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COLLEGE OF HEALTH SCIENCES

UNIVERSITY OF GHANA



**A STUDY OF SHORT-LIVED CLIMATE POLLUTANTS ASSOCIATED WITH SOLID
WASTE MANAGEMENT ACTIVITIES IN ACCRA**

BY

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DECLARATION

I, Betty Akua Nartey, do hereby declare that except for cited references that have been duly acknowledged, this work is the result of my own original research done under supervision, and that this dissertation, either in whole or in part has not been presented elsewhere for another degree.

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DEDICATION

This study is dedicated to my mother, Mrs. Georgina Ahiable for her immense contribution towards my education and my entire life.

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All praise, glory, and adoration go to the Almighty God for seeing me through my research work. It has never been easy from day one, but the Lord has been good to me and has been by my side guiding every step I take. Indeed this is the day the Lord has made, and I will be glad and rejoice in it.

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ABSTRACT

Background: There are considerable implications of rapid population, industrialization and urbanization on global health, food security and climate change. As global population increases, solid waste generation rates also increases. Waste management activities are as diverse as the short-lived climate pollutants (SLCPs) they generate, since at every stage of the waste management process SLCPs are released. This study assessed the contribution of urban solid waste management activities to local climate change by estimating the quantities/ amount of short-lived climate pollutants emitted using the solid waste emission estimation tool (SWEET) in order to inform local climate change and urban air quality policy.

Methods: The study was an analytical study which made use of routinely generated planning and administrative data as well as published data obtained from the solid waste management sector to estimate SLCPs associated with waste management activities. The solid waste emission estimation tool (SWEET) was used for estimating and quantifying SLCPs. Data were analyzed by developing scenarios for urban waste management (UWM) for Accra, informed by existing sector policy-change implementation.

Results: The per capita generation rates in- and out-side formal collection zones were 0.75 and 0.62 kg/person/day respectively. According to the data sources, the percentage generation rates in- and outside the formal collection zones were 67.5% and 32.5%. Waste burning was the highest source of all climate forcing emission and thus generated an emission of 125,792.50 metric tons CO₂ eq with the least emission coming from organic management or composting (2,275.82 CO₂ eq.). Using 2020 as the diversion scenario start year, the results indicated that by expanding recycling, methane emission will decrease from 161,653.39 metric tons CO₂ eq. to 144, 360.94 metric tons CO₂ eq in

2020; capturing landfill gas will also reduce methane emission from 161, 653.39 metric tons CO₂ eq. to 148,088.05 metric tons CO₂ eq. On the other hand, black carbon emission from waste burning in 2018 was 43,534.99 metric tons CO₂ eq. By ending open burning in 2020, black carbon emission is expected to decrease from 55,125.14 metric tons CO₂ eq. to 9,009.14 metric tons CO₂ eq.

Conclusion: Waste management sector activities in Accra appear to contribute SLCPs emission loading into the ambient environment. However, diversion of solid waste via composting and recycling is effective in lowering emission levels of some of the SLCPs. Additionally, ending open burning and capturing landfill gas was found to be successful in reducing climate forcing pollutants. It is therefore important that solid waste management in the country be considered in an integrated manner in order to reduce SLCP emissions.

Keywords: Short-lived climate pollutants, solid waste management, climate change, Accra, air quality

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LIST OF ACRONYMS

AMA	Accra Metropolitan Assembly
BC	Black Carbon
CCAC	Climate and Clean Air Coalition
CCC	Communal Container Collection
EPA	Environmental Protection Agency
Eq.	Equivalent
GHG	Greenhouse Gas
GWP	Global warming potential
Gt	Gross tonne
HDA	High Density Aerobic
HIC	High Income Country
HtH	House-to-House
IBC	Integrated Benefits Calculator
ICLEI	International Council for Local Environmental Initiative
IGES	Institute for Global Environmental Studies (Japan)
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long-range Energy Alternatives Planning
LFG	Landfill Gas
LIC	Low Income Country
MDAs	Municipal District Assemblies
MSWM	Municipal solid waste management
MSW	Municipal Solid Waste
MCF	Methane correction factor
OECD	Organization for Economic Co-operation and Development
SLCP	Short-lived climate pollutants

SWEET	Solid Waste Emission Estimation Tool
SWC	Solid Waste Collection
SWM	Solid Waste Management
UHI	Urban Health Initiative
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
UVR	Ultraviolet Radiation
UWM	Urban waste management
WHO	World Health Organization
WMD	Waste Management Department

CHAPTER ONE

1.1 Background

As global population increases, solid waste generation also increases (Hoornweg & Bhada-Tata, 2012). Unsustainable solid waste management is a global issue in terms of its negative impacts on the environment, air quality, and human health (Ferronato, 2019). In developing countries, rapid urbanization and increase in population growth results in a corresponding increase in waste generation thereby exerting much pressure on an already over strained solid waste management system (Vij, 2012). This has necessitated the demand for improved waste management services.

Global warming, an important global environmental problem is a cause for concern and action as a result of its significant effects on humans (Hoornweg & Bhada-Tata, 2012). Global warming is caused by the release of greenhouse gases into the earth's atmosphere as a result of anthropogenic activities which trap heat near the earth, preventing the loss of heat to space. The warming of the surface of the earth has been reported to exacerbate rainfall variability, flooding, drought, and extreme temperatures (Pachauri, 2014). The impacts of global warming are being felt at the global scale but those most severely impacted and most vulnerable are in Africa (Serdeczny et al., 2017) because of their weak health infrastructure and unpreparedness in addressing the impacts of climate change. Africa is experiencing warming greater than the global annual average and thus, considered a part of the world that is most vulnerable to the consequence of climate change (Hoornweg & Bhada-Tata, 2012). Climate change is thus considered a threat to the fight to improve the health of the poor.

In recent times, it been realized that solid waste management sector activities are associated with greenhouse gases and are therefore associated with global warming at the local scale (Trenberth,

2007). For instance, it is now widely known that some components of solid waste management activities are associated with short-lived climate pollutants (SLCPs) which are potent greenhouse gases and air pollutants. According to the Climate and Clean Air Coalition (CCAC), SLCPs have shorter lifespan in the atmosphere as compared to long-lived climate pollutants. For instance black carbon has a life span of about days to weeks in the atmosphere, whereas methane has a lifespan of around 12 years compared to 100 years and more of CO₂. Despite this short period of time in the atmosphere, SLCPs have a remarkable effect both directly and indirect on local climate change, agriculture and human health. Some examples of SLCPs include methane, hydrofluorocarbons (HFCs), black carbon, and ground-level ozone. In view of this, the Climate and Clean Air Coalition are emphasizing the need for GHGs reduction to be done together with target on SLCPs to ensure that average global temperatures does not exceed 2°C (UNEP 2017). There are emission estimation tools such as the Solid Waste Emission Estimating Tool (SWEET) and the Long-range Energy Alternatives Planning (LEAP) – Integrated Benefits Calculator (IBC) which have been widely used in quantifying SLCPs. This study however employed the use of SWEET, an excel-based tool in quantifying SLCPs emissions because it was readily available, more user-friendly and less complex than the rest of the tools.

The Intergovernmental Panel on Climate Change (IPCC) has reported human activities to have caused about 1.0°C increase of global temperatures above pre-industrials levels in the past few decades, and this is likely to increase to 1.5°C between 2030 and 2052 (IPCC, 2018). According to the World Bank's report (Hoornweg & Bhada-Tata, 2012), there is a significant association between urban solid waste generation rates and short-lived climate pollutants (SLCPs) emissions and many scientist in developed and some developing countries have confirmed these findings (Friedrich & Trois, 2011;Gentil & Christensen, 2009;Friedrich, 2013;Bogner, Pipatti, & Kjeldsen,

2015). In the year 2000, developing countries contributed approximately 29% of these emissions. This is expected to increase to 64% and 76% in 2030 and 2050 respectively due to copious amount of methane gas emitted from landfill site (Bogner et al., 2015). Methane generated from landfills contribute to about 90% of emissions from the waste sector and approximately 18% of global anthropogenic emissions in the year 2004 (Bogner et al., 2015). Short-lived climate pollutants (SLCPs) regardless of their short atmospheric lifespan are known to cause considerable impacts in terms of their local global warming potential (GWP). According to the World Bank's report, SLCPs are also released from diesel vehicles, refrigerators and open burning of solid fuels.

Intergovernmental Panel on Climate Change (IPCC) has defined municipal solid waste (MSW) as all wastes generated from households including plastics, cans and organic waste. According to the World Bank, waste generated world-wide is expected to increase from about 1.3 billion tons per year, to about 2.2 billion tons per year by 2025. Urban centers in low income countries produce large quantities of organic waste compared to high income countries where majority of their waste is inorganic (Hoornweg & Bhada-Tata, 2012). Whereas in rural areas in developing countries, due to their low economic status, residence only buy fewer products which are mostly reusable, thus generating reduced volumes of waste compared to urban areas; urban areas are milieu of intense economic activities and thus generate huge volumes of waste per square meter. Waste collections varies by region and by income (Hoornweg & Bhada-Tata, 2012) and municipal authorities are challenged with management of waste generated in homes and on streets. In lower-middle countries, this problem is further exacerbated by lack of accessible roads for waste collection, inadequate funds for waste collection, inadequate waste equipment among others (Fobil, Kolawole, Hogarh, Carboo, & Rodrigues, 2010). This usually results in a deficit between what is collected and cycled and what is uncollected. In developing countries, home collection is limited to those who

are willing to pay. Collection of solid waste in poor urban communities is inadequate thus residence in these areas are left to contend with their own waste leading to open burning and indiscriminate dumping of solid and liquid waste with a concomitant pollution of the environment and water bodies. Given the role of organic waste in the emissions of short-lived climate pollutants, municipal waste management processes, including collection, composting and recycling are therefore important measures in maintaining healthy ecosystems which invariably plays a role in maintaining environmental sanitation in cities around the world as well as decelerating global warming and its harmful effects.

1.2 Problem statement

As SLCPs are released into the atmosphere, they pollute the quality of air and cause diverse acute and chronic illness such as lung cancer and cardiovascular diseases (Jiang, Mei, & Feng, 2016). The World Health Organization estimated that, in 2016 close to 5 million deaths were attributed to outdoor air pollution. Ambient air pollution accounted for about 16% of the lung cancer deaths, 25% of chronic obstructive pulmonary disease (CODP) deaths, about 17% of ischemic heart disease deaths and stroke deaths and about 26% of respiratory infection deaths (WHO, 2016). Globally, landfills are the third largest source of anthropogenic methane emissions (Singh, 2018). In Ghana, landfilling are the most common disposal option for solid waste (Kusi, Nyarko, Boamah, & Nyamekye, 2016). Large amounts of methane gas are produced from these landfill sites due to the large amount of organic waste being deposited. Methane gas contributes to the formation of tropospheric ozone, an air pollutant that has adverse effects on the human health and causes diverse diseases.

It has also been predicted that, the quantity of SLCPs emitted from waste management activities in developing countries will increase considerably in the near future (Friedrich & Trois, 2011).

Also, whereas in some developed countries, the levels of climate pollutant emissions are decreasing due to strict air quality regulations, the situation is the opposite in developing countries due to lack of laws regulating air quality, waste management and lack of political will to enforce these laws if they were even existent (Hoornweg & Bhada-Tata, 2012). In Ghana, there are no estimates of SLCP emissions, which make it quite difficult to monitor climate changes and even implement any strategies to mitigate climate change. Furthermore, solid waste mismanagement continue to be an unending problem in major urban cities for example, Accra- the capital of Ghana- for years. Short lived climate pollutants has a direct influence on local climate, air quality and public health as well as indirect impact on the ecosystem and agriculture. Additionally, black carbon together with other pollutants emitted from open burning, charcoal burning and the use of outdated vehicles for transport are all sources of fine particulate matter (PM_{2.5}) emissions (Ferronato, 2019). Ambient (outdoor) PM_{2.5} air pollution causes about 7 million premature deaths worldwide annually. The US EPA has estimated that, municipal solid waste contributes to about half of global black carbon emission excluding emissions from waste collection and waste transportation. It is also worthy to note that, developing countries depend largely on natural resources for food, income and the general wellbeing of their population (Kumar et al., 2017). Without policies and actions to mitigate climate change in developing countries, the sustainability of these resources will be compromised leading to a reduction in income of families and communities (Kumar et al., 2017), increase in hospital visits as a result of effects on the health of citizens as well as increased burden on health systems. Measures put in place to prevent black carbon emissions can go a long way in reducing emissions, increase crop yields and prevent premature deaths. The short life time of SLCPs together with their high global warming potential means that SLCPs mitigation can provide air quality and health benefits within a relatively short period of time. Reducing SLCPs through proper management of waste will therefore benefit local and national health, and the development of the economy.

1.3 Justification

Waste generation, aside being a challenge in most developing countries is one that affects every aspect of life for majority of the world's population. The United Nations Environment Programme (UNEP) has revealed that, efforts in reducing SLCPs in the atmosphere could result in a 0.6°C reduction in global warming by 2050, 2.4 million reduction in premature deaths from air pollution by 2030 and 52 million tons of avoided annual crop losses. Even though Ghana generates large quantities of waste, little is known about how these wastes contribute to GHGs emissions and about how the waste management sector can help reduce GHGs emissions. As a result, more information is needed on local emissions of GHGs from the waste management sector. This is very important in order to inform decisions of policy makers and local authorities who plan and enforce changes in communities and the nation as a whole. Despite the seemingly low contribution of the waste sector to the emission of GHGs, it is important to investigate by how much the waste sector contributes in order to properly evaluate the most appropriate strategy to reduce the emissions of SLCPs to very low levels (UNEP, 2010). The lack of coherent and consistent reporting for all waste management activities at both local and national levels are major problems in Ghana that need to be addressed. Proper waste management strategies based on an informed decision process, mass media dissemination of information on studies in this sector, public education on these environmental hazards and climate change in this regard could be important tools in tackling this problem. Results from this study will serve as a baseline study, making data available for future studies and influencing policy decisions on solid waste management in Ghana. It will also serve as an advocacy for composting of waste as manure for agricultural processes and recycling of other products that can be put to good use. Finally, by assessing, quantifying and comparing SLCP emissions released at refuse disposal sites or landfill sites, this study will also serve as a means of

identifying suitable alternative strategies for the development of climate friendly waste management systems.

1.4 General Objective

To assess the contribution of urban solid waste management activities to local climate change by estimating the quantities/ amount of short lived climate pollutants emitted using the solid waste emission estimation tool (SWEET) in order to inform local climate change and urban air quality policy.

1.5 Specific objectives

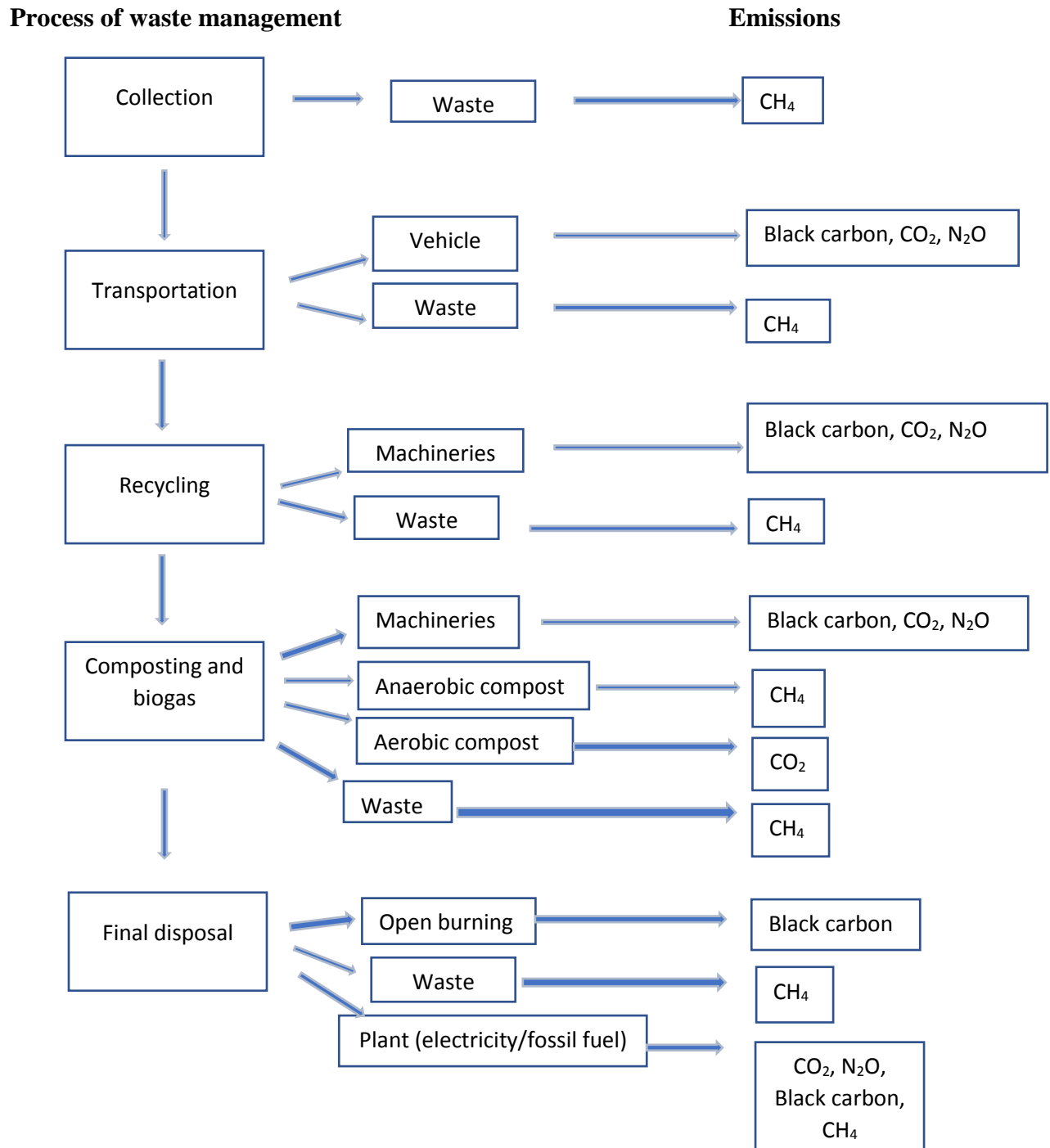
1. Determine the per capita waste generation rates inside and outside formal collection zones
2. Compute the annual percentage growth rate of waste collected
3. Determine the total waste collected and generated annually inside formal collection zones
4. Quantify short-lived climate pollutants emissions according to defined scenarios built based on waste management policy.

1.6 Research Questions

1. How much of each of the types of SLCPs [black carbon, Nitrous oxide (laughing gas) and methane (CH₄)], is associated with urban waste management activities in Accra in 2018 and what are the projected increases?
2. How much reduction in SLCPs emission is associated with “stop waste burning” scenario?
3. What combinations of best solid waste management strategies can ensure effective SLCPs reduction at the present generation rates in Accra?

1.7 Conceptual Framework

Fig. 1 Conceptual Framework showing GHG/SLCP emissions from waste management activities.



Source: Adapted from Singh (2018)

1.7.1 Narrative to conceptual framework

The above conceptual framework shows the specific SLCPs emissions that are released by municipal solid waste management activities. Waste management activities are as diverse as the SLCPs they generate, since at every stage of the waste management process SLCPs are released. The processes of waste management include collection, transportation, recycling, composting and final disposal. These waste management processes can have different health impacts on people due to the emission of diverse pollutants during these activities. The use of poorly maintained waste collection vehicles releases black carbon, a component of PM 2.5, into the atmosphere which negatively affects air quality. Black carbon; which exists in the form of small black particles in atmosphere, results from incomplete combustion of bio-mass and the burning of waste. Black carbon is estimated to be 3,200 times more potent in warming the earth, and thus considered the third largest contributor to global warming after CO₂ and methane (*Strategy on Short-Lived Climate Pollutants – 2017*, 2017). According to (Bogner et al., 2015), methane from landfills and wastewater accounts for approximately 90% of emission from the waste sector and approximately 18% of global anthropogenic emissions. Methane has the potential to warm the earth faster than CO₂ despite its short lifespan thus giving it a higher Global warming potential rating than CO₂. In comparing black carbon to methane, it can be said that, blackcarbon has a life span of about days to weeks in the atmosphere, whereas methane has a lifespan of around 12 years compared to 100 years and more of CO₂

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, an analysis of studies on solid waste management both globally and nationally is done. The chapter further reviews literature on the various problems affecting the solid waste sector and compares short-lived climate pollutants released at every stage of the waste management processes across different countries and among different populations.

2.2 Global overview of solid waste management

Waste management has been a major problem in most rapidly growing cities across the globe. The global impact of solid waste is fast growing as a result of increase waste generation, urbanization and economic development. Solid waste, a byproduct of urban life is increasing even faster than the rate of urbanization (Hoornweg & Bhada-Tata, 2012). Globally, world cities generation one billion tonnes of solid waste each year, which according to the World Bank, is expected to double by 2025. Waste generation rates varies from region to region. Studies conducted by Hoornweg & Bhada-Tata (2012), revealed that the Organization for Economic Co-operation and Development (OECD) countries generates 572 million tonnes (2.2 kg/person/day) per year compared to 270 million tonnes (0.95 kg/person/day) in East Asia and 62 million tonnes (0.65 kg/person/day) in Sub-Saharan Africa generates about 62 million. Globally, high income countries recycle and compost more than lower middle income countries (Hoornweg & Bhada-Tata, 2012). In some developing countries, waste picking and recycling is mostly by the informal sector (Hoornweg & Bhada-Tata, 2012). However, in HIC, high technology is used in sorting and processing. The overall recycling rates in these countries are thus higher compared to LIC (Hoornweg & Bhada-Tata, 2012).

2.3 Solid waste management (SWM) in Ghana

The SWM sector in Ghana is a deliberate collaboration among multiple stakeholders with the Ministry of Local Government and Rural Development (MLRD) and the Environmental Protection Agency playing key roles as implementer and regulator respectively. The responsibility of the MLRD is discharged through the District, Municipal and Metropolitan assemblies which are directly under the MLRD and the Environmental Protection Agency (EPA). Waste management planners in Ghana are currently using the “collect and dispose” approach of waste management. The “collect and dispose” approach places more emphasis on the final disposal of waste rather than seeing waste as a resource (Asomani-boateng, 2015). Waste management planners in Ghana have failed to adopt the participatory and inclusive approach to managing waste which in many developed countries is the norm (Asomani-boateng, 2015). Government of Ghana have privatized solid waste collection to increase collection rate. To tackle solid waste challenges, waste management was decentralized to promote accountability and effective waste collection. Waste management in Ghana consists of many actors with different roles and responsibilities. For instance the MLRD is responsible for formulating and implementing policies related to solid waste management and sanitation. They also develop and issue technical guidelines on environmental sanitation services and their management. It is their duty to also promulgate national legislation and bye laws as well as provide direction and supervision of the National Environmental Sanitation Policy Co-ordination Council. On the other hand, the EPA has been mandated to regulate the environment by educating the general public on sanitation issues.

The municipal, district and metropolitan assemblies (MDAs) which is the implementing body of the MLRD has the sole responsibility for waste collection and disposal. Waste management in the country is carried out by the waste management department within the MDAs. They may provide

the services directly, or indirectly through private contractors or franchisees. There are also laws that gives instructions on how to keep the environment clean and also protect it.

Studies conducted by Monney, Makimula, & Bagah (2013) revealed two main types of solid waste collection (SWC) services in Ghana. This according to them includes house-to-house (HtH) waste collection and communal container collection (CCC). These forms of SWC are based on the income levels of residents as well how accessible their homes are. The house-to-house waste collection is mostly rendered in developed and more advanced areas, whereas the communal container collection (CCC) is rendered in less developed and rural areas.

2.4 Solid waste management (SWM) challenges

The SWM sector in Ghana still faces numerous problems which are manifestations of implementation conflicts in current institutional arrangements; including weaknesses in the existing laws. Most lower-middle income countries have also been struggling with solid waste management. Majority of the people in these countries see waste as useless and thus discard it anywhere without thinking about its repercussion in the near future. Despite the interventions being put in place to tackle this problem, the challenge still lingers. This review therefore reveals some top challenges in the waste management sector by presenting pockets of data from published and unpublished works.

Some problems of solid waste include indiscriminate disposal of waste at unauthorized places, littering, inadequate service coverage and irregularities in waste collection. There are many reasons why these things happen. Most importantly, population growth and urbanization in Accra has led to the rapid expansion of the city resulting in urban sprawl. Also rapid and unregulated population growth results in a rapid generation of waste. This leads to a situation where the rate of waste generation far outpaces the establishment of waste service infrastructure posing serious problems

to sanitation and waste management authorities. Secondly, inadequate funds by the central government to support waste management activities makes it difficult for waste management companies to effectively carry out their duties. Thirdly, solid waste management has never been a priority for this country. The lack of political will and lack of enforcement of sanitation bye-laws and building regulations by metropolitan, municipal, and district assemblies also accounts for much of Ghana's waste problem. Studies conducted by Douli, Abanyie, & Ampofo (2017) among people in the Bawku municipality revealed the lack of public awareness and participatory approach by citizens on issues regarding solid waste management, thus resulting in the indiscriminate disposal of refuse. There is little knowledge about the existence of environmental laws and policies. People flaunt the laws and they are left unpunished. This encourages others to continue in similar unacceptable bad behavior. Policies are made as guidelines for various actors in the waste management sector to implement. The laws and policies are required to help address the overwhelming challenges of poor sanitation in Ghana. However, since the various roles of all the actors in the waste management sector overlaps, they are unable to function and do their work properly. There is therefore the need for the roles of the various actors in the waste management sector to be clearly defined to enable them discharge their duties well without any overlaps.

Asomani-boateng (2015) found in his studies that the main challenge in SWM is attributed to the copious quantities of waste generated and its management. According to him waste reduction or minimization is critical in dealing with the problem of SWM in the country. If household are able to reduce the waste they produce, it will decrease the amount of waste that is disposed of at the landfill site.

According to the deputy director of the environmental protection agency, poor planning is one major problem affecting the country. Settlements and cities in some urban areas in Accra are poorly planned with lack of access routes to waste trucks, making it difficult for waste collection. The lack

of access routes for trucks to carry waste from human settlements to landfill sites affects the rate at which waste is collected.

2.5 Waste generation and collection

Waste generation is the first component of any waste management system (Friedrich & Trois, 2011). It has proven beyond reasonable doubt that population growth, affluence and rapid urbanization in the city translates into generation of copious amounts of solid waste. Waste generation data in the city that will inform effective planning on waste management is not readily available and in some cases even absent (Miezah, Obiri-Danso, Kádár, Fei-Baffoe, & Mensah, 2015). Douti, Abanyie, & Ampofo (2017) found that, in Ghana, waste management departments of the municipal assemblies lacked quantitative data on the amount of waste being generated in their municipality. According to the AMA, Accra alone generates approximately 2,200 tonnes of solid waste daily and this is expected to reach 4,419 tons by 2030. Miezah *et al.*, (2015) found that on average, the rate at which waste is generated in Ghana was 0.5 kg/person/day whereas the rate at which was generated in Accra was found to be 0.74 kg/ person/ day. According to the same authors, the range of waste generation rates across Ghana irrespective of their socioeconomic considerations was from 0.2 to 0.8 kg/person/day (Miezah *et al.*, 2015). In Mexico, Reyna-bensusan, Wilson, & Smith (2018) revealed that about over 112,300 t day⁻¹ was generated in 2010 which can be translated as 0.98 kg capital⁻¹ day⁻¹. Out of the amount total amount of waste generated per day, an estimated rate of generation per capital included 0.80 kg day⁻¹ in urban area, 0.69 kg day⁻¹ in peri-urban areas and 0.43 kg day⁻¹. However, Studies done by Douti *et al.*, (2017) have shown that majority of waste generated in developing countries is organic. The same was found in studies by Miezah *et al.*, (2015), where more than 60% of waste generated from all regions of Ghana was organic. Additional finding by (Douti *et al.*, 2017) also suggests that increase use of plastics in Bawku was due to increased use of plastic bottles in the production of pure water sachet, drinking

plastic bottles and polythene bags. Metropolitan areas generate higher amount of waste than municipals and districts due to high active activities. Studies according to Miezah et al., (2015) showed that average household waste generation rate from the metropolitan areas was 0.63 kg/capita, municipal 0.40 kg/capita and the district 0.28 kg/capita. Results from studies conducted by (Miezah et al., 2015) revealed how food waste formed majority of the organic waste generated. In concordance with previous studies, Asomani-boateng (2016) recommended that since 60% of the city's municipal waste was organic, composting will be the best option in achieving waste reduction, which intend minimizes the quantity of waste diverted to final disposal sites. The Ghana statistical service has stated that about 60% of solid waste generated by household is collected whereas about 30% are openly dumped in gutters, drains and water bodies or either burnt or buried (Ghana Statistical Service, 2014). Studies have recorded a significant increase in collection rates from 51% in 1998 to 91% in 2000 (Julius N. Fobil, Armah, Hogarh, & Carboo, 2008). Waste collection in Accra has been outsourced to private agents. Waste collection in the city is mainly by house to house collection in well planned settlements and accessible homes. It is also worthy to note the upsurge of individuals who do door to door waste collection in the various localities in open-top tricycles. According to Reyna-bensusan et al. (2018), about 84% of waste generated in Mexico is collected, 10% recycled and close to 12% openly burnt.

2.6 Short-lived climate pollutant associated with waste generation and collection

Waste generation is important in quantifying the amount of greenhouse gas generated from the waste sector (Friedrich & Trois, 2011). The results of studies conducted by (Gamaralalage et al., 2018), revealed that methane emissions associated with uncollected waste was 363 kg CO₂ eq / tonne of waste. In the Philippines, the total SLCPs emissions generated out of 40,730 tonnes of waste was 4.62 million tonnes of CO₂eq. The study again found that, highest amount of black

carbon emissions from open burning in the Philippines was 0.11 kg / tonne of waste generated (Gameralalage et al., 2018). Couth & Trois (2010) found that rural areas have a lower waste generation rate than urban areas, thus, most SLCPs associated with waste are normally from urban areas. More than anything else, the composition of waste is essential in determining the quantity of SLCPs released into the environment. In Accra where majority of the waste is organic, high amount of methane gas can be released when it degrades (Couth & Trois, 2010). There is also a vast difference in methods used for waste collection in developed countries and developing countries (Friedrich & Trois, 2011). Whereas in the developed world, waste collection is mechanized and well structured, including vehicles and sweepers, which makes the process more efficient, the situation is different in developing countries.

2.7 Waste transportation

Douti et al., (2017) found that waste management institutions in the Bawku Municipality employ the use of mechanical equipment such as skip loader and manual means such as tricycles in transportation of waste to the landfill site. This is in conformity with studies conducted by Amoah & Kosoe (2014) in Wa which also identified mechanical and manual methods as the main means of transportation. With respect to the mechanical method the vehicles such as skip loader or roll-off trucks are used for lifting waste containers and transporting it to the disposal sites. According to the authors, tricycles which are manual approach are used in collecting waste from homes and on streets to be transported to disposal site. There are many challenges when it comes to waste transportation. Prominent among these challenges include the untimely collection of waste bins and communal waste containers whenever they full. Another challenge that militates against timely and efficient collection has been the inability to pay service providers on time. Studies conducted by Douti et al., (2017) revealed that the problem facing waste transportation is the inadequate number

of waste trucks, waste handling equipment and the cost of maintenance. The poor maintenance of vehicles coupled with the worse traffic in most parts of the city results in the use of more fuel when disposing off waste to landfill site.

2.8 Short-lived climate pollutant associated with waste transportation

Studies have revealed some factors that have contributed to the emission of climate pollutants from the transport sector. These factors include distance, population, type of waste, age of vehicle and maintenance (Friedrich, 2013). Recent studies have shown that, road transport has higher SLCP emissions compared to other means of transportation (Eisted et al., 2009). Therefore distance covered by the waste vehicle in collecting and disposing of waste determines the amount of SCLPs emitted. Collection and transportation of waste from a densely populated area is more efficient compared to a less populated area (Larsen et al., 2009a). Whereas older and poorly maintained vehicles produce higher GHG emissions (Friedrich, 2013). Greenhouse gas savings in waste transportation can be achieved by using efficient fuels and choosing the best routes. However in Africa, there are problems associated even with waste collection and transportation due to lack of access routes for waste collection (Fobil et al., 2008). There are differences in the amount of GHG emission from waste transportation sector in developed and developing countries. In developing countries, Friedrich and Trois (2008) estimated that about 15.53 kg of CO₂ e per tonne of is emitted from waste collected and transported in Durban (South Africa)

2.9 Waste recycling

There are currently three main recycling plants in operation in Greater Accra Region; the Accra compost and recycling plant (ACARP), Jekora ventures and Integrated Recycling and Compost Plant (IRECOP) which was recently commissioned in March 2019. These plants could play an important role in waste management and to realize the president's vision of making Accra the

cleanest city in Africa. One main challenge faced by recycling companies in Accra is the lack of separation of waste into the various components.

Scrap metals create jobs for many youth in Ghana (Nkansah, Attiogbe, & Kumi, 2015) which have made some contribution to country's economy. Households and refuse dumps are the highest source of collection for scrap metals (Nkansah et al., 2015). Scrape metals are bought by trade dealers and delivered to wholesalers in Tema (Nkansah et al., 2015). Students have revealed that informal recycling of electronic waste (e-waste) is an emerging source of income form most of the youth as well as a source of environmental pollution in Ghana (Feldt et al., 2014). Toxic chemicals released from the informal recycling of heavy metals are a major health concern for exposed individuals. Due to the negative environmental and health implications associated with the informal recycling of metals, it is now if paramount importance to expand the formal recycling of heavy metals in a city like Accra where large amount of electronic waste and metals are deposited on dumpsites.

2.10 Short-lived climate pollutant associated with waste recycling

Studies conducted by (Gamaralalage et al., 2018) revealed that waste recycling and material recovery could help in avoiding climate pollutants emissions. According to the authors, recycling has a net saving of 0.017 kg per tonne and thus would considerably contribute to the reductions of black carbon emission through the recovery of materials. This is in agreement with studies conducted by (Friedrich & Trois, 2011), whose findings showed that highest SLCPs are achieved through recycling. According to Friedrich (2013), emission factors savings per tonne of recyclables ranged from -290 kg CO₂ e (glass) to -19111kg CO₂ e (metal -Al). A review conducted by (Friedrich & Trois, 2011) that sought to compare greenhouse emissions from the various processes in waste management in Africa revealed that, at every stage pollutants are released. The results from their study also showed how recycling is important in reducing the amount of GHG emitted.

2.11 Composting

Composting is the breakdown of organic waste by bacteria. Composting is important since it enriches the soil when used for farming and it is also an environmentally friendly way of reducing waste. Waste segregation at source makes it easier for composting to be done. Studies conducted by (Fobil, Carboo, Attuquayefio, Rodrigues, & Sory, 2010) revealed that in Accra, about 90% of total waste generated is made up of compostable materials. The Accra Composting and Recycling Plant is a large scale plant that receives approximately 600 tons of municipal solid waste per day. The recently built IRECOP also has the capacity to process about 200 metric tonnes of waste. These plants are owned and operated by a private company through a public-private partnership with the city. Since majority of the waste generated in Accra are mostly organic, composting will help in reducing the quantity of waste disposed of. The lack of skilled personnel in managing composting facilities is a challenge (Fobil et al., 2008).

2.12 Short-lived climate pollutants associated with composting

Studies conducted by Gamaralalage et al., (2018) revealed black carbon emission from composting is very minimal. This is because composting does not consume significant amounts of fossil fuel.

2.13 Waste disposal

Disposal of waste in most parts of the world poses serious risk to people's life and the environment (Reyna-bensusan et al., 2018). In most low income countries, the problem of waste management is exacerbated by the unsustainable practices of open burning and open dumping that increase the releases of toxic chemicals into the atmosphere, reducing air quality and spreading diseases (Ferronato, 2019). This situation is further worsened in slums due to overpopulation, lack of social amenities, poor housing water problems and air pollution. Additionally, smoke from burning debris close to residential areas and the smell of decomposing waste can be detrimental to the health of

people when they inhale the air (Ferronato, 2019). Open burning according to (Reyna-bensusan et al., 2018) is a significant source of air pollution. Recent reports from the United Nations have revealed that eliminating open burning and open dumping of waste could help in achieving the strategic objective in the sustainable development goal (Reyna-bensusan et al., 2018)

In the capital city of Cambodia, about 361,000 metric tons of municipal solid waste was openly dumped and burned in 2008 and this increased to 635,000 tons in 2015 (Seng, Fujiwara, & Spoann, 2018). In Thailand, approximately 60% of solid waste was burnt openly (Ferronato, 2019). In Abuja, Nigeria, four disposal sites located in the country were closed in 2005 due to poor management of the site, bad odors, air pollution and on site burning of waste (Aderoju, Dias, & Gonçaves, 2018). One of the major impacts of open dumping has to do with the seeping of leachate into surface and ground water bodies. In India, heavy metals that had leached in water bodies was found to pose serious illnesses on humans (Parameswari, Padmini, & Mudgal, 2015). Similar findings was seen in Thailand where high concentrations of heavy metals was found boreholes (Prechthai, Parkpian, & Visvanathan, 2007). Another important environment issue associated with open dumping is the emissions of SLCPs (Ferronato, 2019). Anaerobic degradation of organic waste on landfill and dumpsites releases methane gas which is a by-product of landfilling MSW. Open dumping results in the direct release of methane into the atmosphere that affects local climate (Ferronato, 2019).

Studies conducted by (Ferronato, 2019), has revealed open dumping and open burning to be the main ways of disposing of waste in most low and middle income countries. According to Douti et al. (2017) the final disposal of waste in Accra was the landfill sites. Accra currently has no landfill because of the lack of sites for its establishment as well as cost-prohibitive to build (Asomani-boateng, 2015). Waste burning releases lots of harmful chemicals into the atmosphere that results

in many illnesses. In some countries for instance in Mexico, waste burning at dumpsites as well as open burning by households have been banned since 2013 (Reyna-bensusan et al., 2018). In spite of this waste burning still occurs in some pockets of the city and some rural areas. According to studies conducted by Reyna-bensusan et al., (2018) waste burning occurred in 22% of urban areas, 37% of periurban areas and 92% of rural areas in Huejutla. The possible reason according to the author could be attributed to the recent introduction of waste collection services which most people are not used to since waste burning has been the accepted and familiar method of waste disposal (Reyna-bensusan et al., 2018).

In Ghana, landfills have been grouped into four categories; open dumps, improved dumps, High Density Aerobic (HDA) and sanitary landfills (EPA, 2002). Open dumps are unimproved, inappropriate dump sites and produce the highest level of methane, whereas improved dumps are usually fenced and produce less methane (Gamaralalage et al., 2018). For HDA landfills, waste is spread out widely over site, with extra leachate recirculation, whereas for sanitary landfill, there is daily cover, treatment and gas management. Currently, in Accra, there are no waste disposal sites. All of Accra disposal sites are closed. Waste collected in the city is transported to a landfill site in Tema, approximately 37 kilometers outside Accra. The landfill site in Tema was constructed in 2012 but started operating in 2013. The daily capacity of the facility is 500 metric tons. However due to urbanization and industrialization, the landfill receives about 1,500 to 2000 metric tons daily. With the increase in waste quantities due to population growth, urbanization and economic development, the need for the country to have properly designed and operated landfills cannot be overemphasized (Kusi et al., 2016). Also informal waste disposal sites in excavated mining sites or abandoned quarries have become a practice in the city. To tackle the challenge of lack of disposal sites and reduce the pressure on existing ones, city authorities signed a contract for the construction

of a new landfill site which as yet has not been designated and unbudgeted for. And the inclusion of a leachate and gas collection system remains unknown. The disposal stage of waste management is known to generate large amounts of methane as a result of biochemical reactions taking place. The process includes anaerobic digestion which takes place in three stages. The first stage is hydrolysis, where fermentative bacteria hydrolyze waste converting it into soluble molecules. Acid forming bacteria then convert these soluble molecules into organic acids. In the final stage, methanogenic bacteria convert the organic formed into methane and carbon dioxide. Methane is a greenhouse gas estimated to be 86 times more potent in warming the earth than CO₂ over a 20-year period (*Strategy on Short-Lived Climate Pollutants*, 2017) and thus it is important for disposal sites to be identified as primary targets for GHG mitigation (Gamaralalage et al., 2018). Disposal sites with large organic waste, produce large amounts of methane gas which can be harnessed to generate electricity for industrial and domestic use. This technology is already in use in the developed world and has also been initiated in South Africa (Climate and Clean Air Coalition, 2006). Measures have to be put in place to manage organic waste. In addition, waste prevention, reuse and recycling activities could help reduce emission of methane from landfills. This will go a long way to lower the warming effects in the atmosphere while serving as one of the alternative sources of energy for Ghanaians.

2.14 Short-lived climate pollutant associated with waste disposal

Open dumps and landfills are direct sources of short-lived climate pollutants (Ferronato, 2019). Studies conducted by Ñ & Ulloa (2006) indicates that as organic waste degrades, it generates about 200Nm³ of methane per metric tons of dry biomass. By comparing the types of disposal sites (open dump, conventional landfills with energy recovery, conventional landfills of mixed waste and landfills receiving low amount of organic waste), Manfredi, Tonini, & Christensen (2009) found

that, open dumps generated the highest amount of emissions ($1000\text{kg CO}_2\text{-eq. t}^{-1}$) which had a global warming potential (GWP) about 50 times higher than emissions from other sources in the SWM sector. The second highest emission was from conventional landfilling of mixed waste ($300\text{kg CO}_2\text{-eq. t}^{-1}$) and then landfills receiving low amount of organic waste ($70\text{kg CO}_2\text{-eq. t}^{-1}$) of landfilling. The least emissions which was about $16\text{ kg CO}_2\text{-eq. t}^{-1}$ was obtained from landfills with energy recovery. According to Gamaralalage *et al.* (2018) open burning generates the highest amount black carbon emission which is 0.33 kg per tonne of waste generated.

Studies conducted in the municipality of Huejutla, Mexico revealed that about 24% of the total waste generated by households was burnt, thus emitting black carbon into the atmosphere (Reynabensusan *et al.*, 2018). It was estimated that 8882 tons of waste burned per year released 1.97 kg BC t^{-1} ($38,553\text{ t CO}_2\text{-eq}$ per year) of methane gas into the atmosphere. The results also showed this $\text{CO}_2\text{ eq}$ produced from open burning of waste ($38,553\text{ t CO}_2\text{-eq}$ per year) was more than 15 times larger than methane emissions from landfills ($1000\text{kg CO}_2\text{-eq. t}^{-1}$).

In India, methane emission in the past years rose from 263,020 in 1980 to 502,460 in 1999 (Kumar, Gaikwad, Shekdar, Kshirsagar, & Singh, 2004). Studies have indicated that most of the waste generated in India are disposed of in the open.

Municipal waste disposal in developing countries is heavily dependent on landfills (Friedrich & Trois, 2011). According to Bogner *et al.*, (2008), landfill disposal is the cheapest waste management option but with the largest SLCPs emissions. Friedrich & Trois (2011), also found that the highest emissions of GHG are from dumpsites and landfills and this is likely to increase significantly. According to Vij (2012), 14 out of 22 cities in India which translates to 63.6% supply approximately 80% of their waste to dumpsites. According to the same author, major generators of waste like Greater Mumbai, Delhi and Kanpur do not have sanitary landfill sites.

The United States of America is the world's largest landfiller followed by China (Themelis, 2008). The USEPA has made possible efforts to collect much of the landfill gas (LFG). In the year 2006, out of the 11.8 million metric tons of methane generated, 6.0 million metric tons was reported to have been captured. Energy recovery from sanitary landfills results in black carbon mitigation of 0.018 kg per tonne of waste generated.

2.15 Short-lived climate pollutants and health

Waste management sector contributes significantly to the emission of SLCPs (UNECA, 2011, Singh, 2018) like methane and black carbon. These pollutants in the atmosphere increase the global temperatures leading to climate change. Climate change has important consequences for human health as well as negative impacts on environmental health and the globe (Singh, 2018). Although climate change is perceived as a far-off problem, its effects on human health are immediate and hence cannot be overlooked. Studies conducted by Reyna-bensusan *et al.* (2018) revealed a greater incidence of respiratory disease in people living in rural areas as a result of open burning of waste. The warming of the atmosphere has resulted in the emergence and reemergence of infectious diseases of public health importance like Ebola, dengue and plaques (Gomes & Phillips, 2013). Scientists have reported high morbidity and mortality during climate events in the Caribbean (Gomes & Phillips, 2013), however it becomes very difficult to estimate the number of people who are likely to be affected by climate change-caused morbidity or mortality in developing countries, especially in Africa. According to UNECA (2011), African countries are most vulnerable to climate change and are therefore likely to suffer from the health consequences linked with climate change. This vulnerability may be associated with poverty and weak institutions (UNECA, 2011). Recent studies in India has revealed that India is currently experiencing the negative effects of climate change (Burney & Ramanathan, 2014). Emissions of black carbon and ozone have increased

significantly in India, resulting in low productivity in 2010 (Burney & Ramanathan, 2014). The negative effects of climate change on human health is both direct and indirect. The direct impacts includes physical injuries, morbidity and mortality caused as a result of flooding, drought and thermal stress (UNECA, 2011). Whereas the indirect effects includes malnutrition, neglected tropical diseases, diarrhea, malaria, and meningitis (UNECA, 2011). According to Gomes & Phillips (2013), extreme heat, natural disasters, infections and diseases are the three climatic dimensions impacting on human health.

Extreme weather events may lead to drought, flooding and thermal stress. The impacts of these events may be greatest in the most vulnerable regions who are not able to defend themselves leading to high number of people dying (UNECA, 2011). The effects on individuals is aggravated by the destruction of properties, damages to infrastructure and health systems. Most people are being forced to migrate worldwide due to rising sea levels, food insecurity and drought. Climate change may result in humans being exposed to ultra violet radiations (UVR). UVR are essential to the human body only in small amount. However excessive exposure to UVR may result in skin cancers, cataract and other eye diseases. Cataract has been estimated to cause about 51% of blindness in 2010 (Pascolini & Mariotti, 2010). The main causes of cataract is age, smoking and UV exposure. Climate change increases the levels of UV radiation in the atmosphere, therefore increasing the risk of cataract. According to IPCC, UVR exposure is responsible for 60,000 premature deaths and 1.5 million disability from skin, eye, and cardiovascular diseases (Confalonieri et al., 2007).

Increasing temperature due to climate change may lead to heat stress which occurs when one is exposed to extreme heat and becomes difficult for the body to get rid of excess heat. Heat stress leads to high body temperature, increase in heart rate, loss of concentration, heat rashes, muscle cramps, fainting, severe thirst or heat stroke. Heat stress may lead to death if the person is not cooled

quickly. Malnutrition is a major cause of death especially in Africa (UNECA, 2011). Recently, studies have revealed that malnutrition causes 1.7 million deaths per year in Africa and therefore considered the largest contributor to death due to climate change around the world. Climate change increases temperature and drought which affects crop production causing food insecurity especially in developing countries. This has resulted in economic problems and led to many negative consequences for families and communities who rely on farming for their daily living. Diarrheal diseases are second only to acute respiratory infections as a cause of climate change.

Climate change alters the distribution of water worldwide (IPCC, 2007) by increasing water scarcity. Rapid urbanization and increase population growth pose challenges for water supply systems. According to the WHO, half of the world's population will be living in water stressed areas by 2025. And this is likely to affect those in developing countries who depend on surface waters. Most people living in poor rural communities and slums have less access to safe drinking water. Everyone has the right to clean, readily available, and continuous water supply. This is also important for public health. Sustainable development goal 6 calls for universal access to clean water.

2.16 Emission quantification tools

SWEET

SWEET is an excel-based tool that assists users to quantify emissions of methane, black carbon, carbon dioxide, PM_{2.5}, NO_x, PM₁₀, and others. It uses information from EPA studies and guidelines, peer reviewed studies, and other credible sources. Emissions calculations are based on established and accepted methods, including Intergovernmental Panel on Climate Change (IPCC) guidelines and tools developed by the EPA and the global methane initiative. In 2012, the Climate and Clean Air Alliance (CCAC) in collaboration with six other countries including Ghana, along

with the United Nations Environment Program (UNEP) created SWEET with the aim to reduce the emission of SLCPs in the atmosphere and improve public health. The Solid Waste Emissions Estimation Tool (SWEET), was developed by Abt Associates and SCS Engineers on behalf of the U.S. Environmental Protection Agency (EPA) and the Climate and Clean Air Coalition (CCAC).

LEAP-IBC

Long-range Energy Alternatives Planning (LEAP) – Integrated Benefits Calculator (IBC) was developed by the Stockholm Environment Institute in collaboration with US EPA and Daven Henze with the support of the Climate and Clean Air Coalition (CCAC). LEAP-IBC is a software and modelling tool used in the estimation of climate pollutants and impacts, premature mortality, crop yield impacts, tracking of energy production and consumption and the analysis of energy policy

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study area was the Accra metropolis (Figure 2). Accra metropolis was chosen because of copious amount of waste generated due to the rapid urbanization and population growth in the city; as well as the lack of access routes for waste collectors which hindered effective waste management practices in some parts of Accra.

The growth rate of Accra is more than 3% which is higher than the growth rate of other cities in Africa. Residents living in Accra produce large amount of waste every day which exerts pressure on SWM system in Accra. Accra alone generates nearly 900,000 metric tonnes of solid waste yearly and approximately 3,000 metric tons of waste per day with a waste generation rate of about 0.5kg/person/day (Climate and Clean Air Coalition, 2006).

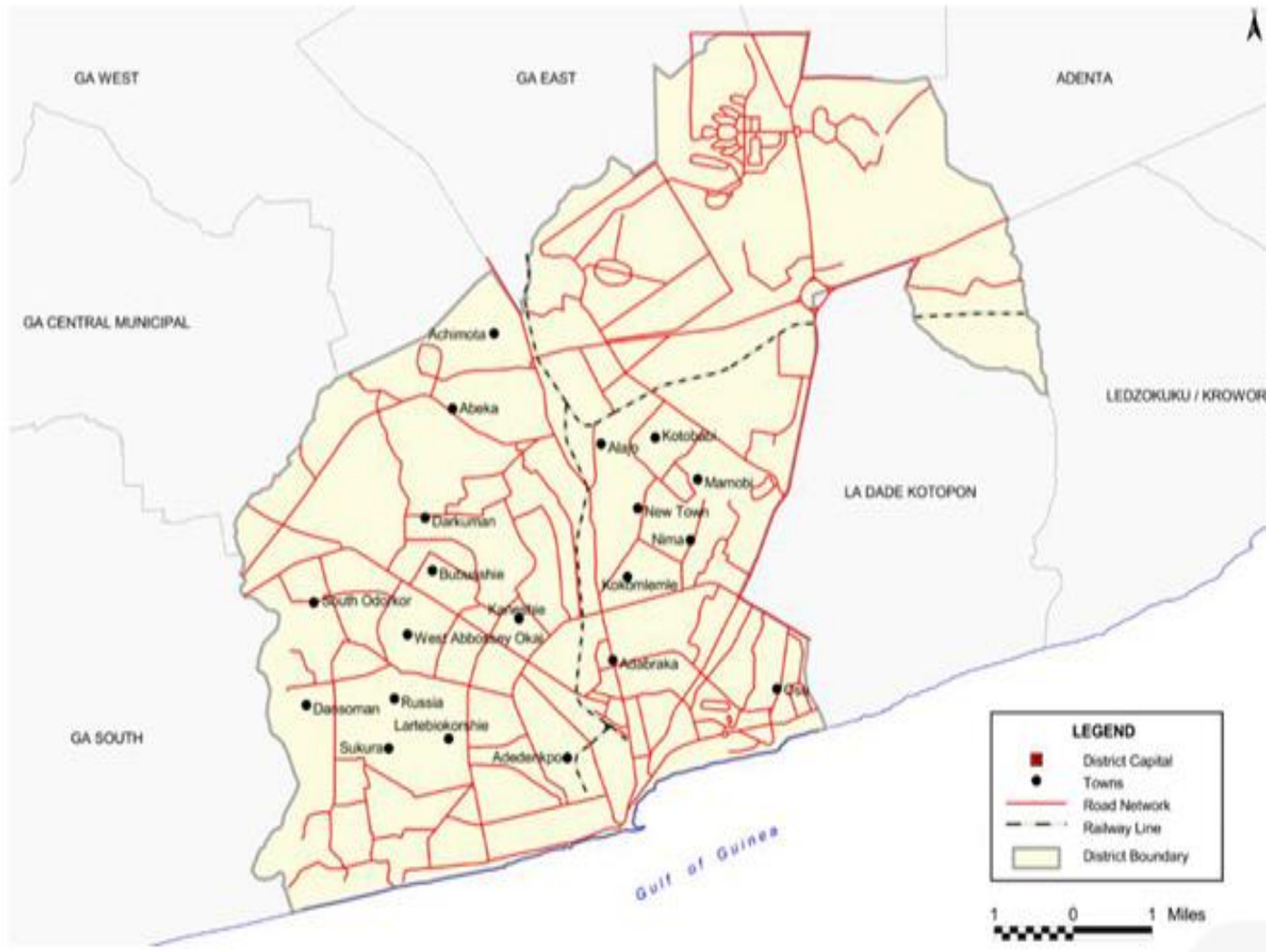


Figure 2: Map of Accra

Source (Ghana Statistical Service, 2014)

3.2 Study design

This was an analytical study which made use of routinely generated planning and administrative data as well as published data obtained from solid waste management sector to estimate SLCPs associated with management activities.

3.3 Data source/ collection

Baseline information was collected from local and national institutions. Relevant waste management data were obtained from institutions such as the Accra compost and recycling plant (ACARP) in Medie, AMA, Nsumia landfill and Tema landfill. Some data were also obtained from Zoomlion Company limited in Accra, J. Stanley Owusu and Co Limited, Metropolitan Waste and Allied Services, Meskworld Co Limited, Tropical Waste Limited and Jekora Ventures Limited. Other data on waste management processes were also retrieved from published sources (journals, extant literature, research reports, census reports, national surveys, statistical statements, annual reports, reports of local government department), as well as through interviews, site visits and direct observations. Keywords such as climate change, short lived climate pollutants and municipal solid waste management were used in addition to finding valuable data on the topic.

3.4 Data Entry

Data obtained from local institutions, national institutions and from published and unpublished works were consolidated and entered into the sweet tool. The SWEET tool required data inputs for all the waste management processes (ie. from collection to disposal) including any form of diversions. The tool also allowed for the creation of alternative scenarios.

3.5 Data Analyses

Data were analyzed by developing scenarios for urban waste management (UWM) for Accra, informed by existing sector policy-change implementation. Four alternate scenarios were created and these included “stop open burning”, “expand recycling”, “expand composting” and “capture landfill gas”. The analyses were done using the Emission Quantification Tool (EQT). Scenarios developed were modeled in accordance with UWM related policy interventions, after which the impacts of UWM on air quality were estimated (considering pollutants available in the

tools, e.g., PM2.5, CO2, BC) as well as on other co-benefits (e.g. burns, occupational accidents). The strength in this method lay in the careful review of previous researches and analysis of waste management sector in Ghana..

Underlying SWEET Equation for Landfill Methane Generation (EPA, 2005)

$$Q_{CH_4} = \sum_{t=1}^n K L_0 M_i (e^{k t i})(MCF)$$

Where: Q_{CH_4} = maximum expected methane generation flow rate (m^3/yr)

i = 1 year time increment

n = (year of the calculation) – (initial year of waste acceptance)

k = methane generation rate (1/yr)

L_0 = potential methane generation capacity (m^3/Mg)

M_i = mass of solid waste disposed in the i^{th} year (Mg)

t_i = age of the waste mass M_i disposed in the i^{th} year

MCF = methane correction factor

3.6 Study tool

The Solid Waste Emissions Estimation Tool (SWEET) tool

The SWEET tool was used in this study for estimating and quantifying SLCPs released during every waste management processes.

SWEET requires more detailed information for quantifying emissions. Some detailed information include waste generation and collection rates, waste flow to different diversion categories, waste characteristics for different diversion categories, and Landfill and dumpsite features. Emissions are

presented in terms of Metric tons of carbon dioxide equivalent. Estimates for each individual source are then presented in tables or graphs for the entire waste sector.

3.7 Quality Assurance

Data from different sources were validated and harmonized and entered in the SWEET tool. The error check box in SWEET gives an alert anytime data are wrongly entered, or data are missing and so this acts as a self-validation and quality checks/assurance. This ensures that all data points needed for the estimation of SLCPs emissions are correctly entered into the SWEET tool. When all data have been correctly entered, the cell will be 'grey' and say 'NO'. However when there are missing data or incorrect inputs, the alert box will show 'red' and say 'YES'. Terms and units of collection used at the time of data collection were carefully scrutinized to ensure the suitability of the data.

CHAPTER FOUR

RESULTS

In this analysis, 2018 was taken as the current base year and data gathered and inputted into SWEET had the resident population in and outside the formal collection zones to be 11,362,000 and 908,000 persons respectively. The city's average annual precipitation and mean annual temperature were also 809 (mm/year) and 26 °C respectively. In terms of waste collection characteristics, the per capita generation rates were 0.75 and 0.62 kg/person/day in- and out-side formal collection zones, with estimated historical and projected annual percentage collection growth rates to be 3.7% and 3.8% respectively. According to the data sources, the percentage generation rates in- and outside the formal collection zones were 67.5% and 32.5% with the proportions of total annual quantities collected and total annual quantities generated computed; based on per capita generation rate, collection rate and the city's population, to be 372,599 tons and 551,998 tons respectively in the formal collection zone.

According to last census data, the majority of households (59.4%) collect their solid waste while about 33.0% disposed theirs through public dumping (Ghana Statistical Service, 2014). Table 1 shows the levels of waste collection in some five low income communities in Accra as captured in the 2000 population and housing census.

Table 1: Waste collection in some suburbs of Accra

Neighborhoods	Percentage (%) of Collected Solid Waste
Nima	8.6
Sabon Zongo	15.1
Accra New Town	25.3
James Town	11.0
Chorkor	2.9

Source: Obeng-Odoom (2013)

The baseline waste stream composition was estimated to be 44.4% food waste, 18.8% green, 2.3% wood, 5.3% paper/cardboard, 2% textiles, 10.4% plastics, 3.1% metal, 2.8% glass, 2.1% tires and 9.3% being other items. Figure 3 shows overall waste sector SLCP emissions including CO₂, NO_x, BC, CH₄, and Organic Carbon in Accra at the given baseline.

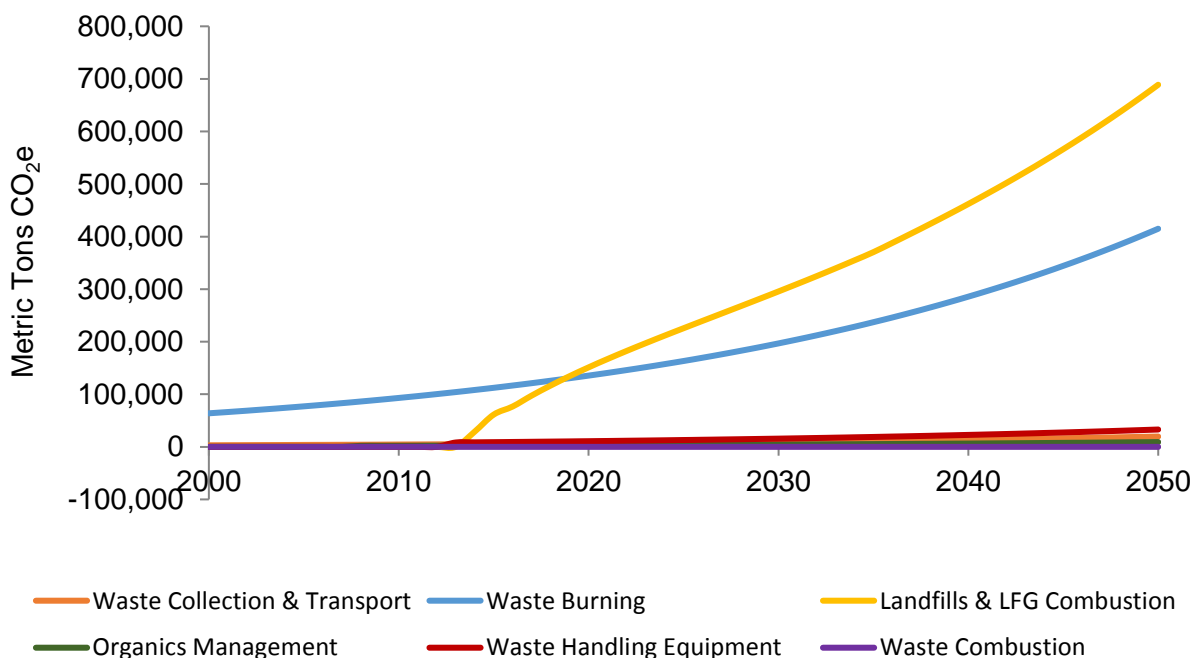


Fig. 3: Total Emissions by source including CO₂, NO_x, BC, CH₄, and Organic Carbon (at baseline)

The highest source of all climate forcing emission was from waste burning. Waste burning generated an emission of 125,792.50 metric tons CO₂ eq. This was followed by landfills and LFG combustion (116,646.92 metric tons CO₂ eq.). Waste handling equipment was the third highest source of emission (9,994.96 metric tons CO₂ eq.) which was followed by waste collection and transport (5,941.03 metric tons CO₂ eq.) and finally organic management (2,275.82 CO₂ eq.). From the results waste combustion/ waste incineration did not emit any climate forcing emission at all. By comparing all the climate forcing emissions released from various sources, it can be seen that there is a sharp rise in climate forcing emissions from two major sources, that is, waste burning and landfill & LFG combustion as indicated by the light blue and yellow lines respectively.

Figure 4 shows baseline black carbon emissions by Source in the waste management sector over time. From the graph, landfill and LFG combustion was found not to generate any black carbon emissions (yellow trend line). The highest black carbon emission was from waste burning (43,534.99 metric tons CO₂ eq.). Waste handling equipment was the second highest emitter of black carbon (4,756.53) followed by waste collection and transport (2,871.36). Black carbon emission was higher in waste burning compared to the other sources of SLCPs in the waste management sector.

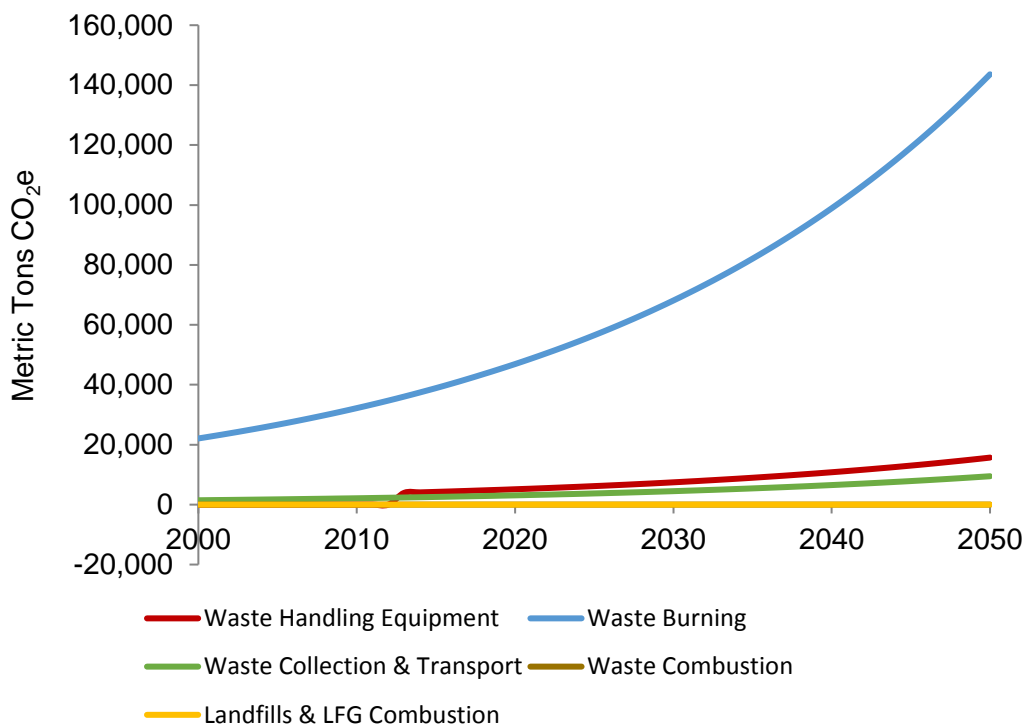


Figure 4: black carbon emissions by source over time (at baseline)

Figure 4, black carbon is expected to rise from about 40,000 CO₂eq in 2018 to about 150,000 CO₂eq by 2050. Black carbon emissions are seen to have risen sharply over time when waste is burned compared to the gradual rise in emissions in the other sources. There is also a wide gap between the black carbon emissions in waste burning compared to black carbon emissions from waste collection and waste transport, landfill and LF combustion, waste handling equipment, organic management and waste combustion.

Figure 5 below shows the output of methane gas under four alternate scenarios in which the municipal authorities decided to stop residents from burning uncollected solid wastes at home, capture landfill gas, expand composting and expand recycling by 2020. By expanding composting to receive 75% food wastes, 15% greens, 5% wood wastes and another 5% paper/cardboard, with

an additional capacity of recycling companies to recycle 25% paper/cardboard, 65% plastic wastes and 10% metals and scraps, it can be seen from the graph (Figure 5) how the alternate scenarios created helped in reducing methane. Using 2020 as the diversion scenario start year, it can be seen that by expanding recycling, methane emission will decrease from 161,653.39 metric tons CO₂ eq. to 144,360.94 metric tons CO₂ eq in 2020. Additionally, capturing landfill gas in the year 2020, will decrease methane emission from 161,653.39 metric tons CO₂ eq. to 148,088.05 metric tons CO₂ eq. Also by ending open burning, methane emission decreased from 161,653.39 metric tons CO₂ eq. to 154,496.71 metric tons CO₂ eq. On the contrary, expanding composting in 2020 (diversion scenario start year) resulted in a 4,941.6 metric tons CO₂ eq. increase in methane emission with the subsequent years showing great reductions in methane emissions.

From the graph (Figure 5), if landfill gas capture continues methane emissions from landfill will decrease to zero by 2040. Again, it is expected that, expanding recycling will decrease methane emission by half by 2040 as indicated by the yellow trend line.

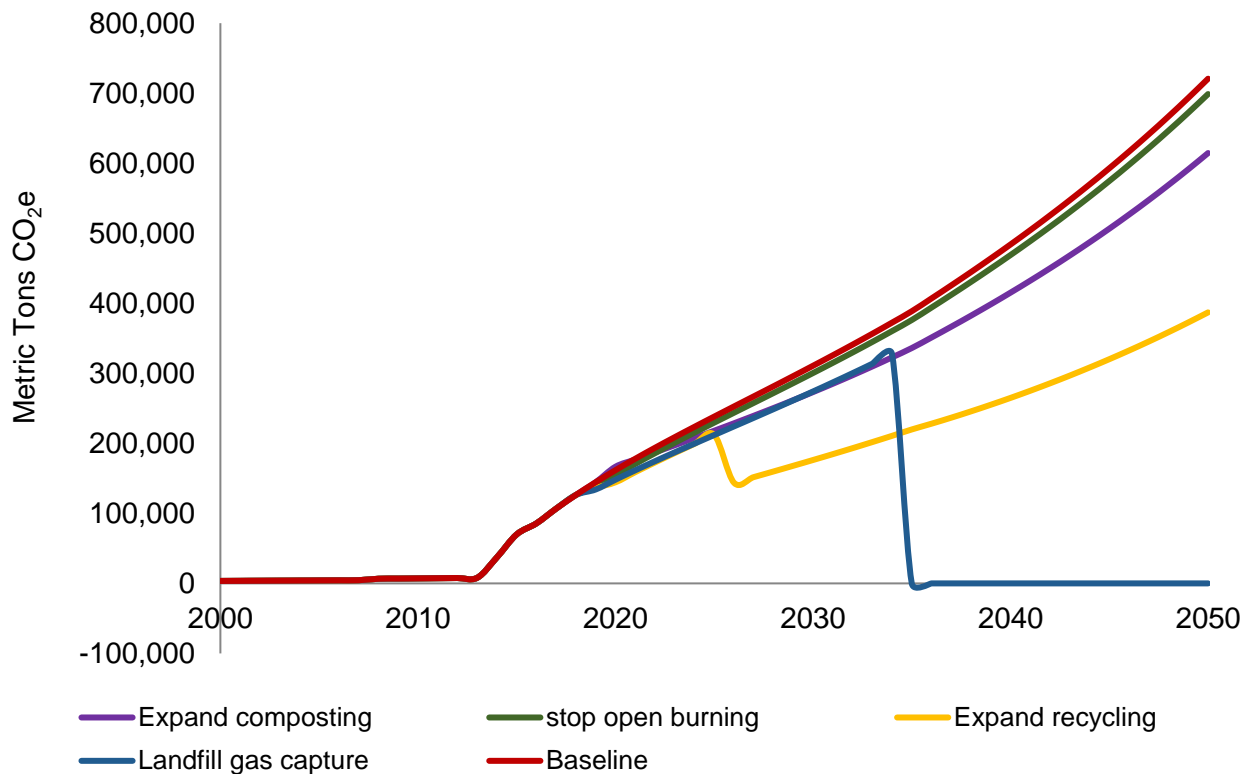


Figure 5: Alternative Scenario Comparison of Methane Emissions over Time

Figure 6 below shows alternative scenario comparison of black carbon emissions over time. From the graph, there was no black carbon emission from landfills since from the beginning of the diversion start year till 2050, black carbon emission remained zero. By ending open burning, black carbon emission reduced from 55,125.14 metric tons CO₂ eq. (baseline, 2020) to 9,009.14 metric tons CO₂ eq. However, by 2040, black carbon is expected to decrease from 116,224.25 metric tons CO₂ eq. (baseline, 2040) to 18,994.59 in 2040 if open burning is stopped. This translates to a 16% reduction in black carbon emission by ending open burning.

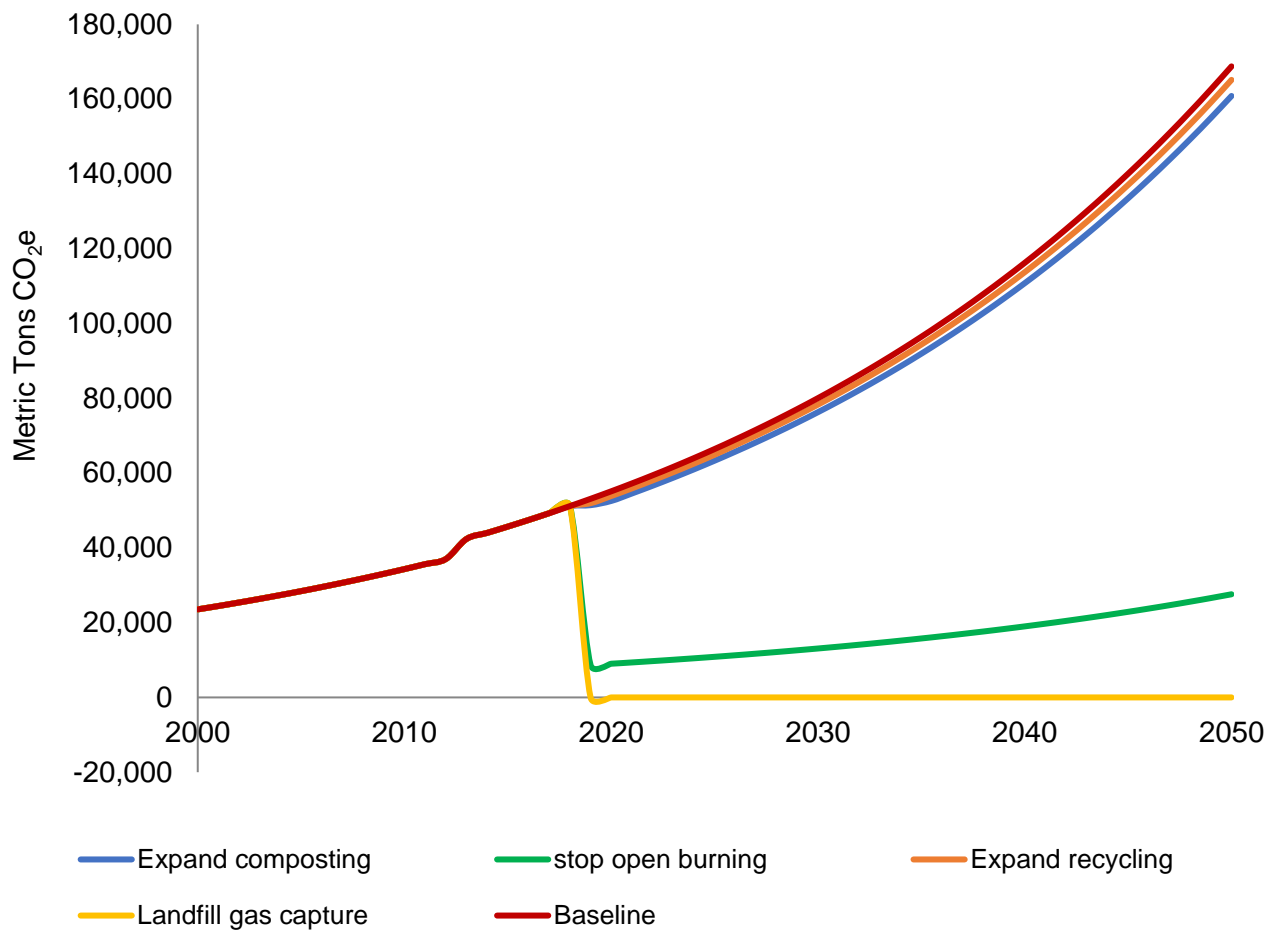


Figure 6: Alternative Scenario Comparison of Black Carbon Emissions over Time

A careful review of literature revealed that while waste generation rate in Accra had increased dramatically, majority of the disposal and recycling plants had broken down completely and many others had also deteriorated (Fobil et al., 2008). Available data from the AMA showed that Accra produces approximately 2,200 tonnes of municipal solid waste daily, and institutional projection based on per capita generation rate and population growth rate indicate that this is expected to reach 4,419 tons by 2030. Out of this total amount of waste to be generated, 65.8% of it will be of organic origin while 5.3% being paper and 10.4% plastic components (Udofia, Gulis, & Fobil, 2017; Fobil

et al., 2008; Miezah et al., 2015; Fobil, Kraemer, Meyer, & May, 2011). Table 2, shows household waste disposal practices in Ghana with disaggregated as per the national, regional and Accra (the national capital) situation.

Table 2: Method of household solid waste disposal

Method of waste disposal	Accra			
	Ghana	Region	Number	Percent
Collected	785,889	502,642	298,178	59.4
Burned by household	584,820	134,654	13,402	2.7
Public dump (container)	1,299,654	266,287	156,481	31.2
Public dump (open space)	2,061,403	87,379	23,647	4.7
Dumped indiscriminately	498,868	22,123	5,408	1.1
Buried by household	182,615	14,003	1,412	0.3
Other	53,805	9,282	3,375	0.7
Total	5,467,054	1,036,370	501,903	100.0

Source: Adapted from census data (Ghana Statistical Service, 2014: 58)

CHAPTER FIVE

DISCUSSION

Like all economic production systems, waste management from its generation through storage, transportation to its final disposal in recycling plants and/or in landfills is associated with externalities most of which manifest as health hazards particularly for those who are directly involved in disposal/recycling and/or those living near waste recycling/disposal sites (Wittsiepe *et al.*, 2015; Wittsiepe, Feldt, Burchard, Wilhelm, & Fobil, 2016; Feldt *et al.*, 2014). Waste management options, such as recycling, composting, sewage treatment, incineration and landfill, can have different health impacts. For example, several studies have specifically reported birth defects and reproductive disorders, cancer mortality and incidence associated with waste management processes (Wittsiepe *et al.*, 2015; Wittsiepe *et al.*, 2016; Feldt *et al.*, 2014).

The per capita generation rates in Accra (0.75 kg/person/day) is lower when compared to that in Mexico. In Mexico, out of the total amount of waste generated per day, an estimated rate of generation per capital included 0.80 kg day⁻¹ in urban area, 0.69 kg day⁻¹ in peri-urban areas and 0.43 kg day⁻¹. Miezah *et al.*, (2015) found that on average, the rate at which waste is generated in Ghana was 0.5 kg/person/day whereas in Accra alone, the rate at which waste is generated was found to be 0.74 kg/ person/ day. The total waste collected annually inside formal collection zones is a clear indication that, there is more that needs to be done to ensure effective waste collection. In Mexico for instance, approximately 84% of waste generated is collected (Reyna-bensusan *et al.*, 2018). However this is not the case in Accra. According to the Ghana statistical service, about 60% of solid waste generated by households in Accra is collected (Ghana Statistical Service, 2014).

There is increased awareness that waste management sector contributes significantly to the release of short-lived climate pollutants (SLCPs) and impact considerably on the quality of ambient air (Hoornweg & Bhada-Tata, 2012; Singh, 2018; Friedrich & Trois, 2011; Gentil & Christensen, 2009; Friedrich, 2013; Bogner, Pipatti, & Kjeldsen, 2015). As such, Emission Quantification Tools (EQTs); such as SWEET, are now being developed to support municipal authorities to conduct rapid assessment of greenhouse gases (GHGs) and SLCPs (Carbon dioxide [CO₂], Nitrous oxides [NO_x], Black carbon, Organic carbon, Methane [CH₄], Sulfur oxides [Sox], Two kinds of Particulate Matter [PM] – PM_{2.5} and PM₁₀), which are known to be associated with municipal solid waste management activities and now widely believed to be contributing to global warming in several regions across the globe (Hoornweg & Bhada-Tata, 2012; Singh, 2018; Friedrich & Trois, 2011; Gentil & Christensen, 2009; Friedrich, 2013; Bogner, Pipatti, & Kjeldsen, 2015). In 2012, the Climate and Clean Air Coalition (CCAC) was founded with the aim to initiate efforts to take collective action on SLCPs as an urgent challenge to sustainable development with commitment to deliver benefits at several sectors – viz; climate, public health, energy efficiency, and food security. To date, the CCAC remains a voluntary partnership of governments, intergovernmental organizations, businesses, scientific institutions and civil society organizations committed to improving air quality and protecting the climate through actions to reduce short-lived climate pollutants (SLCPs) at multiple fronts.

In the waste sector, the processes of waste management include collection, storage, transport, recycling, composting/bio-gas generation and final disposal through combustion/incineration and land-filling, which are all associated with the production of SLCPs as well as co-benefits such as improved sanitation and clean air quality. This means that waste management activities are as diverse as the SLCPs that are generated as by-products. For instance, whereas collection activities may only generate methane gas (CH₄), waste transport, recycling, composting/biogas generation

and final disposal in landfills as well as combustion/incineration release into the ambient environment; complex mixtures containing black carbon, CO₂, N₂O and CH₄. Specifically, while waste composting/bio-gas generation and recycling activities (machinery and waste decomposition) release black carbon, CO₂, N₂O and CH₄, waste transport and final disposal activities (open burning, waste decomposition and plant – electricity/fossil fuels generate black carbon, CH₄, CO₂, N₂O , Black carbon and CH₄ as by-products. Whereas SWM machinery (electricity/fossil fuels) are associated

It is obvious from the results that waste burning was the highest source of all climate forcing emissions (CH₄, BC, OC, NO_x, CO₂) in 2018. This could be attributed to the high amount of black carbon and carbon dioxide gas that is released into the atmosphere through the burning of solid waste. According to (Ferronato, 2019) waste burning increase the releases of toxic chemicals into the atmosphere and this could have accounted for it being the highest emitter of climate forcing emissions. The second highest source of all climate forcing emission was from landfills. This could be due to the high quantities of methane gas released from landfills due to the degradation of organic materials. According to Gamaralalage *et al.* (2018) the large amount of methane generated from landfills reveals the need for final disposal sites in the country to be a primary target for SLCPs interventions. Short-lived climate pollutants released waste handling equipment and waste collection and transport were the third and fourth highest source of all climate forcing emissions respectively. According to Friedrich (2013), there are many factors that determine the amount of SLCPs emissions emitted from waste transportation. These factors according to the same author include distance, population, type of waste, age of vehicle and maintenance. The author added by stating that, a poorly maintained vehicles emits more SLCPs than a properly maintained vehicle (Friedrich, 2013). Therefore distance covered by the waste vehicle in collecting and disposing of waste determines the amount of SCLPs emitted. Greenhouse gas savings in waste transportation

can thus be achieved by using efficient fuels and choosing the best routes (Nguyen and Wilson, 2010; Arribas *et al.*, 2010).

Apart from being the highest source of all climate emissions, waste burning is again the main contributor of black carbon in the atmosphere. Open burning has been identified as the main drivers of black carbon emission in the atmosphere (Gamaralalage *et al.*, 2018). Studies conducted by Reyna-bensusan *et al.* (2018) have revealed that burning waste generates large amount of black carbon.. This result is again in accordance with studies conducted in the Philippines by (Gamaralalage *et al.*, 2018) which recorded highest amount of black carbon emissions from open burning.

From the four alternate scenarios created, expanding recycling had the highest potential of reducing methane emissions over time. According to Gamaralalage *et al.* (2018), recycling helped in preventing SLCPs emissions through material recovery with a net saving of 0.017 kg per tonne of mixed recyclables. From the results of this study (figure 7), it is evident that landfill gas capture had the second highest potential in reducing methane in the atmosphere. In the Philippines, Gamaralalage *et al.* (2018) revealed that landfill gas recovery has a strong potential of decreasing the amount of methane generated on landfills. The results has also been confirmed by Friedrich & Trois (2011), who indicated that, there will be an increase in methane emission from landfills if landfill gas is not captured. Studies have shown that landfills and open dumps produce large amounts of methane (Ferronato, 2019). According to Bogner *et al.*, (2008), even though landfill disposal is the cheapest waste management option, it generates lots of SLCPs emissions. Municipal waste disposal in developing countries is heavily dependent on landfills (Friedrich & Trois, 2011). With the marked growth in population and waste generation in developing countries, there is the tendency for more waste to be sent to the landfills, thus the need to capture landfill gas. Studies

conducted by (Asomani-boateng, 2015) showed that in Ghana the “collect and dispose” approach is mostly practiced thus placing more emphasis on the final disposal of waste rather than seeing waste as a resource. According to Vij (2012), 14 out of 22 cities in India which translates to 63.6% supply approximately 80% of their waste to dumpsites. As more waste are being sent to the landfills, methane emissions would also increase with time. According to the Ghana statistical service, about 30% of waste generated in Ghana is either burnt, buried or thrown into open drains and gutters. From figure 7, it can be seen that black carbon emission is projected to decrease sharply if open burning ends. From figure 8 black carbon avoidance rate can be increased by ending open burning. Landfill capture has no effect on black carbon emission. Expanding composting and recycling as seen from the graph helped reduced black carbon emission. According to Gamaralalage *et al.* (2018), composting produces smaller amounts (<0.001 kg/tonne of waste) of black carbon. This is due to the fact that composting does not use significant amount of fossil fuel.

Solid waste sector is among the sectors targeted by the 11 initiatives for reduction of SLCPs (Hornweg & Bhada-Tata, 2012). Waste initiative has a specific focus to address methane, black carbon and other air pollutants emissions across the municipal solid waste sector by working with cities and national government. Solid waste sector activities are associated with the production of SLCPs. It is estimated that around 10-20% of global greenhouse gas emissions could as a consequence be reduced by waste management sector (Hornweg & Bhada-Tata, 2012).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATION

Waste management sector activities in Accra appear to contribute SLCPs emission loading into the ambient environment and with the current waste generation and deposition rates; the level of the city's waste management sector emissions forcing on local climate can be considerable. However, diversion of solid waste via composting and recycling is effective in lowering emission levels of some of the SLCPs. Additionally, ending open burning and capturing landfill gas was found to be effective in reducing climate forcing pollutants. All cities in Ghana therefore need to undertake a rapid assessment of these emissions and identify suitable alternative solutions in order to develop climate friendly waste management system for the country. To do this effectively, all major cities (i.e., the regional capitals) need to collect MSW data, conduct work plans to identify the appropriate opportunities for managing waste sustainably and obtain technical as well as financial analysis supporting SLCPs mitigation projects. Another important consideration that needs to happen in order to strengthen SWM sector is to build capacity through workshops, webinars, and access to online resources, such as free expert advisory services as well as city partnerships with and participation in allied activities within international waste networks. The impact of SWM on SLCPs needs to be estimated through Emissions Quantification Tool with additional piloting of direct policy support to local government authorities. Finally, it will be an effective strategy to bring the leadership of the Mayor including top-officials to be part of city initiatives on SLCPs in a consultative and participatory process involving all other key stakeholders.

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APPENDICES

Appendix A- Introductory letters



UNIVERSITY OF GHANA
DEPARTMENT OF BIOLOGICAL, ENVIRONMENTAL
AND OCCUPATIONAL HEALTH
SCHOOL OF PUBLIC HEALTH

Ref. No.:

April 11, 2019

**The Head
Waste Management
Accra Metropolitan Assembly
P.O. Box GP 385
Accra Central**

Dear Sir/Madam,

LETTER OF INTRODUCTION- BETTY AKUA NARTEY (10488304)

I am pleased to introduce to you the above-named Master of Public Health student in the Department of Biological, Environmental and Occupational Health Sciences in the School of Public Health, University of Ghana, Legon.

As part of the requirement for the award of Master of Public Health Degree , She is conducting a research on **"A study of Short-lived Climate Pollutants Associated with Solid Waste Management Activities in Accra"**

The general objective of this study is to assess the contribution of solid waste management activities to local climate change through emission of short-lived pollutants.

It is my hope that you will give her the necessary assistance to enable her carry out the research work.

I count on your support and assistance.

Yours faithfully,


Prof. Julius Fobil
(Head of Department)

Cc: The Operations Manager
Universal plastic products and recycling Ltd., Tema
Jekora Ventures Ltd., Accra
Zoomlion Ghana Ltd., Madina

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UNIVERSITY OF GHANA
DEPARTMENT OF BIOLOGICAL, ENVIRONMENTAL
AND OCCUPATIONAL HEALTH
SCHOOL OF PUBLIC HEALTH

Ref. No.:

May 31, 2019

The Operations Manager
J. Stanley Owusu Company Ltd
P. O. Box 3751, Accra

Dear Sir/Madam,

LETTER OF INTRODUCTION- BETTY AKUA NARTEY (10488304)

I am pleased to introduce to you the above-named Master of Public Health student in the Department of Biological, Environmental and Occupational Health Sciences in the School of Public Health, University of Ghana, Legon.

As part of the requirement for the award of Master of Public Health Degree , She is conducting a research on **"A study of Short-lived Climate Pollutants Associated with Solid Waste Management Activities in Accra"**

The general objective of this study is to assess the contribution of solid waste management activities to local climate change through emission of short-lived pollutants.

I would be grateful if you could provide her with information on the amount of waste received from Accra in 2018 and also specific areas in Accra where these waste are coming from. It is my hope that you will give her the necessary assistance to enable her carry out the research work.

I count on your support and assistance.

Yours faithfully,

Prof. Julius Fobil
(Head of Department)

COLLEGE OF HEALTH SCIENCES

• Telephone: +233 (0) 289 109 002 P. O. Box LG 13, Legon, Accra, Ghana. • Website: www.publichealth.ug.edu.gh
• Email: sph-beohs@ug.edu.gh

Cc:

The Operations Manager
Meskworld Co. Ltd
P. O. Box 8368

Metropolitan Waste and Allied Services

Tropical Waste Ltd

Nsumia Waste Disposal site



UNIVERSITY OF GHANA
DEPARTMENT OF BIOLOGICAL, ENVIRONMENTAL
AND OCCUPATIONAL HEALTH
SCHOOL OF PUBLIC HEALTH

Ref. No.:

April 17, 2019

**The Head of Department
Waste Management
Tema Metropolitan Assembly
P.O. Box 301
Tema**

Dear Sir/Madam,

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Appendix B- SWEET data inputs

Solid Waste Emissions Estimation Tool (SWEET) Version 2 - Data Inputs

Current State	Value (Metric tons)	References
Composting	Amount of waste composted in Accra 2018	
	Composition of Waste Diverted from Disposal to Composting (%)	Food Waste Green Wood Paper/Cardboard
Recycling	Amount of waste recycled in Accra 2018	
	Composition of Waste Diverted from Disposal to Recycling (%)	Wood Paper/Cardboard Textiles Plastic Metal Glass Tires Other

Collection – Transportation

Variable	Value	Reference
Number of heavy-duty diesel trucks in operation each year		
Number of heavy-duty gasoline trucks in operation each year		
Number of light-duty diesel trucks in operation each year		
Number of light-duty gasoline trucks in operation each year		
If Data Is Available (Optional Data)		
Kilometers traveled by typical heavy-duty truck per year		
Kilometers traveled by typical light-duty truck per year		
Hours spent idling for typical heavy-duty truck per year		
Hours spent idling for typical light-duty truck per year		

Waste Handling Equipment

	# Of Pieces Of Equipment	# Of Hours In Use Per Year (If Known)	Average Horsepower Rating (If Known)	Annual Fuel Usage (Gallons) (If Known)	Reference
Diesel					
Excavators					
Graders					
Forklifts					
Loaders					
Bulldozers					
Tractors/ backhoes					
Other					
Gasoline					
Excavators					
Forklifts					
Loaders					
Tractors/ backhoes					
Other					

Waste Burning

Variable	Value	Reference
If Data Is Available (Optional Data)		
Percentage of uncollected waste that is burned in the open by residents living outside formal collection zones.		
Percentage of uncollected waste that is burned in the open by residents living inside formal collection zones.		
Percentage of waste disposed at landfills or dumpsites that is ultimately burned at the landfill or dumpsite .		
Amount of waste received from landfill in 2018		
How deep is the waste in the landfill		