UNIVERSITY OF CAPE TOWN

Department of Chemical Engineering

INVESTIGATION OF THE APPLICABILITY OF A CLEANER PRODUCTION APPROACH TO ROAD SIDE CATERING IN URBAN AFRICA

A thesis submitted for the degree of
Doctor of Philosophy
May 2017

By
Rissa Vénérande Niyobuhungiro

Supervised by:
Prof. Harro von Blottnitz
University of Cape Town

PLAGIARISM DECLARATION

I Rissa Vénérande Niyobuhungiro, declare that this thesis is based on my own work, save for that which is properly acknowledged. It is being submitted for the degree of Doctor of Philosophy in Engineering in the University of Cape Town. It has not been submitted before for any degree or examination in any other University.

Student number: nybris001

Signature: Signed by candidate

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ABSTRACT

In urban Africa, informal street food trade is often accompanied by processing activities, including slaughtering, brewing, grilling or cooking. Food and drinks are often prepared on open fires using wood as a fuel. When wood is used as a fuel, it generally emits smoke containing various pollutants.

Previous studies showed that limited capital, lack of education and expression are the main barriers to the implementation of new technologies in the informal sector. It has been argued that the use of cleaner technologies, especially those relevant for the energetic aspect of informal production, would provide affordable net benefits to society in terms of public health, climate change mitigation and food security, but without showing how this could be done in a specific case.

This thesis investigated whether a cleaner production approach would be beneficial: economically and for health and safety to road side vendors in an informal context. The study aimed to provide insights as to whether government could show presence in such settings not only as (unwelcome) regulator, but in a supportive way by introducing cleaner and more efficient means of production, mainly clean-burning technologies in the informal food and drinks preparation.

The specific objectives of this thesis were to:

- Compare the resource usage and pollution loads associated with traditional vs. cleaner methods of informal roadside food and drink preparation;
- Establish whether the cost-savings deriving from increased resource efficiency of cleaner methods would be sufficient motivation for producers to adopt these;
- Observe and document other constraints to the adoption of cleaner methods of production by attempting to demonstrate resource efficiency gains and emission reductions possible under real conditions of informal food and drinks production.

Two cleaner technologies were considered: efficient wood stoves, which are known to have sizeable benefits in terms of reduced fuel wood usage and smoke emissions (though investigated to date mainly in the context of household energy usage), and anaerobic digestion, which can potentially serve simultaneously as receptacle and treatment for organic wastes, and produce biogas to serve fuel needs.

This study combined qualitative and quantitative field observations in a case study setting with experimental work to study the biogas production potential of slaughtering waste. The case study location, Nyanga township in Cape Town, served as a representation of the many urban African settings in which roadside catering occurs.

Nyanga township has both formal and informal housing. Its population including many unskilled and unemployed people also makes it a good place for informal activities.

One common informal economic activity in Nyanga is the production of cooked meals and drinks. This is done on street corners alongside the road around the transport interchange, where many people pass by and vendors provide various services. The cooked meals include roasted lamb, pork and beef. Live chickens are slaughtered and plucked, and also sold whole for home preparation. An African beer known as *umqombothi* is locally prepared in two processes, with each process involving approximately two hours of cooking using a 230 L drum.

In the field work, it was investigated how much wood was used in open fires compared to efficient wood stoves, specifically for the activity of chicken plucking and *umqombothi* mashing. The respective fuel costs were calculated and the air quality in the street-side work place were measured in term of levels of particulate matter less than 10 micron (PM_{10}).

It was observed in the field that in most cases sheep and chicken slaughter waste was dumped alongside the road. This dumping was due to the lack of slaughtering facilities in the area. Many other reports have stated that the lack of adequate infrastructure in informal settlements is the cause of inappropriate waste dumping.

The qualitative observations confirmed that the meat and other cooked meals were prepared using inefficient methods linked not only to the waste of resources but also to waste of money and exposure to polluted air from burning wood.

Air quality measurements showed smoke levels near open fires to be about 8 times higher than when using an efficient wood stove. PM_{10} levels of 4 900 ±1 500 $\mu g/m^3$ were measured near chicken pluckers using open fires for their hot water, while when using a stove the PM_{10} averaged 590 ± 130 $\mu g/m^3$. Smoke levels near biogas stoves were measured at 310 ±140 $\mu g/m^3$.

The stoves used in this study reduced the quantity of wood used for plucked chicken production by a factor of 6. This reflected a reduction in energy otherwise wasted around the pot in the inefficient traditional cooking method. Stove use reduced the solid waste as well as the smoke accordingly. If a stove lasted 3 years, the vendors would save an estimated R33 700 on fuelwood in case they used harvested wood, and if wood waste is used, the fuelwood savings over three years would be R6 300.

It was estimated that 100 kg of slaughtering waste dumped every day could generate enough biogas for 7 vendors to be provided with enough thermal energy for their catering trades. Based on the experimental work conducted, it was calculated that a digester of a size of 76 m^3 would be needed for this amount of slaughtering waste.

The main conclusions of the thesis are:

- Cleaner technologies, in the form of efficient wood stoves and biogas reactors and stoves, showed significant saving potential in the informal roadside food and drink production processes investigated in Nyanga, Cape Town.

- The wood stoves investigated in this study were suitable for chicken plucking (which use 25 L pots) but not for the mashing stage of *umqombothi* preparation (which is done in 230 L drums).
- The use of these stoves resulted in a 6-fold reduction in wood burned, as well as an 8-fold reduction in particulate air pollution in the work place. These stoves also offered a very fast payback time (of the order of a few weeks) and significant fuel wood cost savings to caterers.
- Biogas stoves were the cleanest of the three methods compared and should be affordable to caterers if a reasonably priced gas supply were available, but the biogas reactor installation represents an infrastructure investment that could not be paid for by the caterers.
- A biogas intervention would ensure the reduction of slaughter waste, which is often indiscriminately dumped and thus a significant health hazard.

The main recommendations of the study are:

- Since wood stoves would offer fast payback times for fuel wood using traders, the local economic development section of local government should aim to stimulate and develop local business to provide such stoves to caterers.
- While the slaughter waste can be used as a substrate for biogas generation, for it to become available to the vendors, local government should invest in this as a form of urban infrastructure.
- Slaughtering facilities should be built for the vendors where the waste can be kept together and may be used by the municipalities or other bodies.
- Similar studies in other developing countries are also encouraged, so as to develop the specific insights on the affordability of achieving benefits to society in terms of public health, climate change mitigation and food security worldwide.

Enough time should be allocated for research that combines social interactions in the field with scientific measurements.

ACKNOWLEDGEMENTS

Firstly, I thank the Lord God Almighty, my maker, my shelter, my rock, my all in all. With Him, all things are possible.

Secondly, I would like to express my sincere gratitude to my supervisor Professor Harro von Blottnitz, for the unremitting support of my PhD study and related research, for his patience, inspiration, and immense knowledge. His guidance, intelligence and humility helped me before and during all the time of research and writing of this thesis. In him, I saw a special mentor and advisor. I could not have imagined having a better supervisor and mentor for my research.

Thanks to the Organization for Women in Science for the Developing World (OWSD) for funding this PhD study. I could not do without you.

I would like to thank Professors Jenni Case, Pieter Levecque, and Jenni Broadhurst, for their insightful comments and encouragement, but also for the hard questions which helped me to widen my research from the narrow perspective I started from.

My thanks also to Prof Niyi Isafiade, and the rest of the EPSE research group. Thanks to Mrs Carol Carr, your enthusiastic assistance in so many ways is appreciated. Thanks to Dr Valentina Russo for reading through my drafts and for encouraging me. Dr Rethabile Melamu, you are such a God-sent sister, friend and advisor. Thank you for your endless devotion in helping me with various thesis related stuff as well as inspiring me generally.

Thanks to Miss Siphesile for helping me with isi *Xhosa* translations. Thanks to the Nyanga informal streets meat vendors and community. Your hard work in very difficult conditions is one of my motivation for this work. I hope that this work will bear fruits in the future in one form or another. Thank to Lesley, Gracia and Chucky for your honest friendship and love. Thanks to my UCT friends. I thank my friends from other institutions. Clemence Ingabire, you are such a friend, thanks for the many edits you did to this work. Thanks to my church community for the prayers and love. Mama Cibelle, thanks for stepping in whenever needed.

My sincere thanks go to my husband Timothy and my son Oriol. Your love and sacrifice during the time that I could not be there for you has encouraged me throughout this thesis, which I dedicate to both of you my men, as well as to my family: my parents and to my brothers and sisters for supporting me spiritually throughout writing this thesis and my life in general. Your love and prayers will forever be reciprocated.

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LIST OF ACRONYMS

AD	: Anaerobic Digestion
CCA	: Chromated Copper Arsenate
CEBER	: Centre for Bioprocess Engineering Research
CP	: Cleaner Production
CPCB	: Central Pollution Control Board (Ministry of Environment &Forests, Government of India)
CPHP	: Crop Post Harvest Programme
CSIR	: Council for Scientific and Industrial Research
E&PSE	: Environmental & Process Systems Engineering
EBE	: Engineering and Built Environment
EiRC	: Ethics in Research Committee
EPA	: Environmental Protection Agency
EWB	: Engineers without Borders
FAO	: Food and Agriculture Organization
FP_3	: Fine Particle Pollution Program
GDP	: Gross Domestic Product
GHG	: Greenhouse Gas
GJ	: Gigajoule
IEA	: International Energy Agency
IPCC	: Intergovernmental Panel on Climate Change
kPa	: kiloPascals
kW	: kilowatt
LPG	: Liquefied Petroleum Gas
MDG	: Millennium Development Goal
MNRE	: Ministry of New and Renewable Energy
NCPC-SA	: National Cleaner Production Centre of South Africa
OHS	: Occupation Health and Safety

PAHs	: Poly aromatic hydrocarbons
pH	: Potential of Hydrogen
PJ	: Peta Joule
PM	: Particulate Matter
RSA	: Republic of South Africa
SHAWCO	: Students Health and Welfare Centres Organization, University of Cape Town
SMEs	: Small and Medium Enterprises
SPCA	: Society for the Prevention of Cruelty to Animals
TAS	: Tactical Air Sampler
TEOM	: Tapered Element Oscillating Microbalance
TS	: Total Solids
UCT	: University of Cape Town
UK	: United Kingdom
UNCED	: United Nations Conference on the Environment and Development
UN-DESA	: United Nations Department of Economic and ocial Affairs
UNEP	: United Nations Environment Programme
UNFCCC	: United Nations Framework Convention on Climate Change
US EPA	: United States Environmental Protection Agency
VOCs	: Volatile Organic compounds
VS	: Volatile Solids
WHO	: World Health Organization

1 INTRODUCTION

1.1 Background: Cleaner Production in the Fuel-Wood Using Informal Economy

Even though the concept of cleaner production is not new, it remains largely unfamiliar in informal production contexts. Over the decades this business management philosophy has been introduced and used in many different countries, with many industry sectors relying on it in overcoming challenges, such as loss or inefficient use of raw materials or resources and the associated generation of waste and pollution.

The inefficient use of resources has, however, repeatedly been observed in small and informal businesses, particularly in developing countries. Regarding fuel wood, many studies, e.g. those by Hosier (1988), Karekezi et al. (2002b), Nissing & von Blottnitz (2007), Niyobuhungiro (2012), Knox (2012), have reported that 'wood' is a resource that is extensively used not just domestically by the poor for heating and cooking purposes, but also as energy source for informal business. In urban areas, harvested wood is rare and waste wood from demolitions or construction off-cuts is often cheaper and therefore used by the caterers in open fires (WHO 2012; Niyobuhungiro 2012; World Energy Outlook 2014). Such preparation processes are both inefficient and harmful to health as wood may contain poisonous chemicals used for wood preservation (Niyobuhungiro et al. 2013).

The informal economy consists not only of retail and service provision, but also of processing activities. The production of food and drink, referred to in this thesis as 'informal catering', is one of these production activities informally occurring in African cities. The following sections provide some further background on the phenomenon of informal catering in Africa, on Cleaner Production generally and on its use in South Africa.

1.1.1 Catering as part of the informal economy in urban Africa

This sub-section examines the similarities between the regional informal economies in Africa where wood is being used as a fuel in the food catering, contrasting the evidence from South Africa with reports from Kenya, Zimbabwe, and several West African countries (Ghana, Ivory Coast, Sierra Leone, Mali and Nigeria).

In all the cases, the people involved in the informal economy, specifically in food catering, are characteristically low income families with limited education. It is clear that street trading faces common challenges of poor sanitation, poor infrastructure, dirty environment and congestion. However, the role of the informal sector in providing employment and complementing the formal sector should be highlighted when considering its effects on the urban management system.

Statistics South Africa (2011) and Willemse (2011) define informal employees as those employees who do not have a written contract of employment who are not registered for income tax or value-added tax, and who do not receive basic benefits such as pensions or medical aid contributions from their employers. An informal economy includes a variety of types of employment and activities, such as transport, repair of old materials, catering, retail of fresh or prepared products, waste collection, personal services and so forth.

The informal economy plays a major role in the economy of many countries in Africa. For instance, in 2012, the informal economy was estimated to contribute between 8 and 10% of South Africa's GDP (Skinner 2012).

Informal trading positively affects the community, having been found to be a major source of provisioning for poor urban households. In addition, it is recognized that informal trading forms a vital part of any emerging economy and plays an important role in transitional and developing countries in facilitating successful adjustment to globalization and structural reforms. However, being mostly an urban phenomenon, the expansion of the informal sector may intensify problems connected with slums, congestion, health and environment (Guha-Khasnobis et al. 2006). In 2008, Horn noted that 72 % of non-agricultural employment in sub-Saharan Africa was informal and that 84 % of that employment is women. Horn (2008) noted that most new employment in Africa was in the informal economy and this serves as waiting area for workers, especially migrants, while they search for formal sector jobs. Given that many informal workers have a low level of education (Blaauw 2011), they do not get upgraded even when opportunities in the formal sectors are available.

1.1.1.1 Nigeria

A study by Ademola & Anyankora (2012) in Lagos, Nigeria revealed a relationship between employment in the informal sector and formal sector unemployment. According to Lawanson (2011), the informal sector is generally viewed as separate and outside the normal organized formal sector, providing employment and edibles through engaging in a variety of activities, such as street trading, hawking, local manufacturing and many others. Lawanson (2011) noted that the sector is characterized by small scale operations, labour intensive techniques, low-income families, private and indigenous ownership of enterprises that are largely unprotected by government.

In general terms, authors defined the main features of informal sector economic units to be: ease of entry; small scale of the activity; self-employment; little capital and equipment; labour intensive technologies; low skill; low level of organization with no access to organized markets, formal credit, education and training or services and amenities; low productivity and low income (Oshinowo 2007; Ademola & Anyankora 2012).

1.1.1.2 Ghana, Ivory Coast, Sierra Leone and Mali

A study by Nicolo et al. (2012) in four West African countries i.e. Ghana, Ivory Coast, Sierra Leone and Mali, showed the same characteristics in the informal food production due to the rapidly growing urban realities. In Ghana 80 % of migrants stay permanently and 70 % stay in urban areas, where Accra and Ashanti host more than half of the migrants. In Ivory Coast, 45 % of the population lives in urban areas. The city of Abidjan hosts more than 5 000 000 people but with less than 50 collective catering services or canteens.

These realities create a situation where formal services and infrastructures cannot keep pace with the increasing food demand of the population and this leaves room for the informal food sector to fill the gap and thrive. In the four cities studied using a sample of 400 street food vendors, 89 % to 98 % were women. The common food sold was garba (steamed cassava with vegetable and fish) in Abidjan, barbequed meat in Bamako, a variety of cooked food in Accra and Freetown as well as prepared local drinks (Otoo et al. 2011). These informal street food vendors had a secondary level of education which reflects their difficulty in accessing the formal jobs: 57 % in Freetown, 47 % in Accra, 30 % in Bamako but only 16 % in Abidjan. This industry employs, on average, more than 37 % of the labour force, and contributes about 38 % to total GDP in Africa, (ENV 2008; Nicolo et al. 2012).

Among the challenges discussed in this study, the way the cooked food is prepared and the effects that can have on both vendors and the environments was not clarified but only mentioned as a safety issues. Instead the major challenges identified were only the low capital, inadequate infrastructure and lack of training and support from the municipalities.

1.1.1.3 Kenya

Kenya is considered to be one of the most industrialized countries in East Africa, yet industry represents only 10 % of its GDP. The government estimates that 76.5 % (5.9 million people) of Kenya's labour force works in the informal sector, and that this labour force continues to grow each year. Recall that Kenya's informal sector consists of varied and dynamic small-scale activities that are not registered and are characterized by low productivity and income, (Kenya country report 2011).

In Kenya the second highest consumer of wood fuel after households are the small industries which include brick making, tobacco curing, fish smoking, jaggaries and bakeries. Other small industries include small restaurants and kiosks and learning institutions. In view of the importance of small industries for income and employment generation and wealth creation, their energy requirements need specific attention to ensure their sustainability (Muinde &Kuria 2005).

As Ahmed et al. (2014) noted, the informal food processors and vendors are key actors in the large informal economies typical of many African urban centres, including Nairobi. However planners and policymakers largely do not recognise the important role that informal food processors play in securing access to food for low-income consumers, providing income generating activities for poor residents and in contributing to the local urban economy. For example, in Mathare located in Nairobi, informal settlements, food processors and vendors face constant challenges in preparing and keeping their food safe to eat. It was reported that wood and agriculture waste and briquettes formed from charcoal chaffs are the main fuels used by the poor informal vendors and households due to other fuels being unaffordable (Kok & Balkaran 2014). Inadequate solid waste collection, surface water drainage and often non-existent sanitation infrastructures are hazards that affect both residents and vendors (Ahmed et al. 2014).

The diversity of activities in the informal sector and their connections with the formal manufacturing, services and agriculture industries make it hard to draw clear boundaries. The informal sector requires relatively very little per capita input to create jobs, can flourish with cheaper infrastructures, conserves scarce foreign exchange and depends largely on local raw materials (Kenya country report 2011).

1.1.1.4 Zimbabwe

In Zimbabwe, the informal sector uses four major fuels in their production activities: wood, paraffin, bottled gas and electricity. Nearly all the food vendors use wood for food preparation and are the major wood-consuming subsector. Since the technological capability is low, wood is used in open fires. This is mostly dictated by the low capital available to the vendors. They also face the challenge of the cost of fuel, hence the use of wood which is sometimes waste wood. The number of food vendors in this sector is high as the process used to prepare food is believed to be simple. This explains why the wood consumption in this subsector is high (Hosier 1988; Karakesi et al. 2004).

1.1.1.5 South Africa

Informal trading in South Africa is a result of a small income and the limited ability of the government and the formal business sector to provide sufficient employment opportunities to people in the economically active age categories (Wills 2009). For instance, a 2002 survey of the Informal Trading sector in Cape Town revealed that many traders had chosen to engage in informal trading as a result of not having, or of losing a job (Ukukhula Business Solutions 2004). This indicates the significant role that Informal Trading plays in absorbing the formally unemployed (Ukukhula Business Solutions 2004).

In 2010, it was estimated that approximately 2.2 million people were employed in the South African informal sector (Statistics South Africa 2011) while an estimated 46,000 additional people entered the sector in the first quarter of 2011, yet, 25 % of the nation's workforce remained unemployed (Statistics South Africa 2011; Willemse 2011). As Statistics South Africa (2013) highlighted, this worsened in the two following years of 2012 and 2013 when the unemployed rate reached 25.2 % and 25.3 % respectively.

Nevertheless, the increase of people into the informal business activities is associated with many risks. A lack of technical business and entrepreneurial skills prevents informal vendors from effectively conveying the opportunities in their informal businesses to financiers (Skinner 2006; Willemse 2011).

More recently, Niyobuhungiro & Von Blottnitz (2013) extended the work of others on environmental challenges created by solid waste and polluted air and confirmed the elevated concentrations of pollutants from waste wood as fuel in this sector. Problems included the inadequate management of slaughtering residues; the use of waste wood for fuel; and the frequent dumping of ash alongside the road. All of these were due to the lack of infrastructure, knowledge and skills.

1.1.2 Overview of a Cleaner Production approach

The term 'cleaner production' (CP) was coined in September 1990 by the United Nations Environment Programme (UNEP). The formal UNEP definition of 'cleaner production' is "a continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment" (Kazmierczyk 2002; Maharaj et al. 2001).

Industrial production strives to remain profitable in a competitive market while research has reported that it has increasingly had to account for its environmental impacts. The challenge is to maximize economic gain while taking steps to minimize environmental degradation caused by one's products, processes and activities. The response to environmental degradation has historically occurred in four successive steps: (1) ignore pollution; (2) dilute waste streams; (3) control pollution; and (4) prevent pollution. Basically, CP promotes a preventative approach and has originated as a response to the overwhelming financial burden brought about by the costs of controlling pollution through end-of-pipe means (Maharaj et al. 2001).

Although the CP concept is not new, it has been applied mainly in the formal sector. It is, however, also important to consider CP in the informal sector where products such as traditional food and drinks are made without applying expertise to managing the environmental impacts of production. It was confirmed by Thorpe (2009) that many small and medium enterprises (SMEs) have no CP expertise and are unaware of the possible cost savings, which results in the slow development of their businesses.

1.1.3 Cleaner Production in South Africa

In line with international trends and the South African national objectives of efficient and effective management of resources, priority is currently given to pollution prevention, unlike previous policies that focused largely on so called "end-of-pipe" [1] treatment, (Maharaj et al., 2001; Rogers & Banoo, 2004). It is indeed stated in the National Environmental Management: Waste Act of 2008 that CP helps to protect the health and the well-being of people and brings about a powerful combination of financial cost savings and environmental improvements (National Environmental Management: Waste Act No.59 of 2008. 2009).

In 2002, the South African Government established a National Cleaner Production Centre (NCPC-SA), co-directing the Centre with strong participation by the business sector and with the Council for Scientific and Industrial Research (CSIR) as the host institution (Rogers & Banoo 2004). The NCPC-SA (2010) reported activities in the following sectors: (a) chemicals; (b) agro processing, automotive and transport equipment; (c) metals and allied processes; (d) pulp and paper; (e) clothing and textile; (f) leather and footwear; (g) tourism and hospitality; and (h) commercial buildings. All the aforementioned areas fall in the formal sector. According to NCPC-SA (2010), there is a need of information on how the concept of CP could be applied to the informal sector.

1.2 Problem statement

From the background provided above, it is evident that the informal production of food and drink plays an important role in the urban African economy, also in South Africa. However, in environmental and health terms, these activities often deploy practices that are wasteful of raw materials and energy and are indifferent to environmental laws and standards, as well as to the health and well-being of the people. The formal production sector globally, and in South Africa, increasingly uses the Cleaner Production approach to reduce emissions and waste, to save energy and use raw materials efficiently. So far, there is not much evidence of a CP approach being used in the informal sector, specifically in catering which is an intensive user of thermal energy.

As regards informal catering, it is known that open fires waste resources and emit pollutants including (PM_{10}) whilst efficient wood stoves reduce emissions, and save resources (and therefore cost), but it is not

[1] An approach to pollution control which concentrates upon effluent treatment or filtration prior to discharge into the environment, as opposed to making changes in the process giving rise to the wastes (Rogers & Banoo 2004)

known whether that cost saving is sufficient to justify the investment by caterers. Further, slaughtering waste is a potential resource for biogas which is a cleaner energy source for informal food and drinks production; but it is not known whether this waste can be valorised to meet the thermal energy demand under these informal production conditions. Experience with cleaner production in both the formal and informal sectors also indicates that even if there are potential gains, public support or pressure may be needed for private producers to realize these gains.

1.3 Aim and objectives

In this research, the use of wood as a source of energy by informal street caterers was investigated with the main focus on how its users could prepare their wares more eco-efficiently, that is, combining lower cost with less pollution and waste.

The study therefore aimed to investigate whether a cleaner production approach would be beneficial and could work in informal contexts, focusing on the case of road-side food and drink production in the Nyanga area of Cape Town in South Africa.

The specific objectives were to:

- Compare the resource usage and pollution loads associated with traditional vs. cleaner methods of food and drink preparation;
- Establish whether the cost-savings deriving from increased resource efficiency of cleaner methods would be sufficient motivation for producers to adopt them;
- Document other constraints to the adoption of cleaner methods of production, to improve resource efficiency gains and reduce emissions and waste, under real conditions of informal food and drinks production.

1.4 Thesis structure

This thesis is divided into 6 main Chapters.

Chapter one has given a brief background of the use of fuelwood in the informal economy. The main terms and pillars of the study have also been introduced. These are "Informal Production" and "Cleaner Production". Some background of the informal economy in Africa and South Africa has been provided in this chapter, but will be detailed in chapter 2.

Chapter 2 reviews literature relevant to this thesis, starting by examining the socio-environmental impact of the informal sector in the global context. The food industry both in the formal and informal sector globally are reviewed followed by a detailed review of the cleaner production approach. It discusses examples in countries where CP has been implemented successfully and then reviews the benefits of implementing CP and the barriers to its implementation.

Chapter 3 presents the methodology used in this study. It discusses the hypotheses and introduces the study location as well as the focus of the study which is on the informal food catering by street vendors. This chapter describes the nature of the research and it discusses the approach used to gather information and analyse the results, explaining how three stages of data gathering were used. Those were the field work around open fires of caterers, field work around efficient wood stoves, and measurements to better understand prospective biogas infrastructure. It discusses the challenges faced during data collection and the ways that they were approached. The ethical considerations are also discussed in this chapter.

Chapter 4 presents and discusses the results based on the traditional methods of cooking, i.e. using open fires. It discusses the types and the amount of waste produced during informal food production at the Nyanga Transport Interchange. It describes how slaughter waste arises in this setting and how it is handled. Similar details are given for wood waste. The smoke emission resulting from fuelwood burning in open fires are described. Greenhouse gases were not measured in this study, only a background from the literature review is provided. The chapter closes with a conclusion.

Chapter 5 describes opportunities for cleaner production in the informal food production. It starts by introducing how the cleaner production opportunities were linked to the current study considering the two interventions chosen. Efficient wood stoves and biogas potential are discussed relative to findings on open fires (chapter 4) in order to evaluate the first and the second objectives of this study. It discusses the results based on suggested cleaner technologies.

Section 5.1 starts with the interventions of efficient wood stoves. It details the use of wood as energy source and its cost. It compares the energy lost in open fires food production with that lost in efficient wood stoves. Section 5.2 discusses the possible biogas intervention and its contributions in terms of resource use, energy saving and cost saving. It reports experimental results and reports observations and views of interviewed caterers. Section 5.3 details the observed factors that hinder the implementation of CP (new and clean technologies) in the informal food production. Section 5.4 consists of concluding notes on benefits associated with the cleaner production approach to informal food production. It discusses the best choice that can be applied amongst those discussed in the previous chapters, based on their costs.

Chapter 6 concludes the thesis and gives key recommendations drawn by revisiting the objectives and the key research questions of the study. Finally the list of references and appendices follow accordingly.

2 LITERATURE REVIEW

This chapter reviews the literature on informal production and on cleaner production, so as to provide a sound basis for the methodology developed in the study. It gives a detailed overview of informal food trading world-wide, highlighting the use of wood in open fires in selected countries, the environmental threats from the use of wood as a biomass energy source due to energy poverty are reviewed. The review ends with a note on the benefits of adopting cleaner technologies in terms of safety and savings.

2.1 Informality of food production in the global context

Note that it is urban and peri-urban households that are involved in informal trading due to the increase of urban populations from rural migration. It is difficult to distinguish between the resource activities by urban households from that by informal vendors because often the same households are also involved in informal trading. Food vending is among the trading done informally and that includes cooking hence the concerns of how the fuel is used to prepare that food.

In Africa, Latin America and Asia the informal sector typically employs over half of the non-agricultural labour force (Blackman and Bannister 1998; FAO 2003). Research has confirmed that this sector is a real polluter and that it is very difficult to effect environmental management over it (Blackman and Bannister 1998; FAO 2003; Knox 2012). Reasons are that firstly, informal businesses have few preexisting connections to the state. Secondly, such businesses are difficult to monitor since they are small, numerous, and geographically dispersed. Thirdly, intensely competitive informal businesses are under considerable pressure to cut costs regardless of the environmental impacts. And finally, informal firms sustain the poorest of the poor.

Urban population development has stirred an increase in the number of street food vendors in many cities throughout the world. Commuting to work or markets has created a daily need among many working people to eat outside the home. Demand for reasonably priced, ready-to-eat food has increased as people (especially women) have less time to prepare meals.

A study on the informal food sector in Bangkok found that the most visible activities relating to that sector are catering (urban and peri-urban), transport and the retail sale of fresh or prepared products, for example the stationary or itinerant sale of street food (FAO 2003). Challenges and limitations in this sector include the lack of specialization on how to do their business, lack of funds and no access to formal credit. It was reported that the nutritional quality of fresh and cooked street food was low and that street vending poses added problems of congestion, safety and environmental pollution (FAO 2003).

In Asia, specifically Bangkok, woodfuel and other biomass fuels are used in the informal food industries and they use outdated and inefficient wood energy devices. The role of woodfuels in the operation of food establishments is of a great measure, given the impacts of increasing population, economic growth and urbanization as well as the change in culture norms of eating in street eateries (Regional wood energy development programme in Asia 1997).

The use of woodfuels and other biomass fuels in industries and enterprises will depend on the price and supply security of these fuels, and will continue to affect the practitioners and the environment. As long as the supply of these fuels is secure, they will be used indefinitely (Regional wood energy development programme in Asia 1997).

Informal food preparation has some similarities to other thermal energy intensive informal production. In the case of informal 'traditional' brick making Mexico, this activity was identified as a leading source of air pollution due to its reliance on cheap, highly polluting fuels such as used tires and scrap wood (Blackman and Bannister 1998). This case is comparable to the informal food/drinks preparation in Nyanga and other informal settlements where pallets and other waste wood are used (Niyobuhungiro et al. 2013). Carbon monoxide and particulates, nitrogen oxides, sulphur dioxide, carbon dioxide and heavy metals are emitted when tires and wood are used as fuels (Blackman and Bannister 1998, Niyobuhungiro et al. 2013).

Knox (2012) reported that small and medium sized industries including (a) brickmaking, (b) lime production, (c) urban businesses (bakeries, laundries, restaurants) and wood fuel traders are largely unregulated, and usually procure wood fuel freely in their environs with little concern for sustainability. These activities are associated with serious health concerns for the people living in the area and the neighbourhood due to the emission of pollutants in the air (WHO 2005).

2.2 Energy, environment and sustainable development

As mentioned above, the term informal food catering in this thesis refers to the production of food and drinks using a traditional way of cooking on open wood fires. To understand the impact that business has on both people and environment, a brief review is presented of the literature on wood fuel use worldwide and in Africa. Wood is reported to be the cheap and easy way to obtain heat as it does not require sophisticated technologies, but its impact on people and environment is of concern. Key literature on this topic is reviewed in the following sections.

2.2.1 Wood fuel consumption and supply in Africa

Historically, wood is the most important source of bioenergy. Wood has been used for cooking and heating since human beings learned to use fire. Wood fuels (charcoal and fuelwood) are the world's most important form of non-fossil energy, with production and consumption concentrated in low income countries. In developing countries, wood is predominantly used for energy generation in the forest industry while in developed countries; it is mainly used for commercial applications (IEA 2006a).

In aggregate, wood fuels share of African primary energy consumption is estimated at 60 % to 86 %, except in North African countries and South Africa, where the wood fuel contribution is less significant (Idiata et al. 2013). In 1994, the wood fuel consumption was found to be highly concentrated in West Africa. Ten major countries contributed around two thirds of total African consumption (67.8 %), while the 45 other countries contributed one third. Nigeria led the pack of ten countries surveyed with a 19.1 % share, of total African consumption, followed by Ethiopia with a 9.1 % share while Cote d'Ivoire was tenth with a share of 3.0 % (Karekezi et al. 2002b; Idiata et al. 2013).

As a sub-Saharan country, South Africa also has its challenges regarding the use of wood. Wood is used inefficiently, in open fires where the full intensity of the heat is not used for its purpose, but much is instead lost in the surroundings. This traditional cooking is used by rural and peri-urban households as well as informal caterers, even though the majority of South Africans rely on other forms of energy such as electricity and paraffin (Blaauw 2011; Docherty, 2013).

As indicated above, the UN-DESA 2004 report by Karakesi et al. (2004) implied that a more nuanced and differentiated assessment of energy consumption in Africa would show that certain regions (e.g. South Africa and North Africa) have experienced a rapid growth in energy consumption that is similar to industrializing countries of Latin America and Asia. Generally within sub-Saharan Africa, modern energy consumption is relatively high in urban areas due to rapidly growing demand for transport energy and electricity to power industrial and commercial enterprises. However, once traditional biomass is taken into account, estimates of sub Saharan Africa's consumption of energy increases significantly, primarily due to the inefficient way in which biomass is used (Karakesi et al. 2004).

An IEA (2012) report showed that in South Africa, of the annual per capita consumption of 95 GJ, only 5 % was biomass; in North Africa it was 11 % out of 34 GJ. In Sub-Saharan Africa by contrast, out of the minimal per capita consumption of only 15 GJ, 73 % was biomass. South Africa has numerous sources of energy but they are not all safe. South Africa was reported to be the highest CO_2 emitter in Africa (IEA 2012) whereas the department of Energy (2012) reported that 90 % of its electricity came from coal which is a depletable fossil fuel and a polluting energy source that importantly contributes to the global phenomenon of climate change.

Given its coal-based energy economy, South Africa is one of the highest emitters of greenhouse gases when compared to other developing countries (Winkler et al. 2006). The quality of air is compromised as well as the environment at large. One should also not miss the serious negative impacts associated with traditional biomass energy use in Africa which range from indoor air pollution (Muchiri & Gitonga 2000; World Bank 2000) to deforestation, as well as an estimated 4.3 million premature deaths due to pollution (WHO 2013).

It could therefore be deducted that the key challenge facing African energy usage is not to increase energy consumption *per se*, but to ensure access to cleaner energy services, preferably through energy efficiency and renewable energy to promote sustainable consumption.

In Cape Town in 2007, an estimated 142 000 tons per annum of waste wood was used by informal communities for thermal requirements, such as cooking and heating by both households and informal caterers (Nissing & Von Blottnitz 2007).

In the whole of South Africa, it has been estimated that about 7 million tons of wood, an energy total of about 86 PJ per year is burned for heating and cooking purposes and this figure is only attributed to poor rural households (Schlag & Zuzarte 2008). Little is said about the poor urban/peri-urban households or those living in informal settlements. Such communities use this fuel for cooking for their extended family members and for sale (informal food production). In this regard and according to City of Cape Town (2011), South Africa needs an energy revolution. For example, although the National Environmental Management Act (Act 107 of 1998) and the National Environmental Management Amendment Act 2003 recognize that sustainable development requires that the use and exploitation of non-renewable natural resources be responsible and equitable, and takes into account the consequences of the depletion of these resources, all this is manageable in the formal sector where the government has a direct connection (IEA 2012).

2.2.2 Energy and environment

A core feature of this study is that it considers informal production processes that use thermal energy intensively. This section reviews key features of the energy-environment relationship. Energy and Environment are closely linked areas with important effects on the economy and the society.

It is well known that when energy sources are used in a wrong way or produced without considering environmental consequences, they can cause serious problems to both humans and the environment. It is accepted that unless the impacts of economic activities on the environment are reduced, environmental constraints on the economy will severely limit the scope for economic development besides affecting many other non-economic variables such as human and ecosystem health, the scope and extent of natural disasters and so on (Rath 2002).

The efficient use of energy resources gains more and more priority in face of climate protection, air pollution and scarcity of natural resources. In their recent ground-breaking work, Shindell et al. (2012) argued that some types of energy usages, such as the use of agricultural waste which increases methane and black carbon in the atmosphere, should be banned, due to their negative impacts on the environment. The United Nations Conference on the Environment and Development (UNCED) at Rio de Janeiro in 1992 recommended a two-pronged approach where priority attention must be given to greater employment and income opportunities for the poor, and also simultaneously, ensure that the rate of use of natural resources and the concomitant degradation of the natural environment must first be slowed and ultimately reversed (Rath 2002).

Although energy is a key consideration in discussions of sustainable development nowadays, there are still many energy generation activities which contribute to pollution, such as inefficient combustion of wood or agricultural residues (Shindell et al. 2012).

Sustainable development requires a sustainable supply of clean and affordable renewable energy sources that do not cause negative societal impacts. In other words, an energy policy which provides affordable, accessible and reliable energy services that meet economic, social and environmental needs within the overall developmental context of society, equitably distributed (Winkler et al. 2006). Such an energy policy always implies a broad context which covers resource grants, existing energy infrastructure, and development needs.

Energy sources such as solar radiation, wind, wave energy and tides are generally considered renewable and, therefore, sustainable over the relatively long term. However these forms of energy are still not explored in a number of developing countries. For example a study done by a group of students at the Gujarat Technological University in 2012 confirmed that wood fuel has remained the most important source of energy in Kenya, meeting over 70 % of the country's total energy consumption needs, with 80 % of the population depending on it and providing 90 % of rural households' energy requirements and 85 % in urban areas (Kenya Country Report 2011). Clearly, South Africa no less than Kenya or other mentioned countries does not have sustainable energy use in place.

It has been reported however that where biogenic wastes are available, biogas technology based on anaerobic digestion should be considered for clean energy production, considering its compactness and cleaner operation (Kothari et al. 2010; Kerr 2012; Shindell et al. 2012). In anaerobic digestion, biogas is produced from a complex process that involves a series of microbial degradation of organic waste materials such as food waste, silage or slaughtering waste. In 2010, a study by the United Nations Framework Convention on Climate Change (UNFCCC), in the Dagoretti cluster of Nairobi, Kenya confirmed the biogas potential of slaughtering waste when it is handled with care. The solid component of slaughtering waste such as rumen contents and dung contain mostly biodegradable matter (CPCB 2004). The total solids in the slaughtering waste from goats and sheep was estimated at ~30 % of which ~88 % is volatile solids (VS) and thus amenable to anaerobic digestion (CPCB 2004). UNFCCC (2010) reported that through anaerobic digestion, one tonne of waste gives 100 m^3 of biogas with an average percentage of 65 % of CH_4. The methane yield was reported to be roughly 200-500 ml of CH_4/g of VS (Budiyono et al. 2011). The typical organic loading rate, a key parameter for reactor sizing, was reported to be 0.5 to 0.6 kg/VS/m^3/day (CPCB 2004).

Biogas has been reported to be a much cleaner technology for low income communities than woodfuel. This technology has a potential to reduce the demand for wood and charcoal use. For example, the use of biogas energy in Rwanda has saved 50% of wood for cooking (Amigun et al. 2012), hence reducing greenhouse gas emissions while conserving resources particularly trees and forests (Amigun & Von Blottnitz, 2010; Shindell et al. 2012).

It is well recognized that if such solid wastes are disposed in dumpsites they will decompose to emit methane. Considering that the potency of methane to trap heat in the atmosphere is about 25 times that of CO_2, anaerobic digestion for slaughtering waste is highly recommended for biogas production for energy purposes. This would reduce the dependence on wood and mitigate atmospheric damages (UNFCCC 2010).

The official definition of air pollution in South African law, is any change in the environment caused by any substance emitted into the atmosphere from any activity, where that change has an adverse effect on human health or well-being or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future (State of air report 2014; City of Cape Town 2007).

The normal clean air is composed of nitrogen (78.1 %), oxygen (20.9 %), carbon dioxide (0.03 %), noble gases such as argon (0.9 %) and water vapour, as well as particulates (dust, ash, sand and pollen). Polluted air, however, contains quantities of gases and particulates that can harm animals and plants, interfere with natural ecosystem and reduce the service life of materials through corrosion (e.g. metals).

Pollutants derive from natural as well as anthropogenic sources. Any activities that involve combustion (heating and burning) create air pollutants. These activities include:

- Combustion of gasoline by motor vehicles
- Coal combustion for electricity generation
- Waste disposal through incineration
- Domestic activities such as cooking and heating using electricity, coal, paraffin, wood or gas
- Mining
- Forest and grass fires.

2.2.2.1 Particulate matter (PM_{10}) and other pollutants from wood fuel burning in relation to the CP approach

Particulate matter consists of liquid or solid particles which are suspended in the air. These particles are categorized by size, thus particulates with an aerodynamic diameter of less than 10 microns are known as PM_{10}. Some particulates occur naturally, for example from volcanoes, dust storms and grassland fires. Human activities such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of particulates.

Pollution prevention is a multi-media environmental management approach which emphasizes the elimination and/or reduction of waste at the generating source. This results in a cleaner production method than the end of pipe method (Asia Invest 2005). However, 'energy poverty', traditionally defined as lack of access to electricity and dependence on solid biomass fuels for cooking and heating, remains a persistent global challenge (Sovacool 2012).

In 2009 approximately 1.4 billion people lived without access to electricity grids, and 2.7 billion people depended entirely on solid fuels such as wood, charcoal, and dung for their household energy needs (Sovacool 2012). This inability to utilize modern forms of energy limits opportunities for income generation and frustrates attempts to reduce poverty (Sovacool 2012). It also severely impacts the lives and livelihoods of women and children (WHO 2013). Additionally, it contributes to global deforestation and climate change through both traditional greenhouse gas emissions and those from black and brown carbon in the form of particulate matter (Steinfeld et al. 2006; Kemfert & Schill 2010; Sovacool 2012; Shindell et al. 2012).

Wood and coal combustion in developing countries is the primary method for heating homes and supplying energy and this is also a contributing source of the PM_{10} in the ambient air (Shindell et al. 2012).

2.2.2.2 GHG emissions from wood fuel burning

The complete combustion of a 'Perfect' Wood (Carbon, Hydrogen, and Oxygen) would give the following as products:

$CH_2O + O_2 \rightarrow CO_2 + H_2O + Heat$ Eq 1

However in real life, 'real' wood is constituted with Carbon, Hydrogen, Oxygen, Nitrogen, and minerals (Calcium, Potassium, Sulfur, Chlorine, Lead, etc.). The combustion of wood is never complete. Generally the incomplete combustion of wood is caused by the use of wood that is wet and the insufficient air, low temperatures, incomplete mixing, etc). Its incomplete combustion with 'Real' Air (Oxygen, Hydrogen, Nitrogen, etc.) would give different product including: Carbon dioxide (CO_2) water vapor (H_2O), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), methane (CH_4), non-methane volatile organic compounds (VOCs),), Formaldehyde, Acrolein, Benzene, Toluene, Polyaromatic hydrocarbons (PAHs). Emissions of nitric oxide and VOCs lead to the formation of ozone and other photochemical oxidants (Department of Environmental Affairs 2012). This emission o gaseous pollutants is associated with that of fine and ultrafine particles: PM_{10} – very small droplets of condensed organic compounds (semi-volatile or not) of wood tar and gases. Mainly a result of unburned fuel and $PM_{2.5}$ – a complex mixture that may contain soot, smoke, metals, nitrates, sulfates, dust water, Sawerysyn 2012; Öostmaan et al. 2007, Dynamics of Wood Combustion (n.d.); Department of Environmental Affairs, 2012).

The reaction of this combustion could be simplified as

$CH_2O + O_2 + N_2 \rightarrow CO_2 + H_2O + NO_2 + Heat$ Eq. 2

From the stoichiometric equations (Eq. 2) one could estimate that the direct emissions from wood combustion are > 1 kg CO2 per kg of wood. Standardized estimates of emissions are available in the form of a CO_2-e emission factor of wood are much lower than this, at 0.0795 kg CO_2-e /kg of wood as documented from IPCC (Intergovernmental Panel on Climate Change) emission factor 2015 for the calendar year 2013. This value is much lower as it is recognized that all the carbon in wood was removed from the atmosphere during plant growth – the "biogenic" carbon is thus assumed to be balanced between uptake and combustion and is not counted. (Ministry for the Environment 2015).

Carbonaceous aerosols and heavy metals are also found in the atmosphere as a result of all types of combustion processes. They comprise about 10-50 % of the tropospheric particulates with particularly high levels found in the urban atmosphere (Air Info Now 2010; Shindell et al. 2012). Exposure induces toxic responses in animals and humans.

2.2.2.3 Particulate matter pollution

Based on known health effects, both short-term (24-hour) and long-term (annual mean) guidelines are needed for PM pollution. An annual average of 20 μg/m^3 (PM_{10}) is considered as the lower end to which significant effects were observed in an American Cancer Society's study (WHO 2005).

In South Africa, the Department of Environmental Affairs and Tourism has established National Standards for the permissible concentration of PM_{10} in ambient air (25°C and 101.3 kPa) to be 120 μg/m^3 and 50 μg/m^3 as the daily (24 hour) and annual average respectively (National Environmental Management: Air Quality Act No.39 of 2004. 2009). These standards applied before 31st December 2014. From January 2015, new National Standards for criteria pollutants including PM_{10} are effective. These are 75 μg/m^3 and 40 μg/m^3 daily and annually respectively. It was reported by Tessema (2011) that PM_{10} exceeds the daily standards more often in Khayelitsha (one of the big townships in Cape Town) than at any of the other of the city's air monitoring sites. Only two of the fourteen monitoring stations are however located in townships. In Khayelitsha, the South African standards were exceeded at various times of the year. The days in which these occurred were considered as "episodes" (table 2-1).

Table 2-1: Number of PM10 episode days in Khayelitsha based on the South Africa standards (Tessema 2011)

Years	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SA standards	0	2	1	4	9	5	6	16	9	5	5

The limited measurements confirmed that levels of PM_{10} close to open smoke sources can be extremely high; an average of 1700 μg/m^3 was measured approximately 2m from wood fires over a 1 hour period, with the highest level of 8000 μg/m^3. Whilst such a proximity to an open fire is more representative of a work-place exposure than to a public environmental exposure, the two are closely linked. This problem arises in areas like taxi ranks, where large numbers of people congregate (Niyobuhungiro & von Blottnitz 2013).

WHO 2013 reported that burning solid fuels can release 100 times higher than acceptable levels of small particles. Their report estimated 4.3 million premature deaths worldwide from inefficient use of solid fuels (WHO 2013; World Energy Outlook 2014). There are many other adverse health, economic, and environmental effects from burning solid fuels over open fires (Global Alliance for Clean Cookstoves 2011). This should encourage the thinking of strategies for changing the cooking methods especially for the poor (Global Alliance for Clean Cookstoves 2011).

The goal of a cleaner production approach is to eliminate or reduce the release of pollution into all media (water, air, land), to save energy and natural resources, and to enact these changes to last for the long term. It requires an extensive range of incentives and practices to achieve sustainable improvements (Asia Invest 2005). This study looks at introducing this approach as a remedy to the challenges described above. It is in line with what Shindell et al. (2012) identified as measures which have a large emission reduction potential as to mitigate climate change and improve air quality. New technologies such as the adoption of efficient biomass stoves and biogas stoves were recommended. It is believed that the introduction of these technologies will strongly reduce the amount of fuel wood used and its emissions. Studies suggest that smoke emissions from cooking fuels could potentially be curbed through the use of improved cooking stoves and devices. In the first place, it is not the fuel that is dirty and polluting, but the inefficient manner in which the fuel is used that causes the pollution (Balmer 2007)

2.2.2.4 Effects of particulate matter

2.2.2.4.1 Health effects

Particulate matter (PM) are fine particles made up of solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Air quality protection regulations concentrate on particles that are 10 µm (PM_{10}) in diameter or smaller ($PM_{2.5}$), because those are the particles that generally pass through the throat and nose and enter the lungs.

Epidemiologic studies have demonstrated an association between exposure to particulate matter and adverse human health effects at concentrations commonly found in urban areas around the world (Karthikeyan et al. 2006).

In recent years, attention is being paid to $PM_{2.5}$[2] as a pollutant more hazardous than PM_{10} because its smaller size allows such particles to enter deeper into the lungs. These fine particles also stay longer in the atmosphere and can travel longer distances than PM_{10} thus increasing exposure (Wright & Oosthuizen 2010).

Before 2010, in South Africa, much work was done to address air pollution. However few monitoring stations measured ambient $PM_{2.5}$. The PM National Ambient Air Quality Standards gazetted in September 2009 did not include $PM_{2.5}$ (Wright & Oosthuizen 2010; State of Air report 2014). During that time, South Africa was following the WHO 2005 interim guideline of 25 µg/m^3 annually.

[2] Not considered in the current study

It has been reported that more than 10.1 million (19.9 %) of the population in South Africa use solid fuel, as do 6.9 % or 2.2 million of the urban population. This implies 3 200 deaths per year from indoor air pollution. While this incidence of deaths due to indoor air pollution is relatively low and thus not a strong case for change, there are many other adverse health, economic, and environmental effects from burning solid fuels in traditional cook stoves or over open fires (Global Alliance for Clean Cookstoves 2011; Kimemia & Annegarn 2011).

Particulate matter from dust, wood burning and diesel was reported by the City of Cape Town to be the greatest air pollutant in Cape Town, especially in winter (State of Air report 2014; City of Cape Town 2007). In their Newsletter no 38, WHO believed that a reduction in the levels of one particular pollutant, namely PM_{10}, could reduce deaths by as much as 15% in polluted cities around the world (WHO 2006).

Numerous scientific studies have linked particle pollution exposure to a variety of problems, including:

- Severe respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing as a result of decreased lung function; aggravated asthma; development of chronic bronchitis and tuberculosis (Guha-Mazumder 2003; Kapaj et al. 2006)
- Irregular heartbeat;
- Nonfatal heart attacks; and
- Premature death in people with heart or lung disease, especially children.

2.2.2.4.2 Environmental effects of air pollution

Haze is caused when sunlight encounters tiny pollution particles in the air. Some light is absorbed by particles and other light is scattered away before it reaches an observer. More pollutants mean more absorption and scattering of light, which reduce the clarity and colour of what we see. Some types of particles such as sulphates scatter more light, particularly during humid conditions. Particulate matter pollution is the major cause of reduced visibility (haze). A brown haze was reported by City of Cape Town (2007) to be a result of particulate matter emission from both vehicles and fuel combustion.

Some haze-causing particles are directly emitted to the air. Others are formed when gases emitted to the air form particles as they are carried a long distance from the polluting source (US EPA 2010).

Particles can be carried over long distances by wind and then settle on ground or water. Depending on the nature of the particles the effects of this settling include; making lakes and streams acidic; changing the nutrient balance in coastal waters and large river basins; depleting the nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems (US EPA 2010).

Particulate matter is one of the six criteria pollutants according to US EPA (Chong et al. 2002; US EPA 2010). It was noted by a group of researchers that cleaner cooking technologies by the poor population generally would reduce the effect of the traditional ways of cooking with regard to the effective and efficient use of resources (Shindell et al. 2012). It would also help to manage the disposal of waste (Draft strategy to address air pollution in dense low-income settlements 2016).

The following section reviews waste management in the South African context.

2.2.3 Waste management in South Africa

In developed countries, most collection of waste is performed by local government, or by firms under contract to the local government or to business and/or industrial waste producers. Hence, in almost all instances, some form of collection reaches all or most of the population at some level of effectiveness. This is due to the ability and capacity for tax paying public for services to ensure a clean and healthy environment. The use of a "communal collection point" in industrialized countries is predominantly for purposes of waste recovery, whereby these points serve as storage points for recyclable material (International Environmental Technology Centre 1996; Puling 2004; Draft strategy to address air pollution in dense low-income settlements 2016).

On the other hand, in developing countries, due to the lack of a tax base to pay for adequate services and the rapid urbanization, which results in poor squatter settlements, the provision of healthy waste collection is almost impossible. This results in illegal waste dumping associated with many dangers such as fire hazards, bad smells, blockage of drainage channels and subsequent overflowing, pollution and nasty health conditions. Under these conditions, the lack of waste collection is also linked to the presence of relatively large volumes of animal (slaughter) or/and human faecal matter in the waste (Puling 2004).

Recent studies by Samson (2009) and Wills (2009) have shed light on the role of waste pickers and street cleaners in municipal waste management systems in South Africa. Both studies highlighted the importance of waste-picking as a livelihood strategy in the context of high unemployment as well as the contribution they make to social and environmental sustainability (Samson 2009). To review how cleaner methods can play a role in reducing the waste and pollutants to the environment and help waste pickers save money while improving their lives, an understanding is needed of a cleaner production approach as introduction in chapter 1.

2.3 Cleaner production techniques and principles

Good management, efficient use of resources and employee participation are important principles in cleaner production (Thorpe 2009). For resources to be well used, the cleaner production approach as interpreted by the World Business Council for Sustainable Development, suggests the introduction of new improved technologies for: (a) Production processes, emphasizing the conservation of the raw materials and energy, elimination of toxic raw materials and reduction of the quantity and toxicity of all emissions and wastes; and (b) Products, reducing negative impacts along the life cycle of a product, from raw material extraction to its ultimate disposal (Asia Invest 2005). Other proactive environmental strategies such as better process control, improved housekeeping and production of a useful by-product are also crucial.

The systematic usage of the above techniques should ensure that pollution prevention and cleaner production approaches benefit both the environment and society (Asia Invest 2005). However in its complete form, Cleaner Production must also integrate four underlying principles to reinforce the effect of its techniques. The four principles are: a) the precautionary principle, b) the preventive principle, c) the holistic principle and d) the public participation principle. This study relies on two of these principles:

The Precautionary Principle

The precautionary principle requires that action should be taken as far as possible to avoid damage to the environment before it occurs and recognizes that there are limitations and uncertainties to scientific knowledge. For example, a company wishing to discharge an effluent that contains untested chemicals would have to acquire information and demonstrate the safety of that discharge, rather than require regulators or the surrounding community to prove that the discharge could be harmful (Thorpe 2009).

The Preventive Principle

Thorpe (2009) reported that it is cheaper and more effective to prevent environmental damage than to attempt to manage or "cure" it. Prevention involves using safer chemicals and eliminating hazardous chemicals, including though substituting effective non-hazardous alternatives.

2.3.1 Implementation of CP (New technologies): Lessons from other formal and informal industries

Human capital, education, experience and the lack of perception that traditional methods endanger the environment have been identified as the leading barriers to the adoption of cleaner technologies in informal sector production (Blackman and Bannister 1998; Van Hoof & Lyon 2012). However, there is evidence that to achieve the adoption of new technology in the informal sector, regulatory pressure and awareness of the private health benefits must be used (Blackman and Bannister 1998; CPHP 2008).

"*It is possible to successfully promote the adoption of a clean technology by intensely competitive informal businesses even when the new technology significantly increases variable costs and imposes considerable one-time fixed costs. In Cd. Juárez, this success was the result of an organized effort to simultaneously lower the fixed costs of adoption and raise the costs of non-adoption by supplying equipment, training, and education free of charge, and by racketing up both formal and informal penalties for continuing to burn debris. The determinants of the adoption of improved cooking stoves in developing countries, showed that adopters often perceived reduced exposure to smoke to be the principal advantage of new stoves"* (Blackman and Bannister 1998).

In addition to regulatory pressure, research has confirmed that training and education, in particular the dissemination of information about the health risks associated with dirty technologies, are an effective means of promoting adoption of clean alternatives (CPHP 2008). Evidence for this claim, from a study very relevant to the current research, came from the Crop Post Harvest Programme (CPHP) experience. This project reported that the systematic management and control approach based on the formation of partnership, training of vendors, inspection of the projects and broadcast through the media has helped the peri-urban informal food vendors from Kolkata (India), Accra (Ghana), Lusaka (Zambia) and Harare (Zimbabwe) to achieve relevant savings and sustainable development, by learning from each other. This control approach has also achieved the following benefits for vendors, consumers and its partners:

- Over 5 000 vendors were trained with suitable training methods. These figures are based on the results of food safety surveys and comprehensive socio-economic studies;
- Partnerships and linkages were formed between vendor organisations from different regions so that they could share experiences;
- Vendors reported increased turnover of between 10 % and 15 % and employed more staff (CPHP 2008). This control approach is compatible with and complementary to the cleaner production approach in the sense that it follows up the implementation of new technologies.

It was reported that since 1990 five million chuhla (firewood saving) stoves were made and distributed in Latin America, their efficiency ranged from 20 to 28 %, they were running on agriculture waste and cow dung and they cost $ 4.7. Metal stoves fabricated in India, Zimbabwe, Rwanda, Mali, Burkina Faso, the Niger and Guatemala, showed an efficiency close to 30 % but were 5 times more expensive than the chuhla stoves. This explains why their dissemination was limited (Vos & Alarcon 2016).

From an economic perspective, informal caterers would need an affordable stove and easy to maintain. In this study local cement and vermiculite stoves were examined. It was hoped by Engineers Without Borders that such stoves would have a better efficiency perhaps close to the clay stoves ones. Clay stoves were reported to have 40% efficiency while a mix of cement and vermiculite has almost the same physical properties (EWB 2012)

2.3.2 Adoption of new technologies in the informal sector

2.3.2.1 Improving the quality of life

Shindell et al. (2012) proposed that if the clean energy production concept is adopted and taken in hand by both government and the community, there will be a remarkable drop in outdoor air pollution, due largely to soot emission reductions. Globally, this would avoid between 700 000 to 4.7 million premature deaths each year. The drop in indoor air pollution would save more than one-third of a million lives annually in India and China alone.

By following the example of the application of the systematic approach of cleaner production practices in the informal catering sector, it was hoped that similar results as observed in the above locations would be achieved through reduction of pollutants in the air. Kandpal et al. (1994) found that changing from dung cake burning to biogas burning reduced Suspended Particulate Matter from 2 900 to 250 µg/m^3.

2.3.2.2 Economic benefits

The application of CP approach helps at the world-wide scale, reported Thorpe (2009). For example, environmental degradation produces serious impacts on human health and results in a substantial drain on the national economy of any country. There are direct economic savings derived from implementing cleaner production within an industrial context in South Africa. If South Africa does not adopt cleaner production principles the consequences are clear: losses due to the cost of environmental degradation by industries in South Africa as observed by industry CP projects.

The Asian Development Bank stated that: "*There is no longer any need to prove that CP can improve the performance of firms and projects in Asia. Now the need is to translate this fact into policies and projects that match the capacity of target economies and stakeholders"* (Evans & Hamner 2003).

In India, the Ministry of New and Renewable Energy (MNRE) (Government of India) declared a National Master Plan in 1994, which incorporated one of the Cleaner Production Technologies (Biogas Technology) as one of the major waste-to-energy options to be developed and adopted in the country (Kothari et al. 2010).

All the examples given above show that the adoption of cleaner production policies has a positive impact on sustainable development. The implementation of CP can result in an improved economy due to increased efficiency of products and processes, a reduction in waste and emissions and a reduction in environmental degradation. The overall result will be an improvement in quality of life. CP aims to combine all aspects of sustainability, since it is promotes the conservation of energy and natural resources; increases efficiency; safe and healthy conditions for workers, communities and consumers (Thorpe 2009).

2.4 Concluding notes

From the review above it can be noted that low income dwellers are the main actors in the informal food production sector. For the food catering, the main fuel used is wood as it is often the cheapest available fuel.

There are many consequences of informal vendors using wood fuel as an inadequate means of cooking. In the first place, wood as a resource is wasted and this can result in increased deforestation where there are accessible forests. Inefficient wood use also results in the increase of airborne pollutants, especially particulate matter (PM) and may occur indoors and outdoors. Such air pollution is associated with respiratory diseases, which increase premature deaths.

The chapter also reviewed the ways of implementing CP techniques. This approach might make it possible for even low income vendors to simultaneously save money and save the environment from pollutants. An example of such an implementation of CP techniques was reported in Mexico by brickmaking vendors. By using cleaner methods to prepare the bricks, money was saved and pollutants reduced. The same improvements were observed in Zimbabwe, Rwanda and Guatemala, where improved and cleaner stoves were used by households, in order to reduce the quantity of fuel, increase the efficiency of the cooking method and reduce the pollutants in the surroundings. It was of core interest in this study, whether the same cooking method can be used in the business sector particularly in informal street catering.

This thesis set out to find local contexts where a cleaner technology is more cost effective and can thus take root in a production setting more easily. Where this is not the case, the study aimed to provide insights as to how government could show presence in such settings not as an unwelcome regulator, but in a supportive way by introducing cleaner and more efficient production technologies into the informal food and drinks preparation, mainly clean-burning technologies. This should help to uncover novel applications where the CP approach has not been applied as yet, and also to develop new insights on the use of cleaner technologies into informal food and drink preparation.

3 HYPOTHESES AND RESEARCH METHODOLOGY

This chapter firstly presents three hypotheses arising from the literature review. It reviews as a case study the Nyanga transport interchange in Cape Town. It then reviews research methodologies relevant to this thesis and based on these it discusses the approach used to test the hypotheses, including the procedures used to collect and analyse the data.

3.1 Hypotheses and research questions

As stated in chapter 1, this research aimed to investigate the prospects for cleaner production in informal contexts, focusing on inefficient and polluting energy uses in catering. It is known that open fires waste resources and emit particulate pollutants whilst efficient wood stoves reduce emissions, save resources (and therefore cost), though it has not been known whether that cost saving is sufficient to justify the investment by caterers. Further, slaughtering waste is a potential resource for biogas, a cleaner energy source for informal food and drinks production; though it has not been known whether this waste can be valorised to meet thermal energy demand under actual informal production conditions. Experience with cleaner production in both the formal and informal sectors also indicates that even if there are potential gains, public support or pressure may be needed for private producers to realise these gains.

The field research was constructed around the following three hypotheses:

1. The gain in thermal efficiency of cleaner energy technologies over traditional methods for heating processes in the informal production of food and drink will yield sufficient cost savings to justify investment in cleaner burning equipment.
2. Slaughtering waste as a source of clean energy in the form of biogas can be of economic value for informal caterers, but the waste management infrastructure costs will be prohibitive for caterers.
3. The sizeable reductions in air pollution and in solid waste (of an order of magnitude) that can be achieved by the use of biogas technology and of efficient wood stoves instead of burning wood in open fires, are sufficient justification for public resources to be mobilised in addition to caterers' private investments.

Corresponding to these hypotheses, three sets of key quantitative questions were addressed as seen in section 3.4.

The approach used to substantiate the hypotheses is discussed in section 3.4. Before presenting this, it is necessary to understand the research methodologies appropriate for scientifically grounded, changeoriented research in socially difficult situations.

3.2 Research Methodology

This study used a grounded theoretical approach, combining experimental and case study methodologies. The case study (informal catering in Nyanga) served as a representation of catering in many urban African settings. This study therefore merged qualitative research with quantitative methods.

The objective of this section is to discuss qualitative research, which includes realistic time estimation as key to a well conducted survey and experimentation, considering the prospects of time allocation in response to unexpected challenges in real life social contexts. It thus explains the challenges and strategic remedies that a researcher in this scientific field should be prepared for when conducting a community-based study.

Qualitative research is a form of social inquiry that focuses on the way people interpret and make sense of their experiences and the world in which they live. A number of different approaches exist within the wider framework of this type of research, but most of these have the same objective: to understand the social reality of individuals, groups and cultures towards the new or existing challenges in life. The basis of qualitative research lies in the interpretive approach to ***"social reality***" (Holloway 1997). The current research combined considerations from both social sciences and quantitative scientific experiments in order to evaluate the study's objectives and make tangible conclusions.

It has been reported that researchers involved with qualitative research rush to present their final findings without a note or a comment on how to proceed with data collection and how to relate to research participants. The result is a lack of information and understanding about the research progression, including the main challenges that the researchers might face and what strategies were used to overcome these challenges and satisfy both researcher and participants (Delany 2007; Shaw 2012).

In this section the common challenges faced by researchers involved with community participation are discussed in the context of data collection in Nyanga informal settlement in Cape Town. The field work focused on the use of different methods of preparation of food and drinks before selling. The strategies used for data collection (field work/ questionnaire/questionnaires) are discussed and hence the nature of this type of data and the way that the data was managed.

3.2.1 Informal catering at the Nyanga transport interchange

Nyanga is one of Cape Town's oldest and largest black townships, having been established in 1955. It lies about 26 km from the city centre along the N2, close to the Cape Town International Airport and like most of townships in South Africa, it was established by the apartheid government in terms of the migrant labour system (appendix 6).

Nyanga is mostly informal and people live in shacks (Wiechowsk & Bak 2007). Organizations have opened businesses in Nyanga and new business openings are frequent. It is vibrant community in which the poor create jobs by starting hair salons, transport, repair of old materials, catering, waste collection, and so forth. Nyanga township was considered for this study due to its complexity. It has both formal and informal housing. Its population also makes it a good place for informal activities due to the number of unskilled and unemployed people. Nyanga was also a suitable research site because previous study results that confirmed high particulate matter emissions from fuel wood use in Nyanga (Niyobuhungiro et al. 2013).

A common informal economic activity in Nyanga is the production of cooked/uncooked meals and drinks. The common uncooked sold food is plucked chickens for customers to cook themselves. Slaughtering and defeathering of chickens is carried out alongside the road on all corners around the transport interchange, where many people pass by and other vendors sit, mainly selling groceries. The cooked meals include roasted meat, commonly known as "braaied" meat (lamb, pork, and beef) (appendix 5) and uncooked plucked chickens. The preparation of the plucked chickens as the focus of this study, is detailed in Chapter 4. *Umqombothi* beer is commonly served in this community, being an African beer made from maize, sorghum malt, yeast and water. It takes two days to prepare with each process involving approximately two hours of cooking. Its preparation is also detailed in chapter 4.

According to the street map of South Africa Nyanga Junction (appendix 7) is about 900 m long and between 28 and 34 m wide. A team of volunteers from Engineers without Borders (EWB, 2011) observed that each vendor used approximately 1.5 m of street frontage over a total street length of 850 m. Based on these observations, it was estimated that there were approximately 1200 vendors along this stretch, distributed along both sides of the road.
A further observation was that about 50% of these vendors sold meat (raw or cooked), 45% sold general goods and 5% sold maize. It was then estimated that 585 vendors sold meat, 527 sold general goods and 59 sold maize (EWB 2011). There is not enough data available to estimate the number of chicken vendors nation-wide (Skinner, 2017).

In these informal food production processes, several pollutants are emitted into the environment including high levels of particulate matter. This is due to the traditional method of using fuel wood in open fires. At times, waste wood treated with poisonous chemicals has been found to be in use, not only in Nyanga but also in other Cape Town informal settlements where the same activities take place (Niyobuhungiro 2012).

To help reduce the negative health and environmental effects of wood use, a group of researchers at UCT, together with volunteers from Engineers without Borders (EWB), introduced some 50 efficient wood stoves into the community as a clean energy burning technology in 2012. A follow-up survey on whether caterers use these stoves and whether they benefit from using them has not yet been undertaken in the past and therefore it was assessed in this study.

3.3 Community participation in scientific research

Scientific research is commonly based on experiments whether involved with laboratory or field work. In many cases the research time taken for experiments can be fairly accurately planned. However, in experimental science involving community participation, more time might be needed than planned due to the vagaries of the community-researcher relations, since the community does not necessarily have the same understanding of the research being done as the researcher. Here, the researcher needs to allocate time to familiarization with the community, particularly when community members are to jointly participate in shaping the research initiative. Scientific research involving the community, therefore takes on aspects of social science research and thus can take a longer time than would be allocated when no community is involved.

Three phases were considered during this research: preliminary, principal and validation.

The preliminary stage consisted of the formulation of concepts and clarifying of objectives, which led to the decision to conduct the research (Simekova 2013). In the current study, this started with a site visit to become acquainted with the prospective participants and decide on which ones to conduct the research with.

The visit started by talking to a community leader to gain permission to move around and speak to people. The leader led us to various corners/places to look for caterers who were involved in different types of cooking e.g. sheep's heads, braai, chicken boilers and *umqombothi* caterers. At this stage the caterers were comfortable but expected something bigger from the researchers. Their expectations were that whatever was to be offered to them had to be given as soon as possible, even before the research was carried out. Thus the researcher was soon made aware of the need to deliver and this sense persisted during the research.

Although Delany (2009) had advised researchers not to give anything to the participants the researcher offered a R20 incentive to each participant to motivate them and this was successful. It helped the researcher to develop a research methodology to reach the study's objectives. This act was considered invaluable at the early stage of concept formulation in developing an understanding of social and cultural phenomena in natural sites in the light of experiences, meanings and views of the participants towards our research. It enabled a smooth flowing to the principal stage of collecting the data.

The third and last validating stage consisted of checking, and matching the conclusions to the objectives and analysing the feasibility of possible policy recommendation. This is presented in chapter 6.

According to Rice-Lively (2005) the main objective of qualitative research is to bring the investigator as close as possible to the community so the community participates and helps empirically in the study. This helps to gain access to the community/participants and gives insight to personal experiences. Some authorities have said that there are no specific hypotheses in qualitative research. It can only serve to match and support the hypotheses tested by the qualitative data (Shaw 2012; Simekova 2013).

In qualitative research the role of the researcher/observer is important; it involves building up a relationship with the study subject through social and physical closeness (Simekova 2013). In deciding what to observe and record, it is necessary for the researchers to think and arrange all the elements needed to help them achieve the study objectives. For example;

A. Who is present? On what is their membership of the group based on? How did they enter the group?
B. What is happening, what is the activity being observed?
C. When does the activity occur?
D. What do the physical surroundings contribute to what is happening and vice versa?
E. Why is the activity happening?

The questionnaire was constructed so that the observations from it had the same focus as the questions above (see questionnaire in appendix 1).

Simply having a schedule of all the data needed from the community was not a green light to start data collection. During data collections at the Nyanga transport interchange, some challenges were faced: 1) Recruitment of the participants, 2) Choosing meaningful information to obtain from them, 3) Language barriers, lack of trust and concerns for the researcher's personal security, 4) Validation of information, 5) Time arrangements.

3.3.1 Recruiting the participants

A critical first step in any research is to identify and recruit research participants (Shaw 2012; Ullman 2011). Participant selection would define the meaning of the research. Hennink et al. (2010) confirmed that one needs to pay particular attention about whom to choose to participate in the study. Shaw (2012) suggested that to recruit participants, the researcher should survey the neighbourhood, tour the community, and familiarize him or herself with major money-making, domestic, and service establishments in the area of interest. This helps to choose community/participants that will suit the research. Questions that must stay in the researcher's mind include: Is this chosen community/participant really helping to achieve the objectives of the research? Am I using enough participants to verify the hypotheses? Does this research really bring and contribute anything to such communities/ participants? Will this help to achieve the expected study outcomes? It is crucial for the researcher to communicate with participants directly about how they would like to benefit or how they think they could benefit from the research.

In this case the initial idea for the target group was the brewers who boil large quantities of water for *umqombothi* using wood. However, after observing properly and understanding their production process it was found that the research could not really satisfy their need in terms of biogas energy demand or the efficient wood stoves suggested for this study. In such a case the researcher needs to step back and rethink the type of participants to choose so that the research stays meaningful. After further investigation and observation, it was decided that the research would work better for the chicken vendors who do not require as much energy for their preparation process as the brewers. However, a note on the use of wood by *umqombothi* brewers is given in Chapter 4, section 4.1.1 and 4.4.1.

From here, it was investigated who owned an efficient stove provided in previous research and who did not. A survey was then done on the amount of wood used in both cases (with and without a stove), as well as the corresponding PM_{10} emissions.

In Nyanga, alongside the road close to the taxi interchange, there were more than 15 chicken vendors. Further from the road were some who brewed *umqombothi*. The investigation was carried out on 10 chicken vendors who worked with open fires and 5 who each owned an efficient wood stove. These numbers were a compromise between the needs of qualitative and quantitative needs, as well as the difficult realities of building and maintaining contacts with a manageable number of participants for repeated visits to the study site. One source states that in qualitative research, saturation is reached at the 4th sample (Guest et al. 2006). Even though the context of that study is significantly different, it was deemed that ten respondents were deemed enough to provide insights into shared and diverging experience of road-side caterers. As the results of the quantitative work will show, measurements related to stove usage were well repeatable, and clearly distinguishable from those related to usage of open fires.

Note on the stoves

The introduction of efficient wood stoves in the community was by Professor Harro von Blottnitz and his research group initiative with the EWB (Engineers Without Borders). This initiative followed the results from previous studies that confirmed the intensive use of wood as a fuel in various townships had health and environmental implications due to the smoke released (Claasen & Sibanda 2009; Niyobuhungiro 2012).

The wood stoves used for this project were constructed by Honeycomb Homes in Durban. These stoves were insulated using a vermiculite-cement mixture, vermiculite being a relatively inexpensive mineral resource with high insulating properties. This made the stoves affordable for informal caterers. The stoves operate on the simple rocket stove principle, where wood fuel is placed into a firebox where combustion takes place and where heat energy and smoke is channelled to the cooking surface through a chimney above the firebox (Figure 3-1). The stoves were chosen so that their efficiency could be tested as this had not been done before. The users had reported reduction in smoke and the amount of wood used but no measures of these had been done to support the encouragement of their use.

The stoves were ordered from a start-up company in Durban and were at first, developed from the EWB project as a benchmark for improved woodstove designs to which future designs could be compared and improved from, based on the stoves users' feedback. At that time, the effectiveness of the implemented design was measured by user experience surveys, verbal questionnaires and focus group discussions (EWB 2012).

Figure 3-1: Implemented Vermiculite-cement stoves, (EWB 2012)

These stoves were targeted because they promised to satisfy the objective to greatly reduce the amount of wood used and, thus the pollution produced. Very little skill is required to produce such stoves. The most difficult obstacle in manufacturing may be the metal cutting and welding required for drum preparation. In Nyanga this can be carried out by local welders.

The approximate cost of producing one large ‘institutional’ stove amounted to about R350. But for the sake of research, their price was placed at R150 for the large stove and R90 for the smaller ‘domestic’[3] stove. The aim in subsidizing the stoves and not merely giving them away was to ensure that a sense of ownership was generated and thereby a responsibility for the preservation of the stove was infused in the owner.

Table 3-1 shows the estimation of production cost for one stove with the prices based on Honeycomb Homes costs in Durban. Costs of materials may change significantly, depending on their source. More research is needed for Cape Town-based production.

Table 3-1:Estimate cost of the vermiculite stoves

No.	Material	Estimate
1.	Large steel drum (common in composite& chemical industries)	R100 / drum, R50/ stove
2.	Vermiculite	R100
3.	Hydrated cement	R100
4.	Steel bar	A few Rand – second hand off-cuts

Source: Stove Construction Manual, EWB 2012

One of the tasks during the current study was to investigate the impacts brought by these stoves as a cleaner technology for food production. The purpose was to associate that technology with a biogas technology to stir the results of the initiative.

3.3.2 Choosing meaningful information from participants

A researcher must also use general knowledge in making observations and notes at the first opportunity to see the participant even before the scheduled time for data collection. A researcher must try to adapt to the participant schedule in order to not miss any relevant information; thus notes and observations are important (Ullman 2011).

In this research the information from participants as scripted on the questionnaire was followed by a scientific experiment to precisely answer some technical questions. However, observation and conversation was the key to relevant and honest answers, as reflecting the real life of the vendors targeted.

[3] Not considered for this study

The questionnaire is available in appendix 1 while the results from observations and questionnaire are presented and discussed in chapter 4 section 4.1 to section 4.5.

3.3.3 Languages barriers, lack of trust and researcher's security

It has been noted that in community-based research, trust is bi-directional and is based not only on authority but also on experience and relationship. Ahmed et al. (2004) observed that in community based research, spending time within the community and getting involved in non-research activities is a key to forming trusting relationships with and to acquiring a better picture of the community's strengths and limitations. It is also personally rewarding. Researchers may get involved in community activities, such as health fairs, school physicals and youth programmes. The researcher may even interact directly with the group who are the focus of the research. It then becomes easier for the researcher to learn about the community and vice versa (Ahmed et al. 2004).

In the first sampling trial, the researcher tried to speak to people in the community about the purpose of the study, explaining to them what was being done, the reason it was done, why their area had been chosen, and what they were going to get out of the research. People did not seem free to give the information needed as the interpreter and the researcher were both from outside the community. The researcher then revised the plan and decided on using a person from the community who spoke both English and isiXhosa as a link between the researcher and the community.

A typical example of the lack of trust was observed when the researcher tried to explain the danger of the open fires burning, surprisingly they seemed keen to hear about it. The next day when the interpreter was present a different story was presented in their own language (isi *Xhosa*); they said that they believe in their processes (traditional method of cooking in open fires). They said that there is no health effect from any type of the wood used since they have been doing same thing for 30 years and no one is ill.

The lack of trust and language barriers gave an impression of the people's views about research done with them. An interpreter from their community is needed for them to feel safe about the information they are going to give. This helped the researcher to understand the basis for the opinions that people present and to try to build on these opinions. For example, the interpreter informed the researcher that the community/participants think that the researchers always look for their own information and do not care about the community. This particular information would not have been given had there been no interpreter that the community considered as one of them.

The lack of trust expressed by some vendors about researchers and the fact that the researcher did not know the local language naturally created a sense of insecurity in the researcher.

From experience, it was realized that all the above mentioned aspects (language barriers, lack of trust and the researcher's security) are complementary in the sense that if one is missing the others cannot be assured. Language being the most crucial tool, it helps the researcher and community to open up to each other and trust comes from the following feeling at ease. Conversely, if the language is not understood it results in disruptions, avoidance and suspicion. It may also result in not understanding or respecting the knowledge held by communities.

3.3.4 Validating the information

Recognising the importance of crosschecking the answers from participants to validate it, notes were taken during the experimental side of the study. Some of the participants tended to dissimulate or feel insecure with some questions. For example, when asked about the amount of the wood used to prepare a round, some participants were not sure or their estimate was far from accurate. In this situation observation and measurement helped in getting realistic estimates. Another important tactic that helped, was to put questions on hold until the participants were relaxed. This delayed the research. In some cases the vendors were busy with clients, or had other plans despite our appointment, but it was necessary to wait on them to be ready. Delaney (2007) observed that getting information from other/ different sources is also a key to validated information, however, it this study the only sources of data used were questionnaires, observations and objective measurements.

3.3.5 Time arrangement

The researcher was dependent on the participants' schedules. After building trust, it also took considerable time to enable them to engage with the research work being done. At many occasions a planned sampling was missed due to miscommunication. I would call a participant for an appointment a week before sampling, the participant would confirm date and time of sampling, I would call again confirm only to be told the participant had changed, was not working that day, and so on. This may have reflected that participants from the informal catering do not have a set agenda or a daily routine because they often work for themselves and have no one to control them or stricture them for lateness. It all depends on the day, for example close to a pay day vendors expect a lot of customers and they work a bit earlier. This same behaviour was observed by Shaw (2012) in a study that involved informal and homeless participants.

Such failed planning affected the researcher's work in terms of staying long on site or lagging behind the schedule and being unable to attend effectively to other planned work. At some times dense traffic would make the researcher late in arriving at the site, which meant the experiment could not be performed. This challenge was met by reaching the site much earlier than the vendors. This put the researcher in danger especially if at that time there is no accompanying local resident.

3.4 Approaches used to substantiate the research hypotheses

To substantiate the hypotheses and answer the research questions, it was necessary to investigate how much wood was used in open fires compared to efficient wood stoves or biogas in gas stoves, and to investigate respective costs and emissions. To confirm the value of slaughtering waste for biogas production, it was necessary to carry out an experiment and use its results in a techno-economic feasibility assessment. The experimental results were up scaled to an estimation of a real-life experience. To confirm the reduction in air pollutants when using the new cleaner production technologies (efficient wood stoves and biogas) vs. traditional methods (open fires), all production methods were observed in the field, taking air samples for analysis. By substantiating the hypotheses with the help of answering the research questions, it was possible to examine how far the research objectives had been reached. Table 3-2 summarises the research approach from the respective hypotheses.

Table 3-2: Summary of the research approach taken to substantiate the hypotheses

Chapter 4	Chapter5: section5.2	Chapter 5: section 5.1
1st Hypo	2nd Hypo	3rd Hypo
Field work	Field work	Field work
• Questionnaire on open fires wood , • Mass and energy balance • Smoke collection with a MiniVol	• Slaughtering waste collection • Investigation the location of the bioreactor	• Questionnaire on wood stoves, • Mass and energy balance • Smoke collection with a MiniVol
Lab work	Lab work	Field work
Analysing the smoke for PM_{10}	Trials on the performance of the slaughtering waste: 242 ml CH_4/g of VS, 72% of CH_4	Implement the biogas work in real life
		Smoke collection with a MiniVol
		Lab work
		Analysing the smoke for PM_{10}

The 1st hypothesis is elaborated by the following research questions:

1. How much wood fuel is needed in the current production methods? At what cost? How does this compare to fuel usage, operating cost and capital amortisation costs for alternative cleaner energy technologies? How do vendors perceive cost, convenience and side effects of traditional vs. cleaner methods?

Given that the thermal efficiency of cleaner energy technologies would yield cost savings, it was necessary to quantify the savings in terms of raw material and the possible burning equipment to invest in. Based on the background of this study described in Chapter 1, section 1.1.1, the slaughter waste generated during meat preparation would be a plausible raw material and prompts the question whether it is attractive enough to invest in a bio digester. Thus the 2nd hypothesis is explained by the following research questions:

2. Can biogas production include significant amounts of slaughtering waste (rumen content and blood) as substrate? What is the expected gas yield and is it more or less than the energy needed for the caterers to boil water for chicken plucking? What is the size and cost of a digester?

After elaborating the two hypotheses, it was realized that they would not be complete unless a pollution measure comparing traditional methods of cooking and cleaner technologies was considered. Therefore the 3rd hypothesis was introduced and elaborated by the following research questions:

3. To what extent would the adoption of clean energy technologies (biogas technology and efficient wood stoves) mitigate the environmental pollution through improving air quality and reducing solid waste hazards? Can these gains be quantitatively estimated? How do they compare to the cost of additional infrastructure supportive of cleaner production? What other factors would have to be considered for cleaner production methods to be adopted?

3.4.1 Thermal efficiency and cost saving from the CP burning equipment

To substantiate the 1st hypothesis, a description was done of the current production (traditional methods) processes with recipes, quantification of material and energy usage, wastes and emissions, and estimation of costs. This was then contrasted quantitatively with cleaner production means. Both old and new production methods were theoretically modelled for likely materials and energy consumption, and likely cost implications. Field work observations and experiments involving all the stages of data collection (open fires, efficient wood stoves and biogas stoves) were found to be a key to robust assessment.

It was important to apply thermal efficiency theory since it is the core pillar of the 1st hypothesis. It would then be easy to understand the comparative trends of the two cooking methods (traditional and efficient wood stoves) in terms of the quantity of fuel used, the cooking time, and their pollution loads (PM_{10}). This highlighted the relationships among the 3 hypotheses especially the 1st and the 3rd as in section 1.4. The 1st hypothesis focused on the thermal efficiency while the 3rd focused on the pollution loads reduction if cleaner cooking technologies were adopted. The more efficient the system the less the fuel used, the lower the pollution load and cost.

The thermal efficiency "η_{th}" is the ratio of the heat utilised by a heat engine to the total heat units in the fuel consumed. The input, Q_{in}, to the device is the heat-content of fuel consumed. The desired output is mechanical work, W_{out}, or heat, Q_{out}. By calculating the energy contained in wood (input) and the energy needed to boil a certain amount of water (output) it was possible to calculate the efficiency of both traditional and CP methods.

Because the input heat has a real financial cost, in this case "cost of wood," a generic definition of thermal efficiency is

η_{th}=*what you get/what you pay for*

Due to inefficiencies such as heat loss and other factors, thermal efficiencies are typically much less than 1.

Specific to the current research, De Foort et al. (2009) defined the thermal efficiency as a measure of both the combustion efficiency of the stove and heat transfer efficiency to the pot. It can be calculated by dividing the amount of energy necessary to raise the water temperature of the pot from its initial to final value by the amount of energy that is available through ideal combustion of the fuel used during the test. The suggested formula of thermal efficiency was then as follows:

$$\eta_{th} = \frac{\overbrace{\left[C_p . m_w . \left(T_{w,f} - T_{w,i}\right)\right]}^{\text{Heat absorbed (water)}} + \overbrace{\left[H_{v,w} . \left(m_{w,i} - m_{w,f}\right)\right]}^{\text{Heat lost (vapour)}}}{\underbrace{\left[\left(m_{F,i} - m_{F,f}\right).\left(1 - \frac{M_F}{100}\right).LHV_F\right]}_{\text{Heat input (wood)}} - \underbrace{\left[\left(m_{F,i} - m_{F,f}\right).\frac{M_F}{100}.\left(C_p.\left(T_b - T_a\right) + H_{v,w}\right)\right]}_{\text{Heat used (moisture)}} - \underbrace{\left[LHV_{char} . m_c\right]}_{\text{Heat left (char)}}} \quad (1)$$

Where,

$\eta_{th,}$ thermal efficiency

C_p is calorific capacity of water =4.186 KJ/kg °C

m_{w} , mass of water (kg)

$T_{w,I}$, $T_{w,f}$, initial and final water temperature respectively (°C)

$m_{w,I}$ $m_{w,f}$,initial and final water mass respectively (kg)

LHV_F , lower heating value of fuel

LHV_{char}, lower heating value of char

$H_{v,w}$,enthalpy of vaporisation of water = 2260 KJ/ kg

T_a T_b, ambient and local water boiling temperature respectively (^oC)

$m_{F,i}$, $m_{F,f}$, mass of fuel before and after burning respectively (kg)

M_F, moisture content of fuel (%)

m_c, mass of char.

The calculated thermal efficiency is independent of the amount of heat lost to steam, the amount of heat lost vaporizing moisture in the wood, and of unreleased heat energy in the char. With that, the only useful heat can be seen below as represented on the diagram (figure 3-2)

The diagram shows that the energy lost to vaporize some cooking water into vapour cannot be retrieved, both shell losses through the walls of a stove to ambient air and the heat consumed to vaporize the moisture content of the wood fuel, are considered energy losses. Unreleased heat in the form of biochar is discarded as waste, thus it is also considered as lost energy.

In other words, a true representation of the stove performance will focus on the net transfer of energy from wood to water.

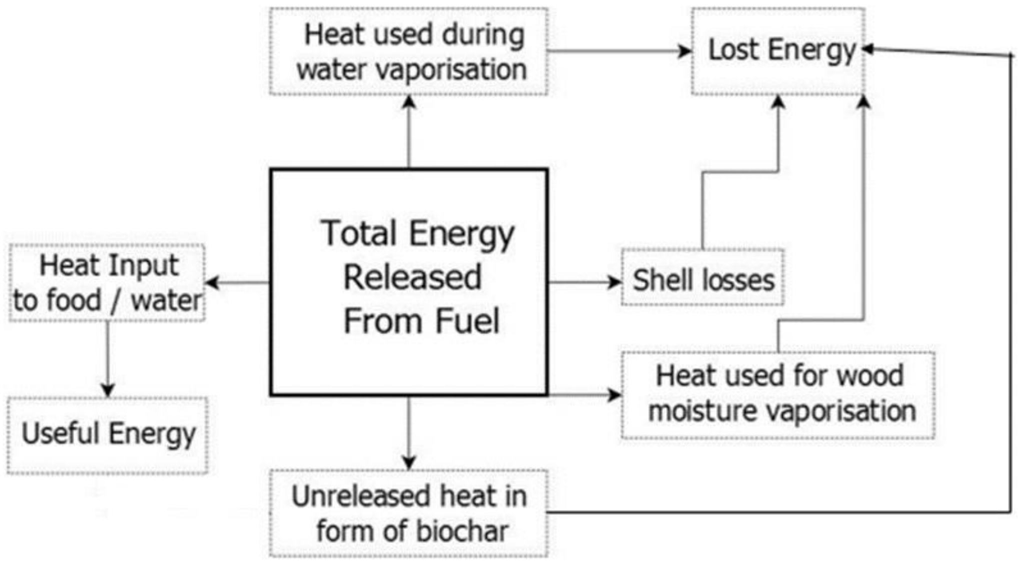


Figure 3-2: Illustration of heat flow of wood fuel

Source: (Docherty, 2013)

A thermal efficiency experiment was performed to quantify the resource usage in open fires and efficient wood stoves. Another useful term considered here was the dry weight of the fuel used. When this is used with the lower heating value of the fuel over the combustion time, one gets the overall firepower rating of the combustion process. The overall firepower rating of a combustion process with the thermal efficiency of that process, gives the useful firepower rating. This helps in comparing the performance of different combustion processes.

$$md,c = ((mF,i - mF,f)\,(1 - \frac{mf}{100})\mathrm{LHVF}) - ((mF,i - mF,f)\,\frac{MF}{100}\left(\frac{Cp(Tb - Ta) + Hv,w}{LHVF}\right)) - \left[\frac{LHVchar}{LHVF}.\,mc\right] \qquad (2)$$

Where $m_{d,c}$ is the dry weight of the fuel used

The overall firepower rating can then be found as follows:

$$FPo = \frac{LHVF.\,md,c}{t} \qquad (3)$$

Where t is the time of combustion

Having the overall firepower rating and the thermal efficiency of the combustion process, the useful firepower rating is: $FPu = \eta_{th}.FPo$ (4)

This measurement applied to wood heating not biogas data collection and analysis procedure where other parameters applied as will be discussed separately later in this chapter.

The following variables are controlled in this measurement: amount of water to heat and its initial and final temperature, wood type (harvested or waste), moisture (harvested, waste), water boiling point in Cape Town (100^{o}C), ambient temperature, heat of vaporization of water, mass of wood used and of char.

Apparatus

The same instruments were used with both open fires and wood stoves because the objective of the study was to compare the two methods. To assess the thermal efficiency, thermodynamic equations were used (see above). The following instruments were considered for the study:

A MiniVol (Air Metrics) and its ancillary equipment to measure the pollution loads; this will be detailed further down in this section;

A drying oven for use at 103-105 ^{o}C *(Laboratory& Scientific Equipment: Memmert, Lasec)* and a muffle furnace for use at 550 ^{o}C *(Carbolite* $^{(R)}$*, type: OAF10/2)* to calculate the moisture of the wood);

A scale: two types of scales were used; a hanging scale bought in 2013 March (portable electronic scale, made in China) to weigh the amount of wood used and a plate scale (bought in 2012 November) to weigh the remaining char. This only applied to open fires and efficient wood stoves;

A thermometer: to check the temperature of water before and after boiling, (borrowed from CEBER laboratory in the Department of Chemical Engineering at UCT);

A ruler: to measure the level of water and the diameter of the pot.

The water to be used by the vendor was put in a pot and its depth was measured with a ruler and the diameter of the pot was measured. The temperature of the water was also measured before and after the heating. The quantity of the wood to be used was measured using a hanging scale and a weighed empty sack as shown in figure 3-3. When the wood weighed before firing was more than that later used, the remaining wood was weighed and the mass of wood used found by subtraction.


(a) (b)

Figure 3-3: (a) Checking the water temperature before heating in front of the chicken vendor's working place, (b) Weighing the wood read to burn

At this stage of the study (field work), questionnaires and observations are combined with the experimental results to ensure and verify the practicability of the answers given by the participants (Neale et al. 2006).

3.4.1.1 Pollution loads (PM_{10})

3.4.1.1.1 MiniVol air sampler

The MiniVol™ Tactical Air Sampler (TAS) (Figure 3-4) is a portable ambient air sampler for particulate matter that can also be configured to sample various air toxins. The manufacturer claims that the patented low flow technology used in the MiniVol™ TAS was developed jointly with the US Environmental Protection Agency (EPA) in an effort to address the need for portable air pollution sampling technology.

The manufacturer made the following claims, which justified the use of this instrument for the intended purpose of collecting smoke samples near informally operating caterers:

"*While not a reference method sampler, the mass concentrations of the MiniVol™ TAS give results that closely agree with reference method concentrations. Both accurate and precise, the battery operated, lightweight MiniVol™ TAS is ideal for sampling at remote sites or areas without power. The MiniVol™ TAS features a 7-day programmable timer, a constant flow control system, an elapsed time totalizer, rechargeable battery packs, and an all-weather enclosure."* (Air Metrics 2002).

Figure 3-4: MiniVol Air Sampler (Air Metrics, 2002)

During the smoke sampling, the MiniVol operated without problems.

3.4.1.1.2 Equipment calibration and controlled smoke sampling

As discussed above, the MiniVol is a portable sampler to determine PM_{10} in the air, for environmental quality control purposes, which loads the captured particulate matter onto a filter, allowing for further analysis.

Before using the MiniVol sampler, which was newly acquired for a study similar to the current research, it was calibrated against one of the fixed air samplers installed at various air quality monitoring sites in the City of Cape Town. In a previous study, the MiniVol was set-up close to a TEOM sampler at the Bellville South Air Quality monitoring Station, during September 2010. The TEOM (Tapered Element Oscillating microbalance) is a fixed air sampler that provides a continuous direct mass measurement of PM_{10}, $PM_{2.5}$, and PM_1 particulate loaded on filters. Sampling was performed over a 24 hour period. In both instruments the particulate matter was collected on filter papers. Gravimetric analyses of the loaded filters give the particulate matter concentrations in the volume of air that passed through the filter papers.
These PM_{10} concentrations were reported in μg/m³.

The PM_{10} concentration read from the TEOM was 61 μg/m³ while the MiniVol showed 58 μg/m³ per 24 h. Baldauf et al. (2001) had found a similar difference of 3 μg/m³ between the TEOM and MiniVol average concentration measurements, also with the TEOM sampler reporting higher values). According to Baldauf et al. (2001), the collection efficiency of the MiniVol is influenced by wind speed. The average differences between the two samplers were considered to be reasonably small, supporting the plan to use the MiniVol to collect particulate matter in smoke from wood fires. The particulate matter was collected on quartz filter media. The PM_{10} concentration was determined by weighing the filters before and after collecting particulate matter.

In the course of this study the same calibration method was applied to the MiniVol to ensure its trustworthy operation. While Baldauf et al. (2001) suggested that the MiniVol should be calibrated once per year or whenever the flowrate was changed and while the flowrate was never changed for the instrument, trials were performed in Khayelitsha, where a TOEM and a MiniVol were run simultaneously over 24 hours as proposed by Baldauf et al. (2001). On the 17th April 2013 and the 28th March 2015, the results from the TOEM were 49 and 32 μg/m^3 while the MiniVol' s were 51 and 34 μg/m^3 respectively, demonstrating no drift in calibration over a two year period. After this, it was time for the study data collection.

To measure the pollution loads or the concentration of PM_{10} in the smoke, during each experiment, the MiniVol was set approximately 2 m from the fire source and approximately 1.5 m above ground. Thus the measurements could be considered occupational rather than ambient. The MiniVol was set running at the start-up of a fire. A control sample was taken before experiments in the analytical laboratory in the department of Chemical Engineering at UCT when the MiniVol was run for 24 h. The sample showed negligible concentrations of PM_{10} of 2 μg/m^3.

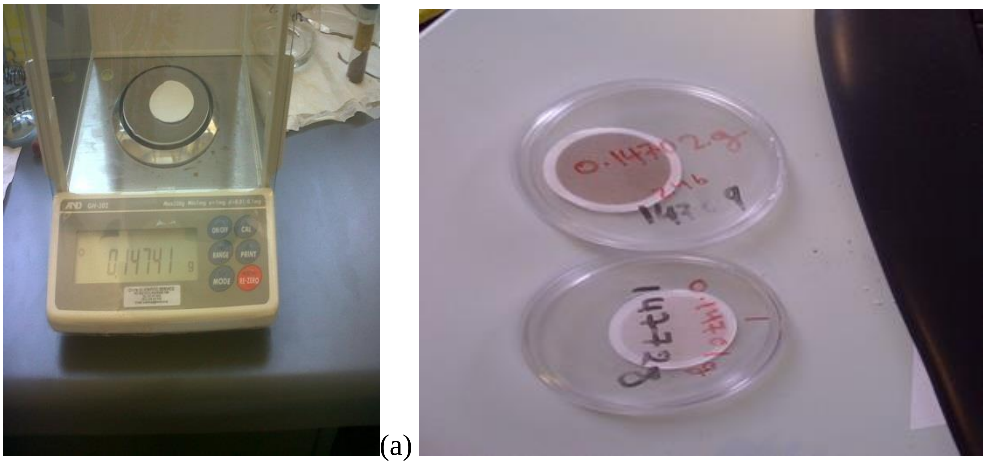
3.4.1.1.3 Additional equipment

The filters used in the air sampler were made of quartz, chosen for their resistance to damage when capturing particulate matter. The filters were 47 mm in diameter with a pore size of 0.5 µm, which is acceptable for PM_{10} sampling. The filters were pre-weighed using a 5 decimal microbalance and kept in clean petri dishes. During sampling, the filter was placed in the filter cassette and put into the inlet containing a PM_{10} impactor. After checking that everything was in order with the MiniVol, the start button was pressed and the instrument kept running until the end of the water boiling process. After the sampling, the loaded filters were removed from the cassette and put in petri dishes to transport them to the laboratory for re- weighing (Figure 3-5).

In summary, the procedure followed on every successful field work was as follows:

- Weigh the blank filter;
- place each filter in a separate petri dish as measured, close it immediately and record the filter mass on it, and make sure that it is ready to be used as soon as possible before the ambient humidity changes the mass as measured;

- at the experiment site, set up the MiniVol tripod at the desired distance from a fire which is ready to start;
- indoors, take a weighted filter out of the petri dish and place it into the filter holder while avoiding touching it (using provided tweezers), as the MiniVol works with small mass differences;
- be sure that the flow rate is set at 5L/min, at this time the battery must be inserted in the instrument;
- check the MiniVol pump for leaks by pressing the palm of the hand on the opening of the pump line, if there no exit of gas then the instrument is ready to use;
- attach the filter assembly to the MiniVol air inlet and turn it on at the same time as lighting the fire;
- record the ambient temperature and pressure (provided by a local weather centre in this study);
- when the cooking process is complete, turn off the MiniVol. In the case where the wood must be weighed, the fire must be smothered in order to measure the remaining wood;
- the start and the end time of each sampling must be recorded to enable the PM_{10} concentration calculations;
- after the test, remove the filter assembly from the unit and take the MiniVol indoors to remove the filter and put it into the same petri dish it was in before the measurement, keeping it closed until close to the 5 decimal balance then weigh the loaded filter, and record the mass;
- the increase in mass on the filter is the mass of the collected particulate matter;
- from here, the calculations detailed in section 3.4.1.2.3 must be applied to get the PM_{10} concentration.



(a) (b)

Figure 3-5: (a) a 5 decimal microbalance, (b) loaded filters in petri dishes

3.4.1.1.4 Calculation of volume of air sampled

From the Air Metrics (MiniVol manual) procedures, calculations are done as follows:

$Q_{act}= (m_{vol}\times Q_{ind} +b_{vol}) \sqrt{P_{std}/P_{act}\times T_{act}/T_{std}}$ (1)

$I_{sp}=[5.0\times(\sqrt{P_{act}/P_{std}\times T_{std}/T_{act}})-b_{vol}]/m_{vol}$ (2)

Where:
Q_{act}**:** Actual flow rate, litres/min

Q_{ind}: Rotameter indicated flow rate, litres/min

m_{vol} = Slope of the least square line and equals to ***1.1409*** for the MiniVol used in this study

b_{vol} = Intercept of the least square line and equals to ***-0.4251*** for the MiniVol used in this study

I_{sp} = Calculated rotameter setpoint, litres/min

P_{std} = Standard atmospheric pressure, (760 mm Hg)

T_{std}= Standard temperature, (298 °K)

P_{act}=Actual ambient pressure, (mm Hg)

T_{act}=Actual Ambient Temperature, (°K).

To calculate the volume of air that passed through the filter during the sampling period at actual ambient conditions, **Vact** (in cubic meters), was done as follows:

Vact= (60 min/hr×Qact×thr)/1000

Where thr = sampling period, in hours

The units of Vact are *cubic metres*.

3.4.1.1.5 PM Concentration Calculation

To calculate the concentration of PM, divide the net mass gain of the filter by the volume of air that passed through the filter.

$PM_{act}= M_{PM}/V_{act}$ *Relation (2)*

Where PM_{act} = PM concentration, in micrograms (μg) per cubic meter (actual) M_{PM}
= Mass of particulate matter collected on the filter, in micrograms (μg).

3.4.2 Rumen content as a source of energy for informal caterers

The 2nd hypothesis was verified by investigating the anaerobic digestion of slaughtering waste under realistic non-ideal conditions, in a pilot scale (100 L) digester under ambient conditions. This was done to estimate how much energy one could expect from that particular substrate and how disposable the sludge would be after digestion. This work was done in a deliberately low-technology digester mimicking as closely as possible the likely field installation. The yields obtained were scaled to a 6 m^3 digester and costing calculations performed to describe the techno-economic feasibility of installing such waste treatment infrastructure near street caterers.

The purpose of the experiment was to predict the methane recovery from slaughtering waste which is mainly a composition of rumen content and blood. This was demonstrated using two 100 L prefabricated fixed-dome type biogas digesters, operating at ambient temperatures, over a period of 90 days.

As mentioned above, sheep rumen content and a mixture of blood and rumen content were used as substrates. This was part of 17 % of the solid waste per total weight of sheep or goat as reported by slaughterers. Slaughtering wastes were collected once in two weeks, packed in zip plastic, transported in cooler boxes and stored at -2ºC in a freezer in the laboratory. The feed was defrosted a day before feeding the digester.

The bio-digesters were fed daily with 80 g of substrate. Note that the rumen content was the main feed rich in carbon, and the blood mixed with rumen content (richer in nitrogen) was added only once the pH inside the bio digesters had dropped, in order to pick it up again. There was however no calculation of the quantity of blood added as it was already mixed with the rumen content at collection.

The characteristics of slaughtering waste from sheep and goat are reported in Table 3-3. The substrates were analysed for total and volatile solids (VS) using the drying oven for use at 103-105ºC *(Laboratory& Scientific Equipment: Memmert, Lasec)* and a muffle furnace for use at 550ºC *(Carbolite (R), type: OAF10/2)*. The rumen content was determined to contain 19 % total solids of which 92 % was VS (Table 3-4). This particular substrate fell in the category of a medium solid anaerobic digestion system that contains 15 to 20 % Total Solids (TS) (Monnet 2003).

Table 3-3: General characteristics of slaughtering waste

Parameters	**Value**
Moisture, %	69
Total solids (TS), %	31
Volatile solids(VS), %	88
Fixed solids, %	12
Organic carbon, %	23
Total nitrogen, %	3
Phosphorous, mg/g	4
Potassium, mg/g	7

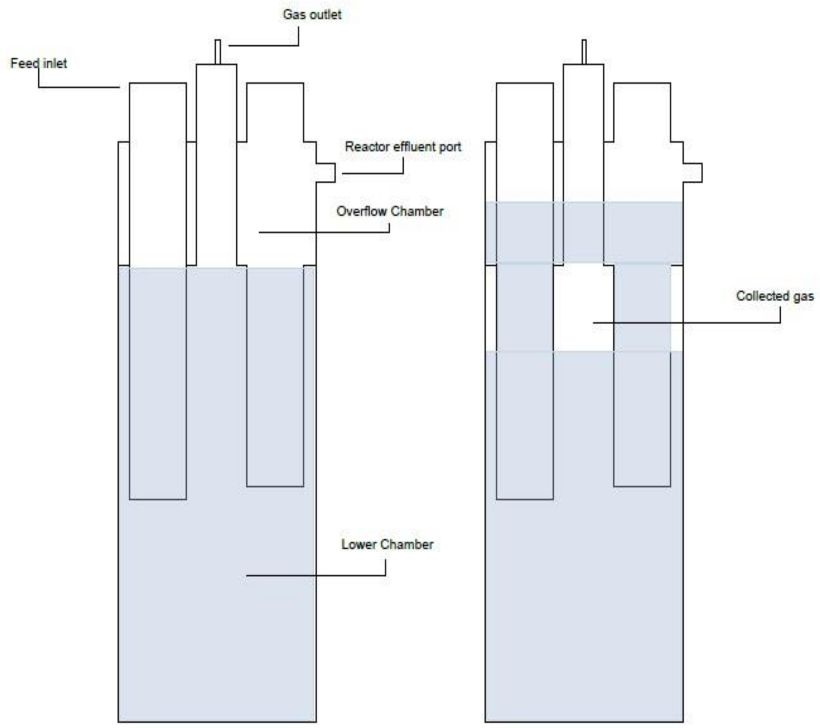
Source: (Ahmad & Ansari, 2012)

Table 3-4: The characteristics of the substrates used for this study (rumen content)

Substrate	**Rumen content**
%Total solids (TS)	19
% Volatile solids (VS)	92
Waste mass (g/day)	80
TS (g/day)	15
VS (g/day)	14
Total VS load (g/l/day)	0.2
Water added (ml/day)	200

Source: Author

The experiment was conducted on two identical pre-fabricated fixed-dome type biogas digesters supplied by Agama Biogas: AD1 and AD2, nominally of 100 L volume of which 60 L are active reaction volume and 40 L for the liquid expansion volume when gas is produced. Figure 3-6 (a) and (b) shows the model and schematic configuration of the reactors used in the experiment. However, at the time when this experiment was carried out, the digesters had been in use for 2 years and they had not been emptied, which may affect the normal active volume due to solids accumulation which may therefore affect the results presented in this study. It is important to consider that different types of substrate had been used in these bio digesters before, depending on the purpose of the experiment. At least one of the prior experiments involved slaughtering wastes (Melamu et al. 2012), so the culture had adapted to this kind of substrate.



(a) (b)

Figure 3-6: (a) model, (b) Schematic configuration of the reactors used in the experiment

The bio digesters were generally subjected to same conditions. In this experiment, the reactors were fed with 80 g of substrate every day except from day 58 to 67 and 81 to 90, where the feeding was doubled to see whether that made a difference to gas production. The gas produced was measured and released every day when the reactors were fed. A sample from the sludge was taken for pH measurement.

The volume of biogas produced was measured by a water displacement method and the methane composition was checked using a gas analyser (Reiken-Kikki GX- 2012A) device which read the methane and oxygen in percentages and CO and H_2S in ppm (parts per million).

After this experimentation the results were promising and thus scaled up to 6 m^3 reactor to assess their applicability to a bigger sized reactor for a real life experimentation.

As suggested at the beginning of the research, the following step would have been to install a 6 m^3 bio digester at Nyanga (at the field of the research) in imitation of the previously successful bio digester installed or led by a group of researchers and co-group members of E&PSE (Environmental and Process Systems Engineering) at UCT. However this could not be done because, for any activity involving public property transformation in Cape Town, permission from government authority must be granted and negotiations between EWB on the researcher's side and the Nyanga local counsellor did not lead to consent, as other authorities involved were not available at the time of the research.

This led the researcher to consider using the above mentioned successful bio digester for the experiments. That 6 m^3 pre-fabricated biogas digester was at a controlled and relatively formal setting, outside a canteen at one of the university residences (Leo Marquard Hall at the University of Cape Town) and was associated with UCT's green campus initiative. The biogas unit was designed to take 20 to 40 kg of kitchen waste per day and twice that amount of water. The installation of that bio digester had followed a conventional engineering project development process, viz. concept and detailed design phases, construction, commissioning and start-up (Melamu 2014). The option to use this digester was also inspired by another successful installation of a biogas digester at Abalimi garden in a periurban area of Khayelitsha by EWB in cooperation with E&PSE group. That was an 8 m^3 bladder digester requiring 20 to 35 kg of organic waste per day and twice that amount of water.

The approach to verify the 2nd hypothesis was then to imitate previous biogas digesters installations led by the E&PSE group. Although the purpose and the feedstock of the two existing installations described above differed slightly from that of the current research, they had the common goal of generating a clean cooking energy and reducing solid waste, particularly organic waste.

Further experiments were then performed at the Leo Marquard Hall biogas digester to demonstrate the utility and feasibility of heating a measured quantity of water needed to pluck 5 chickens as it is done at Nyanga. Note that the Nyanga plan was to use slaughter waste rather than food waste as was done at Leo Marquard.

Using the same pot as in the case of efficient wood stove (15 L) on a 3 kw stove, 10 samples were collected, daily measuring the quantity of methane produced. A detailed description of the experiment and equipment used for the Leo Marquard Hall biogas digester was the same as what is described above in the case of 100 L reactors.

As the reactor was outside the canteen, a long pipe line was used to conduct the gas to the stove station. On the pipeline, a few cm from the stove, was a gas desulfider to remove the impurities in the gas from the reactor and a kilo Pascal (kPa) gauge that showed the pressure of the gas generated and used. The biogas volume was determined using initial pressure (before using the gas) and final pressure (after using the gas) with the time of combustion. $P = \rho \mathrm{gh}$

From the formulae above, the height could be deducted and together with the cylinder radius of the bio digester (where the gas was) enabled calculation of the volume of the gas by the formula

$\Delta V = \pi r^2 (\Delta \mathrm{h})$, where Δh was the height of water displaced by the gas used.

The volume of biogas, the time to heat water to a certain degree and the flame's intensity would determine if such a bio digester could be recommended for informal caterers. The bio digester suggested for this study cost R 25 000 from AGAMA (2012). The results of this experiment are discussed in chapter 5.

3.4.3 Air pollution reduction from the CP burning technologies

To substantiate the 3rd hypothesis, efficient wood stove and biogas interventions were tested under real conditions and their benefits quantified by air quality measurements. The public value of the improved air quality and hygiene were described and estimated. Particulate matter was collected for open fires, efficient wood stoves and biogas stoves. And this was analysed in context of the type and quantity of the fuel used. For instance money spent on wood in the case of open fires and efficient wood stoves was calculated to compare these technologies in terms of cost saving, wood fuel and slaughter waste management. Other aspects of a cleaner production approach were also considered to gain a general picture of how a new clean cooking technology could change the daily life of an informal vendor. Such CP impacts would include good housekeeping, input change, etc. as detailed in chapter 5.

It was important to see the interrelationship between the hypotheses of the research, since one could not be verified without involving the other. For instance the 1st hypothesis focused on the thermal efficiency of a cooking method (traditional or cleaner technologies) while the 2nd focused on one particular intervention of cleaner technology. In all configurations the pollution loads were considered in the 3rd hypothesis (figure 3-7.)

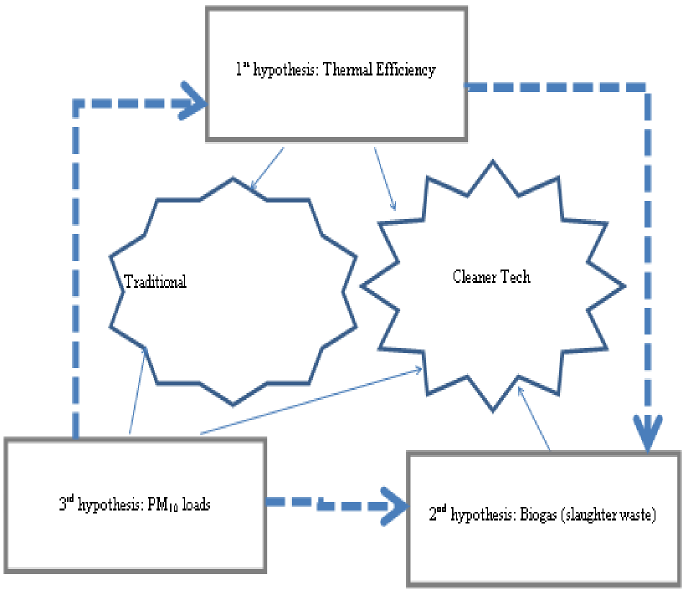


Figure 3-7: Schematic interrelationship between hypotheses

After detailing the approaches used to verify the hypotheses proposed for this research, it was necessary to choose the order or methods to apply them so that satisfactory results could be reached.

3.5 Scope

This research centrally focused on the socio-economic, health and environmental implications of the informal production of food and drink in urban Africa. Health implications were presumed to arise from exposure to particulate matter in the form of smoke from the incomplete combustion of wood (section 2.2.2.2). Air quality measurements were thus used to infer health implications. Environmental implications were described by resource efficiency and waste intensity, while the socio-economic implications were deducted from the cost of fuel when using traditional and clean methods of cooking. African urban informality was represented in this research by working with informal caterers who used wood to prepare food and drinks in the vicinity of the Nyanga transport interchange.

3.6 Ethics

To ensure that proposed research conforms to acceptable ethical standards, the Engineering and Built Environment (EBE) faculty stipulates that when it involves human participants for data collection, the proposal has to undergo an ethics review. As this research required human participation for data collection and as such approval from the EBE Ethics in Research Committee (EiRC) was thus necessary; the ethics form was filled in and was approved (Appendix 2).

All participants were assured of their anonymity and that there would be no direct reference made to them. Only numbers and pseudonyms were used and participants were informed about that practice. The participant's consent form is available in appendix 3. All information collected from participants was used only for research purposes only and remained confidential.

3.7 Summary

This study used a grounded theoretical approach, combining field observation, experimental and case study methodologies. The case study (informal catering in Nyanga) served as a representation of catering in many urban African settings. This study merged qualitative research with quantitative methods. In qualitative studies, purposive samples are the most commonly used form of non-probabilistic sampling, and their size typically relies on the concept of "saturation" (Hennink et al. 2010), or the point at which no new information or themes are observed in the data. Hennink et al. (2010) reported that studies that use more than one method require fewer participants.

As described in the results chapters, 6 participants were selected for cleaner cooking technologies and 10 for traditional cooking methods, respectively. The literature recommends at least 6 samples (Guest et al. 2006). The biogas experiments were repeated 10 times but without the participation of the targeted community i.e. Nyanga, being carried out on the UCT campus.

A meeting with a vendor would be set up in advance with the help of an interpreter who also helped with questionnaires. The time spent with vendors was longer than planned due to the simultaneous business related work by the vendor. Meetings with vendors would happen 3 days a week in the pre-collection of data. However on some days the data were not collected due to the miscommunication.

Field activities would last for at least 4 hours. The 1st hour consisted of arranging the wood, measuring it, taking the temperature of the water and its quantity and lighting the fire. The 2nd hour was taken in waiting for the water to boil while the vendor was busy setting up for her day. During that time the researcher observed and asked questions with the help of the interpreter. The last two hours or so were taken up in discussing the business while also taking note according to the questionnaire.

The findings in this study were subject to careful interpretation. With the acknowledgment that one limitation of case studies is the poor generalization of the results (Guest et al. 2006), the findings in this study applied specifically to roadside caterers in Nyanga, but should have relevance to similar situations in Cape Town, elsewhere in South Africa and indeed elsewhere in Africa, as well as to other informal catering production activities in similar settings requiring thermal energy.

4 WASTE AND EMISSIONS PRODUCED DURING FOOD PROCESSING ON OPEN FIRES

This chapter presents the observations and insights developed from the field observations of current informal catering processes at Nyanga. It focuses on the open fires i.e. the traditional ways of cooking. All types of catering-related waste are also described and their current management is critically discussed.

The chapter describes and discusses the qualitative and quantitative results separately. Sections 4.1 to 4.5 cover the qualitative observations and the information collected from the questionnaires, while section 4.6 covers the measurements taken in the field. At the end of the chapter a synthesis of qualitative and quantitative findings is presented.

The study focused on the informal food vendors who did their business alongside the roads. Two activities, in particular, were studied: chicken vendors who sometimes have a side business of sheep meat selling, and brewers of traditional beer.

The following qualitative descriptions cover fuel wood use, solid wastes and their management, effluents, emissions to air and caterers' perceptions of their work environment, particularly of smoke.

4.1 Fuel wood use by caterers

As was stated in chapter 3 section 3.4.1 and 3.4.2, the study started with investigating and identifying all the chicken vendors around Nyanga, when it was found that other types of meals such as barbequed meat, as well as the traditional *umqombothi* beer were also being sold.

Although these various offerings do not necessarily need the same quantities of wood fuel to prepare the meals, the vendors need to buy or to have wood fuel. This wood is sourced from the surroundings or bought from sellers who pass by the area, possibly on their way to the disposal site. In this latter case, it is bought at a cheaper price (figure 4-1).

Figure 4-1: Fuelwood in Nyanga; old doors and other waste wood adding to a stock of other pallet wood used by the vendors

Source: Taken by the author during sample collection on 6 March 2013 at 11:27 am.

An open fire is a traditional method of cooking in both rural and peri-urban areas of South Africa. It commonly uses three stones on top of which a pot is placed in order to make fire underneath the pot (figure 4-2(b)). Traditionally the cooking is completed with adding more fuel (wood) and the pot is often left open. The pot can also be put on the ground and the fire just built around it (figure 4-2 (a)). This method uses lots of fuel since the heat is dispersed in all directions around the pot.

The cooking techniques used by the food vendors in Nyanga as mentioned above, were found to involve building a fire at a high heat so they could cook food relatively fast in order to meet the urgent need of their passing clients. The method was to create a big fire of planks or other large pieces of wood upon which a steel drum or a pot was placed. Heat losses were observed due to the openness of the fire (figure 4-2 (a)). The big poles and pieces of wood were sometimes split into two or burnt as they were, making them difficult to ignite. Considerable waiting time and a sizeable fire were needed for the big pieces to ignite. The flames were higher than required for the job needed, and most of their heat lost as shell losses.

 a)

 b)

Figure 4-2: Cooking means: a) Steel drum heated on a traditional three-stone fire place for umqombothi preparation; b) chicken vendor ready to pluck a chicken in Nyanga

Source: Photo (a) taken by the author, photo (b) taken by M Rodriguez-Pascal in Nyanga

4.1.1 Chicken plucking

4.1.1.1 Observation

In the morning the vendors arrived at their stands or business places, which were sometime just the front area of their homes. Every vendor had somebody (mostly a family member) to help them. In a truck on the other side of the road, a chicken supplier waited for the vendors to come buy as the supplier continued selling live chickens in the area. Each vendor bought at least 5 chickens at R30 to R60 each depending on the size of the chicken. The chickens were tied together waiting for water to boil in a 25 L drum serving as pot as seen in figure 4-2 (b) above. It was noted that the pot was not covered. Once the water boiled, which was after at least an hour on the fire, the chickens were killed by cutting off their heads. The chicken carcasses were immersed one by one into the boiling water. The smaller drum could accommodate only one chicken at a time (figure 4-2 (b)).

The chicken was then taken out of water and plucked. The feet were then removed to be prepared with the heads and sold separately. While the first chicken was being plucked, the water stayed on the fire to keep it hot for the next chicken. Using a stop watch, it was observed that the chicken was first soaked in hot water for 14 ± 1 sec to soften the big feathers. When the feathers are almost taken off the small and young feathers were removed after soaking the chicken again in hot water for 32 ± 2 secs.

The fire stayed on for hours even if the chicken preparation was finished. Thus the vendors burned more wood than necessary and their exposure to the smoke increased. This was observed in both winter and summer time.

No further was preparation was made on the chicken, meaning that the chicken was sold uncooked and with the innards in place at R40 to R80 depending on the size (figure 4-3). However vendors also had a side stall for barbequed sheep and other meat. No cooked or barbequed chicken was observed.

Figure 4-3: Plucked chickens as they are sold to customers

The hygiene of the chicken sold was compromised by all the feathers, bloody waste and the slaughter waste from sheep from the next vendor, all left lying around the selling area. There were flies and an unpleasant smell. No fridges were seen in the selling space for storing chicken temporarily or if not sold. Hygienic conditions were worsened by water taps being distant from the selling space.

As stated above, fuel wood, utensils, meals and waste were all kept in one small space, which might have given a bad impression to clients but they still bought presumably due to the cheapness of the merchandise. Some clients seemed not to notice the poor conditions. This situation was similar to that observed by Ahmed et al. (2014) in informal settlements of Mathare in Nairobi, where the food processors faced challenges to keep their food safe, as mentioned in section 1.1.1. Many other concerns could arise from this informal selling. Thus when asked informally (out of the formal questionnaire) whether the chicken sold are monitored by a veterinary official, the answer was NO. The chicken supplier simply had an arrangement with the vendors and brought chickens to them. No-one could know whether a particular chicken was sick, such a one would simply be sold along with the others.

The infrastructures available did not allow the vendors to work indoors, making a difficult situation for them, especially in winter. To avoid shack fires, the fires were made a few metres away from the shacks but that might still not have been enough precaution.

4.1.1.2 Chicken plucking temperature

Using 10 thermometer measurements, it was found that the water is heated to at least 90°C. The literature reports that the required temperature to scald a chicken varies between about 63 and 66°C when using a plucker or hand plucking (Huddler Lifestyle 2009[4]; Kimball 2009[5]). The highest temperature reported is about 71°C but this can be accompanied by skin damage of the chicken which makes it difficult to pluck (Kimball 2009). It is also possible to scald two or more chickens at once depending on the size of the pot. This would suggest that scalding at 90°C is harmful to the skin of the chicken, wasteful of energy and wood while the smoke also continues to disperse. However, no study was done on the condition of the chickens' skin which may well vary from one chicken to another depending on how they are fed and raised.

4.1.2 *Umqombothi* preparation

The vendors in Nyanga and other South African townships are also known for selling this African beer. The beer preparation involves doing the starch saccharification step on open fires. The common southern African traditional beer, called *umqombothi* in the isiXhosa language, also known as *'Chibuku'* and *'Munkoyo'* or *'Ibwatu'* in Malawi and Zambia respectively, is a beer made from maize (corn), maize malt, sorghum malt, yeast and water. It is very rich in Vitamin B. The beer has rather low alcohol content (usually less than 3 %) and is known to have a heavy and distinctly sour aroma. In appearance, the beer is opaque and light tan in colour. It has a thick, creamy and gritty consistency (from the maize).

Umqombothi is cheaper than commercial beers that are brewed from barley and flavoured with hops flowers.

4.1.2.1 Traditional method of umqombothi preparation

Umqombothi is brewed following traditional customs which vary slightly between regions. The recipe is often passed down through the generations. The beer preparation traditionally is carried out in part over a fire outside of the house. It then passively cools to ambient temperatures outside the house and is left overnight (between 10 to 15 hours) to ferment. See figure 4-2 (a).

The ingredients used are: equal measures of maize meal, crushed mealie malt (corn malt) and crushed sorghum malt. The maize malt provides a lighter-toned beer with a mellower flavour. The sorghum malt provides a darker beer.

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[4] Available at http://www.backyardchickens.com/t/381163/what-temperature-of-the-water-when-you-are-ready-topluck-a-chicken.

[5] Available at http://thedeliberateagrarian.blogspot.com/2009/02/how-to-properly-scald-chicken-my-never.html.

Figure 4-2 (a) also shows how in Nyanga the fire was made to make the quantity of water needed boil quickly. Large drums were used because the beer was made to sell and it had many customers. The vendors said that a pair of drums could last for two days meaning the process repeated twice or thrice a week.

The whole process of *umqombothi* production has two stages and takes two days. The first day is to prepare *isidudu*. In this process, the ingredients are mixed in a big bucket or two as was seen in Nyanga. Four measures of hot water are added. The hot water is prepared as seen in figure 4-2 (a). The mixture is left overnight. The mixture starts fermenting and bubbles appear. A sour odour can be detected and this is the wort. A small portion of the wort is removed and put to one side. The remaining mash is cooked until a crusty sediment forms. This product is known as *isidudu* and can be eaten as porridge. When making beer, the *isidudu* is left to cool for a day.

The second stage of this beer preparation involves using the wort to prepare the *umqombothi*. The process requires a significant amount of fuel due the long process of preparation and large quantities of water required. Significant smoke pollution may thus occur. In Nyanga it was observed that to prepare one round of *umqombothi* or boil 230 L of water took at least 2 h and the wood used was compared to that by chicken vendors as reported later in the experimental section. However, after the process was complete the fire was smothered unlike what was observed in the chicken plucking activity. It is important to recap that *umqombothi* was prepared twice or thrice a week while chicken plucking happened 6 days a week.

When the brew is ready, the fermented mash is filtered through a large metal strainer, to remove the spent grains. The sediment at the bottom of the vat is known as *intshela*. The *intshela* is added to the strained beer, to give extra flavour. In Nyanga the spent grains were squeezed out and usually cast onto the ground for chickens. The remaining *intshela* was dumped outside the house. The money flow for *umqombothi* was not investigated in this study, but the thermal efficiency of the cooking method was investigated.

4.1.3 Comparative notes

All vendors questioned and observed in this study stored their firewood outside, but in the rainy winter season, a portion of wood about to be used was stored inside the shacks. No measures were noted to control the introduction of waste wood into the community.

A previous observation made by the author in 2010 was that vendors commonly preferred using waste wood over harvested wood due to its lower cost. This was again the response from all ten out of ten responding chicken vendors, when asked whether harvested or waste wood is most used. The respondents added that waste wood burns faster and nicely because in winter time harvested wood is wetter.

One danger of this practice is that in open fires, the vendors would leave the fires burning for hours even after they had done with the chicken plucking. This would unnecessarily increase exposure to the smoke from wood burning.

However, it was observed that the African beer (*umqombothi*) brewers did not leave their fires burning the whole day.

4.2 Solid wastes

4.2.1 Bottom ash

In this study, the ash remaining after wood burning was not measured but typically, it was assumed to be between 0.43% and 1.82 % of the total dry mass of the wood before burning (Misra et al. 1993). It was observed that ash was dumped on the roadside together with slaughtering waste. Sometimes street cleaners would collect it from the road once a week. The use of ash in gardens was not observed in this study because there were no gardens around the premises of the commercial and residential areas. Normally, wood ash is rich in calcium carbonates $CaCO_3$ (25-45 %), potash KCO_3 (<10 %) and phosphates PO_4^{3-}, which is a good component of soil fertilizer (Hume 2006). However the ash generated in Nyanga needed special attention because in most cases, the wood came from demolitions/constructions sites where it may well have been impregnated with wood preservatives as mentioned above. These preservatives may leach out of the ash to pose threats to the soil, water and environment.

The picture (figure 4-4) shows bottom ash collected together with slaughter waste waiting for informal waste collectors to pick up. Observing carefully it was seen that the ash was not collected completely due to inefficient ways of collection. This originated in the inefficient traditional method of cooking because in an open fire, some ash remains at the fireplace from where it is almost impossible to remove completely after cooking; also traditionally the ash must not be removed completely because 'it helps the next fire to light so fast', in the words of one chicken vendor. It is believed that efficient wood stoves would resolve that problem since the bottom ash remains inside the stove and as the stove must be cleaned up before next use, the disposal of ash without spilling should be simpler.

Figure 4-4: Bottom ash, the white bucket containing a mixture of slaughter waste and ash

Source: photo taken by the author on the 06 March 2013 at 11:52 AM

4.2.2 Slaughter waste

Figure 4-5: Slaughter waste dumped on the road side

Source: photo taken by the author on the 06 March 2013 at 11:52 AM

Figure 4-5 shows how slaughter waste was handled in Nyanga. Due to the lack of adequate infrastructure, animals were slaughtered on the road close to the business place and the waste was left there. The author observed that at least 40 sheep and 50 chickens were slaughtered daily. The main constituents of the unusable meat from sheep are rumen content which is at least 2.5 kg per sheep. The other waste is blood (not quantified) collected in a container at the slaughtering site and thrown away with the other waste. From chicken, only the feathers were thrown away.

The water used to clean the meat and used utensils, was thrown onto the rumen content as seen in figure 4-5.

4.2.3 Solid waste management at Nyanga informal food production stands

An observation made at Nyanga, was that all types of waste were dumped without order and all together without considering who might be responsible of that waste or the individual characteristics of each waste type. Thus the chicken waste and the sheep waste were dumped all together on the sidewalks, waiting for the collectors. The vendors threw away whatever they did not want. They saw no further use for that waste except to be taken away by the collectors or anyone who was interested.

The ash, blood and rumen content were all together for collection as they lay because at that stage separation by the collectors was made impossible by the mixture of liquid and solid waste. Flies and mosquitos flew all over the waste because some waste remained for long periods. Sometimes, the waste was roiled by dogs who ate from the rumen content and blood. Added to this were bones both raw and from the braised sheep as well as feathers from chickens that were discarded by both vendors and customers. This increased the untidiness of the area in general.

Although waste collection in the informal sector is still a problem generally, the City of Cape Town claims to get engaged in changing of how solid waste is managed, including in part of Nyanga. For instance, as a response to the Cape of Good Hope's Society for the Prevention of Cruelty to Animals (SPCA) the City has recently promised informal abattoirs to the caterers This offers a solution to some of the challenges, included insufficient sanitary facilities and ablutions, poor waste management, disposal of blood and body fluid from slaughtered animals into storm water, lack of drainage and contamination of food products from dust, dirt and contagious germs (Gontsana 2015).

If this plan is executed as promised, it would considerably reduce the amount of slaughter waste generated and it would ease the waste disposal, thus ensuring better housekeeping. From the vendors' view, cooperation and trust between them and the City of Cape Town is crucial to reaching the desired goal.

Another report highlighted that the City of Cape Town has prioritized a massive allocation of resources to improve living conditions in informal settlements in general. In terms of solid waste management the City has increased their budget by approximately 112% from the 2006/2007 level. "In 2013 an estimated budget of R141 million has been budgeted for the provision of solid waste management services to informal settlements." specifically in the provision of refuse removal and area cleaning, water, sanitation and electricity, by providing refuse bags, collection and area cleaning, as well as litter collection and picking between the informal dwellings in the settlement (3S Media, August 2015).

4.3 Effluents

As introduced above and illustrated in figure 4-5, the water used to clean utensils drained onto the road.

Some of it failed to enter the storm water drains due to solid slaughter residues blocking the way.

From an informal conversation with some vendors it seemed that most were not aware of where the water thrown on the road went. Studies have reported that the drained water from slaughtering causes odour problems, the release of greenhouse gases and the deoxygenation of rivers (Massé & Masse 2000). The dumping of slaughter wastewater onto the road transports fats, blood and other organic matter into storm water retention ponds, where it is harmful in attracting flies and mosquitos in the neighbourhood, not to mention the bad smell and other threats to human health and quality of life.

4.4 Emissions to air

Emissions discussed in this section were considered to have two sources:

- Emissions from the degradation of slaughter waste:

Besides the bad smell from rotten slaughter waste dumped illegally at the roadsides and in between shacks, flies and mosquitoes flying around on the prepared meat and utensils presented clients with a forbidding image. However those who managed to cover the meat and plates with magazine papers were observed to get more customers. In this study, no analysis was done on the air emissions from the degradation of slaughter waste. As introduced in the literature review, any organic waste digested anaerobically generates biogas, a useful gas for cooking and lighting. That motivated a biogas experiment as detailed in chapter 5.

Additionally, the effects of methane and carbon dioxide on the environment such as global warming are discussed in the literature review (section 2.2.2.2).

- Emissions from wood burning in the form of smoke:

Figure 4-6: Water boiling by chicken vendors alongside in Nyanga

Source: the author

Figure 4-6 shows the smoke from a chicken plucking station. Unlike in *umqombothi* preparation, the smoke was intense due to the use of much fuel from piles that were not well dried. This prevents the air from reach the fire easily and resulted in incomplete combustion. Many vendors were observed to cough a lot but the causes of their coughs were not investigated in this study. Irritation of the eyes may also have been due to the smoke seeing that a number of particles and gases come from the incomplete wood combustion as mentioned in section 2.2.2.2. In this study, only PM_{10} are presented in section 4.6 and 5.1 for traditional cooking and cooking with an efficient wood stove respectively. An estimation of CO_2-e is given in section 5.1.1.3

Watching the sky over Nyanga from a distance, a dense cloud of smoke was observed over the various stations of meat vending in Nyanga. This meant that if the smoke affected people, it would have affect all the people in the area, not only the vendors or their clients.

4.5 Vendor perceptions on wood fires

As discussed in section 3.3, chicken vendors were given questionnaires to gain insights into their perceptions of the use of traditional methods of cooking. This section summarizes answers that focused on the open fires; vendors' views on wood stove use are presented in Chapter 5. More detailed notes from the questionnaires are available in appendix 4.

The purpose of the questionnaires was to understand their experiences of chicken preparation, in order to compare their experiences with the stove owners' experiences in terms of quantity of wood used and cost as well as the smoke emitted. This gave an understanding of to what extent the stoves helped and whether they were highly recommended to the rest of the vendors.

The first round of questionnaires was for vendors who did not own stoves. Amongst 10 respondents, 8 were working for themselves and 2 employed by either a relative or another business owner. Nine respondents were females but two of them employed male relatives. All had started their businesses more than 5 years before the date that the questionnaires were handed to them.
The chicken vendors reported that they survived only from that job.

Amongst 10 respondents, 3 used a mix of waste and harvested wood while the others used waste wood only. The ratio of the mix (waste/harvested) wood is not measured but the waste wood was dominant. The vendors worked six days a week and slaughtered at least 5 chickens every day. The reason why they cooked traditionally was given by 7 respondents to be that it is fast and easy. Two of them said that it is normal and there is no other way of doing it. One respondent said that it cheap and common (Appendix 4). All the respondent said that they are used to open fire cooking.

When asked if there is any other way to prepare water for chicken plucking (appendix 1), all the respondents said "No". However, four respondents said that they own a gas stove. When asked what they do with the stoves, they said that they often cooked strong meals at the work place using open fires and used their gas stoves only used to cook soft meals such as soft vegetables (spinach, carrots, cabbages, etc.). When asked why (appendix 1) they cook only soft food on a gas stove, they responded that the gas is expensive and strong meals will take long to be cooked on a stove (appendix 4). They said that cleaner cooking like a cook stove or a gas stove was not appropriate for their business because it would be expensive and time demanding.

Even though the questionnaire did not contain a question about the origin of the fuel wood, some/all vendors were asked whether they knew where the wood fuel suppliers got their wood from. The vendors said that they do not know. It was observed that they preferred waste wood, saying that pallet wood is better than the forest wood because it burns fast and is cheap. All the vendors were sceptical about harm from the smoke released from wood (particularly waste wood), saying that every fire releases smoke and it is natural. It was clear that the vendors were not aware of the dangers associated with waste wood burning in open fires. This is evidenced by the fact that all the respondents said they are used to traditional cooking even though they cough and irritated in the eyes. They do not know how safe or otherwise their cooking method is.

4.6 Quantitative observations

In this section the quantitative measurements of wood used in traditional open fires are presented. The thermal efficiency of this cooking method is estimated as well as the cost of firewood. Particulate matter measurements of air in the vicinity of the vendors' workplaces are also presented.

4.6.1 Utilization fraction of fire and fuel cost

4.6.1.1 Utilization fraction of fire

Measurements on *umqombothi* preparation were done only once, for comparison purposes. The research was mainly focused on the chicken plucking production as explained in section 3.2.1. For the chicken plucking, 10 samples were considered. Therefore, the comparison in this section are on one sample of *umqombothi* preparation vs the average of 10 samples of chicken plucking preparation. The comparison is made based on the useful firepower rating.

As stated in Section 3.4.1.1, the dry weight of the fuel used, together with the lower heating value of the fuel over the time of combustion, gives the overall firepower rating. Having calculated the thermal efficiency of the combustion process, together with the overall firepower rating, one gets the useful firepower rating. It is then possible to compare one method to another. The factors considered for the fire utilization fraction comparison are presented in table 4-1 except the time which was estimated as follows: In *umqombothi* preparation, the cooking process was estimated to be 1.5 h while in the chicken plucking it was 1.4 h. In *umqombothi* preparation, 230 L of water were heated while in the chicken plucking, only 25 L were heated.

Table 4-1: Comparison of fire usage of umqombothi and chicken plucking in open fire

Item	***Umqombothi***	**Chicken plucking**
Quantity of water used (L)	230	25
Thermal efficiency (%)	3	3
Total wood used (kg)	113	21
Dry wood fuel consumed (kg)	86	16
Overall firepower (kW)	270	54
Useful power (kW)	9	2
Lost power (kW)	260	53
Lost power (%)	**97**	**97**

In the case of *umqombothi* preparation, the overall power used to heat the amount of 230 L of water, was 270 kW. The useful power was 9 kW. This means that all the 260 kW (97 %) were wasted in the surroundings. In the chicken plucking an average of 54 ± 6 kW to heat 25 ± 1 L of water was used. In this case, only 2 kW were used and 53 kW (97 %) were lost.

The thermal efficiency for the *umqombothi* preparation and the chicken plucking were both estimated to be 3 %. In both cases, the open fires process was used could explain why their thermal efficiency were similar. The details of how the thermal efficiency was determined are present in section 3.4.1.

The results above show that even though the amount of fuel used in both cases was different due to the different amounts of water heated, the magnitude of fire energy wasted was almost 97 % and only 3 % of the total fire was used to heat the water. In other words, the more the wood used, the more the smoke released and the more the money spent on wood.

4.6.1.2 Fuel cost

The amount of money spent on wood fuel by *umqombothi* and chicken vendors was estimated based on the quantities used, and is shown in Table 4-2. This estimation only considered waste wood or pallets as fuel. The selling price of harvested wood was R12 for 6.2 kg of wood versus R25 for 70 kg of waste wood.

Table 4-2: Fuel cost estimates comparison for umqombothi and chicken preparation

	5 L of *umqombothi*	R 16.00
	Chicken	R 40.00
	Cost of waste wood/kg	R 0.36
	Umqombothi (L)	Chicken plucking (no.)
Production per batch	230	5
Amount of wood (kg)	113	21
Cost of wood	R 40.36	R 7.56
Income per batch	R 745.60	R 200.00
Income – fuel cost	R 705.24	R 192.44
Income per kg of wood	R 17.48	R 25.46

Table 4-2 compares the two cases in terms of money spent on wood and money got after selling the whole product, without considering the money spent on raw product (chicken before preparation: in the case for chicken plucking or flour and other ingredients: in the case of *umqombothi*). The estimates shown in table 4-2 indicate that in the case of chicken plucking, per 1 kg of wood used, an income (net of fuel costs) of R 25.46 was earned, while in the *umqombothi* case per 1 kg of wood purchased, earnings were R 17.48. Wood fuel costs are very small in comparison to the value of the product made: 5.4 % for the *umqombothi* preparation and 3.8 % for the chicken plucking preparation.

4.6.2 Measurement of particulate matter air quality

The current study measured the smoke in proximity of chicken vendors, so as to develop a comparison of the smoke levels of open fires and wood stoves.

Table 4-3: PM_{10} levels close to chicken plucking activities using open fires

Sample	PM_{10} (µg/m^3)	Time (min)	mass of wood (kg)	Volume of water (L)
1	4 500	81	22.1	25
2	2 500	91	23.6	25
3	4 600	90	20.9	25
4	6 200	83	24	27
5	5 200	85	19.3	25
6	3 200	85	18.1	23
7	7 100	93	26.5	28
8	6 000	85	20.7	25
9	4 070	80	20.2	25
10	6100	82	18.8	24
average	**4 900**	**86**	**2.6**	**25**
Stdev	**1 500**	**4**	**21.4**	**1**

Table 4-3 shows that chicken pluckers were exposed to workplace PM_{10} levels of 2 500 – 7 000 µg/m^3. These PM_{10} levels were measured in semi-controlled environments, in which 25 ±1 L of water was heated in 86 ± 4 minutes using 21 ± 3 kg of wood. In a previous study done in Nyanga (Niyobuhungiro 2012) an estimate of > 2 000 µg/m^3 of PM_{10} was recorded over a duration of less than 4 hours. To put an 86 minute exposure to 4 900 µg/m^3 of PM_{10} into context, even if the pluckers breathed air with zero PM_{10} for the remaining 1 354 minutes, 24 h average PM_{10} exposure would be 293 µg/m^3, which is highly elevated compared to the South African average daily Standards of PM_{10} in ambient air (25°C and 101.3 kPa) of 75 µg/m^3.

In the case of *umqombothi* preparation, the only one sample considered (section 4.6.1) showed about 4 200 µg/m^3 of PM_{10} collected only over 57 minutes which is 166 µg/m^3 compared to the South African average daily Standards of PM_{10} in ambient air. This low level of PM_{10} compared to what measured in the case of chicken plucking could be explained by the fact that fire in the *umqombothi* does not stay on after the water boils. More samples in the case of *umqombothi* would indicate better the extent of PM_{10} emissions.

4.7 Synthesis

This Chapter set out to present insights into the waste generation from food processing in Nyanga around the informal caterers stands. This insight was based on field observations, questionnaires and measurements made in Nyanga, focused on the activities of chicken slaughtering and plucking on the one hand, and traditional beer brewing on the other

The observations showed how chicken plucking was done and how the waste was handled. The waste, being chicken feathers, was dumped close by i.e. together with other slaughter waste. The ash was dumped not far from the slaughter waste while the remaining wood could be used the next day. In this method of heating water on open fires, the fire was commonly left burning even after chicken plucking, which unnecessarily increased fuel usage and the smoke in the area. The water used was dumped on the road. This dumping is due to the lack of slaughtering facilities in the vending areas. Many other reports have stated that the lack of adequate infrastructure in informal settlements is the cause of inappropriate waste dumping.

It was observed that in the preparation of *umqombothi*, a huge amount of wood is used in this process as larges drums are used (figure 42 (a)). Unlike in the case of chicken plucking, the beer brewers do not leave the fire on after they finish preparing the needed water.

Quantitative observations detailed above helped to estimate just how inefficient water-heating or cooking on open fires is. For both the chicken-plucking (25 L pot) and the beer-brewing (230 L drum), the magnitude of fire energy wasted was estimated at 97 % with only 3 % of the total fire being used to heat the water. Despite this clear wastage of fuel resources and thus of money, the cost of fuel wood is only of the order of 5% of the value of the product made.

Open fires also release air pollutants, of which particulate matter in the inhalable range was measured over periods of 1 hour and more in the immediate vicinity of the fire. In the case of chicken plucking, PM_{10} level was averaged at 4 900 ± 1 500 µg/m^3 over a period of 86 ± 4 minutes or a 24 h average PM_{10} concentrations of 293 µg/m^3 while in the case of umqombothi, the PM_{10} level was measured at 4 200 µg/m^3 over a period of 57 minutes or a 24 h average PM_{10} concentrations of 166 µg/m^3 . This low level of PM_{10} compared to what measured in the case of chicken plucking could be explained by the fact that fire in the *umqombothi* does not stay on after the water boils.

5 CLEANER PRODUCTION OPPORTUNITIES FOR STREET CATERING

In this chapter, two cleaner production interventions are investigated: the use of efficient wood stoves and biogas stoves, as suggested in section 1.4 of this study. In each case the clean technology is compared to the traditional technology.

Section 5.1 discusses the cleaner techniques with regard to the efficient wood stoves interventions while section 5.2 discusses the cleaner techniques with regard to the biogas stoves interventions. Section 5.3 discusses the factors that influence the implementation of Cleaner Production techniques. Section 5.4 presents concluding notes on the implications of the interventions described above. In each case, the gains such as reduced resource use, reduced energy use and monetary savings are discussed. The chapter ends with a summary.

5.1 Efficient wood stoves

The use of 'commercial-size' rocket stoves was observed for the activity of chicken plucking. The stoves used in this project were made of a cement-vermiculite mixture, in a drum-like metal housing as detailed in section 3.3.1. Real-life performance and efficiency tests and air pollution measurements were carried out, to better understand their full potential as Cleaner Technology.

Section 5.1.1 presents and discusses field measurements and observations when using an efficient wood stove. This section starts with presentations of the results on field measurements. Section 5.1.1.1 discusses the field measurements/observations and the vendors' perceptions. The fuel saving that arise from the use of an efficient wood stove is estimated in section 5.1.1.2. Lastly the emission reduction from the use of an efficient wood stove is presented in section 5.1.1.3.

Section 5.1.2 discusses the cleaner production opportunities with regard to an efficient wood stove. It discusses the CP techniques with regard to what the vendor perceive about those techniques.

5.1.1 Measurements and observations

This section presents the results from field trip measurements in terms of wood used, time spent water boiled and PM_{10} level associated.

Table 5-1 compares the traditional cooking with efficient wood stove cooking in terms of time spent on boiling water, quantity of wood used as well as temperature rises.

Table 5-1: Characteristics of water boiling: Open fire results (average and stdev) and efficient wood stoves results

Sample	PM_{10} (µg/m^3)	Time (min)	Mass of wood (kg)	Volume of water (L)
Efficient wood stoves				
1	660	69	3.1	21
2	560	44	2.8	21
3	380	35	2.5	17
4	630	33	2.8	20
5	710	24	2.4	17
Average	**590**	**41**	**2.7**	**19**
Stdev	**130**	**17**	**0.3**	**2**
Open fire (without a stove (N=10))				
Average	**4 900**	**86**	**21.4**	**25**
Stdev	**1 500**	**4**	**2.6**	**1**

In open fires the average boiling time was 86 ± 4 minutes as against 41 ± 17 minutes with efficient wood stoves method. The big standard deviation in this case was because the 1st sample in this experiment was collected when the wood used was wet. This prolonged the cooking time. Considering only the remaining samples the standard deviation would be ± 4 minutes as in the case of open fires. Even though the quantities of water boiled in the two cases differ slightly by 6 L, the number of chickens prepared was the same in both cases.

5.1.1.1 Measurements/ observations in terms of wood used and time spent

This section discusses the results from field trip measurements/observations in terms of wood used and time spent.

The respondents using open fires affirmed that an open fire is easy, common and fast, but the measurements shows this to be an illusion due to the fire waste around the pot as seen on figure 4-5.

After analysing these findings, it was decided to perform one more simple measurement to satisfy curiosity in terms of temperature rises in both cases. This measurement did not give full understanding on the nature and properties of water boiling but rather, of the efficiency of the new technology. A sample of water at 20°C was divided into two equal portions of 20 L: one was boiled on an open fire using the long pot as used in traditional cooking while the other 20 L was boiled using an efficient wood stove with the optimally suitable pot as suggested by the cleaner method of cooking. Below are the temperature readings measured at intervals of 20 minutes.

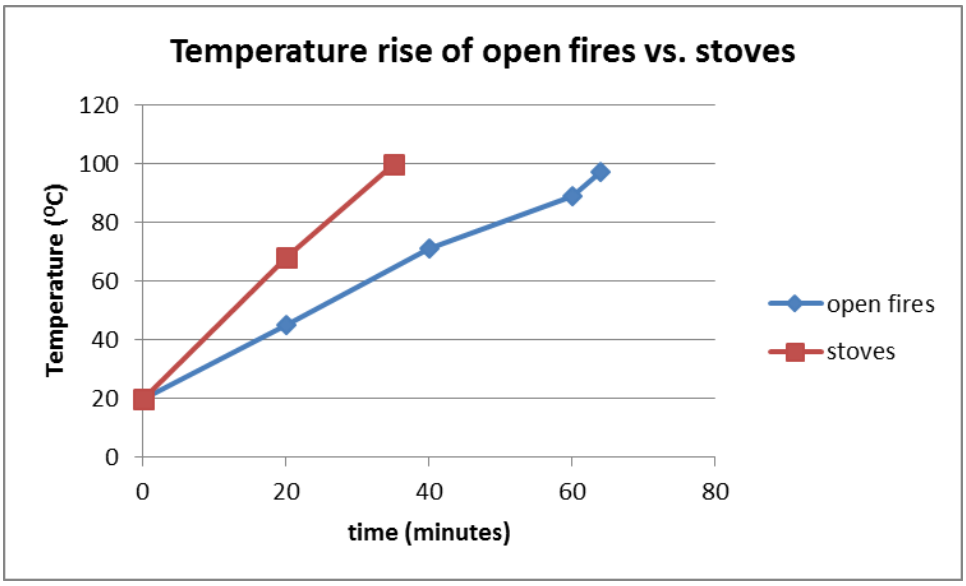

Figure 5-1: Comparison of the temperature rises in the case of an open fire vs. efficient wood

The rapidity in boiling on a stove may be attributed not only to the fire efficiency (as the fire transmits the heat to the stove and the stove conserves it instead of wasting it to the environment) but also to the use of a lid on the pot.

As mentioned in chapter 3, section 3.2.1, the stoves were first thought to be suitable for use by all the vendors i.e. of African beer, plucked chicken and sheep's heads. But the size of the available stoves proved not applicable to beer vendors due to very large quantities of water needed in this business. In this regard a sub group of EWB decided to improve and adapt the stove design for beer preparation, developing a prototype stove. The prototype consisted of a big drum with a combustion chamber, a support frame and a big water tank volume (Figure 5-2).

Figure 5-2: Completed stove assembly for umqombothi preparation

Source: Docherty, 2013

The water tank is seated on the frame assembly and the combustion chamber is positioned on the flue opening in the base of the water drum. This prototype is intended to suit the African beer vendors.

(a) (b)

Figure 5-3: Water boiling for chicken plucking in Nyanga: (a) CP (stove use with a new pot), (b) Traditional way

(Source: (a) the author, (b): EWB, 2012)

The stoves tested in this study would more suit vendors of chicken and sheep's head. Such a vendor who wanted to adopt a stove technology would however need a new pot suitable for the stove because the tall pots (long drums) used on open fires cause a danger of toppling (figure5-3 (b)). This was apparent when during the EWB campaign, a drum of boiling water almost spilled on a woman due to the big piles of long wood pieces used for fire.

5.1.1.2 Fuel savings

This section discusses the fuel saving opportunities from an efficient wood stove.

The Wood Heat Organization (2004) indicated that advanced combustion stoves and fireplaces burn wood about 90 % cleaner and one-third more efficiently than older conventional methods. However results for the vermiculite stoves used in this study showed the following pattern:

Similarly to the method used in section 4.6.1 for open fires, the dry weight of the fuel used, together with the lower heating value of the fuel over the time of combustion, gives the overall firepower rating. Having calculated the thermal efficiency of the combustion process, together with the overall firepower rating, one gets the useful firepower rating. It is then possible to compare one method to another.

In open fires, 25 ±1L of water were heated in 86 ± 4 minutes, using 21 ± 3 kg, or 16± 2 kg of wood on a dry weight basis (cf. section 3.4.1 for the wood moisture content). The thermal efficiency in the open fires was averaged to 3 ± 0.2 %, the overall power rating was 54 ± 6 kW. The useful firepower rating was 2 ± 0.2 kW or 3 % of the total power. This shows that a total of 53 kW or 97 % was lost.

In the efficient wood stove, 19 ± 2 L were heated in 41 ± 17 minutes, using 3 kg (2 kg of wood: dry weight). The thermal efficiency in the case of an efficient wood stove was averaged to 18 ± 1 %, the overall firepower rating was 16 ± 5 kW. The useful firepower rating was 3 ± 0.8 kW or 18 % of the total power. The lost power was therefore 13 kW or 82 %.

The observations and measurements showed that in open fires, big pieces of wood were used without being broken up, which created a big fire around the pot but only 3 % of its intensity was transmitted to the water. While using a stove, 18 % (6 times more than with open fires) of the energy was transmitted to the pot (figure 5-4). This also explains why the stoves heated water faster than did open fires. Besides that the space taken by open fires was relatively large due to the big pieces of wood that occupied a big part of the vendors' space, making the vendor's space untidy and small, while an efficient wood stove improved these conditions since the fire was contained and the wood was cut into small pieces.

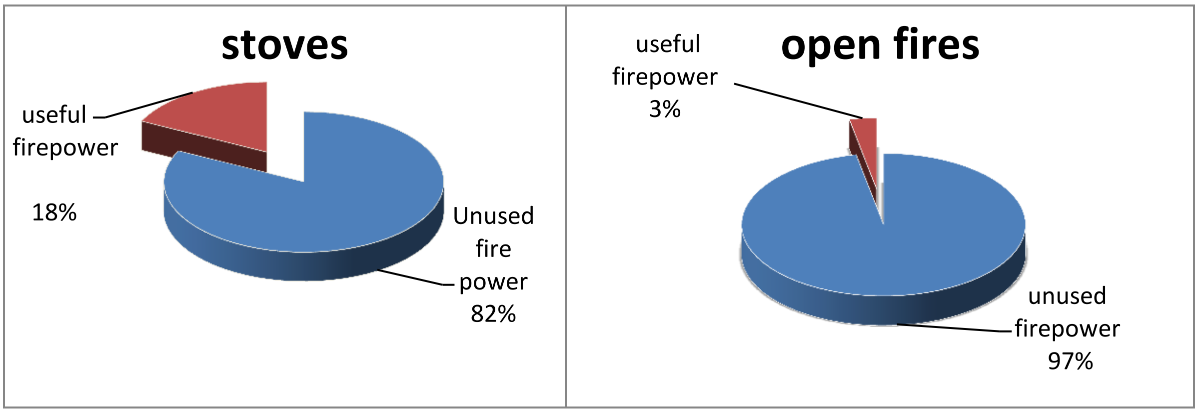

Figure 5-4: Fire utilization of stoves vs. open fires

5.1.1.3 Emission reductions

This section presents the PM_{10} results and discusses reduction estimates of PM and GHG emissions in terms of CO_2-e, by presenting comparisons of cooking with an efficient wood stove versus open fires. The estimates presented are associated only to wood fuel use.

The measurements showed that with one round in open fires, PM_{10} levels reached an average of 4 900 ±1 500 µg/m^3. While using a stove this fell to 590 ± 130 µg/m^3 (table 5-1). In other words, the particulate matter concentration near open fires was on average 8 times higher (and at least six times higher) than when using an efficient wood stove. This correlates well with the 6 to 7-fold lower amount of wood used as a consequence of cooking with an efficient stove.

Figure 5-5 shows a graphical comparison of PM_{10} in open fires vs. efficient wood stoves.

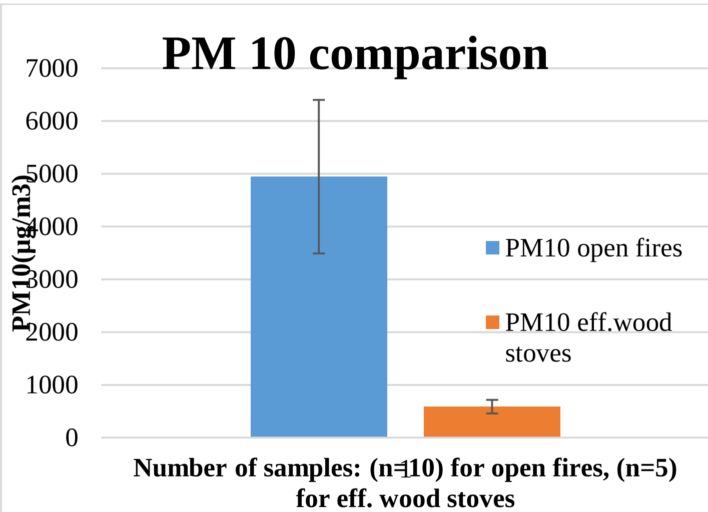

Figure 5-5:PM_{10} levels near the fires of chicken pluckers

These results are significant in relation to the interventions suggested by Shindell *et al.* (2012), who identified and combined all the measures to target emissions from incomplete combustion leading to BC (black carbon): those are technical measures covering diesel vehicles, clean-burning biomass stoves, brick kilns, and coke ovens, as well as primarily regulatory measures including banning agricultural waste burning, eliminating high emitting vehicles, and providing modern cooking and heating. The above results confirm and quantify the reductions of emissions from wood burning by the use of efficient wood stoves. Although specific quantities of PM or BC were not provided, they reported that the reduction of these two will ensure health benefit in South Asia and Africa.

In terms of GHG emissions from fuel wood burning, a more efficient use of this fuel would mean that less is used for the purpose at hand, potentially becoming available to replace other fuels in other places. The stoichiometric approach gives a reasonable estimate of direct CO_2 emissions that can be avoided (section 2.2.2.2). By the assumption that all 585 meat vendors in Nyanga plucked chickens and worked 6 days per week (section 3.2.1), the estimated greenhouse gases from their production per year was calculated as shown in Table 5.2. The quantity of wood used comes to some 3900 t/year; for the estimate of CO_2 released from its combustion, the moisture content of 16.7 % and ash content of 2.7 % are also used,

Table 5-2: GHG estimates from wood burning

$CH_2O + O_2 + N_2 \rightarrow CO_2 + H_2O + NO_2 +$ Heat Eq 2, wood moisture % = 16.7, ash content % = 2.7									
Item	Vendors who sell chicken in Nyanga	Days worked per year	CH_2O (kg)	CO_2 (kg)	Dry mass of wood used per day (kg)	Moisture content (kg)	Ash content (kg)	CO_2e per day/vendor(kg)	CO_2e per year /all vendors (t)
Open fire	585	312	0.03	0.044	17.3	3.6	0.58	25.3	4600
Eff w stove					2.2	0.5	0.07	3.2	600

The direct emissions from traditional method of cooking were estimated at 4 600 tons CO_2-e per year. In the case that an efficient wood stove was used, the direct emissions were estimated at 600 tons CO_2-e per year reflecting a reduction of this emission by a factor of 7.6. Although the current study did not estimate the GHG from such activities countrywide, the intervention of efficient wood stove would considerably contribute to GHG reduction.

5.1.2 Discussion: Cleaner Production Opportunities

Considering the five recognised CP techniques as discussed in section 2.3 (technology change, modification of input material, good housekeeping, product change, reuse/recycle of a by-product and process control), the interventions of the efficient wood stoves linked three of these: technology change, process control and good housekeeping. Technology change is the most complex of these adaptations and is the base of the others. This is discussed in the next two sub-sections.

5.1.2.1 Technology change and process control: perceptions from the caterers

This section considers the caterers' views combined with observations in the field. The implementation of new technology needs the caterers' involvement. This section gives details on how the new clean technology made the chicken plucking job easy, fast and flexible. It was found that the more the people were asked what to do and how to do it, the more they participated and were excited by what was offered them.

For example, when the researcher and the translator told vendors that we wanted to show them how to cook with safety using a stove, they rejected us, saying that they were good at their work and their practices were safe. But when we asked them to teach us how they normally cook, they were happy and confident. Assuring vendors that researchers can learn something from them helped to introduce a discussion about stoves. From there we managed to ask them to bring the stoves along so that we could see how they performed.

The questionnaires with stove owners revealed the following[6]: When asked what was needed for them to use the stoves, all five of the interviewed caterers said it was difficult because beside that carrying the stoves up and down was not easy for ladies, they also needed to get new pots as the pots they had used before did not fit the stoves. Three of the five interviewed used the stove twice a week, one used it thrice while the one used it rarely.

The stoves were used to cook small portions of food and heat their houses as they said that if they used the stoves for their business it would require more activity such as chopping a lot of wood, bringing the stoves to the stands, getting an appropriate pot, etc. When asked how they liked the stoves, all the respondents said that the stoves are much cleaner, the smoke was reduced considerably, the neatness around was improved, the amount of wood was small, however, chopping the wood into small pieces took time and the stoves released small heat.

When they tried to use the stoves with long pieces of wood, we suggested that the wood should be cut into small pieces so they could see the difference themselves. Using an axe[7], they chopped the wood into small pieces of wood that could easily fit in the stove. The fire would then light very well and be contained inside the stove not around it so the water boiled fast. These experiences by the caterers attracted other residents of the Nyanga neighbourhood who were passing by, and they came to us to order the stoves, (unfortunately there were none in the store at that time). It was assumed that the caterers were pleased to encourage their

[6] The responses are available in appendix 4

[7] It is also used in open fires to just cut big piles of wood

neighbours about the good features of the stoves. This dissemination could not have been done easily by ourselves, but because it came from the users of the stoves it was well received.

This demonstrated that technology change must come from the people who should use it. This agreed with Slaski & Thurber's (2009) report that a technology introduced from top down, often imposed unsustainable solutions. This meant that the local community/caterers in particular, though they had limited resources, needed to participate in whatever was being implemented hopefully for their benefit. As a group of scientists in the Raffles dialogue on human wellbeing and security (Pang et al. 2015) commented, ideas to support and to understand how the new technology is perceived by the locals are of a great importance. New technology needs local ownership, trust between all the parties involved, respectful partnerships and long term commitment.

It was not believed by vendors that the stoves were faster than open fires until a stop watch was used to confirm that open fires took more time than stoves to boil a desired quantity of water. Another point raised by the vendors was that if only one vendor had a stove, she could not use it because that would be seen as unusual and proud; also she would not feel comfortable to have what others did not. They suggest that if all the vendors had the stoves and were told by the government to use them, adoption would be easier.

These observations emphasised the danger of the traditional cooking methods used by the vendors, highlights how good housekeeping and technology change would help in reducing risks ranging from dirtiness and discomfort to unnecessary waste of the fuel (wood) and thus waste of money.

5.1.2.2 Good house keeping

Good housekeeping is defined as a standard of quality in living and work conditions. It is the simplest type of the cleaner production options to adopt because it requires no investments. Good housekeeping differs from other CP techniques in the sense that it is about common sense and can be implemented as soon as the alternatives are identified (Vietnam Cleaner Production Centre 2000, OHS 2014). Good housekeeping is important in Cleaner Productions as it complements other techniques. Once new technologies are adopted, good housekeeping plays a role in ensuring that the working space is kept tidy, the equipment is always clean and is used only when needed.

Like other CP techniques, good housekeeping provides significant benefits in terms of saving resources. For example in the case of efficient wood stoves, chopping the wood could save wood since only small pieces of wood would enter the stoves therefore avoiding the use of unnecessary wood. In efficient wood stove technology the wood is cut into small pieces to facilitate ignition. This makes it easier to clear the hearth, to transport the wood, to place it in the stove and to ignite efficiently.

In the traditional cooking method, an axe is used to cut big pieces of wood. With an efficient wood stove, the chopping of wood is eased in that 7 times less of wood is needed compared to the traditional cooking method. The chopping of the wood also brings benefit in terms of safety and attraction of customers. In Nyanga, it was observed that more customers tended to go to a clean stand.
The use of lids on the pots would help in reducing the spilling of water therefore reducing some accidents happening to caterers and their clients caused by slippery floors. Less water spillage would also help in reducing the flies around the spoiled water.

Even though the use of lid on the pot was not controlled during this study, it was observed that the lid helped in keeping the water vapour inside the pot thus allowing the water to boil faster. This would apply whether one used a stove or an open fire.

Smothering or dousing the fire once the chicken plucking was done would also save wood and reduce the smoke fouling the environment. Heating the water to the optimal temperature for plucking would also help to reduce the quantity of wood used thus the money spent on it. It would also save the caterer's time.

The impacts of using an efficient wood stove intervention are summarised in table 5-3

Table 5-3: Interventions of an efficient wood stove

CP technique	**Changes**	**Outcome**
Technology change	Acquire and use a stove	Reduce the amount of wood burned, reduce the money spent on fuel, reduce the smoke
	This also requires a new pot	
	Stoves also require wood size reduction	
Good housekeeping	Equip pot with lid	Create space which used to be a store, and it can be used for Something else, reduce the waiting time for water to be ready to pluck chickens
	Chop the wood	
	Use the fire only when needed and safely extinguish[8] (not with water) thereafter	
	Heat water only to optimal temperature for plucking, not higher	

[8] By using a fire poker to spread out the wood and ambers. Using a shovel, bury the wood and ambers with cool ash and wait for it to be collected (www.doctorflue.com/ how to safely extinguish a fire in a wood burning place

5.2 Biogas generation from wastes and use in gas stoves

5.2.1 Experimental estimate of biogas yield from slaughter waste

The exploration of a biogas intervention was motivated by the observation that in Nyanga, slaughter waste, a potentially useful source of biogas, arises regularly and it is not managed. The waste left lying on the road and close to the meat vendors' stands could possibly be used to generate energy. The feasibility of this intervention was explored firstly by trying it at small scale as introduced in chapter 3 section 3.4.2. In the following paragraphs, key findings from this experiment are presented and discussed[9].

The measurements made showed that the rumen content of sheep slaughter waste at small scale (100 L) and at ambient conditions produced an average biogas yield of 0.36 Lg^{-1} of VS (Figure 5-6).

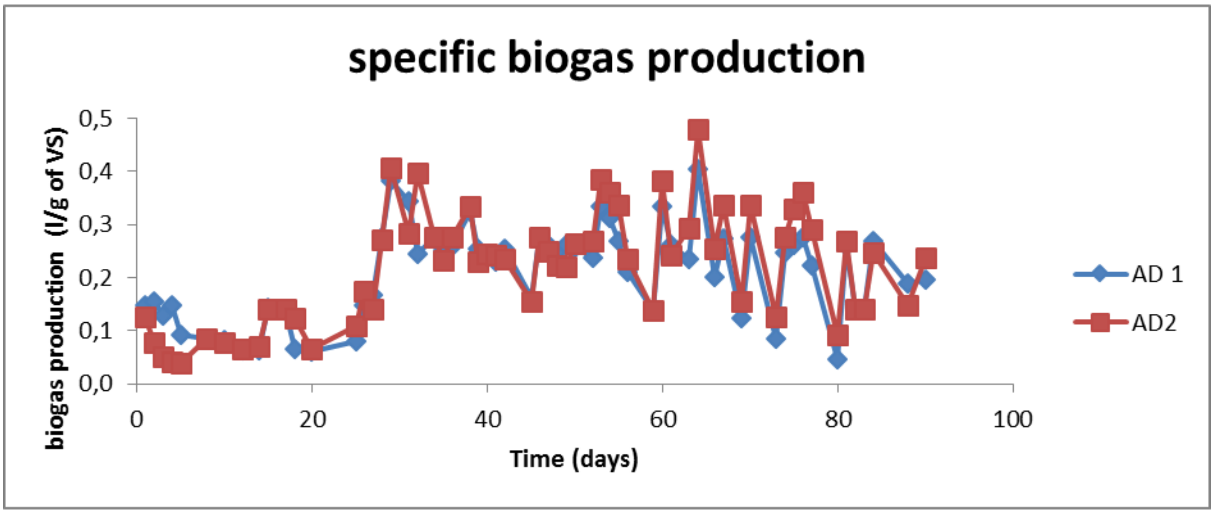

Figure 5-6: Specific biogas production

Table 5-4 presents an estimate of how much biogas would be needed to heat a 25 L pot of water to boiling point for the chicken-plucking activity. It further shows the quantity of rumen content that would suffice if the biogas yield of 0.36 Lg^{-1} VS could be achieved in an installation in the Nyanga setting.

[9] Note that this work has also been written up separately, and accepted for publication as a chapter in a book featuring South African bioenergy research (Niyobuhungiro & von Blottnitz 2016).

Table 5-4: Energy calculations for water heating

Item	Value
Quantity of water (kg)	25.3
Heat used to boil 25.3 L of water (kJ)	8 705
Heating value of biogas (kJ/m^3)	21 300
Theoretical biogas needed to generate the needed heat (m^3)	0.4
Biogas needed considering an over-design factor of 45%	0.9
Quantity of VS (Volatile Solids) (kg) needed to generate 0.91 m^3	2.5
TS (Total Solids) for 2.5 kg of VS (kg)	2.7
Mass of substrate needed for 2.7 kg of TS (kg)	14.3

14.3 kg of waste would thus be enough to generate 0.91 m^3 of biogas, sufficient for one vendor to boil enough water to pluck 5 chickens a day as observed. At an organic loading rate of 0.23 $gL^{-1}day^{-1}$, and a daily substrate feed of 2.5 kg VS this would require a bio digester reactor of a bigger volume than 6 m^3 (the one considered for this study)

With 40 animals slaughtered daily and 2.5 kg of slaughtering waste (rumen content) from each animal thrown away, 100 kg/day of waste would be available. This means that enough biogas could be generated daily for 7 chicken vendors, requiring a total reactor volume of 76 m^3. At the significantly higher OLR (Organic Loading Rate) of 0.53 $gL^{-1}day^{-1}$ and bio-methane yield of 0.6 $Lg^{-1}VS$ reported by

Melamu et al. (2012) for co-digestion of blood with paper waste, a digester of half this size could produce twice as much biogas as estimated here. Field-work is recommended to test what performance can be achieved in real settings.

5.2.2 Biogas stove performance

As discussed in section 3.4.2, the performance of a biogas stove was tested to determine whether a vendor could boil quantity of water needed for plucking a chicken, as in the case of Nyanga chicken vendors.

Due to time schedule and the City of Cape Town plans for an Nyanga upgrade, the plan to build a bio digester of 6 m^3 in Nyanga as proposed at the beginning of the research was not possible, but a similar bio digester was considered for the experiment as stated in section 3.3.3. The bio digester used was fed food waste, and this report presents two sets of results. One run was done from the 5th July to the 26th 2014 (Winter months) and the other set was done from the 10th to 14th of March 2015 (Summer months). Table 5-5 (a) and (b) below show the biogas use on a stove to heat water in winter time and summer time.

Table 5-5:Biogas use in stove to heat water

(a) Winter time

Sample	Volume of biogas (m^3)	P1 (kPa)	P2 (kPa)	Combustion time (min)	Volume of water (L)	T1 (°C)	T2 (°C)
1	0.49	3.2	1.8	38	14	18	67
2	0.35	3.0	2.0	34	12	16	55
3	0.49	3.8	2.4	35	14	15	66
4	0.49	4.0	2.6	35	14	15	80
5	0.64	4.2	2.4	38	15	15	68
6	0.60	3.7	2.0	39	15	15	67
7	0.71	4.0	2.0	39	14	15	79
8	0.49	3.8	2.4	40	14	15	58
9	0.64	3.8	2.0	31	13	14	62
10	0.71	4.0	2.0	35	14	14	60

(b) Summer time

Sample	Volume of biogas (m^3)	P1 (kPa)	P2 (kPa)	Combustion time (min)	Volume of water(L)	T1 (°C)	T2 (°C)
1	0.35	3.2	2.2	36	13	20	74
2	0.49	2.8	1.4	26	15	21	70
3	0.71	3.8	1.8	26	15	19	70
4	0.71	4.0	2.0	28	14	21	69

Where,

P1 was the initial pressure inside the digester (the pressure before heating the water)

P2 was the final pressure inside the digester (the pressure after heating the water)

T1 was the temperature of water before heating

T2 was the temperature of water after heating.

The experiment showed that the temperature rise of water depended on the pressure of biogas that reached the stove. Once the pressure fell below 2.8 kPa (after approximately 30 minutes) the water temperature did not go up any more. The biogas pushed from the tank decreased in intensity as the pressure dropped. This made the water start cooling down before it could be used.

The biogas stove used in the experiment was a Safegas C30 model. The biogas stove itself cost R 315 and it could only be used by one caterer at a time. During winter, it was estimated that the thermal efficiency of the biogas stove used ranged from 18 to 36 % as shown in table 5-5 (a), averaging 25 ± 5 %.

During summer, the same biogas stove was again used for measurements. Thermal efficiency then averaged 27 ± 9%, with a highest calculated value of 39 % as shown in table 5-6 (b).

Table 5-6: Estimations of the thermal efficiency of the biogas stove used

(a) Winter time

Sample number	Volume of biogas (m^3)	Combustion time (min)	Cp (kJ/kg °C)	Water mass (kg)	Tf-Ti (°C)	Qout (kJ)	LHV of biogas (kJ/m^3)	Qin (kJ)	Thermal eff.
1	0.49	38	4.19	14	49	2 900	21300	11 000	0.28
2	0.35	34		12	39	1 900		7 500	0.25
3	0.49	35		14	51	2 900		11 000	0.27
4	0.49	35		14	65	3 700		11 000	0.36
5	0.64	38		15	53	3 300		14 000	0.25
6	0.60	39		15	52	3 300		13 000	0.26
7	0.71	39		14	64	3 700		15 000	0.24
8	0.49	40		14	43	2 600		11 000	0.25
9	0.64	31		13	48	2 600		14 000	0.19
10	0.71	35		14	46	2 700		15 000	0.18
average	**0.56**	**36.8**	**-**	**13.9**	**51.07**	**3 000**	**-**	**12 000**	**0.25**
stdev	**0.12**	**2.8**		**0.9**	**8.25**	**600**		**2 400**	**0.05**

(b) Summer time

Sample number	Volume of biogas (m^3)	Combustion time (min)	Cp (kJ/kg °C)	Water mass (kg)	Tf-Ti (°C)	Qout (kJ)	LHV of biogas (kJ/m^3)	Qin (kJ)	Thermal eff.
1	0.35	36	4.19	13	54	2 900	21300	7 500	0.39
2	0.49	26		15	49	3 100		10 000	0.29
3	0.71	26		15	51	3 200		15 000	0.21
4	0.71	28		14	48	2 800		15 000	0.19
average	**0.57**	**29**	**-**	**14**	**50.5**	**3 000**	**-**	**12 000**	**0.27**
stdev	**0.18**	**4.8**		**1**	**2.6**	**180**		**3 750**	**0.09**

Where:

Cp is the capacity of water

Qout is the heat used to heat the water

Qin is the total heat generated.

The summer month results showed similar capability in terms of temperature raise. In an average time of 29 ± 5 minutes, water could be heated by 51 ± 3ºC while in winter, the same quantity of water was heated through the same temperature in an average of 37 ± 3 minutes.

It should be noted that the volume of gas available in the digester when doing these stove tests was less than that needed to heat the chosen quantity of water to boiling point. This particular size of digester, and its mode of operation, would thus be insufficient in a catering situation where several vendors would repeatedly need to use gas during a working day.

The heating rate of the biogas was not measured in detail, but it was noted that in the first 20 minutes the temperature of water rose quickly, probably because the gas pressure in the digester was still high enough to produce a strong flame at the stove burner. After around 30 minutes, it was observed that the biogas pressure dropped considerably which made the flames at the stove burner go weak thus the water temperature could not raise anymore.

The particular bio digester considered in this study with 6 m^3 capacity would be more suitable for household use where time pressure is not an issue than use by a chicken vendor.

Based on the experimental results it is estimated that 100 kg of slaughtering waste dumped every day could generate enough biogas for 7 vendors to be provided with enough thermal energy for their catering trades and that a digester of 76 m^3 would be needed for this amount of slaughtering waste.

However, whatever size a bio digester is, its use can accomplish one role or another not necessary heating water for chicken plucking and other benefits can accrue such as the reduction of undesirable waste and its related effects.

5.2.3 Particulate matter measurements

This section present two sets of results. One was acquired in winter and the other in summer, for comparison purposes as shown in Table 5-7 (a) and (b).

Table 5-7: PM_{10} measurements from a biogas stove

(a) Winter time

Sample	PM_{10} (µg/m^3)	Volume of biogas (m^3)	Combustion time (min)	Volume of water (L)
1	240	0.49	38	14
2	560	0.35	34	12
3	270	0.49	35	14
4	100	0.49	35	14
5	190	0.64	38	15
6	380	0.6	39	15
7	530	0.71	39	14
8	320	0.49	40	14
9	250	0.64	31	13
10	320	0.71	35	14
Average	**310**	**0.56**	**36.8**	**13.9**
Stdev	**140**	**0.12**	**2.8**	**0.9**

(b) Summer time

Sample	PM_{10} (µg/m^3)	Volume of biogas (m^3)	Combustion time (min)	Volume of water (L)
1	150	0.35	36	13
2	80	0.49	26	15
3	160	0.71	26	15
4	210	0.71	28	14
Average	**150**	**0.57**	**29.0**	**14.3**
Stdev	**52**	**0.18**	**4.8**	**1.0**

The average particulate measurements were 310 ± 140 µg/m^3 in winter and 150 ± 52 µg/m^3 in summer. Comparable measures of PM_{10} were 4 900 ± 1 500 µg/m^3 for open fires (section 4.6.2) and 590 ±130 µg/m^3 for wood stoves. The winter month results thus broadly agree with the reported reduction of suspended particulate matter from 2 900 µg/m^3 using dung cake burning to 250 µg/m^3 using biogas burning (Kandpal et al. 1994; Semple et al. 2014).

The summer month results show that even greater reduction of PM_{10} could be achieved. However further studies should be done to confirm the precise quantity of particulate matter released from an operational bio digester outdoors premises, where no other cooking activities could affect the instrument reading as in the case of this study where, the particulate sensor was placed inside a kitchen where emissions from other cooking appliances were present.

A recent study by Semple et al. (2014) on the effect of switching to biogas also indicated the importance of deep study in this area as previously there was no relevant literature about the emission reduction by introducing biogas stoves. Their research reported that the use of biogas might improve indoor air quality by between 66–99 % over the use of Liquefied Petroleum Gas (LPG).

In term of emission reduction, the literature does not provide sufficient information on the effect of biogas stoves compared to the traditional ways of cooking. However, the measurements in this study showed a greater reduction of particulate matter from traditional methods than efficient wood stoves.

5.2.4 The biogas intervention in the case of road side informal catering

The biogas intervention would include 4 out 5 techniques of the CP approach. Those 4 are discussed below, relating them to the Case of Nyanga informal food production to examine its feasibility.

The general goal of this intervention was to prevent slaughter waste dumping while saving money on wood fuel. Therefore, the onsite treatment of this waste would result in an intrinsic output, which is the energy for cooking. If one could cook using this new technology, wood use would be accordingly reduced. This would result in money saving from fuel wood, less emissions from dumped waste as well as from wood burning, and thereby improved quality of life of the people.

5.2.4.1 Input/raw material substitution

The slaughter waste, regarded as input material for cooking energy generation, would replace the firewood. However this would come with a change of technology (from open fires to biogas stoves) with the same purpose of reduce the waste dumped on the road, the GHG from the waste, bad smell as well as flies. This would improve the general cleanness of the space. The use of slaughter waste would also eliminate waste being dumped on the road. Thus the storm water would be free of slaughter waste. The collection of the exhausted slaughter waste would also be one way of job creation for the community.

5.2.4.2 Good house keeping

The installation of a bio digester would ensure that organic waste, particularly slaughter waste, would be disposed in the bio digester instead of deteriorating in the environment. As in the option of using a stove, the neatness of the space, as well as the reduction of smoke released from burning wood, would promote clean breathable air. As it is impossible to avoid this type of waste, it can be valued by using it in the bio digesters. The use of pots with lids, would also impact on the cleanness of the space since no spillages would appear on the floors and this would also help in optimising the heating time as the water vapour would remain in the pot.

5.2.4.3 Reuse /recycle of waste or by product

In biogas technology, as the inputs or feed are organic, what is left after digestion still contains organic matter. This can be reused as compost. The sludge can also be used in organic gardens instead of being thrown away on the road where it can affect storm water, cause smell and attract flies. Animal skin might be sold to shoe makers and other recyclers might use the skin, corn, feathers for ornaments.

5.2.4.4 Technology change

The installation of a bio digester would bring new cooking experience to the caterers, from open fires to smokeless cooking. This option comes with an overall cost because expert engineers would need to come to install the bio digester and educate the vendors about maintenance issues once the bio-digester started to operate.

None of the options above involve the introduction of a novel technology as biogas and efficient wood stoves are well established technologies, and are both recognised as effective means for solid waste management worldwide. What was novel was measurement of the effects in the low income communities. The options discussed above are generally complex, as they all originate from technology change. Further and more detailed investigation is needed to ensure that the socio- environmental role of each option is adequately understood for truly beneficial intervention.

A summary of effects of the biogas stove intervention is shown in Table 5-8

Table 5-8: Intervention of biogas

CP technique	Change	Outcome
Change of input raw material, good housekeeping	Use of slaughter waste	Avoid the use of wood thus reducing excessive smoke from wood, reduce the dumped slaughter waste and GHG that can come from it, ensure the neatness of the space, and create space devoted to storage, and it can be used for something else, prevent waste at source
	New pot with lids	
	Biogas stove	
Re use a by product	Selling the skin, feathers and corns	Extra income, waste reduction, and save storm water system from slaughter waste
	Use the sludge and residue as compost	
Technology change	Installation of a bio digester	Neatness, reduction of smoke, prevention of waste at source
	Biogas stove	

5.3 Factors that influence the CP implementation of informal food production

The results presented thus far in this chapter 5 clearly show the opportunities that rise from the cleaner productions technologies in term of good housekeeping, technology change and input substitution for both efficient wood stove and biogas stove. These results further show the gain in terms fuel saving, money saving and pollutions reduction that come with the implementation of the cleaner production techniques. However, the implementation of these techniques is not always welcomed as it should due to a number of causes. This section describes observed factors that affect the implementation of cleaner production technologies in Nyanga.

5.3.1 Spatial considerations

In the informal settlements around Cape Town, houses are small and wood-framed. Cooking traditionally i.e. in open fires cannot happen inside these houses. The vending and working area, also small, are a few meters away from the houses where the stoves might be kept. This makes it almost impossible to put up new and expensive equipment for their business. Since the efficient stoves are big and heavy, they are difficult to carry between house and working area. The unpaved and uneven floors of the houses and the working area hinders the proper use of the stoves.

The low roof height in the working place makes it difficult for an open fire or a stove to operate safely. New infrastructures will be needed to implement the new technologies.

5.3.2 Social perceptions

All the 10 out of 10 respondents who cook traditionally (open fires) and had been in roadside catering for a long time, claimed to be fit and without any serious sickness. This made it difficult for them to adopt a new technology on the grounds that it would improve their health (section 4.5). On the other hand, all those respondents who own a stove confirmed that the stoves are useful. Misperceptions were identified around the fast heating and fuel saving that come with an efficient stove. Seven of the 10 respondents using open fires believed that their traditional method was faster than the stove (section 4.5; appendix 4) but all the 10 respondents were sceptical about the stove using less fuel (section 4.5). Three of the 5 vendors who own a stove suggested that if they were to use the stove (cleaner technology) all of them must get one otherwise those using the stoves would be singled out as proud (section 5.1.2). This perception would hinder the implementation of the technology. Some evidence was thus found pointing to a belief that the new technology would not make things better, which is a barrier to its implementation.

5.3.3 Education and awareness

During this study it was found that a lack of awareness about the disadvantages of the inefficient traditional method of cooking was one of the factors hindering the implementation of new technologies. For background on this issue, in 2012 the author together with members of Engineers Without Borders had a good experience when chatting with a small group of street vendors and community leaders about the dangers of smoke pollution, poor cooking practices, Chromated Copper Arsenate (CCA)-treated wood and how to recognise it, as well as alternatives to current cooking practices. During that time, stove demonstrations were carried out at the community event organised by EWB, (2012), involving more than 100 community members including street vendors, as seen below in figure 5-7.

Figure 5-7: Community event at SHAWCO centre in Nyanga,

Source: EWB, 2012

In the same way as during 2012, the author engaged vendors in the research process. In the company of two members of the E&PSE research group, two vendors from Nyanga were invited to Leo Marquard Hall at University of Cape Town campus, where a 6 m^3 bio digester is installed, for a demonstration of how a biogas stove works. There, small dishes (including eggs and soup) were prepared. The vendors were happy and satisfied with the performance of the biogas stove due to the cleanness, and the neatness. After this event, the vendors who experienced the biogas technology disseminated the news to their colleagues and they next time they saw us, they were all asking about when and how their own bio digester will be installed. The importance of awareness and education was also shown when the author demonstrated to the vendors how to use the stove with chopped wood. The experiences of using a stove attracted other residents and they came to order the stoves. It was assumed that the caterers were pleased to encourage their neighbours about the advantages of the stoves. This dissemination could not have been done easily by ourselves, but because it came from the users of the stoves, it was well received (section 5.1.2).

These communications about a new technology with the vendors were of great importance because they demonstrated a key way to knowing what the vendors desired and how the technology will be perceived (section 5.1.2). This enables to make changes where necessary and encouraged the vendors as they participated in implementing the technology. For example, on the 8th February 2014[10], at the first renewable energy festival in Cape Town, we approached the roadside vendors from Nyanga to showcase what they did with the stoves. We asked them to come and pluck a chicken at the festival but they instead insisted on cooking their traditional food (*umngqusho)* which they could sell to people who would come to the event. They were starting to see how a stove could be more convenient and presentable than an open fire and this could help them to make money. After discussing all the necessary arrangements with them, they agreed and participated in the event even though they could not cook the *umngqusho* as they wished.

Informal conversations were held with people from other areas of Nyanga who were passing by and saw the stoves in action, were interested and wanted to know more about them. This helped the dissemination of news about the stove to the point that orders were still being placed until late 2013. However the stove could not be supplied due to the close down of the manufacturers. In response the EWB introduced a project to teach the vendors how to manufacture affordable stoves themselves. The project is currently running with the assistance of the Trust for Community Outreach and Education (TCOE) based in Cape Town[11].

5.4 Concluding notes on benefits of cleaner production

5.4.1 Resource use, energy saving and cost saving of an efficient wood stove

5.4.1.1 Resource use and energy saving

The stoves used in this study showed a high saving of raw material in terms of the quantity of wood used per round of production. Vendors would see a saving factor of 6 if they used efficient wood stoves.

In open fires, the amount of wood used was averaged to 21 ± 3 kg while using an efficient wood stove the amount of wood used was 3 ± 0.3 kg. This means that by adopting an efficient stove technology, the amount of wood brought to the vendors would become less and the space used for wood storage as seen in figure 4-1 could be used for something else.

The reduction in the quantity of wood implies the reduction in energy waste around the pot when using the inefficient traditional cooking method. This would reduce the solid waste as well as the smoke.

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[10]Faculty of Engineering and the Built Environment, Faculty Newsletter, Vol 11 Issue 1

[11]36 Durban Road, Mowbray, Cape Town, P.O BOX 323 Athlone 7760

5.4.1.2 Cost saving[12]

To estimate the money that would be saved if an efficient wood stove were used, two types of wood were considered: Forest or harvested wood and planks or waste wood. The prices of these two types of wood are shown in Table 5-9.

Table 5-9: Estimation of income and cost from traditional method vs. efficient wood stove

(a) Averaged wood used and cost

Number of chicken per day	5
Cost to the vendor of 1 chicken	R 30.00
Sale price of 1 chicken	R 40.00
Cost of 1 kg of forest wood	R 1.90
Cost of 1 kg of planks (waste wood)	R 0.40
Cost of traditional method	R 0.00
Average of wood used in (kg) in open fires	R 21.40
Average mass wood used (kg) using a stove	R 2.70
Cost of the stove	R 150.00
Life time of the stove (years)	3

(b) Income and cost per day

Traditional method/day	**Value**
Money spent by the vendor on 5 chicken before plucking	R 150.00
Sale income of 5 plucked chickens	R 200.00
Cost of harvested wood	R 41.50
Cost of waste wood	R 7.70
Income per day if harvested wood is used	R 8.50
Income per day if waste wood is used	R 42.40
Efficient wood stoves/day	**Value**
Cost of harvested wood	R 5.30
Cost of waste wood	R 1.00
Income per day if harvested wood is used	R 44.70
Income per day if waste wood is used	R 49.00

[12]The cost considered were documented in 2013 during the writing of this Thesis

1. Forest (harvested wood): This wood was available in bundles but vendors did not use it often due to the cost. The responses from vendors showed that 3 vendors out 10 used this type of wood. The cost of a bundle of 6.2 kg cost was R 12, (table 5-8 (a)).

In this case, vendors spent up to R 41.50 on fuel wood to dunk 5 chickens into hot water before plucking. They could heat the same volume of hot water for R 5.30 using an efficient wood stove and thus save R 36. The payback time for such a stove costing R 150 was projected as between 5-20 days. If the stove lasted 3 years, the vendors would save on firewood approximately R 36/day x 312 days/year x 3 years ~R 33 700.

2. Planks (waste wood): This was the wood commonly used by the informal street vendors. It was relatively cheap but was sometimes treated with chemical which made it more polluting than the first type. The vendors bought large amounts of it in by trollies. Questionnaires with vendors together with calculations from weighing wood in the trolleys revealed that 70 kg of wood cost R 25, table 5-8 (a).

If wood waste were used, the vendors would spend R 7.70 per day in open fires, and R 1 if an efficient stove is used. On wood they would save approximately R 6.70/day x 312 days/year x 3 years ~R 6 300.

These calculations from observations led to the conclusion that waste wood was preferred by the vendors over harvested wood because of its cheapness. It is however recommended to encourage awareness of the health hazards associated with waste wood, which proves the adage that cheap is always expensive.

5.4.2 Resource use, energy saving and cost saving of a biogas stove

Waste reduction through maximising the reuse potential

It is suggested by the CP techniques that a product must be used for a maximum time before it is disposed of. In the informal meat catering in Nyanga, the products (chickens, sheep) and what are considered as waste (blood and rumen content) are all organic materials that can be used as resources for other useful purposes such as harvesting energy. For instance, when animals are slaughtered, what is needed is to dispose of the waste in a way that it can be used in bio digesters; if the bio digesters are not locally available, the waste can be collected or sold to municipalities and other interested bodies who know what to do with it. The bio digesters could help in reducing the waste generated from slaughtering animals.

If the biogas stove were chosen in this sector, vendors would save energy as firewood would not be needed. It would also save the environment from the excessive smoke that comes from wood burning. It would reduce the Green House Gas that would come from dumped slaughter waste on the road and other unsafe places in the environment.

The cost saving in using biogas was not studied. However, on the face of it, and aside from the start-up cost of bio digesters, vendors would save money otherwise spent on wood as the input material for a bio digester (slaughter waste) would be free.

5.4.3 Summary

The observations led to the conclusion that efficient wood stoves present very strong saving potentials to vendors.

The biogas option would be a more advanced technology for the case studied. Wood stoves could be considered as a good transition stage between the open fires of traditional cooking methods and the biogas technology. The biogas digester suitable for this sector would need to be at an institutional scale, of the order of 100 m^3 volume, and thus a municipal infrastructure investment for decentralised waste treatment. The 6 m^3 scale studied in this study would be suitable for households not for clusters of lowincome business.

6 CONCLUSIONS AND RECOMMENDATIONS

This thesis set out to understand opportunities and procedures for applying cleaner production (CP) techniques in informal production, by focusing on two specific informal food processing cases, in the Nyanga area in Cape Town. The investigation was carried out with the knowledge that, in past decades, the CP approach has been shown to work for big, medium and small companies in the formal sector of the economy. This final chapter summarises the results from chapters 4 and 5, presents conclusions and offers recommendations. It develops the conclusions by inspecting how the findings answered the key research questions, thus providing the evidence for supporting or failing to support the hypotheses developed in chapter 3. However, in order to put the conclusions and recommendations in context, the chapter first discusses lessons learnt from carrying out a research that combined the methodology of social science and scientific research.

6.1 Notes on a mixed-methods methodology

As stated in section 3.2 and 3.3, this research was undertaken with the knowledge that a social science sensitivity would be needed in addition to quantitative scientific measurement and experiment, especially when embarking on an investigation of the behaviour of informal caterers towards the introduction of a new technology.

The objective of this thesis was to investigate whether a cleaner production approach would be beneficial and could work in informal contexts, focusing on the case of road-side food and drink production in Nyanga. Three specific objectives were formulated:

- Compare the resource usage and pollution loads associated with traditional vs. cleaner methods of food and drink preparation;
- Establish whether the cost-savings from the increased resource efficiency of cleaner methods would be sufficient motivation for producers to adopt these;
- Observe and document other constraints to the adoption of cleaner methods of production by attempting to demonstrate resource efficiency gains and emission reductions possible under real conditions of informal food and drinks production.

To achieve the first and third objectives, field work involving the researcher and participating caterers (one by one) was done. At each visit, a MiniVol particulate matter sampling device was set up at the same time as the caterer started the fire for chicken plucking water and was stopped when the water started boiling. The MiniVol collected particulate matter on a quartz filter which was weighed in the laboratory before and after use to determine the mass of particulate matter collected near that particular caterer's fire, and thus determined the air quality near that fire. Fuel wood consumption was also measured during each visit, thus enabling a comparison of the relative efficiency of open fires and efficient wood stoves when used for the same purpose.

A questionnaire was used to find what caterers had to say about the current ways of cooking and the proposed cleaner cooking methods.

In support of objective two, slaughtering waste arising at the site was sampled, and used in an experiment in two 100 L bioreactors to investigate whether the organic waste generated from chicken and sheep slaughtering could be used to generate enough energy for the caterers to perform their chicken plucking activities economically. Further, biogas generated from a 6 m^3 digester was used to test if a digester of that size could power biogas stoves for the energy needs investigated, and particulate matter air quality measurements near these stoves were also completed.

During this study, a few lessons were learned from this combination of qualitative and quantitative methodologies.

After trust had been built between the researcher and the caterers, security assured, and the participants had been chosen, theoretical sampling was started, where the objectives were to explain the research purposes to the caterers and collect some preliminary data. Four to six samples were collected to gain an idea whether it will be possible to reach the objectives, and see what it would involve. After that, and based on the initial results, the researcher was able to decide how data was to be collected, how much and what data to collect and from whom.

The methods used in the qualitative research were mainly field work observation, as well as questionnaires. Of these, field observation provided the initial qualitative insights in that the practices in focus were studied in their environment. During the observation stage, the researcher was collecting data in the form of notes, recording what people do and say and trying to fit into that particular community's culture as a trained researcher from another culture. In doing the field work, it was kept in mind that:

- The observation by the investigator is crucial and part of the phenomenon being studied because in order to understand personal meanings and subjective experiences one has to be involved with the lives of the people being studied.
- It is necessary also to recap that this was done in tandem with a scientific quantitative method so as to acquire precise measurements parallel to the information provided. But here the investigator's involvement in the lives of the informants using direct observation is considered as a primary data gathering device.

It was seen that information given by the participants did not always reflect the actual status of the phenomenon; observation made a distinction between what was real and verbally apparent. In the preliminary stage the researcher also learned that it is better when questions are asked in the local language.

During the field research it was noted that the dress of the investigator must not draw attention from the participants. Clothes that were discreet and closely similar to those of Nyanga residents made it easier for them to reveal themselves to the researcher. However they also knew that the researcher came from the other side and had a different background and this made them expect something different from the researcher. For example a chicken boiler once asked me why I was putting on old shoes like hers and yet I said that I was from UCT.

It was found important to be careful about displaying one's special skills and knowledge, being a good listener was not enough, reflecting back on what was heard and observed helped to draw meaningful interpretations. In that sense, the advice by Israel et al. (2006) was confirmed: having planned the field work with appropriate social science knowledge helped to build and maintain relationships, sustain the research, and interpret the findings.

6.2 Conclusions

In the following sections the research questions are revisited, to inspect whether the answers to them supported the hypotheses, and to allow for development of conclusions.

The 1st set of research questions were:

1. How much wood fuel is needed in the current production methods? At what cost? How does this compare to fuel usage, operating cost and capital amortisation costs for alternative cleaner energy technologies? How do vendors perceive cost, convenience and side effects of traditional vs. cleaner methods?

The results, as reported in chapter 4, showed that for the activity of chicken-plucking, the traditional open fire consumed 21± 3 kg of wood per working day, costing R 41.50 if harvested or R 7.70 for waste wood. Measurements reported in chapter 5 showed that replacing the open fire with efficient wood stoves would reduce this fuel usage to 3 kg at R 5.30 if harvested or R 1 for waste wood. The findings further showed that in the case of harvested wood, if an efficient wood stove were adopted at the cost of R150 and it lasted three years, the vendors could pay back the stoves in 5-20 days, and save ~R 33 700 on fuel wood in three years. If waste wood were used, vendors would still save R 6 300 on fuel wood in three years.

The thermal efficiency of open fires and efficient wood stoves for the purpose of heating water for chicken plucking was estimated at 3 and 18 % respectively.

Considering a biogas stove, it was found that the thermal efficiency of the Safegas C30 biogas stove used in the study ranged from 18 % to 36 %. The biogas stove itself cost R 315, which again could be amortized in a relative short period of time, depending on the cost of the gas used to power it and thus replacing the open fire with its regular wood purchases.

Like an efficient wood stove, a biogas stove could be used by only one caterer at a time. This could cause unhappiness for caterers waiting in the queue to boil water or dunk chicken for plucking. From the experimental discussion in chapter 5, it was seen that to boil water needed for chicken plucking, took at least 30 mins with a biogas stove, compared to 41 mins for the efficient wood stove and more than an hour for an open fire. This boiling time was influenced by the produced gas pressure in the digester (the lower the pressure, the lower the flames' intensity and the longer the cooking time).

The questionnaires and observations with vendors who did not use a wood stove revealed that they were not aware of the health effects of the smoke from wood. They believed that the smoke was natural and did not affect them, even though they coughed they considered that was normal. They further pointed out that pallet wood is cheap and burns fast. This explains their preferences of waste wood over harvested wood. These vendors seemed ignorant of the danger from emissions from this fuel that include PM, volatile organic compounds from wood fire as well as heavy metal emissions if the wood was treated with preservative chemicals.

The vendors thought that having to chop wood to fit the stoves would be a difficulty not encountered with open fires, but they appreciated that this was not an issue since a stove needed at least 7 times less wood than an open fires. The vendors had thought that the stove released little heat due to the small flames but they then saw that the water boiled within half the time compared to the traditional method of cooking. However they complained about the stoves being heavy and that stoves could not accommodate their usual pots.

These answers clearly substantiate the 1st hypothesis stating "the gain in thermal efficiency of cleaner energy technologies over traditional methods for heating processes in the informal production of food and drink will yield sufficient cost savings to justify the investment for cleaner burning equipment", for the efficient wood-stove technology, and possibly for biogas stoves, depending on the cost of the gas. It should be noted though that the evidence for this came from field work on one particular foodprocessing activity, viz. chicken-plucking. For the other activity studied, traditional brewing, the size of the vessels to be heated made both contending cleaner production methods infeasible.

The 2nd set of research questions stated:

2. Can biogas production include significant amounts of slaughtering waste (rumen content and blood) as substrate? What is the expected gas yield and is it more or less than the energy needed for the caterers to boil water for chicken plucking? What is the size and cost of a digester?

The experimental results from anaerobic digestion of a mixture of rumen content and blood, at pilotscale representing a low-technology installation, showed a gas yield of 0.36 $Lg^{-1}VS$. Theoretically, this value should be enough to provide 0.91 m^3 of biogas from 14.3 kg of such slaughtering waste, which would be enough for a vendor to boil a sufficient quantity of water to successively dunk 5 chickens as observed. However, this might require a sizeable bio-digester to be installed; the household scale 6 m^3 bio-digester at which the stoves were tested would suffice only for the needs of a single caterer, as it could produce of the order of the 0.91 m^3 of biogas needed once to twice per day. On the other hand, there would be sufficient waste to produce gas for multiple chicken-pluckers (or other caterers operating pots up to 25 L in size). In the Nyanga situation, this amount of biogas (to bring one 25 L pot to the boil) could come from 14.3 kg of waste, which was the amount of waste deriving from 6 sheep whilst 40 sheep were slaughtered daily.

It was estimated that 100 kg of slaughtering waste dumped every day could generate enough biogas for 7 vendors to be provided with enough thermal energy for their catering trades. Based on the experimental work conducted, it was calculated that a digester of 76 m^3 volume would be needed for this amount of slaughtering waste.

However, whatever size needed for a bio-digester, the biogas produced could accomplish other purposes than chicken plucking. For instance other benefits coming with the introduction of a bio-digester in general, would include the reduction of waste and its related effects.

In this regard, the 2nd hypothesis stating that "Slaughtering waste as a source of clean energy in the form of biogas can be of economic value for informal caterers, but the waste management infrastructure costs will be prohibitive for caterers" was fully substantiated. The use of slaughter waste would be of great impact in terms of improved solid waste management. It would also ensure the reduction of wood burning and thus of particulate emissions.

The 3rd set of research questions focused on waste and pollution reduction potentials of public benefit:

3. To what extent would the adoption of clean energy technologies (biogas technology and efficient wood stoves) mitigate the environmental pollution through improving air quality and reducing solid waste hazards? Can these gains be quantitatively estimated? How do they compare to the cost of additional infrastructure supportive of cleaner production? What other factors would have to be considered for cleaner production methods to be adopted?

The results showed that the air pollution loads were reduced 8-fold when an efficient wood stove was used. An average of 4 900 ± 1 500 µg/m^3 of PM_{10} was recorded to be released when boiling 25 ±1 L of water using 21 ± 3 kg of wood, while when using an efficient wood stove the PM_{10} averaged at 590 ± 130 µg/m^3 when boiling 19 ± 2 L of water with 3 kg of wood. This 7-fold reduction in resource usage would also result in a 7-fold reduction in ash waste, complementing the 8-fold reduction in air pollution levels. The use of a biogas stove reduced particulate air pollution even further, to an average of 310±140 µg/m^3 when heating 14 ±1 L of water.
The direct emissions from traditional method of cooking in the Nyanga study area was estimated at 300 tons CO_2-e per year. In the case that an efficient wood stove used, the direct emissions was estimated at 8 times less or 40 tons CO_2-e per year. Although the current study did not estimate the GHG countrywide, it is clear that the intervention of efficient wood stove would considerably contribute to the reduction of GHG emission.

The questionnaires and observations with the efficient wood stove users revealed that these vendors noted for themselves the fast heating and neatness of the stove in terms of smoke reduction and fuel use. These experiences by the caterers attracted other residents of the Nyanga neighborhoods who were passing by, and they approached the researcher to order stoves for themselves, (unfortunately there were none available at that time). It was assumed that the caterers were pleased to encourage their neighbors about the good features of the stoves. The dissemination could not have been done easily by the researcher, but because it came from local users of the stoves, it was well received.

On the other hand, the vendors suggested that for them to use the stove (cleaner technology) all the vendors would need to get one. Otherwise those using the stoves would be seen as proud. This was one of the barriers to implementing a new technology. Other vendors' perception that the new technology would not make things better, kept them relying on the old traditional method of cooking.

The results above provide some evidence in support of the 3rd hypothesis which stated that "The sizeable reductions in air pollution and in solid waste (of an order of magnitude), that can be achieved by the use of biogas technology and of efficient wood stoves instead of burning wood in open fires, are sufficient justification for public resources to be mobilized in addition to caterers' private investments". The work has also clearly shown that the ability of caterers to invest privately would be limited to appliances (stoves) and changes to production practises, but that these in themselves would not be sufficient to achieve all the possible public benefits.

Since local government is obliged to ensure an air quality conducive to good health, as well as provide waste management services in the interest of public health and environmental protection, these results present at least a strong argument for the mobilisation of public resources to reduce wood fire smoke.

In summary, the 1st hypothesis could be validated for the activity of chicken-plucking though not for beer brewing: where chicken plucking can be shifted from an open fire onto an efficient wood stove the fuel savings can pay back the cost of the stove. The 2nd hypothesis was also fully substantiated: slaughter waste can be anaerobically digested with technology suitable for road-side installations, to produce enough fuel for at least some of the thermal needs of roadside-caterers, but the capital cost of such infrastructure could not be recovered from savings on fuels. The 3rd hypothesis was partially substantiated: there would be sizeable benefits from using biogas in terms of reduced air pollution from road-side catering, making the case for situation-specific cost-benefit analyses for public investment into biogas infrastructure vs. other ways in which public money could be spent to improve public health.

This study thus concludes that the implementation of cleaner technologies, which is a core feature of a Cleaner Production approach, is feasible in this informal catering sector. The 'trader-size' vermiculite wood stoves investigated in this study are suitable for the cleaner production approach for informal street caterers for chicken plucking, with a very short payback time. A cleaner-burning innovation would still be needed for caterers who produce *umqombothi;* they could possibly adopt the type of stoves mentioned in section 5.1.2.2. In addition to the cleaner technology intervention, a number of observations were also made and presented in this thesis for interventions of a 'better housekeeping' nature, another core principle of the cleaner production approach.

6.3 Recommendations

Based on the conclusions presented above, the following recommendations are made:

1. Efficient wood stoves were shown to be effective for catering activities using pots up to a 25 L size, with a fast payback time on wood savings, and with sizeable reductions in air pollution. This should be followed with the cooperative control or pressure applied to all the vendors to use the provided facilities and whoever does not obey should be charged with polluting.

2. Water temperature for chicken-plucking: a follow-up study with vendors, for them to learn the benefits of heating to the optimal (and lower) temperature.

3. Slaughter facilities should be built for the vendors where the waste can be kept together. Since the slaughter waste can be used as a substrate for biogas generation, it is recommended that local government test the feasibility of including a suitably sized bio digester in such a slaughter facility, making the produced gas available for sale.

4. Vendors should be encouraged to keep the waste together in covered containers while waiting for its proper handling. To this end there is a need for the municipalities to educate and train waste collectors about different types of waste and how to handle them.

5. The study has found that CP techniques work for low-income practitioners through a number of options as suggested in Chap 5. It is therefore recommended to the local government to enforce the implementation of such techniques and encourage further studies to investigate other contributions of other CP options for reducing solid waste in lowincome communities as well as their economical values to the vendors.

6. Similar studies in urban settings in other developing countries are also encouraged, as understanding by operators, derived from seeing better practises working, is key to the cleaner production approach.

7. In such research, which involves both social and scientific-technical participation, enough time should be planned to build trust and understanding. Whatever is done should consider the views, the involvement and ultimately the participation of the community of caterers.

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APPENDICES

Appendix 1: research Questionnaire

Questionnaire for caterers

1) Date:
   Time:
   Gender:
2) Type of occupation
   Owner
   Employed
3) Type of business No
   -chicken
   Yes
   -Brew beer Yes No 4) How

do you prepare the meat/ beer?

-Open fire on the ground Yes
How often?
Why...
No
Why?... -Wood
stoves and pot Yes
How often?
Why?...
No
Why?...
-Other..

5) What fuel do you use?
   -Forest wood
   -Waste wood : pellet
   -Other..
6) How much fuel do you use per round?
   Trollies Kg?
7) How much do pay for the fuel? R................../ Unit
8) a) How long does it take for a unit fuel to get finished?
   Hours days weeks

   b) How long does it take for the round of the meat/beer to get read? Hours

   d) How much meat/beer for a round? .... Kg of meat/ round ....L of beer/round
9) Is there any other way of cooking what you sell? Yes No
   If Yes, which one? And why haven't you chosen that as an alternative way to cook?
   Cost Yes No

Availability Yes No

Time Yes

No Customers don't like us using it Yes

No

Appendix 2: The ethics form

EBE Faculty: Assessment of Ethics in Research Projects (Rev2)

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791).
NB: A copy of this signed form must be included with the thesis/dissertation/report when it is submitted for examination

This form must only be completed once the most recent revision EBE EiR Handbook has been read.

Name of Principal Researcher/Student: Rissa Niyobuhungiro Department: Chemical Engineering

Preferred email address of the applicant: nybris001@myuct.ac.za

If a Student: Degree: PhD Supervisor: Prof. Harro von Blottnitz

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: Investigation of the applicability of a cleaner production approach to informal catering in urban Africa

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	NO ✓
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES ✓	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	NO ✓
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	NO ✓

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate. Ensure that you refer to the EiR Handbook to assist you in completing the documentation requirements for this form.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	RISSA NIYOBUHUNGIRO	30.04.2013

This application is approved by:

Supervisor (if applicable):	Prof. Harro Von Blottnitz	30.04.2013
HOD (or delegated nominee): *Final authority for all assessments with NO to all questions and for all undergraduate research.*		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		26/08/2013

ADDENDUM 1:
Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:

ADDENDUM 2: To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

	YES	NO
2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification?	YES	NO ✓
2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups?	YES	NO ✓
2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?)	YES	NO ✓
2.4 Will any confidential data be collected or will identifiable records of individuals be kept?	YES ✓	NO
2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous?	YES	NO ✓
2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research?	YES	NO ✓
2.7 Does the research include making payments or giving gifts to any participants?	YES	NO ✓

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

2.4. The confidential data will be stored in coded mode and the researcher will have the pass codes to the main documents. The information will be used for research purposes only and will remain confidential. The participants will be assured of this.

A questionnaire of needed information is attached.

ADDENDUM 3: To be completed if you answered YES to Question 3:

3.1 Is the community expected to make decisions for, during or based on the research?	YES	NO
3.2 At the end of the research will any economic or social process be terminated or left unsupported, or equipment or facilities used in the research be recovered from the participants or community?	YES	NO
3.3 Will any service be provided at a level below the generally accepted standards?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

Note This aspect of the work might be revisited in a few month's time when the biogas aspect is better defined.
If the ethics implications change, permission will be sought for the additions to the work plan.

ADDENDUM 4: To be completed if you answered YES to Question 4

4.1 Is there any existing or potential conflict of interest between a research sponsor, academic supervisor, other researchers or participants?	YES	NO
4.2 Will information that reveals the identity of participants be supplied to a research sponsor, other than with the permission of the individuals?	YES	NO
4.3 Does the proposed research potentially conflict with the research of any other individual or group within the University?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

Appendix 3: Consent form

<u>CONSENT FORM FOR INFORMAL CATERERS</u>

Investigation of the applicability of a cleaner production approach to informal catering in urban Africa

Hello,

My name is Rissa Niyobuhungiro, I am conducting a research towards a doctoral degree. I am researching about how cleaner production techniques can be applied to informal catering specifically those who use wood as a fuel to prepare food and drinks to sell. I am glad to invite you to participate in this project.

The project looks at how the new burning technologies (efficient wood stoves and biogas stoves) reduce fuel consumption and emissions comparing to traditional methods (open fires).

All we need from you is to

- Let us set up our air sampler close to your fires before you start till the end of the process.
- Let us weigh the fuel (wood) before it is thrown into the fire
- And answer the questions on the questionnaire

I would like to clarify that the participation is voluntary. If you don't feel like participating feel free to say no. There is no negative consequence. However to motivate participation R20 is offered to the participant straight after the data collection. This payment is provided by the research project.

There is no harm risk in participating in this project. No interviews done in this research. Personal information provided remains confidential and will be kept as pseudo codes.

The data collected will only be used for research purposes. Feedback will be given to the caterers at the beginning of the last sampling to make them understand why the participation was important. The type of information that will be reported back is the emission level from traditional methods. This will be done at the end of the study.

Thank you,

Rissa

Appendix 4: Questionnaire responses

name/number	date	gender	own a stove	open fire	SINCE	stove	how many days in open fires	how many days with a stove	why	forest wood	cost	waste wood	cost	other fuel	why
1	18/6/2013	f	no	yes	5		6		it is easy and fast	yes	R 12 PER 6.2kg	yes	R 25 PER 70 kg		
2	21/7/2013	f/m	no	yes	7		6		cheap and common			yes		gas for food	cost
3	22/7/2013	f	yes/no	yes	6		6		that is how it is done, it is normal			yes		gas for food	cost , time
4	26/7/2013	m	no	yes	10		6		we are used to this, no other way			yes			
5	24/8/2013	f	no	yes	5		6		it is easy and fast			yes			
6	25/8/2013	f	no	yes	7		6		it is easy and fast	yes		yes			

7	27/8/2013	f	yes/no	yes	10		6		it is easy and fast			yes		gas for food	cost , time, availab ility
8	31/8/2013	f/m	no	yes	8		6		it is easy and fast			yes		gas for food	time, availab ility
9	03/9/2013	f	yes/no	yes	8		6		it is fast	yes		yes			
10	04/9/2013	f	no	yes	6		6		it is easy and fast			yes			
stoves															
1	20/11/2013	f	yes	yes		yes		3	umunwosho			yes		not common	
2	21/11/2013	f	yes	yes		yes		2	umunwosho			yes		not common	
3	12/02/2013	f	yes	yes		yes		2	to heat inside and cook in winter			yes		not common	
4	08/4/2014	m	yes	yes		yes		1 a week	small pot needed			yes		not common	
5	08/4/2014	f	yes	yes		yes		2 a week	less smoke, but not common and too much work			yes		not common	

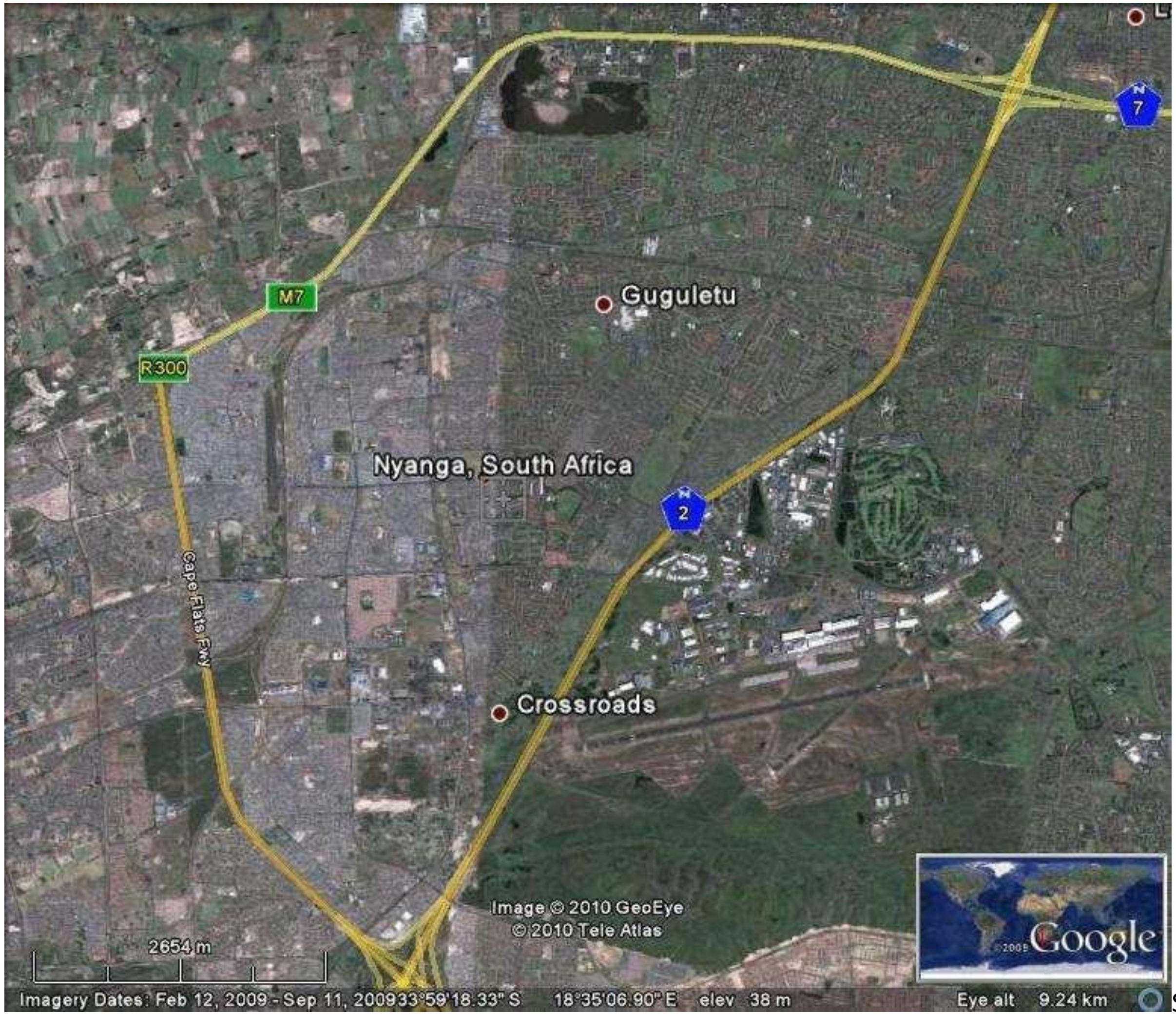
Appendix 5: Other activities done by the vendors in Nyanga


(a)


(b)

(a) On site slaughtering, (b) meat braaing with wood

Appendix 6: Geographical location of Nyanga



Source: www.googleearth.com

Appendix 7: Nyanga aerial view

Source (EWB 2011)