hh	Standard Adults hh	Fuel Consumption kg/day/hh	Standard Adults hh
Mean	0.64	5.0	0.89	4.1
Min	0.28	1.6	0.53	0.8
Max	0.67	10.1	1.27	9.7
SD	0.09	2.02	0.20	2.0
COV	14%	40%	22%	49%
Family N	33		27	
Min Sample size	14		15	

The mean fuel saving achieved due to the use of efficient cookstove is estimated as the difference between the baseline and the project consumptions. Estimated values of fuel saving for Maputo/Pemba programme are reported in the following table.

Table 25: Fuel saving values

	Year 1	Year 2
Mean fuel saving (kg/day/hh)	1.71	1.46
p-value	$1.14*10^{-19}$	$2.22*10^{-11}$
Significance	***	***

The fuel saved during first year of project activity was 1.71 kg/day/hh, 82% of baseline fuel consumption. Fuel saving decreased to 1.46 kg/day/hh during the second year of stove usage, sill 62% of fuel consumed in household using traditional cookstoves.

4.2.3 Gilè programme field data

The baseline survey conducted in Gilè reserve buffer zone was aimed to assess cooking habits and technologies. Surveyors interviewed 119 families, targeting mostly females, since they are usually in charge of cooking in the 14 communities involved in the project activities. The results show a homogenous situation in terms of cooking habits. Nearly all the families use the three-stone fire to prepare their meals, except three of them which use a traditional charcoal stove. The number of standard adults per family is 4.7 and the average number of meals prepared per day is 2.1. The main source of income for the 97% of the households is agriculture, although during the survey it has been observed that some families breed chicken and goats to provide an additional source of income. Regarding the cooking area, 39% responded to be cook in semi opened areas, 30% outdoors and 28% indoors (Table 26 and Figure 42).

Table 26: Cooking Areas

Area	Number	%
Inside	**33**	**28%**
Semi-open	46	39%
Outside	36	30%
Other	4	4%

Figure 42: Outdoor (left) and semi opened (right) cooking areas

It has to be considered that the three-stone fire is a portable system. Households tend to move the cooking area depending on the season and weather conditions. For instance, 92% of the families declared to use the fire for space heating, mainly during the cold months (June, July and August), and it is reasonable to suppose that during this period the three-stone fire is located inside the house.

Families were also asked if exposure to smoke causes them any kind of health problems. The majority of them suffer eyes discomfort and respiratory problems.

The wood supply area and harvesting methods were also investigated to assess impacts on forest due to wood collection. It has to be underlined that forest cover in the area is high. Therefore, all the surveyed families pointed out that wood harvesting takes place in the area nearby the houses, within a ratio of around 1 km. The wood supply area and harvesting methods were also investigated to assess impacts on forest due to wood collection. Households harvest wood either by cutting trees, branches or collecting wood from the ground. A very small number of households prefer tree cutting as method of wood collection. The majority of them cut branches from living trees or collect wood from the ground (Figure 43).

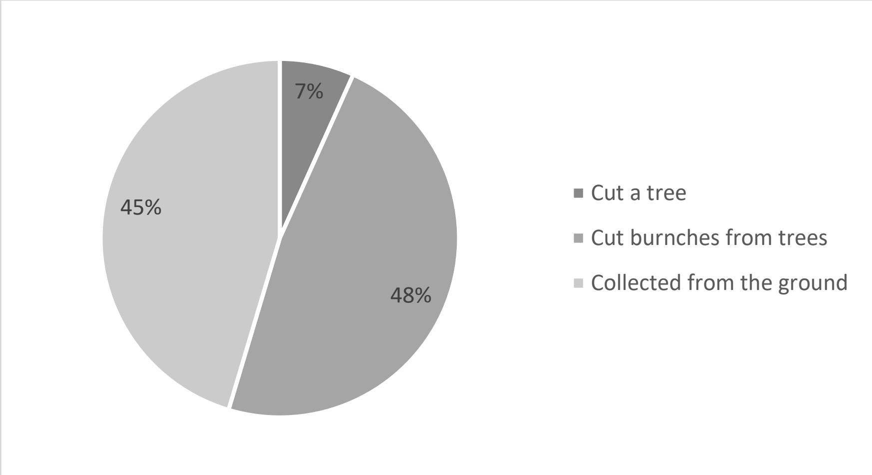


Figure 43: Wood harvesting methods

The reason of the preference for ground collection and branch cutting can be identified in the fact that the size of fuel used is generally small. Branches are easy to transport, cut and light up, furthermore they are abundant on the ground and on the lower parts of trees. The mean daily fuel consumption, calculated from fuel bundle weighing which was carried out as part of the survey, is 9 kg per day per household (Table 27).

Table 27: Mean fuel consumption (kg/day/hh)

Mean	**9.1**
SD	4.1
COV	47%
Min	3
Max	20

Coefficient of variation and standard deviation of the fuel consumption data are rather high and minimum/maximum values span from 3 kg up to 20 kg per day. This high variability may be related to subjective estimation on how long the weighed fuel bundle would have last and the kinds of meals cooked. For instance, legumes and preparation of alcoholic beverages require long cooking compared to mantioca mush or pancakes. The value of mean daily fuel consumption assessed during the survey was then compared to the results of the 3-day wood consumption assessment performed during the field visit. Mean values are nearly equal, showing that the survey provides a good estimate of the daily wood consumption of a family (Table 28).

Table 28: Mean fuel consumption form the three-day fuel assessment (kg/day/hh)

Mean	**9.2**
SD	5.5
COV	55%
Min	3.0
Max	14.5

During the site visit, the urban area of Pebane was investigated regarding the king of cooking technologies used in the area. The results of the analysis point out that around 65% of the sampled families uses traditional charcoal stoves, resulting in a much lower share than 95% in Maputo and Pebane urban areas. The remaining families (35%) prefer the three-stone fire.

The high number of households which use three-stone fire may be explained by the abundance of wood resources in some outskirt areas of Pebane. Indeed, by geo-referencing the sampled households it is clear that the ones using the three-stone fire are located nearby mangroves or per-marine areas (yellow arrows in Figure 42), which are rich in woody biomasses. On the contrary, households located nearby the city centre, far from wood sources prefer to use charcoal as cooking fuel.

Figure 44: Map of Baseline survey in Pebane. Blue placemarks locate households using charcoal stoves, yellow placemarks families using three stone fire. Arrows point wood supply areas.

The charcoal consumption assessment in Pebane shows that the mean daily consumption per household is 2.75 kg which is 17% higher than in Maputo (Table 29). However, the consumption of charcoal per standard adult is lower than in Maputo. The prices of charcoal in Pebane is generally cheaper than in Maputo, mainly because it is produced locally. As a consequence, households are used to purchasing big bags (around 30 kg) rather than buy small quantities every day. The mean price of charcoal bags is 150 MZN per bag (around 2.4 USD).

Table 29: Comparison of Maputo and Pebane baseline charcoal consumption

	Units	Maputo	Pebane
Mean Consumption Per hosehold	kg/day	2.35	2.74
Standard Adults	n	4.1	7.2
Charcoal price	MZN	12	5
Mean consumption per standard adult	Kg/day	0.57	0.38

4.3 Assessment of GHG emission reduction

Calculation of emission reduction is related to the lower consumption of fuel achieved through the use of efficient cookstoves. In order to calculate both ex ante and ex post emission reduction it is necessary evaluate the number of days the project technologies have or will be used by households.

4.3.1 Maputo/Pemba programme emission reduction

The stove database of the Maputo/Pemba programme reports the records of stoves sold and expected sales from October 2016 and it has been used to calculate the cumulative number of days the family make use of project stoves. Figure 45 reports the number of stoves distributed within the Gold Standard pilot project in 2014 while Figure 46 reports the stove distributed within the CDM project and the expected sales starting from October 2016. The total number of days the families have been using the project stove is calculated based on this data and the share of families involved in the project.

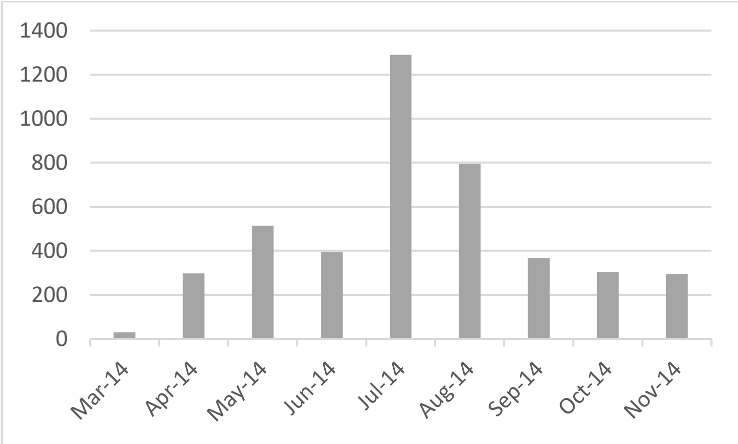


Figure 45: Number of stoves distributed GS pilot Project

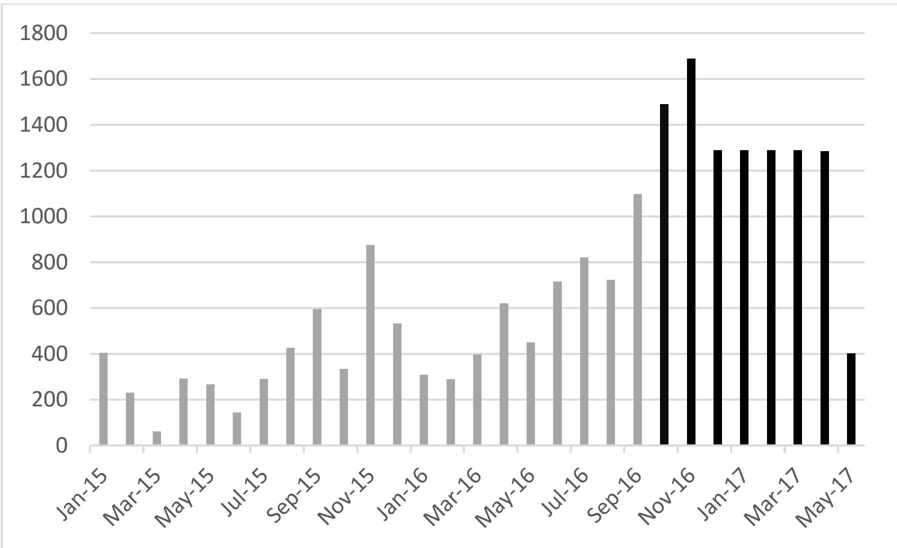


Figure 46: Number of stoves distributed CDM Project (grey) and expected sales (black)

The cumulative number of households involved in the Maputo/Pemba programme at September 2016 is 11,479, expected to rise at 19,888 by the end of 2017.

Based on the data collected on the field with the usage surveys, the KTPs and the selling database, it is possible to calculate fuel reduction achieved at the end of second monitoring period for the GS project (March 2016) and at the end of first monitoring period for the CDM Project (January 2016). These values are presented in Table 30.

Table 30: Emission reduction Maputo/Pemba programme

	$N_{p,}$	$U_{p,}$	$P_{p,b,}$	Fuel Saved	Emission Reduction
	days	%	Kg/day	tons	tons CO_2 eq.
GS 1st Monitoring	455,460	94%	1.71	732	7,237
GS 2nd Monitoring	1,163,985	79%	1.46	1,343	13,271
CDM	483,556	87%	1.71	719	7,111

The total amount of emission reduction achieved by the end of September 2016 is estimated to be 27,618 tons of CO_2 equivalents, around 5.32 tons of CO_2 eq. per household. The average emission reduction per household per day is 13 kg of CO_2 equivalent. The emission factor used, calculated as described in paragraph 3.6.1, is 9.4 kg/CO_2 eq. per Kg of fuel used.

As previously underlined, this study also provides an assessment of potential ex ante emission reduction. In this case, the calculation of fuel reduction is based on the difference between thermal efficiency of baseline and project technology, as calculated during laboratory tests. The first estimation was performed before the implementation of both GS and CDM project and it is presented in table 31.

Table 31:Ex Ante emission reduction Maputo/Pemba project

Year	μ_{hold}	μ_{new}	Fuel Saving (kg/day/hh)	Emission reduction (tCO_2 eq.)	
				GS	CDM
1	0.21	0.38	1.05	4,733	5,025
2	0.21	0.37	1.02	11,692	23,306
3	0.21	0.36	0.98	11,266	55,366
4	0.21	0.35	0.94	10,815	56,634
5	0.21	0.34	0.90	10,338	54,136
6	0.21	0.33	0.85	9,832	51,486
7	0.21	0.32	0.81	9,294	48,670
TOTAL				67,971	294,623

The first ex ante assessment of emission reduction did not include drop off rate since they were difficult to estimate. The total amount of ex ante emission reduction estimated for the Maputo/Pemba programme are 362,594 tons of CO_2 equivalent, of which 19% from the GS project and 81% for the CDM project. Results of the comparison of ex ante and ex post emission is provided in Figure 47.

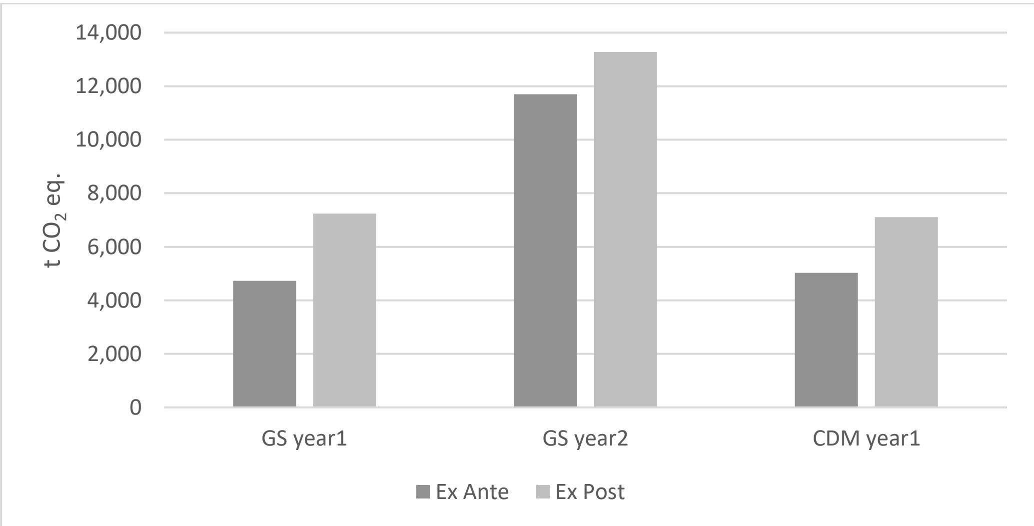


Figure 47: Comparison of ex ante and ex post emission reduction

Ex ante emission reduction calculation underestimated the real emission reduction achieved as per ex post assessment. This difference is considered particularly relevant since ex post emission reduction takes into consideration discount rates as well. The differences in ex post and ex ante emission reduction can be explained analysing mean daily fuel saving per household (Table 32).

Table 32: Comparison of ex ante and ex post fuel saving and differences in stove thermal efficiencies

	Mean fuel saving (kg/day/hh)			Δμ old/new	
	Ex ante	Ex Post	Δ	Ex ante	Ex Post
Year 1	1.05	1.72	64%	45%	74%
Year 2	1.02	1.46	44%	43%	62%

The first-year estimation of ex ante fuel saving is 1.05 kg/day/hh of charcoal. This saving has been calculated from the difference in thermal efficiencies between traditional charcoal stove and CH2200 which is 45%. The ex post fuel saving, calculated as result of on field data collection, is 64% higher. This demonstrates that real on field difference of stove thermal efficiency is more likely to be around 74%. This can be related to differences in thermal efficiency of the traditional charcoal stove tested in laboratory and the traditional stoves used on field, which is more likely to be around 10% than the 21% calculated in laboratory. This may be due to the age and poor quality of the materials of the stoves used in Maputo and Pemba. The difference of ex ante and ex post fuel saving for the second year of stove usage although high, decrease to 44%. This may be due to a reduction of thermal efficiency due to CH2200 aging is higher than the 10% supposed for ex ante estimation and it is close to 28% loose of thermal efficiency yearly.

At present, the Maputo/Pemba programme seems to perform better than expected before project implementation. It has to be pointed out that the first comparison between ex ante and ex post project emissions was conducted in 2015 for the GS pilot project. The achieved emission reduction during the first year of activity was 53% higher than expected and this was one of the main reasons behind the implementation of the scale up in 2016 with the CDM project.

The emission factor used to calculate both, ex ante and ex post GHG emission reduction are form IPCC, as described in paragraph 3.6.2. The value used is 9.88 kg CO_2 eq. per kg of fuel saved. This value was used with the purpose to calculate emission reduction eligible to generate Carbon Credits for both the voluntary and the regulated carbon market. However, it is conservative and it does not include all the emissions caused by charcoal lifecycle. Indeed, it does not encompass GHG emission generated during the production process. Furthermore, it is not technology dependent since it provides mean values for a given fuel instead of a given technology.

This study also provides an analysis of potential GHG emissions arising along the supply chain of charcoal. The emission factors for the stages of charcoal life cycle are reported in the following table.

Table 33: Charcoal emission factors (life cycle method)

Phase	**Kg CO_2eq./kg charcoal**	
Carbon loss in forests	2.77	
Production	8.93	
Combustion	Traditional	CH2200
	3.22	4.51
TOTAL	**14.92**	**16.21**

Emission factor for charcoal combustion depends on the cooking technology used. However, charcoal production is the stage of the supply chain with the highest impact. Emission factors calculated with the life cycle method are higher than the one from the IPCC default value, 55% in the case of traditional charcoal and 64% for the CH2200.

As a result, emission reduction achieved through project activities and calculated with the life cycle method are greater than the ones calculated with

IPCC values. Figure 48 provides a comparison of daily emission reduction per household for year 1 and year 2, calculated with both methods.

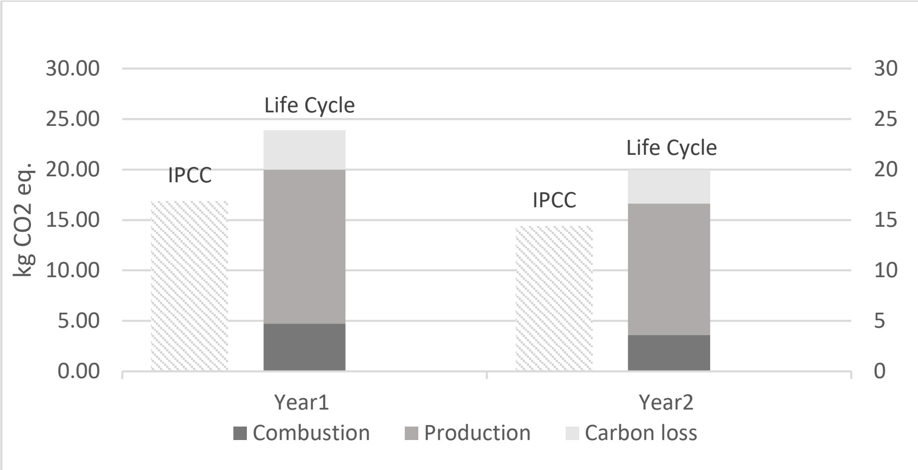


Figure 48: Comparison of daily emission reduction per household using IPCC and Supply chain emission factors

During the first and second year of activity, daily emission reduction per household are estimated to be respectively 23.88 $kgCO_2eq.$ and 19.55 $kgCO_2eq.$, compared with the 16.90 $kgCO_2eq.$ and 14.43 $kgCO_2eq.$ calculated with IPCC EF. Total ex post emission reductions are estimated to be 61,454 $tCO_2eq.$, 122% higher compared with ER calculated with IPCC method. Figure 49 reports ex ante emission reduction, which are estimated to be 529,698 tons of CO_2 eq., overall 46% higher than calculated with IPCC EF.

Assessment of the emission reduction throughout the entire charcoal supply chain is considered to be more realistic than the use of IPCC default emission factor. However, there are some uncertainties related to estimation of charcoal production emissions and loss of carbon in forests. By consequence, following a conservative approach, it cannot be used to assess emission reduction with the purpose of carbon credit issuance.

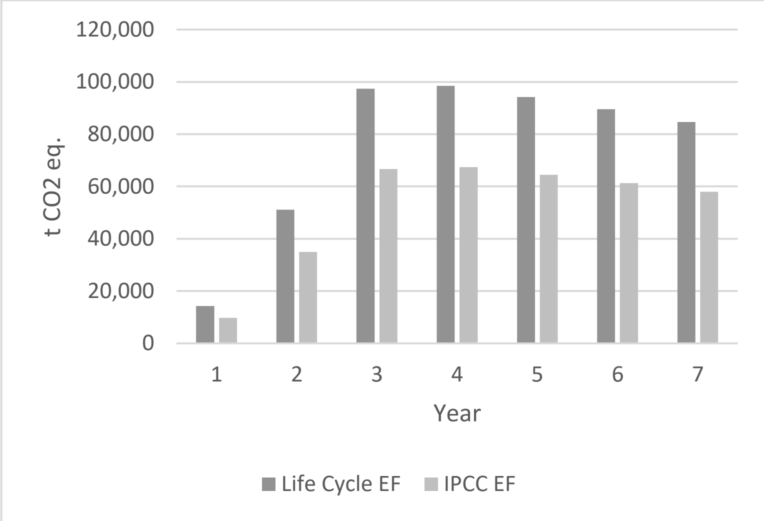


Figure 49: Comparison of Ex ante emission reduction calculated with IPCC and Life Cycle emission factors

The emissions which account for carbon loss from wood left to decay in forest do not encompass carbon loss from belowground biomasses. This is because it not clear what are be the chemical or biological processes which interested carbon content of belowground biomasses once the tree has been cut. However, it is possible to estimate potential contribution to charcoal life cycle in the hypothesis that all this carbon is emitted as CO_2 in the atmosphere, which is 3.6 kgCO_2 eq. per kg of charcoal burned.

During the site visit in the Gilè natural reserve, it has been visually observed an extreme degradation of soil as result of charcoal production activities, with important losses of soil organic carbon. These emissions should be included in the EF for charcoal use, however, further studies are needed to investigate emission patterns from degraded forest soil as result of charcoal production.

4.3.2 Gilè programme GHG emission reduction

The distribution of 4.000 efficient Rocket Works stoves in the Gilè project area is expected to start in April 2017. The first assessment of ex ante emission reduction was based on the data collected during the site visit and the laboratory test performed on three-stone fire and Rocket Works.

The Gold standard emission factor for baseline daily fuel consumption is 1.35 kg per household which heavily underestimates the real on-field fuel consumption as estimated during the October site visit. Therefore, this last value (9.1 kg/day/hh) has been used with the purpose of estimating ex ante emission reduction. An extensive baseline KPT will be performed in 2017 to confirm this value.

Table 34: Ex ante emission reduction Gilè programme

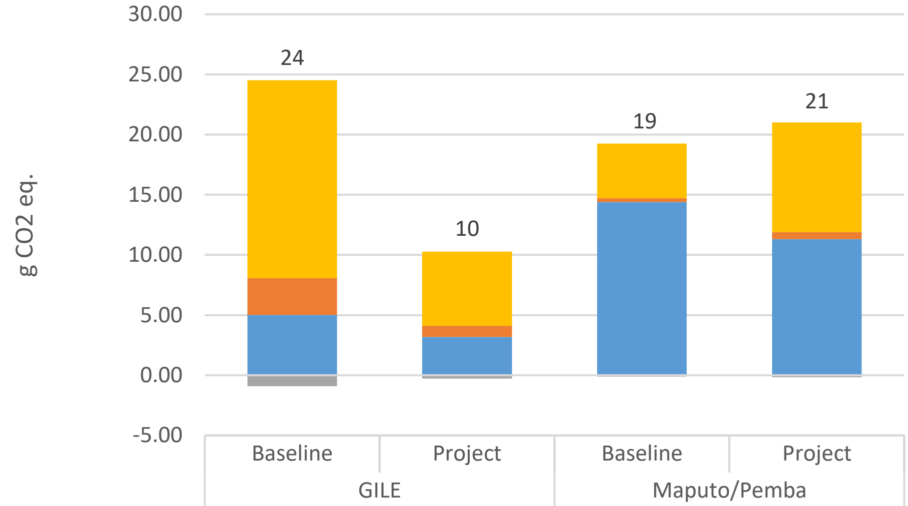
Year	μ_{hold}	μ_{new}	Fuel Saving (kg/day/hh)	Emission reduction (tCO_2 eq.)
1	0.15	0.33	4.96	3,322
2	0.15	0.32	4.83	8,459
3	0.15	0.31	4.70	8,094
4	0.15	0.30	4.55	7,704
5	0.15	0.29	4.39	7,288
6	0.15	0.28	4.23	6,842
7	0.15	0.27	4.04	6,363
TOTAL				48,070

The ex-ante estimation of potential emission reduction, for the 7 years crediting period is estimated to be 48,070 tons CO_2 eq.

The fuel consumption survey performed in Pebane Urban Area allowed to estimate a mean daily fuel consumption of 2.74 kg of charcoal per household. Substituting traditional cooking technologies with the CH2200, the potential fuel saving per household would be of 1.23 kg/day/hh. This corresponds to a potential emission reduction of 12 $kgCO_2$ eq. calculated with IPCC EF and 16 $kgCO_2$ eq. considering the charcoal life cycle.

4.4 Emission reduction of other climate pollutants

Inefficient biomass combustion leads to the emission of substances other than GHGs, which contribute to climate change. Laboratory tests demonstrate that efficient cook stoves have the potential to reduce emissions of such substances, which are mainly products of incomplete combustion. Figure 50 reports the emission factors for climate pollutants related to the combustion of 1 MJ of fuel in the baseline and project technologies.



	GILE Baseline	GILE Project	Maputo/Pemba Baseline	Maputo/Pemba Project
VOCs	16.46	6.18	4.54	9.12
Organic Carbon	-0.92	-0.28	-0.10	-0.17
Black Carbon	3.05	0.92	0.34	0.58
CO	5.01	3.18	14.39	11.31

Figure 50: Emission factors of climate pollutants other than GHGs in gCO_2 eq. per MJ of fuel burned

The three-stone fire has the highest emission factor among the project technologies (24 gCO_2eq./MJ) while the rocket stove has the lowest (10 gCO_2eq./MJ). Volatile organic compounds have the higher contribution to EF of woody stoves while CO greatly contributes to EF of charcoal stoves.

Overall, emission saving of climate pollutant (CP) is estimated to be 23,555 tCO_2eq. for the Gilè programme and 17,872 tCO_2eq. for the Maputo/Pemba (Table 35).

The contribution of CP to Gilè programme emission reduction can be relevant, representing up to 33% of total emission reduction achievable through project activities. This contribution is less relevant in the Maputo/Pemba programme and it represents 3% of total emission reduction.

Table 35: Climate Pollutant emission reduction in tCO_2eq.

Year	Gilè	Maputo
1	1,433	498
2	3,769	1,772
3	3,739	3,346
4	3,707	3,353
5	3,673	3,168
6	3,636	2,972
7	3,596	2,763
TOTAL	**23,555**	**17,872**

4.5 Reduction of health damaging pollutants

It is not in the scope of this study to provide an assessment of health effects related to exposure to product of incomplete combustion. However, it possible to estimate emission reduction of such pollutants related to the use of efficient cooking technologies. Pollutants targeted in this study are particulate matter, NO, NO_2 VOCs and Carbon Monoxide. Results are reported as the difference between baseline and project scenario (Table 36). Calculation is based on the average daily fuel saving per household over the seven years of project activities.

Table 36:Health pollutant emission reduction

Substances	Gilè		Maputo/Pemba	
	g/day/hh	Δ	g/day/hh	Δ
CO	256.4	-71%	296.9	-57%
NO	3.977	-73%	0.733	-62%
NO2	0.949	-62%	0.115	-47%
VOCs	133.1	-83%	-2.483	+11%
PM1	2.179	-86%	0.008	-6%
PM2.5	3.981	-88%	0.228	-43%
PM10	4.382	-89%	0.601	-56%

The distribution of Rocket Works in Gilè area is expected to generate substantial benefits for household health. All pollutants emission in the project scenario decrease substantially. Emissions of Carbon Monoxide and fine particulate matter ($PM_{2.5}$ and PM_1), which are the most dangerous pollutants in biomass smoke, are expected to decrease respectively by 71%, 88% and 86%. Such a high reduction is due to the high efficiency of the Rocket Stove and is one of the reasons why this cooking system has been chosen.

Maputo/Pemba programme activity are also expected to show to a reduction in health damaging emissions, except for VOCs. Volatile organic compound emissions are expected to be 11% higher in the case of families using project technology. Emission of all the other substances are expected to decrease, although less widely compared with Gilè project. Estimated reduction of PM_1 is only 6%. Carbon Monoxide and $PM_{2.5}$ are 57% and 43% lower than in the baseline scenario.

4.6 Fuel cost savings

In Maputo and Pemba households have to dedicate a substantial amount of their income to buy fuel. In Maputo, the price of charcoal is 12 MTZ per kg. On average, a family using the traditional charcoal stove spends around 12 meticais per day to purchase fuel, 874 MTZ per month (11 USD). Although it may appear a relatively low amount of money, for families living under the poverty line (less than 1.90 USD) it represents an important part of the family budget. The reduction of fuel consumption with the use of CH2200 stoves, may have important economic benefits for families involved in the programme. Table 37 reports the yearly saving per household in Meticais and dollars. During the first year of stove usage, when fuel saving is highest, a family using the CH2200 in Maputo can save up to 7,500 meticais which are equivalent to 119 USD (October 2016 exchange rate).

Table 37:Yealry money saving for household (MZN and USD)

Year	MZB	US
1	7,490	119
2	6,395	102
3	4,289	68
4	4,117	65
5	3,936	62
6	3,743	59
7	3,538	56
TOTAL	33,507	532

The cost of a CH2200 (included import taxes and international transport), is around 20 USD and it is sold to household at 600 MTZ (8.6 dollars). Thanks to fuel saving, the stove payback time is only 25 days, less than a month.

To encourage household investments in efficient cooking devices, the CH2200 is often paid in instalments. This is necessary to face the completion of a traditional stoves whose price is around 100 MTZ for the single fire and 350 for the double fire (baseline assessment). Indeed, it is necessary a strong marketing approach to support stove diffusion and related benefits. Marketing strategy and money saving have been the strongest elements that guarantee the success of stove distribution in Maputo and Pemba.

It is not in the scope of this study to present a financial analysis of the stove programmes and contribution of Carbon Finance. However, project implementers confirmed that income from Carbon Credits selling are essential to subsidize stove selling and therefore guarantee success of Maputo/Pemba projects.

Charcoal in Pebane is much cheaper than in Maputo and potential saving related to the use of efficient stoves are lower. A household using a CH2200 during the first year would save 2263 meticais, corresponding at 36 USD.

Regarding the Gilè programme, no substantial economic benefit can be related to the use of efficient stoves, since wood is harvested by households and therefore free of charge. Furthermore, families declared that fuel harvesting does not represent a demanding task and does not subtract relevant amount of time to other family activities.

4.7 Reduction of deforestation and land degradation

Charcoal production is one of the main causes of deforestation and land degradation. The main reason is the large quantity of charcoal used in urban areas and the inefficiency of the charcoal production process. The wood to charcoal ratio used in this study is 6, although some studies in Mozambique estimate this ratio may be up to 7.16 (Falcão 2008). In order to reduce pressure on forests, a decrease in charcoal demand is to be targeted rather than intervening on the efficiency of the production process. The supply basins in Mozambique are located nearby forests, which are tropical dry Miombo forests. Minor supply basins may be located in Mangrove forests, particularly in coastal areas such as Pebane district. This study provided an assessment of forest area not impacted (in hectares) thanks to demand reduction achieved with Maputo/Pemba programme. It has been supposed that all wood comes from Miombo forests, where the average carbon content is 63 tC/ha. The use of efficient stoves in Maputo/Pemba will reduce the demand of charcoal avoiding to cut 265,515 tons of wood. The total area of forest not affected by charcoal production as a result of Maputo/Pemba programme is estimated to be of 2,003 hectares.

Table 38: Avoided deforestation due to Maputo/Pemba programme

Year	Saved Wood (tons)	Avoided Deforestation (hectares)
1	7,226	54
2	25,918	193
3	49,344	368
4	49,949	373
5	47,745	356
6	45,408	339
7	42,925	320
TOTAL	268,515	2,003

In Gilè programme area, the impact of cooking activities on forest is estimated to be limited. Only 7% of the families interviewed during the baseline survey declared to cut trees to collect wood. Overall, the use of the rocket works stove in the area is estimated to reduce deforested area of 99 hectares.

5 Conclusions

This study assesses the potential benefits related to two efficient cookstove programmes developed in in Mozambique. These benefits regard the reduction of climate impact related to cooking activities, the decrease of anthropic pressure on forests, economic saving for the beneficiary households and reduction in health pollutant emissions.

The research work encompasses both laboratory test and field data collection. Laboratory tests were aimed to provide an assessment of the traditional and improved stove performances used within the project areas: traditional charcoal stove and CH2200 efficient stove for the Maputo/Pemba programme and three-stone fire and Rocket Works for the Gilè programme. The laboratory was specifically designed to assess stove efficiency metrics and emission of pollutants in the combustion exhausts. Efficient stoves, independently of the fuel used, have a better thermal efficiency and lower specific fuel consumption and firepower than traditional baseline stoves. Furthermore, efficient stoves have higher CO_2 emission factors which indicate an improved combustion and an overall reduction of product of incomplete combustion. Field data collection was aimed to provide real data on fuel consumption during baseline and project scenarios, efficient stove adoption and penetration among households, as well as on population perception of social and environmental benefits related to efficient cookstove usage. Baseline surveys confirmed that preferred cooking system in urban areas, where the Maputo/Pemba programme has been implemented is the traditional charcoal system while in the rural area of Gilè it is the three-stone fire. The families involved in the Maputo/Pemba activities respond well to the introduction of the CH2200, with very low technology drop off rates after the second year of project activities. Overall, the efficient stove allows to decrease significantly the amount of charcoal used compared to baseline situation. Efficient stove activities have the potential to reduce use of wood also in the Gilè programme, based on the baseline fuel consumption assessment and increased thermal efficiency of

Rocket Works stove as assessed during laboratory tests. This reduction needs to be confirmed by further surveys after stove distribution.

Both efficient cooking stoves are estimated to reduce the impact on climate caused by cooking activities. This reduction is more consistent for the Maputo/Pemba programme, not only because of the higher number of stove distributed but also because emissions related to charcoal supply chain are much higher than for wood. Furthermore, reduction in fuel consumption and improved combustion efficiency reduce emissions of air pollutants with potential benefits on health. However, further studies are needed to assess exposure to such pollutants which vary depending on the location of cooking areas (outdoor/indoor) and the time people spend attending the stove.

Thanks to the use of efficient cooking technologies, families involved in the Maputo/Pemba project have been able to save a consistent amount of money which were dedicated to fuel purchase. This saving is particularly important for families living in the project areas, which interest poor suburbs were the majority of households live under the poverty line. Charcoal production is considered one of the main causes of deforestation in Mozambique, due to the high demand and inefficiency of carbonization process. Reduction of charcoal demand achieved through the distribution of efficient stoves, have the potential to reduce deforestation and land degradation of Miombo forest areas. On the other side, the consumption of wood in Gilè rural area seems to have a limited impact on forests, since wood resources are abundant in the area.

The two cookstove programmes aim to generate Carbon Credits to be sold either on voluntary and regulated carbon markets. Incomes from Carbon Finance are necessary to assure economic sustainability of the projects. Furthermore, they allow project developers to sell stoves at a highly-subsidized price, encouraging the diffusion of efficient cooking technologies.

This study is part of a research on ongoing stove projects. Further information, data and testing material will be available in the following years. It has been planned to import traditional stoves from the field to assess their efficiency instead of using a copy made in Italy which may has a higher efficiency. Furthermore, efficient stoves will be tested to investigate efficiency drop over years and durability. Nitrous Oxide was not included in the pollutants measured during laboratory tests. It would be recommended to include a N_2O sensor to avoid using default emission factors. Reduction of health damaging pollutants is one of the most valuable benefits related to clean cookstove use. Portable measurement devices cloud be used to monitor household exposure to such emissions during further field data collection. Furthermore, these devices can be used to measure emissions during charcoal production processes, providing additional information on charcoal supply chain impact on climate.

ANNEX I:

Sample of project monitoring survey questionnaire

INQUERITO DE MONITORIA (CARBON SINK GROUP – AVSI)

DADOS GERAIS		
1. Nome do Inquiridor		
2. Data do inquérito (mm/dd/aaaa)		
FINAL – DADOS DO USUÁRIO		
3. Nome		
4. Género	Masculino / Feminino	
5. Nº do BI		
6. Telefone		
7. Endereço	Rua, Avenida, Beco	
	Nº da casa	
	Nº do Quarteirão	
	Bairro	CHAMANCULO C
8. Número de membros da família (pessoas para quem você cozinha todos os dias	Crianças de 0-14 anos	
	Meninas > de 15 anos	
	Homens entre 15-59 anos	
	Homens > de 60 anos	
DADOS DO FOGÃO EFICIENTE		
9. Quantos fogões eficientes a carvão possui?	a. Zero b. Um, indique o nº de identificação________________________ c. Dois, indique os números de identificação_____________ e _________________ d. Mais (*especifique quantos fogões e os números de identificação*) •	
10. A quanto tempo você tem o fogão eficiente a carvão? (*indique em meses*)		___________ meses
• Segundo fogão (*se aplicável*)		___________ meses
11. Você ainda está a usar o (s) fogão (ões) eficiente(s)?		Sim / Não
12. Se sim, o seu fogão eficiente está em bom estado de conservação? •		Sim / Não

• Segundo Fogão *(se aplicável)*	Sim / Não
13. Para que tipo de alimentos(cozinha) você usa o (s) fogão (ões) eficiente (s) a carvão	a. Doméstica b. Comercial c. Ambas, doméstica e comercial d. Institucional (*especifique*): •
14. Você usa o fogão todos os dias? Quantas refeições você prepara com o(s) fogão (ões) eficiente (s) por dia (*Indique o número de refeições diárias*)	Sim / Não Se sim por favor indique com que frequência usa o fogão. Refeições por dia: ____________
DADOS DO FOGÃO TRADICIONAL	
15. Você usa outros fogões além do fogão a carvão eficiente?	Sim / Não

16. Se sim, que tipo de fogão você usa?	Quantas refeições você preparou com este fogão na semana passada? (*indique o nº de refeições em semanas)*
a. Fogão a carvão tradicional, 1 boca	Refeições/Semana
b. Fogão a carvão tradicional, 2 bocas	Refeições/Semana
c. Fogão eléctrico	Refeições/Semana
d. Fogão a gás	Refeições/Semana
e. Outro fogão (*especifique*)_________	Refeições/Semana

HÁBITOS DE COZINHA		
17. Local para cozinhar	Fogão eficiente	• Outros fogões
	a. dentro de casa b. aberto c. semi aberto	d. dentro de casa e. aberto f. semi aberto
18. Você usa diferentes fogões em diferentes estações (Seca/Húmida)	Sim / Não	
19. Se sim, por favor especifique as diferenças (tipo de fogão usado em cada estação)	Estação húmida a. Fogão tradicional a carvão, 1 boca b. Fogão tradicional a carvão , 2 bocas c. Novo fogão eficiente d. Fogão eléctrico e. Fogão a gás f. Outro fogão (*especifique*)___________ Estação seca a. Fogão tradicional a carvão, 1 boca b. Fogão tradicional a carvão , 2 bocas c. Novo fogão eficiente	

	d. Fogão eléctrico e. Fogão a gás f. Outro fogão (*especifique*)__________
20. Você usa fogões diferentes em ocasiões diferentes (*fins de semana, férias ou festivais*)?	Sim / Não
21. Se sim, especifique por favor as diferenças (*tipo de fogão usado em cada ocasião*)	**Fins de semana** a. Fogão tradicional a carvão, 1 boca b. Fogão tradicional a carvão , 2 bocas c. Novo fogão eficiente d. Fogão eléctrico e. Fogão a gás f. Outro fogão (*especifique*)__________ **Férias** a. Fogão tradicional a carvão, 1 boca b. Fogão tradicional a carvão , 2 bocas c. Novo fogão eficiente d. Fogão eléctrico e. Fogão a gás f. Outro fogão (*especifique*)__________ **Festivais / Cerimónias** g. Fogão tradicional a carvão, 1 boca h. Fogão tradicional a carvão , 2 bocas i. Novo fogão eficiente j. Fogão eléctrico k. Fogão a gás l. Outro fogão (*especifique*)__________ **Outras ocasiões (*especifique por favor*)** a. Fogão tradicional a carvão, 1 boca b. Fogão tradicional a carvão , 2 bocas c. Novo fogão eficiente d. Fogão eléctrico e. Fogão a gás f. Outro fogão (*especifique*)__________
22. Existem variações na quantidade dos alimentos cozinhados, por exemplo por causa das estações seca/húmida, épocas festivas, férias escolares ou nos fins de semana?	Sim / Não
23. Se sim, especifique por favor as diferenças	a. Nós cozinhamos mais para a festa de ________________

	b. Nós cozinhamos mais na estação ________________ c. Nós cozinhamos menos no período de ___________ porque_____________ d. Outros (*especifique por favor*): ________________________________		
24. Você usa o fogão para aquecimento? •	Sim / Não		
25. Se sim, especifique por favor o período:	1. Janeiro □ 2. Fevereiro □ 3. Março □ 4. Abril □ 5. Maio □ 6. Junho □ 7. Julho □ 8. Agosto □ 9. Setembro □ 10. Outubro □ 11. Novembro □ 12. Dezembro □		
26. Você adoptou novas tecnologias para aquecimento de ambientes depois de comprar o novo fogão eficiente? • Se sim, qual?	Sim / Não _________________________		
27. Você já promoveu os novos fogões eficientes para parentes e amigos? • • Quantos deles efectivamente compraram um fogão eficiente?	Sim / Não _____ pessoas compraram um fogão eficiente depois da minha recomendação		
28. Você já vendeu ou ofereceu como presente aos seus parentes e amigos os seus fogões velhos depois de ter comprador os novos fogões eficientes? • Se sim, quantos fogões velhos você vendeu ou ofereceu?	Sim / Não _____ fogões velhos		
COMBUSTÍVEIS			
29. Que tipo de combustível você usa?	Sim / Não	Quantidade por mês (plásticos pequenos/ saco grande - com os kg equivalentes)	Preço por mês (MT)
a. Carvão			
b. Lenha			
c. Outros combustíveis (*especifique*) _____________			
30. Como você obtém o combustível? a. Carvão			

As fontes de combustíveis	Esforço despendido
□ Comprado em (*insira o lugar de compra*):_________________________________	□ Distância percorrida: ________ km
□ Colectado à mão	□ Custo da viagem:________Mt
□ Colectado à mão e transformado	□ Pessoas que colectam/Horas de colecta/Transformação por semana:_________________
□ Outro (*especifique*):_________________	

b. Lenha

As fontes de combustíveis	Esforço despendido
□ Comprado em (*insira o lugar de compra*):_________________________________	□ Distância percorrida: ________ km
□ Colectado à mão	□ Custo da viagem:________Mt
□ Colectado à mão e transformado	□ Pessoas que colectam/Horas de colecta/Transformação por semana:_________________
□ Outro (*especifique*):_________________	

c. Outros combustíveis (*especifique*)__________

As fontes de combustíveis	Esforço despendido
□ Comprado em (*insira o lugar de compra*):_________________________________ ____	□ Distância percorrida: ________ km
□ Colectado à mão	□ Custo da viagem:________Mt
□ Colectado à mão e transformado	□ Pessoas que colectam/Horas de colecta/Transformação por semana:_________________
□ Outro (*especifique*):_________________	

31. Você usa diferentes combustíveis em diferentes estações?	Sim / Não

32. Se sim, especifique por favor a razão e as diferenças entre os diferentes períodos	Estação seca a) ____________________________________ __________________ b) ____________________________________ __________________ c) ____________________________________ __________________ Estação húmida a) ____________________________________ __________________ b) ____________________________________ __________________ c) ____________________________________ __________________

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