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Aron Asgedom

ENERGY RECOVERY POSSIBILITIES FROM MUNICIPAL SOLID WASTE IN ADDIS ABABA, ETHIOPIA

Examiners:

Professor Mika Horttanainen
Jouni Havukainen (PhD)

ABSTRACT

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Energy Recovery Possibilities from Municipal Solid Waste in Addis Ababa, Ethiopia
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Jouni Havukainen (PhD)

Key words: Solid waste, Municipal solid waste, Energy recovery, Refuse derived fuel, Anaerobic digestion, Landfill gas, Biogas, Incineration, Biological and mechanical treatment, Waste characterization.

This Thesis analyses the challenges on MSW management faced by the Addis Ababa city and forwards possible recommendations. The population of Addis Ababa is increasing from time to time and the city is showing impressive economic growth trends as well. With this population increase and economic growth, the municipal solid waste of the city is highly increasing. The way municipal solid waste of Addis Ababa currently managed is becoming challenging with a big landfill laid in 33 hectares of land for the last fifty years. The disposal system is rough and exposed which hauls the trashes using vehicle, spreads and levels using bulldozers and compacts using compressor. The Reppi (Koshe) dumping area is on full, enclosed by residential zones, nuisance and health risk for people proximate, has no fence and in general poor municipal solid waste management system. This challenge in turn prompts to look for different alternatives to manage the MSW with consideration to the environment. One of the alternatives to manage this waste is to look for energy recovery possibilities from municipal solid waste in Addis Ababa.

With the objective of solving this challenge of municipal solid waste management, relevant literature is reviewed, and three different scenarios are made for future situation which estimates the potential of energy (electricity) recovery to reduce the quantity of MSW in Addis Ababa. Scenario 1 analysed “Biological and Mechanical Treatment (BMT) of MSW” which is a combination of refuse derived fuel (RDF) and anaerobic digestion (AD) with potential of 11.76 MW and 9.80MW electricity respectively. Scenario 2 “Mass incineration in grate fired furnace” produced a potential energy of 37.41 MW electricity. Scenario 3 “Landfill gas production from MSW” produced an estimated energy potential of 1.12 MW electricity.

As a result of the evaluation and analysis of these scenarios, mass incineration in grate fired furnace (scenario 2) offered the highest potential energy of 37.41 MW electricity of the three scenarios. Mechanical and biological (MBT), scenario 2, which is a combination of refuse derived fuel (RDF) and anaerobic digestion (AD) has the second highest potential energy of 21.56 MW of electricity of the three scenarios for the city. Finally, Landfill gas production from MSW (scenario 3) has the least (1.12 MW) potential energy of the three scenarios. Therefore, considering the result of the scenarios and the literature review, the study has recommended scenario 2 and scenario 1 in their order for implementation for the Addis Ababa city to solve the challenges of municipal solid waste.

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LIST OF ABBREVIATIONS

AD	Anaerobic digestion
AU	African union
DH	district heating
DOC	Amount of organic carbon in waste
DOC_F	Share of degrading organic carbon
F	Share of methane in landfill gas
GDP	gross domestic product
GHG	Greenhouse gas
IPCC	Intergovernmental panel on climate change
ISMW	Integrated solid waste management
LFG	Landfill gas
LHV	lower heating value
MBT	Mechanical biological treatment
MCF	Methane correction factor
MSW	Municipal solid waste

MSW_F	Share of waste disposed to the land fill
MSW_T	Total amount of MSW
MW	Mega watt
MWh	Megawatt hour
NCV	Net calorific value
NIR	Near infra-red
OECD	The organization for economic Cooperation and development
OX	Oxidation degree
PtH	Power to heat ratio
R	Amount of recovered methane
RDF	Refused derived fuel
SRF	Solid recovered fuel
tAPL	Annual peak load
VOC	Volatile organic compound
WDF	Waste derived fuel
WtE	Waste to energy

1 INTRODUCTION

Waste to energy recovery is the transformation of degradable and not biodegradable waste resources to serviceable heat, electricity, or fuel by different methods, comprising combustion, gasification, pyrolysis, anaerobic digestion and landfill gas recovery. Population growth, urbanization and economic progress are likely to yield growing amounts of waste overloading present waste managing schemes (Rajasekhar et al, 2015).

The production of worldwide solid waste is projected to increase with world´ s population growth and urbanization. For example, in 1900 the global annual generation of solid waste was estimated 110 million tons and 1.1 billion tons in 2000, which is tenfold. The worldwide municipal solid waste production is projected at almost 1.3 billion tonnes annually, and anticipated to grow to about 2.2 billion tonnes annually in 2025. The global population raised to 7 billion in 2010 from 3.1 billion in 1960 and estimated to be 8 billion in 2025. Global urban population likewise grew to 1.5 billion by 2010 from 1 billion in 1960 and is estimated to be 4.5 billion in 2025. A substantial rise of waste production proportions per person is likewise estimated from the present 1.2 kg per person daily to 1.42 kg per person daily by 2025 (Scarlat et al., 2015).

The population in Africa similarly faced rapid increment, to 1.0 billion in 2010 from 294 million in 1960. The metropolitan inhabitants increased to 409 million in 2010 from 56 million in 1960 and estimated to be 672 million by 2025. In 2010, above 42% inhabitants of African urban inhabitants were in urban areas, growing to 47% in 2025 from 20% in 1960. In line with the increment of inhabitants, urbanization and advanced standard of living, the amount of waste are anticipated to rise, which creates further difficulties to waste managing schemes and the environment (Scarlat et al., 2015).

The population of Ethiopia is growing at a rapid pace. In 2000, the population was 63.5 million; the current population is more than 100 million, second largest in African countries and by 2025 projected to be more than 125 million. Addis Ababa is the biggest metropolitan in Ethiopia having population of more than 3 million. Addis Ababa is the capital of Ethiopia, the African Union, place of more than 120 countries` diplomatic residences. It holds almost 20% of the Ethiopian urban population (Worldmeters.info, 2016).

The Population of Addis Ababa is increasing from time to time and showing impressive economic growth trend. With this population increase and economic growth, the municipal solid waste is highly increasing. The way municipal solid waste of Addis Ababa currently managed is becoming challenging, with a big landfill laid in 33 hectares of land for the last five decades (Regassa et al., 2011).

This challenge of waste management system in turn prompts to look for different alternatives how to manage and utilize waste with consideration to the environment. One of the alternatives to manage and utilize waste is energy recovery possibilities from municipal solid waste in Addis Ababa, which is the topic of this paper. Therefore, this makes important that the Addis Ababa city municipal solid waste has to be managed effectively with possibility for energy recovery.

In 2014/15 Ethiopia´s total electricity, generating capacity was 4 180 MW (3 722 MW from hydro, 434 from diesel, and 24 from geothermal) with an average performance of 42% of all power projects and coverage of 2.31 million customers. Ethiopia has planned to generate from hydropower 13,817MW, wind power 1224MW, solar power 300MW, geothermal power 577MW, reserve fuel (gas turbine) 509MW, wastes 50MW, sugar 474MW, and biomass 257MW. Currently there is no power generated from waste and industry that uses power from waste but with a waste to energy plant in establishment process to produce 50MW from wastes (GTP II) of 2015/16-2019/20 (National Planning Commission of FDRE, 2016). In Ethiopia Power generated from any source, goes directly to the national grid, so no direct benefit for the city of Addis Ababa. The utmost significant unit in energy balance of Ethiopia is the whole consumption of 5.23 billion kWh annually with per capita of 53 kWh (WorldData.info, 2016).

1.1 Objective of the Study

This study is with the objective to evaluate possibility of energy recovery from waste in Addis Ababa, Ethiopia. This also contributes to the management of waste which is currently the challenge of the city. The study assesses the options of energy recovery to contribute to the sources and diversification of energy. The specific objectives of the study are:-

- Estimating the potential of energy production using MSW as source of energy;

- Comparing different possibilities of waste to energy from energy production point of view using different scenarios;
- Forward recommendation from the different possibilities of waste to energy scenarios.

Therefore, managing effectively the Addis Ababa city municipal solid waste (MSW) with possibility for energy recovery and consideration to the environment is the focus of this thesis.

1.2 Methodology of the study

Waste to energy from municipal solid waste in Addis Ababa, Ethiopia, is focus of this study. The method of data collection was in a systematic way through primary and secondary means. These methods were used to ensure that the best and right facts and figures are obtained. The research objectives of the study were met through the collection of secondary data and literature review. Relevant literature was identified, reviewed and incorporated in the study. Different waste to energy techniques was reviewed. Primary data through field visits, direct observation, and discussions with relevant authorities was used to further enhance the understanding and verify the quality of information gathered. Furthermore, review of published materials, reports, and applicable policies were undertaken in the process of the study.

The collected data was analyzed and evaluated using three different scenarios which helps the study to indicate the potential energy output in each scenario. Different equations were used to calculate and arrive at the potential outputs in the three scenarios. The three scenarios which were used to assess potential energy output in the study were Mechanical and biological treatment (MBT) (scenario 1) which is a combination of refuse derived fuel (RDF) and anaerobic digestion (AD), Mass incineration in grate fired furnace (scenario 2), and Landfill gas production from MSW (scenario 3).

These three scenarios basically enabled the study to offer the output of the potential energy for the Addis Ababa city. As a result, the study could forward conclusion and recommendations which helps to implement the waste to energy scenarios in the Addis Ababa city and improve waste management treatment.

1.3 Limitation of the study

The exclusion of detailed material recovery, flare gas treatment, air pollution control and ash handling is the limitation of this study.

2 QUALITATIVE AND QUANTITATIVE INFORMATION OF WASTE

2.1 Waste

2008/98 EC directive of EU on waste framework has set concept and definition associated with management of waste, for example, recovery and recycling of waste. In addition, the EU directive has formulated guideline on waste that shows at what time waste becomes and not becomes waste and how waste is formed by differentiating waste and results of products. One of the important concepts of the waste framework directives is definition of waste. According to article 3(1) of this new directive, waste is defined as "any substance or object the holder discards or intends or required to discard." In the perception of chemicals legislations of EU, the words "substance" and "object" were not understood. However, these concepts have to be understood generally as independent notions of waste legislation (Falkenberg, 2012).

Any waste that deliberately discarded for removal by one and used as an input by another can be considered as waste. This waste can be material or liquid obtained because of inefficient and inappropriate use of resources. Some wastes can be finally turn into resources more important than others do after discarded and produced in each phase of development and manufacture (Hoornweg and Bhada-Tata, 2012). Waste is an inexorable by-product of utmost human action. The importance and return of this resource depends on its proper management. If appropriately managed, some of the waste can be recycled, and consequently converted into inputs for manufacturing or production of energy ((Tchobanoglous and Kreith, 2002).

Creation of waste is progressively increasing as a normal effect of population growth and economic development. The kind and amount of generated waste is associated to human actions, way of life, and ecological consciousness level. Waste is becoming a constantly raising challenge internationally, regionally, and nationally. This constantly raising challenge is speeded up by increases in consumption and waste creation situations and increasing global urbanization. As a result, most countries are in a particularly difficult position in managing waste, mainly developing countries, such as Ethiopia, Addis Ababa

City (Massoud and Merhebi, 2016). Therefore, waste is solid or fluid waste, unwanted and rejected as undesirable in the process of consumption and/or production, however, can be used as an input by another once that leftover is converted into waste after users cease making use of it.

2.2 Municipal Solid Waste

Municipal solid waste is a waste gathered by municipalities or other local authorities usually identified as either garbage or trash, comprises of day-to-day items such as food scraps, clothing, grass clippings, product packaging, bottles, furniture, newspapers, batteries, paint, and appliances metal. These weastes are commonly in the form of either a solid or a semi-solid. Furthermore, municipal solid waste can be categorized as biodegradable wastes comprising of (Massoud and Merhebi, 2016):

- biodegradable resources like paper and grass;
- nourishment and kitchenette waste;
- composite wastes like clothing and tetra packs, etc.

In general, municipal solid waste is presumed to comprise the entire wastes created in a community, with the exclusion of waste created by Industrial and agricultural processes, treatment plants, and municipal services (Tchobanoglous and Kreith, 2002).

Municipal solid waste is considered to be generated from residential, commercial, institutional, or industrial areas. The sources and types of MSW originate under these sources are shown in table below (Young, 2010).

Table 1: Sources and types of MSW (Young, 2010).

Sources and examples of MSW	Types and examples products of MSW
1. Residential: single and multifamily homes;	• Papers, clothing, disposable tableware, food wrapping, cans and bottles, food scraps, yard trimmings;
2. Commercial: office buildings, retail and papers, wholesale establishments, restaurants;	• Grooved boxes, food scraps, office disposable tableware, paper napkins;
3. Institutional: schools, hospitals, prisons;	• Refectory and bathroom trash can wastes, office papers, classrooms wastes, yard trimmings;
4. Industrial: wrapping and managerial; not process wastes.	• Grooved boxes, plastic film, wood pallets, lunchroom wastes, office papers.

Therefore, the sources of municipal solid waste are (Tchobanoglous and Kreith, 2002):

- Residential sources include the type of wastes from single-family homes, duplexes, town houses;
- Commercial sources include the type of wastes from office constructions, shopping malls, storerooms, hotels, airports, cafeterias;
- Institutional sources include the type of wastes from schools, medical facilities, prisons;
- Industrial sources include the type of wastes such as wrapping of parts, workplace wastes, and bathroom wastes.

There are extensive types of more nonhazardous wastes, which are not included in municipal solid waste source that frequently dumped to landfills together with municipal solid waste, for example, municipal sludge, combustion ash, harmless manufacturing process wastes, building wasted, and vehicle bodies (Tchobanoglous and Kreith, 2002)

2.3 Amount and composition of municipal solid Waste

The global current MSW production amounts are about 1.3 billion tonnes annually. This amount is projected to grow to about 2.2 billion tonnes in 2025. The per capita waste production rate is to be grown from 1.2 to 1.42 kg/person daily in the coming 15 years. The OECD, Africa, South Asia countries generate 44%, 5%, and 5% consecutively of global waste in which Africa and south east countries is the smallest quantity of waste. (Hoornweg and Bhada-Tata, 2012). The volume of MSW generated in various regions of the world is illustrated in table 2 below.

Table 2: MSW in different parts of the globe (Hoornweg and Bhada-Tata, 2012).

Region	Urban population (milj.)	Waste generation kg/person/day	Waste generation t/day	Waste generation, Milj. t/year
Africa	260	0,65	169 100	62
East Asia and Pacific	780	0,95	739 000	270
Europe and Middle Asia	230	1,1	254 400	93
Latin America and Caribbea	340	1,1	437 500	160
Middle East and North Africa	160	1,1	173 500	63
OECD	730	2,2	1 566 300	572
South Asia	430	0,45	192 400	70
Total	2 980		3 532 300	1 289

Collection of municipal solid waste is key part in supporting public health. From the current global MSW generated in different regions of the world, the collection rate of waste ranges from 46% in Africa to 98% in OECD countries.

The collection rate of waste is: in Middle East and North Africa 85%, Latin America and Caribbean 78%, Europe and Middle Asia 78%, East Asia and Pacific 72%, and South Asia 63% (Hoornweg and Bhada-Tata, 2012). Waste collection rate in different regions of the world is shown in figure 1 below.

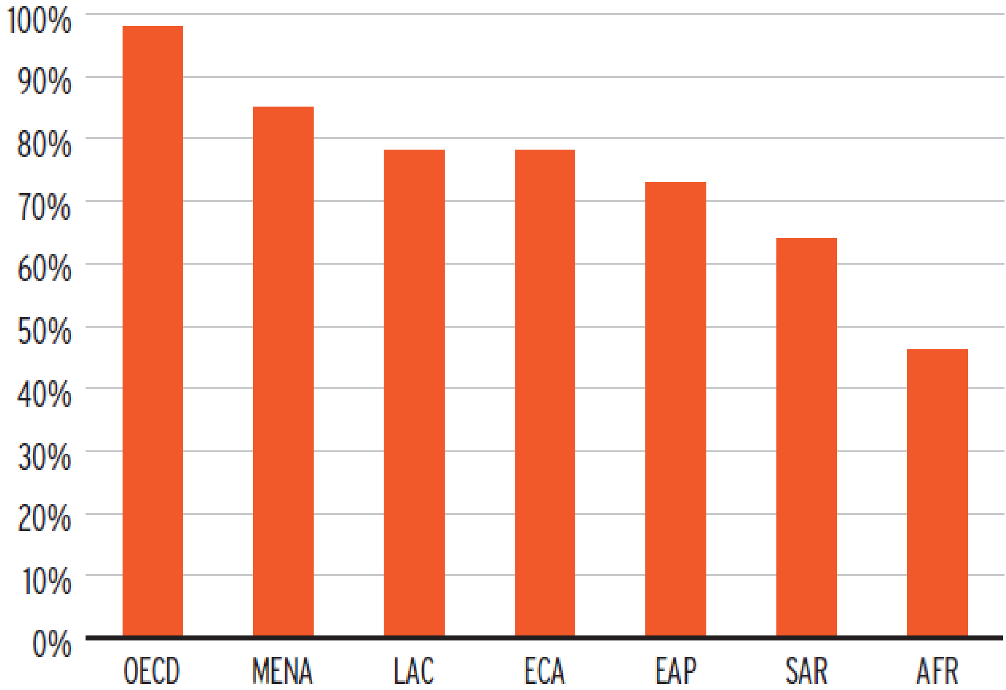

Figure 1: Waste collection rate in different regions (Hoornweg and Bhada-Tata, 2012).

The total amount of MSW disposed of worldwide to landfill is 380 million tons, recycle 180 million tons, waste to energy (WtE) 140 million tons, dump 75 million tons, compost 70 million tons, and others 50 million tons. Landfill and recycle are the most common techniques of treatment (Hoornweg and Bhada-Tata, 2012). Total MSW Disposed of Worldwide in millions of tons/year and disposal options are presented in figure 2 below.

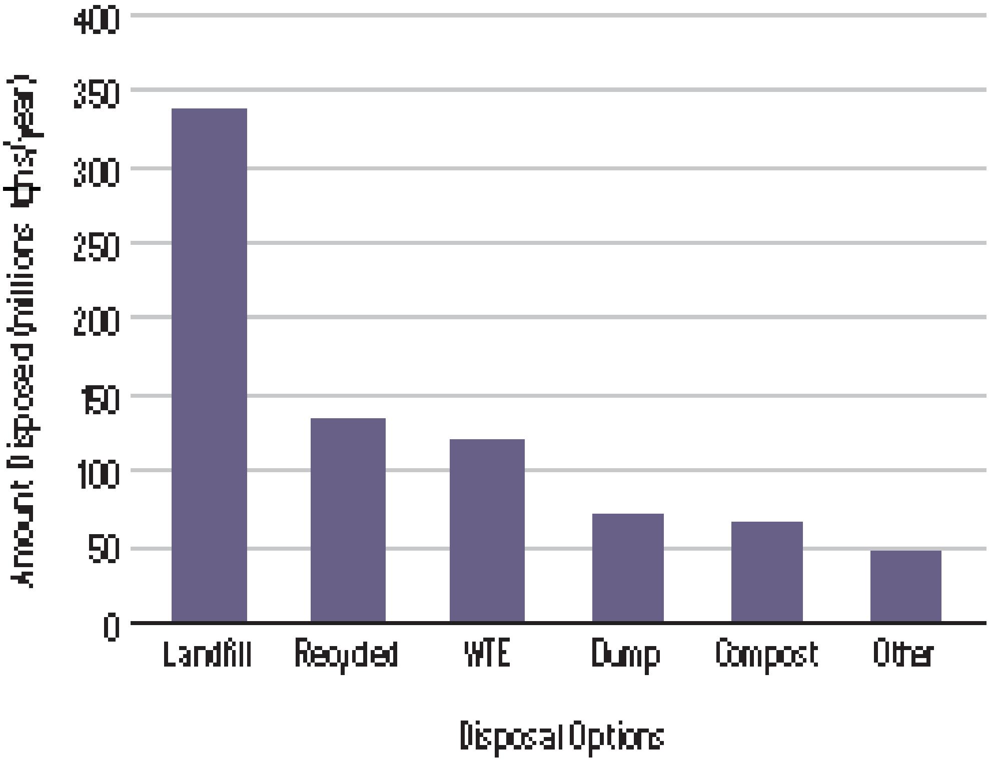

Figure 2: Total MSW Disposed of Worldwide in millions of tonnes/year (Hoornweg and Bhada-Tata, 2012).

MSW treatment in Africa is at its lowest level when compared to the OECD countries. There is no illegal municipal solid waste dumping in OECD countries, whereas the illegal municipal solid waste dumping in Africa is 2.3 million tonnes per year. The legal landfilling in Africa is 2.6 million tonnes per year whereas in the OECD countries is 242 million tonnes of municipal solid waste. The quantity of recycled municipal solid waste in Africa and OECD region is 0.14 million tonnes and 125 million tonnes per year respectively (Hoornweg and Bhada/-Tata, 2012). This urges the greatest need of reform of waste treatment in Africa. Municipal waste treatment comparison in Africa & OECD region is shown in table 3 below.

Table 3: MSW treatment in Africa and OECD-region (mill. Tons/year) (Hoornweg and Bhada/-Tata, 2012).

Type of Treatment	Africa	OECD
Illegal dumping	2.3	-
Legal landfilling	2.6	242
Composting	0. 05	66
Recycling	0.14	125
Combustion	0.05	120
Other treatment	0.11	20
Urban population (mill.)	260	730
Waste generation kg/day/inhabitant	0.65	2.2

From the Global Solid Waste Composition, organic solid waste has the highest share which is 46% and the next highest is paper which is 17% (Hoornweg and Bhada-Tata, 2012). The global solid waste composition is shown in figure 3 below.

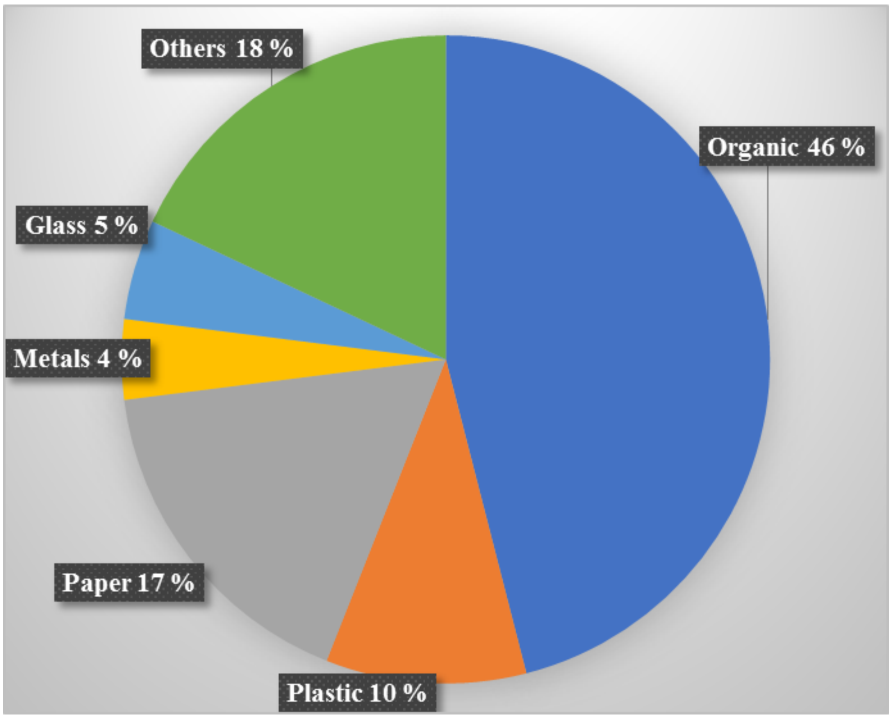

Figure 3: Global Solid Waste Composition (Hoornweg and Bhada-Tata, 2012).

Organic solid waste has the highest share which is 57% in the Africa solid waste composition as well just like in the global solid waste composition. Unlike the global one which is paper, plastic has the second highest share in the Africa solid waste composition which is 13% (Hoornweg and Bhada-Tata, 2012). The Africa solid waste composition is shown in figure 4 below. The African organic solid waste has highest share when compared to the global organic solid waste.

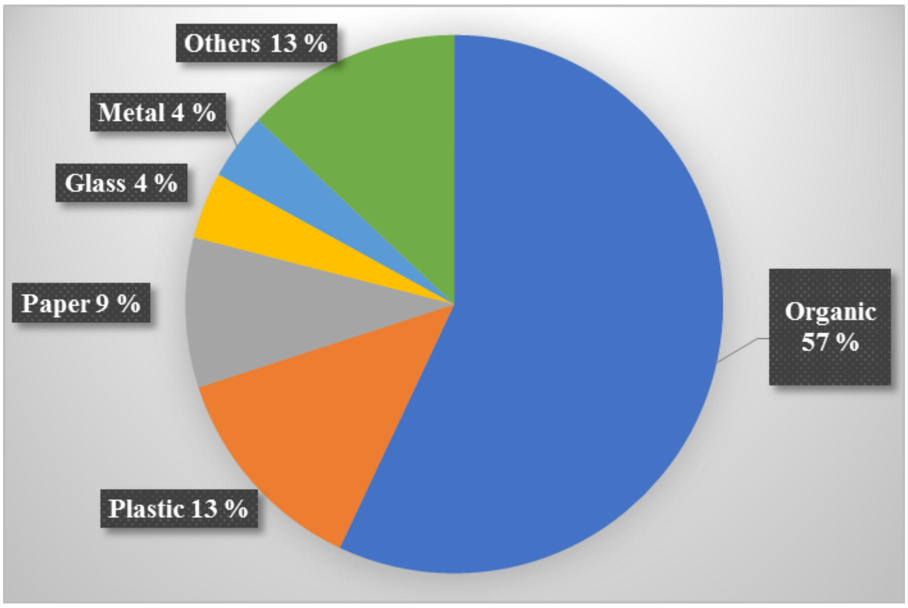

Figure 4: Africa Solid Waste Composition (Hoornweg and Bhada-Tata, 2012).

2.4 Effect of waste on living being and the environment

Depending on waste treatment and disposal mechanisms, waste impacts the community and the environment. Pollution and illness persists in an environment where there is inappropriate waste management system. Waste that is inappropriately gathered or disposed has harmful effect on human wellbeing and the environment. Improperly handled solid waste is sources for upbringing vermin, insects, and scavengers which in turn transmits different types of diseases such as water and air borne diseases. Furthermore, not properly managed wastes pollute soil, air (open burning) and water (leachate) and contribute to poor hygiene. As municipal solid waste (MSW) landfilled becomes source of a number of ecological difficulties for example, leachate, the existence of vectors, public health danger eruption and burning, suffocation, vegetation injury, and greenhouse gas (GHG) emissions. MSW is becoming source of GHG emissions and a main concern as post-consumer waste is projected to take share of nearly 5% of entire worldwide greenhouse gas releases (Hoornweg and Bhada-Tata, 2012).

These in turn become sources of health problems such as communicable disease that can cause skin, respiratory, blood contaminations and diseases as cancer and reproductive disorders. This in turn, upsurges the figure of patients, health expenditure which decreases revenue level of residents. This also leads to reduction of productive people, production and wealth, quality of life and upsurges poverty and death which in turn lead to threatening existence of civilization and generation. So, the impact of waste on our society is threatening and risky to the survival of all living things and the safety of the environment in general and to human being in particular (McGeehan, 2009).

2.5 Components of MSW

The key mechanisms of MSW are: 1) generation of waste, 2) storage and processing of waste, 3) collection of waste, 4) transfer and transportation of waste 5) processing and recovery of waste, and (6) disposal of waste (Massoud and Merhebi, 2016).

Waste generation is the identification of resources that are not useable by or left over from the first user and collected to be dropped out or for schematized removal. Storage and processing of waste are on site handling of waste near the waste production areas to accelerate collection in a simpler manner. To accumulate wastes, waste bins are usually put near the areas where sufficient waste is generated. Collection of waste is the activity of gathering wastes from the placed bins to areas or points where wastes collected and drained to vehicles that collects waste (Massoud and Merhebi, 2016).

Transfer and transportation of waste are the moving of wastes from the lower waste storing services to waste disposal sites employing bigger waste transportation vehicles and other equipment. Treating and recovery of waste is the activity of enhancing the efficiency of practical components of waste management and recovering biodegradable and non-biodegradable resources from waste. Disposal of *waste* is the last stage of waste management where wastes are schematically removed into landfills (Massoud and Merhebi, 2016).

Integrated Solid Waste Management (ISWM) is about how to choose and apply suitable management systems, technologies and methods to attain specific waste management purposes and objectives. ISWM encompasses waste source reduction, recycling, waste combustion and landfills. Their application can be in a combined or hierarchical way. Most countries select hierarchy of waste management in the order of priority of: reduction from its source, reuse, recycling, composting, and disposal of waste, as a working guideline (Massoud and Merhebi, 2016).

Reduction and Reuse: Lessening consumption, escalating the endurance of goods and supplies, use them again, and decreasing the means used to expand and market them can help to achieve waste reduction. **Waste Collection:** waste collection is conducted after reducing the amount of waste produced. Shipment of waste to the relevant organizations is made for action or removal. **Recycling:** Recycling is particularly promising alternative for Municipal Solid Waste from an eco-friendly standpoint as it has comparatively down negative ecological effect, preservative function of natural resources using again abandoned ones, and keeping energy through decreasing and refining processes (Massoud and Merhebi, 2016).

Composting: Composting, an ecological friendly and economy wise feasible method in handling biodegradable municipal solid wastes, is changing natural resources through microscopic creatures to a steady final produce. **Energy Recovery:** Waste to Energy (WtE) is transforming waste to, electricity or heat (or fuel), a practical type of energy. The major kinds of WtE processes, to mention, are incineration, gasification, pyrolysis, and anaerobic digestion. **Disposal of waste to Landfills:** wastes refused from recycling, composting and remains of processes from, for example, combustion is disposed to landfill (Massoud and Merhebi, 2016).

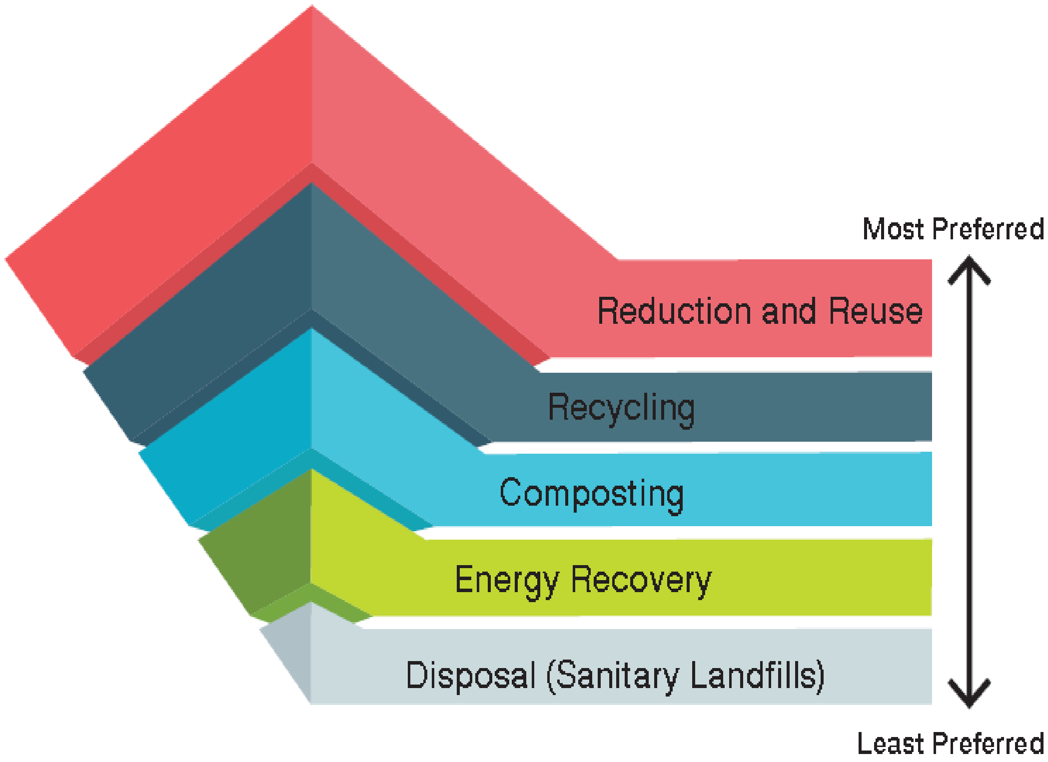

Figure 5: Waste Management Hierarchy (Massoud and Merhebi, 2016).

2.6 Waste Management and Energy Production

Waste materials can be utilized as fuels using the technologies of incineration/combustion of waste; anaerobic digestion of organic waste to produce biogas to heat houses; and Landfill gas gathering and recovery. Energy production harvests solid waste for waste management and Waste management needs energy of electricity for pre-treatment, heat for warming, and waste-heat is used for waste treatment (Niessen, 2002).

Energy production, waste to energy, is one alternative and aspect of waste management. Energy production is one component of waste management hierarchy. Proper waste management is a source of energy production. To manage the constantly increasing generated municipal waste, development and application of waste to energy technologies becomes crucial. This is the reason why many countries build and operate waste to energy technologies to manage the continuously rising produced municipal solid waste. Waste management using energy technology turns waste to energy production (Massoud and Merhebi, 2016).

3 ENERGY RECOVERY TECHNIQUES AND APPLICATIONS

Energy recovery from waste is transformation of waste ingredients to functional electricity, heat or fuel by different methods, comprising of incineration, anaerobic digestion (AD), gasification, pyrolysis refuse derived fuel, landfill gas to energy (LFG). The energy recovery techniques in transforming energy from waste can be categorized into thermal processing, biochemical, and chemical. These techniques are outlined below in Figure 6 (Suthapanich, 2014).

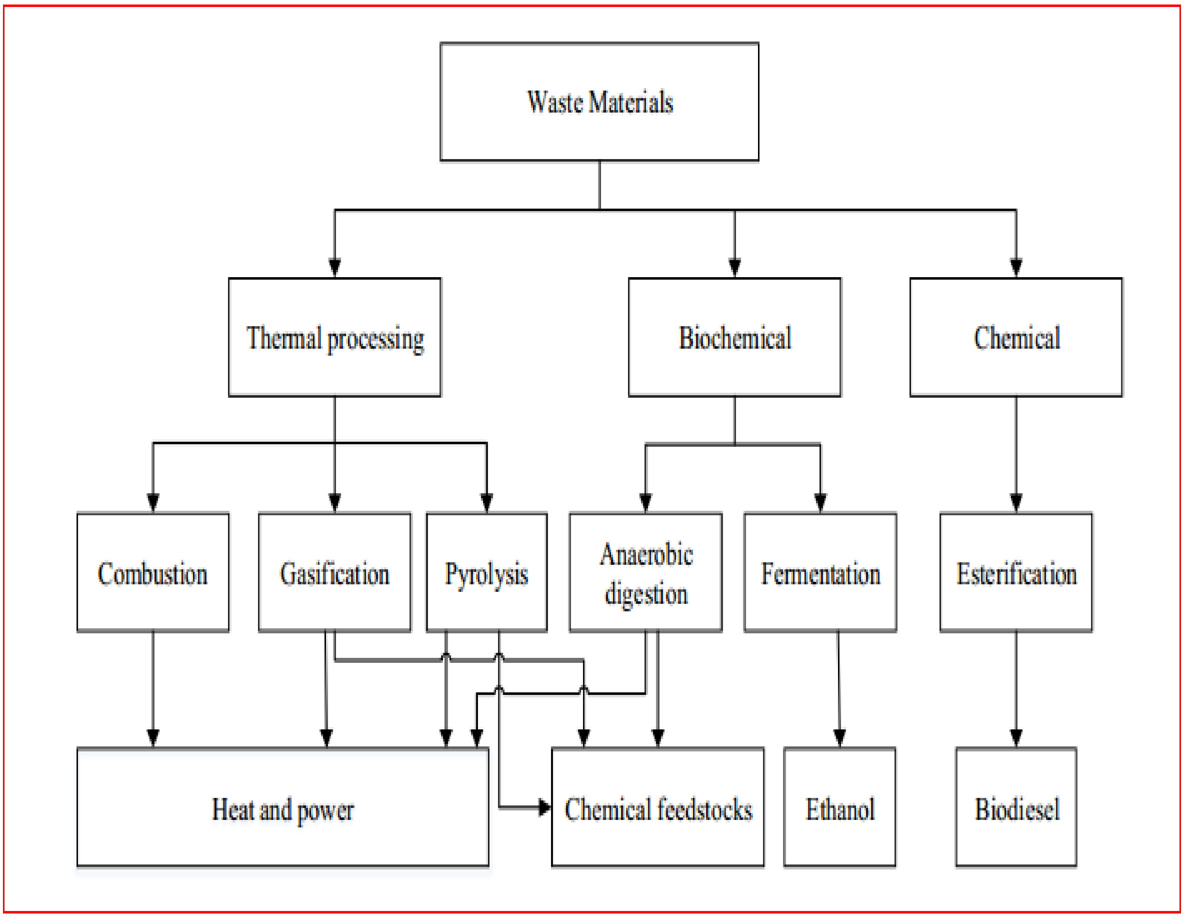

Figure 6: Pathways of waste to energies technologies (Suthapanich, 2014).

3.1 The Thermal Method of Waste to Energy Recovery

Thermal technology decreases the amount of waste in order to save land for landfill use and recovers energy in waste which is rich in biochemical, destroys toxins in waste, and handles residual waste after recycling and organic materials are separated. The Thermo-chemical transformation methods are convenient for wastes comprising of high proportion of organic non-recyclable material with a content of low moisture. The key technical alternatives in this sort comprise of Incineration, Pyrolysis, Gasification and plasma arc gasification. (D. Y1 et al., 2015). The process and application of each of the thermal conversion methods are briefly explained below.

3.1.1 Incineration

The term incineration has no good meaning in the attention of the community because of the ineffective process of certain waste combustors in olden times. Consequently, the word waste-to-energy combustion is nowadays commonly applying instead. Here, Incineration therefore, denotes the contemporary exercise of incineration of waste that cannot be reprocessed in an economical manner. Incineration provides high opportunities lessening the size of waste to the landfill and in making heat and power. Fresh solid waste provides a heating value from 9.3MJ/kg to 16.3 MJ/kg where the source separation of bio-waste works well compared to coal that discharges almost 23.3 MJ/kg. Therefore, a big quantity of heat can be discharged through combusting municipal waste municipal waste so that heat is utilized to produce electricity (Tchobanoglous and Kreith, 2002).

The incineration or combustion of organic things in an oxygen-rich atmosphere characteristically in a heat above 850^{o}C generates leftover fume set up mainly water plus carbon dioxide. Extra gas releases sulphur dioxides, nitrogen oxide, and others. The mineral level of waste is converted to remnants using wide range of fuel as thermal method. Decreasing size of waste using the deep hole again is objective of such technique. This recovered power can be utilized to heat, produce steam, and manufacture electric power. The classic quantity of pure power manufactured from a ton of indigenous leftover is around 0.7 MWh of electric power and 2 MWh localities warming. Therefore, around 17 MW electricity and 1,200 MWh localities heating is generated every day from incinerating around 600 tons of waste per day (Moustakas and Loizidou, 2010). The incineration technique can be practiced in the treatment of varied solid residue and pre-nominated waste management. The method can lessen the volume and mass of the MSW in 90% and 75%respectively. This technique can be feasible to thermal action of large amounts of dense leftover, which are above 100,000 tons a year. Furthermore, in order to have appropriate combustion of the managed solid waste completes certain requirements need be fulfilled. These requirements are (Moustakas and Loizidou, 2010):

- Sufficient resource for petroleum and oxidation;
- Attainable burning heat;
- Appropriate mix ratio of different waste materials;
- Incessant treatment of the gases formed in the combustion period;
- Constant treatment of the combustion residues;
- Preservation of appropriate hotness in the incinerator;
- Turbulent flow of fumes;
- Sufficient residence time for the waste in the burning place

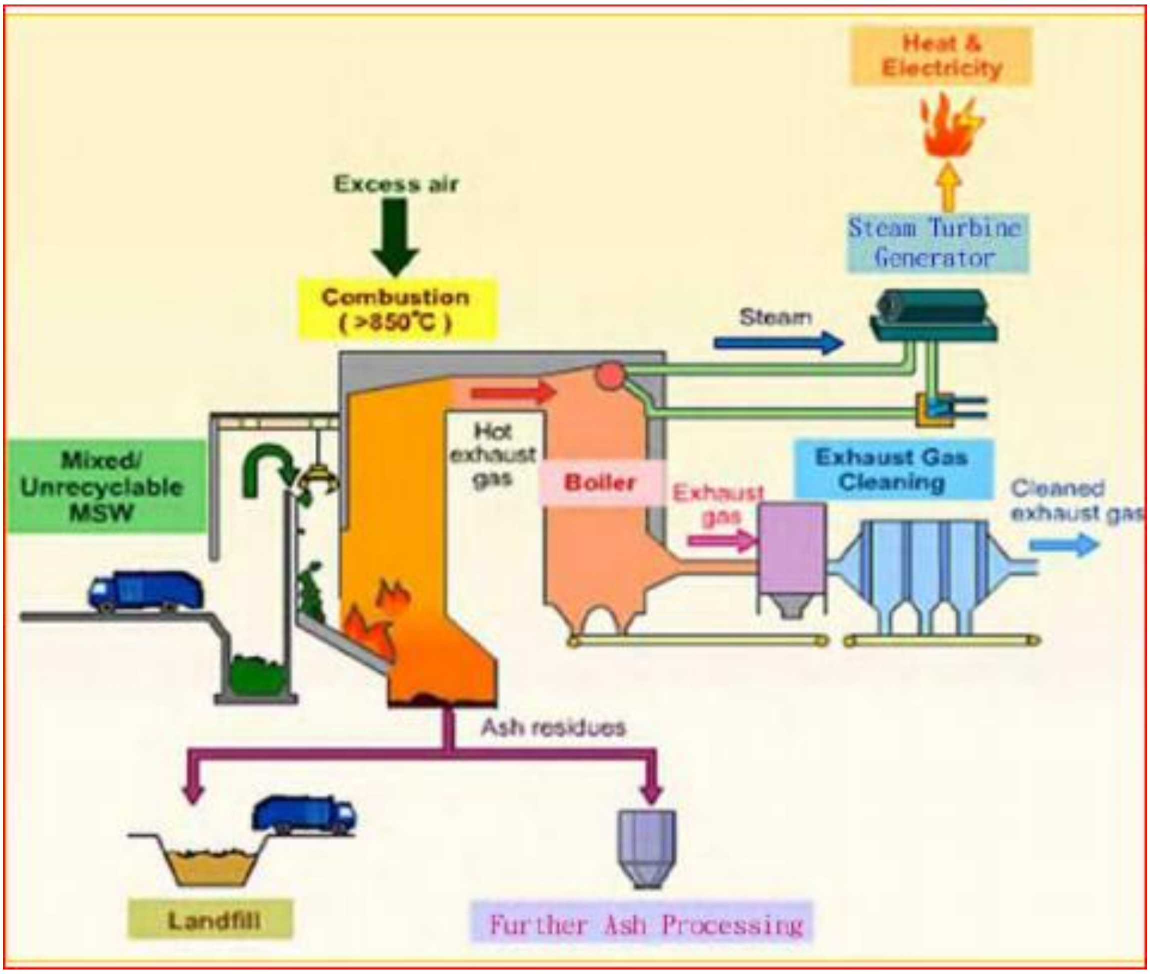

Figure 7: Incineration process (Moustakas and Loizidou, 2010).

To determine the incinerability of wastes is important in the process of incineration. These are wastes combustible and feasible entrants for incineration. In determining the incinerability of wastes, the following issues have to be taken into consideration (Tchobanoglous and Kreith, 2002).

- **Waste moisture content:** If moisture content of waste is higher than normal situation, more fuel is needed to incinerate the waste. Normal situation is that when there is no need for additional fuel except in startup or some temporary situations. If the fuel moisture content is significantly higher than 50 %, there can be need for additional fuel to achieve high temperatures (> 850 °C) to destroy the toxic organic compounds. Wastes with extremely high moisture content which could be higher than 95 percent are taken as poor sources for incineration (Tchobanoglous and Kreith, 2002).

    - **Heating value:** Incineration is a thermal conversion method in which waste is thermally converted to flue gases and solid mineral end product. Heating value in this case refers to the net caloric heat released by combusting a quantity of waste fraction during combusting and the latent heat vaporization of water is not recovered. Different waste fractions or waste compositions have different lower heating value or net calorific value. For instance, waste fraction such as paper, plastics, wood, vegetable in Greece MSW were found to have 14.2 MJ/Kg, 29.3 MJ/kg and 13.6 MJ/kg and 5.59 MJ/kg of lower heating value on received basis respectively (Anttila, 2013). There are elements such as hydrogen, carbon and nitrogen which have positive effect on the heating values. Not only elements but there are also compound, for example, methane, ethane and benzene which lead to the increment of the lower heating values.

      Without a substantial heating value, incineration could not be applied the disposal technique. A waste such in practice does not have a heating value but they are inert in combustion as accepted is not appropriate for incineration. Normally, material blocks or boulder wastes having heating value below 2.3 MJ/kg as received is not pertinent for incineration. However, vacant drum of remaining cover of biological thing on its internal part and gravel out of wastewater purification factories are pertinent for incineration even with a small heating value (Tchobanoglous and Kreith, 2002).

- **Inorganic salts:** Wastes with high content of inorganic and alkaline salts are difficult to dispose in a conventional incineration scheme. A substantial portion of the salt can be suspended in the air. Making a slag, or cake, which harshly lessens the efficiency of an incinerator to perform properly, will accumulate on furnace surfaces (Tchobanoglous and Kreith, 2002).

- **High sulfur or halogen content:** The existence of chlorides or sulfides in a waste is usually outcome of the production of acid-forming combinations in the off gas. To protect the production of acid-forming combinations, the charge for protecting equipment from acid attack has to be comparable or less against the charge of other charge of other disposal techniques for the waste in enquiry. (Tchobanoglous and Kreith, 2002).

- **Radioactive waste:** Incinerators can be made to destroy radioactive waste materials. However, if the incinerator is not planned precisely to destroy radioactive waste, an incinerator must not be utilized to incinerate radioactive waste. (Tchobanoglous and Kreith, 2002).

Emissions from incineration

Certain emissions are resulting in a process of incinerations. These comprise of: fume discharges, wastewater, and solid residue. These produced fume discharges encompass the normal burning yields of CO, CO_2, NOx, SO_2, oxygen, dirt elements and further mixes such as H2O and N2 make large share of flue gas though they are not harmful. The existence and the absorption of other compounds, such as HCl, HF, suspended particles comprise of weighty irons, dioxin, furan, which rely on mixture of leftover which is exposed to incineration. In the course of incineration, a quantity of 4,000 – 5,000 m^3 of fume discharges is produced for every metric ton of leftover. Fume discharges have to stay regulated using proper anti-pollution schemes, for instance using Bag filters; Electrostatic precipitators; Cyclones; Wet cleaning systems, etc. (Moustakas and Loizidou, 2010).

Types of Incinerators

Incineration system could be categorized into two sorts: mass burn, burning of pre-heated as well as standardized waste. Mass burn, that extensively utilized, is method of straight burning when solid waste accepted. Mass burn may contain incinerators, for example, moving grate, rotary kiln, fixed grate incinerator, fluidized bed incinerator. (Suthapanich, 2014).

Moving grate incinerator is extensively utilized and is verified for its practical performance which is suitable and proficient to burn variety of waste. Mass burn incinerator is with moving grate where burning takes place. From the beginning to the end of the overhead, grate travels and carries waste. The winch grabs waste to feed to the excavation before it puts to combustion chamber. Then, the waste is dehydrated by heat in the furnace in advance to burning at higher temperature in the air. Ash and waste that can't burn easily is poured from the grate as bottom ash. From the different kinds of grates to mention are movements of forward, backward, and double. The method does not require waste classification or pre-treatment, may transact extensive variety of composition of waste and heating value, has up to 85% thermal efficiency in combined heat and power production, and up to 1,200 tonnes daily capacity of incinerator, 50 tonnes/hour. Nevertheless, it has high cost of upkeep and operation (Suthapanich, 2014).

Rotary kiln incinerator: a type of mass incineration when waste is combusted in a cylindrical chamber that revolve round an axis. In this incinerator the waste travels through the walls of the revolving kiln incinerator along the flat angle. The length of the cylinder's diameter can be one to five meters and eight to twenty meters. It burns solid waste of 2.4 tonnes/day to almost 480 tonnes/day. Rotary kiln incinerator has greater extra air ratio than moving grate as well as fluidized bed incinerator. Furthermore, it has lesser energy efficiency but more than 80% in combined heat and power production. This method does not require waste classification or pre-treatment, has up to 85% thermal efficiency, has agreement with most waste composition and heating values. Nevertheless, rotary kiln incinerator is utilized rarely in waste composition. High cost to upkeep and operate the method is its drawback (Suthapanich).

Fluidized bed incinerator: a method of incineration utilized to burn organized and condensed size of solid waste to generate additional standardized fuel. The process of sorting and size reduction of the waste is carried out in the pre-treatment process. This fuel is served for combustion chamber that contains fluidized bed of slow moving material as well as air is provided since the lowest part of the chamber. Fuel from waste will be served by harbor then over the bed by the burning chamber. Waste combustion materializes inside the fluidized be. Here, heat is recovered by instruments placed in the bed chamber. The elimination ash is conducted in the lowest part of the chamber. Advantages of such type of incinerator are: low cost of upkeep as well as operating due to its modest arrangement, has thermal efficiency up to 90% in combined heat and power production, appropriate to different types of fuel such as solid as well as liquid waste. Nevertheless, as it has a limit of size and composition of waste, needs treatment before incinerating (Suthapanich).

Finally, a well-designed and standardized incineration plant is essential with all its requirements to apply the incineration of waste into a waste to energy in a city or an area.

3.1.2 Pyrolysis

Pyrolysis is thermal conversion of organic, plastic, varied municipal solid leftover without oxygen to yield solid end products, fixed carbon, liquid pyrolysis oil, as well as product gas. Working level of hotness or coldness ranges from 400 to 800°C. Pyrolysis oil is the key petroleum to produce energy. The oil produced is utilized to burn a boiler. Long experience period through slight temperatures of 400 – 500˚C is to exploit char, limited experience period, a lesser amount, through elevated temperatures of 500 to 1000˚C, denoted as ‘flash’ pyrolysis, is provided greater share gas otherwise fluid (Suthapanich, 2014).

Even though pyrolysis is an ancient technique, the use in biomass and leftover ingredients is a somewhat new growth. A substitute word to pyrolysis is thermolysis that is theoretically correct about biomass energy methods since the schemes are typically in need of aerial instead of the absolute nonexistence of oxygen. Pyrolysis oil is key and valuable for energy production although all yields of pyrolysis are valuable. To realize the fruitful action for facility of pyrolysis, incessant control is required because of the complicated processes happening in time of developing a system. The yields manufactured from pyrolysing materials are char and, syngas, though few of unstable constituents create tars and oils eliminated and recycled. The syngas is a combination of fumes (carbon monoxide, hydrogen, methane plus an extensive variety of different VOCs). The syngas characteristically is with net calorific value within 10 and 20 MJ/Nm^3. If prerequisite becomes important, the condensable portion is gathered through refrigerating syngas, possibly to consume as fluid fuel when necessary (Moustakas and Loizidou, 2010).

3.1.3 Gasification

Gasification method is in recurrent education and growth from 19^{th} century. The method was revealed in the period of Second World War. This method was vanished because of petroleum up to this period. The technique becomes exciting when the novel choice substitutes of fuel from fossil due to the absence of energy and worry to the environment. Warming biological municipal solid waste without oxygen to change to molecules of simple type as well as to yield flammable gas is gasification. It materializes in temperature, usually from 500 – 1,0000°C. Generally, the course of gasification effects through the transformation of organic solid materials into gaseous stage. Its final yields comprise of solids, ash, slag, fluids, mixture gas/syngas, from a mix which is predominantly carbon monoxide, hydrogen, carbon dioxide, ethane (Suthapanich, 2014).

The syngas from gasification is used to produce electricity as well as heat. Syngas are changed into methanol, synthetic gasoline. It can also be use straight to substitute natural gas and can be mixed with it. In addition, gasification from waste yields supernumerary normal gas, chemicals, and fuels for transport although needs quite heavy treatment for the syngas. The process of gasification comprises of arrangement of waste, pre-treatment of waste, gasification, gas handling and gas use. The rudimentary kinds of gasifies are: Perpendicular stable bed; flat stable bed; Fluidized bed; Manifold hearth; revolving kiln. Amongst the entire 5 kinds of fixtures, progress of perpendicular and flat stable bed amenities and fluidized bed are usual than others.(Suthapanich, 2014).

3.1.4 Plasma

Plasma arc technique is a thermal procedure used for organic waste without incineration, however utilizing exceedingly great heat in the absence of oxygen situation to entirely decay waste material into easy molecules through discharging electrically powered current using little force air part. Plasma curve incinerate, the temperature basis, is a method to yield greater heat plasma fume designed to combustion. The warmest maintainable temperature basis a plasma gas has varieties beginning 1,482 to 6,649°C. This technique can be utilized in conjunction with numerous features of solid, fluid and partially solid (Suthapanich, 2014).

3.1.5 Refuse derived fuel (RDF)

Refuse derived fuel (RDF) is recovering of combustible waste like plastics and paper and creating of burnable produce using mechanical treatment. Here, municipal solid waste is crashed into pieces, non-burnable ingredients segregated, and burnable combination appropriate fuel is produced. The procedures in the production of refuse derived fuel are: at source sorting, manual sorting, size separation, mixing, drying and palletization (though not always done), storing. The municipal solid waste is crushed using vibrate crusher following the elimination of non-burnable ingredients. Then, in advance to sorting out the bigger elements, ferrous ingredients are eliminated using magnetic separator. The remains are crushed to pieces to create the refuse derived fuel. The quantity of refuse derived fuel made for every ton of waste is determined by the process and quality of fuels in need. Waste composition, storage practice, and processing define the element of refuse derived fuel. Calorific value, ash content, moisture, sulfur, chloride are the essential characteristics of refuse derive fuel. RDF is with a content of great calorific value when compared with gathered municipal solid waste, simple to store, transport, operate, and ecologically suitable. (Suthapanich, 2014).

3.2 Biochemical treatment

The bio-chemical transformation methods are chosen for wastes with high proportion of organic recyclable material and high standard content of wetness that supports bacterial activity (D. Y1 et al., 2015). Biological treatment is a technique usually applied to biomass of biological waste to recover biogas energy from waste. Biological waste is contravening through the act of microorganisms into very small particles using aerobic digestion generating carbon dioxide, water/anaerobic digestion generating methane, water with a few carbon dioxide as well as hydrogen. The generated gases are formed through anaerobic digestion procedure, recovery of landfill gas as well as fermentation. Each of these methods is briefly clarified in the following 3.2.1 to 3.2.3 (Suthapanich, 2014).

3.2.1 Anaerobic digestion

Anaerobic digestion is normal handling procedure of organic waste for energy conversion by means of biogas. In anaerobic treatment only biodegradable waste such as food, plant and dung are processed. Here, decaying of MSW, organic waste and livestock manure is processed without oxygen to produce biogas, for example methane and carbon dioxide for creation of electricity as well as heat energy. In this digestion numerous anaerobic organisms collectively convert biological part of waste to a steady final produce and biogas (Niessen, 2002).

The phases in the process of anaerobic digestion remain hydrolysis, acidification, acidogenesis, and methanogenesis in this order. Anaerobic digestion occurs in bio-digester or reactor. Anaerobic handling takes lesser managing period than aerobic, compositing, handling, however, greater than thermal, incineration, and handling. Anaerobic digestion constantly happens also in a site of landfill in addition to bio-digester or reactor. (Suthapanich, 2014). Example of an anaerobic digestion process is shown in diagram below.

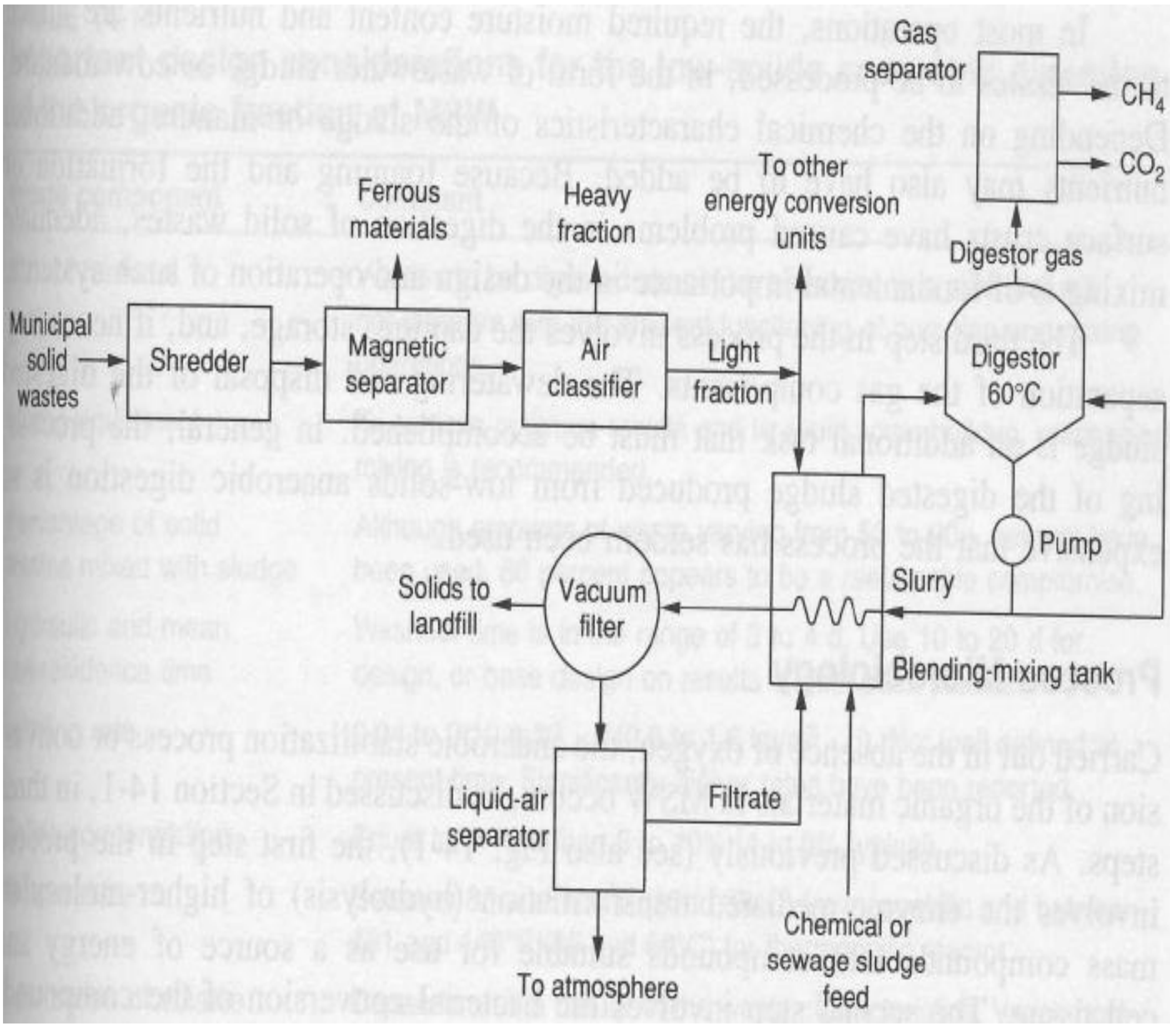

Figure 8: The low Solids anaerobic digestion process for the organic fraction of MSW flow diagram (Tchobanoglous and Kreith, 2002).

3.2.2 Landfill gas utilization

Energy of landfill gas is prepared for lessening emission as well as gas retrieval in the landfill activity. It contains process of pretreatment scheme, hygienic landfill activity, land gas gathering scheme, gas consumption scheme, and ecological control scheme which can help to the formation of landfill gas comprising around 45-55% methane. This may be recuperated using a system of gas gathering tubes and used as a basis of energy. A tonne of municipal solid waste produces around 50 –200 m3 landfill gas. Landfill gas encompasses mostly methane, carbon dioxide, nitrogen, and oxygen. Landfill gas is gathered and consumed mostly in big landfills. The degree and size of landfill gas generated rely on the time of life and composition of waste of landfilled, its wetness stock, geology of the location, leachate stage, temperature spreading inside the landfill, existence of oxygen, and efficacy of covering of the site (Niessen, 2002).

3.2.3 Fermentation

Fermentation is the conversion of biological compound into alcohol which is known as ethanol or bioethanol. Using bacteriological fermentation by means of enzymes, organic wastes is transformed into ethanol. Ethanol is acquired from biological waste is known as cellulosic ethanol. The manufacture of Cellulosic Ethanol includes the usage of woodland, grasses, and the stems, leaves and stalks of non-grass plants. The physical part of vegetation has to be smashed down into sugar in advance being fermented into ethanol. To make this energy option a sustainable industry lessening the cost and refining the efficacy of sorting out and transforming cellulosic ingredients into fermentable sugars is crucial (Suthapanich, 2014).

3.3 Chemical Treatment

Chemical treatment is the usage of chemical interactions in converting biomass into different practical energy. Trans-esterification, highly cost-effective, is the universally known type of chemical-based treatment. Trans-esterification is not applied to treat solid waste, however can convert bio-oil, animal fat, or tree oil to biodiesel. Biodiesel is a popular end-product of trans-esterification. Biodiesel has less toxic as well as more eco-friendly fuel when compared to petroleum. Normally, it is mixed to fuel diesel to make available renewable energy (Suthapanich, 2014).

3.4 Advantages and disadvantages of the four technological options

Each of the four technologies discussed above have their own advantages and disadvantages. Comparing the drawbacks of various techniques is important for the making of decision in devising appropriate technical alternatives. Judging the advantages and disadvantages of the four technologies is helpful in selecting appropriate technique for MSW handling and removal.

Table 4: Advantages and Disadvantages of the Technological options (Suthapanich, 2014).

Technology	Advantages	Disadvantages
Incineration	•High flexible for waste •Reduce high mass & volume •Take shot time for disposal •Produce high energy/calorific value •Thermal energy recovery for direct heating or power generation •Hygienic •Suitable for small area	•High capital and operation & maintenance cost •Overall efficiency low for small power stations(>250 tonnes/day of waste to get profit) •High technology •Skilled personnel require for O&M •Least suitable for aqueous/high moisture content/low calorific value and chlorinated waste. Excessive moisture and inert content affects net energy recovery, auxiliary fuel support may be required to sustain combustion. Concern for toxic metals that may concentrate in ash, emission of particulates, SOx, NOx, chlorinated compounds, ranging from HC1 to Dioxins
Refuse Derived Fuel (RDF)	•Reduce emission •Can apply with pyrolysis and gasification •Small disposal facility, can establish to the various spots at source generation •Use less area •Fuel can storage long time	•Need final disposal •Less market
Anaerobic Digestion	•Reduce emission •Suitable for organic water to get high digestion •Uncomplicated operation •Energy recovery with production of high grade soil conditioner •No power requirement unlike aerobic composting, where sieving and turning of waste pile for supply of oxygen is necessary •Enclosed system enables all the gas produced to be collected for use •Modular construction of plant and closed treatment needs less land area •Net positive environmental gain can be done small-scale	•Less marketing •Heat released is less-resulting in lower and less effective destruction of pathogenic organisms than in aerobic composting. However, now thermophilic temperature systems are also available to take care of this. •Unsuitable for water containing less organic matter •Requires waste segregation for improving digestion efficiency •Need promoting organic waste separation at source
Landfill Gas to Energy	•Reduce methane emission to atmosphere •Reduce risks of explosion/fire in landfill area •Uncomplicated technology •Least cost option •Highly skilled personnel not necessary •Natural resources are returned to soil and recycled by decaying and composting •Can convert low lying marshy land to useful areas •The gas produced can be utilized for power generation or at domestic fuel for direct thermal application.	•Require more than 1 million tonnes of waste at landfill to get cost benefit •Difficult to forecast Gas generation rate •Low knowledge •Greatly polluted surface run-off during rainfall •Soil/Groundwater aquifers may get contaminated by polluted leachate in the absence of proper leachate treatment system •Inefficient gas recovery process yielding 30-40% of the total gas generation •Balance gas escapes to the atmosphere (significant source of two major Green House gasses, carbon dioxide & methane) •Significant transportation costs to faraway landfill sites may upset viability cost of pretreatment to upgrade the gas to pipeline quality an leachate treatment may be significant •Spontaneous ignition(explosions due to possible building up of methane concentrations in atmosphere Large land area requirement.

4 CURRENT WASTE VOLUME, MANAGEMENT AND ENERGY RECOVERY PRACTICES IN ADDIS ABABA, ETHIOPIA

Ethiopia is located at the Horn of Africa between the 14th and 15th degree of latitude with an area of 1.13 million km^2. It is the second most populous nation in Africa with more than 100 million inhabitants (Worldmeters.info, 2016). Its economy is dominated by agriculture that accounts for 44% of the total GDP. As per the magazine of the Economist, the country will have the fastest economic growth in Africa and the 3rd biggest in the world next to India and China (Cambridge Industries 2013).

Addis Ababa is the capital and largest city of Ethiopia. It is with an area of 54,000 hectares and highest population, currently more than three million and projected to be 12 million by 2024 (Kelly, 2012). It is situated in the central Ethiopian highlands at 2,700 m above sea-level. The city hosts the African Union (AU) and several UN offices, therefore indicating the city's regional and international political significance. Moreover, Addis Ababa hosts embassies from most foreign governments, offices of several development agencies and NGOs (Freiburg & Addis, 2015).

Due to migration from rural areas, population fertility, and expansion of urbanization agonizes Addis Ababa a great increase in residents. One of the main challenges of Addis Ababa city is management of solid waste. The city at this time intimidates waste management problems associated with superfluous buildup on open land, water contamination, largely community annoyances. MSW adds around 70% of entire leftover produced in the city. According to latest studies on municipal solid waste of the city, Waste production in Addis Ababa has increased by 3.79 % annually since 1993 (Kelly, 2012).

The Reppi (Koshe), the largest only one landfill site, which was established in 1964 and remote then but currently located in the center of the city is health hazard. This can be seen in figure 9 below. As a result, the aesthetic quality of the city and the health condition of the inhabitants are under grave threat. The health hazard in turn created a financial burden to the city costing over one billion Ethiopian Birr which is more than 40 million USD every year. Consequently, waste management is a major priority to the City Administration of Addis Ababa and is keen to solve this long-lasting problem in the city (Cambridge Industries 2013).

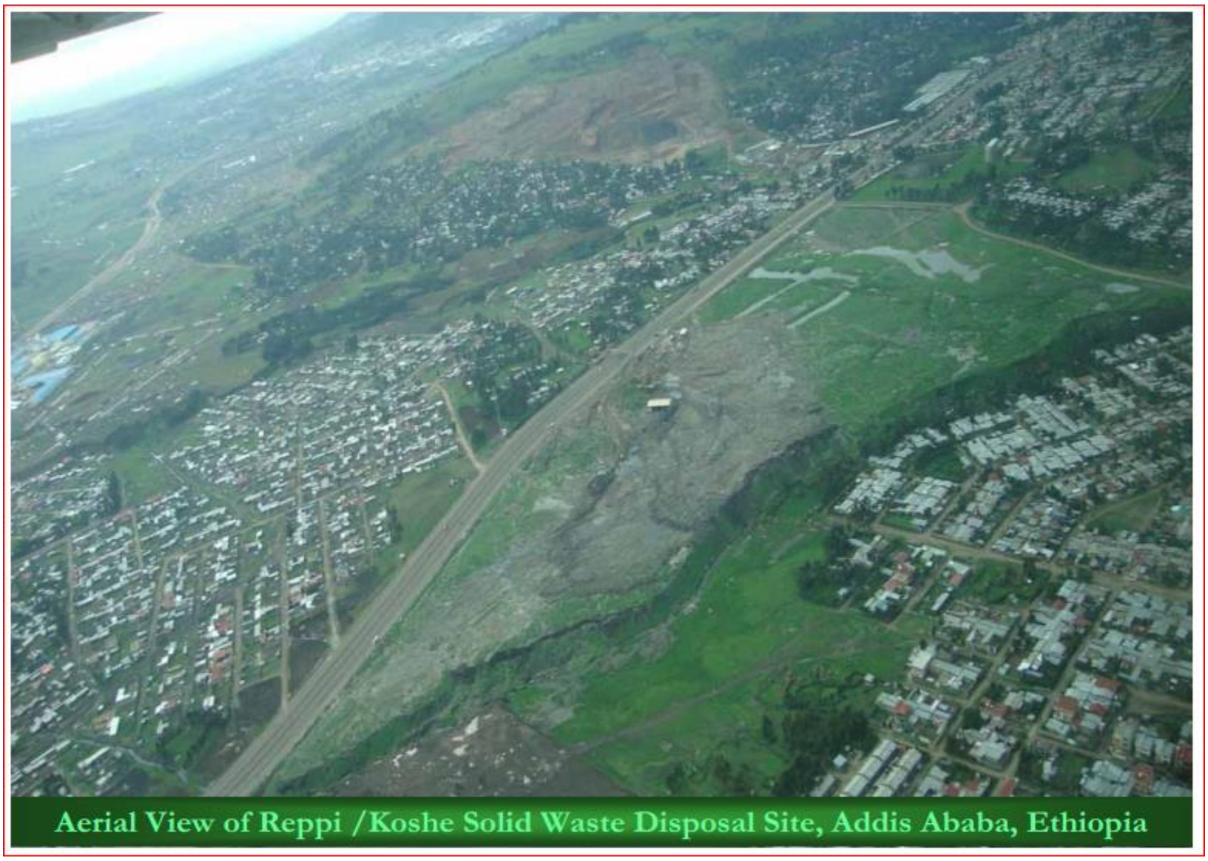

Figure 9: Reppi (Koshe) solid waste disposal site (Cambridge Industries 2013).

4.1 Quantity of Solid Waste

A person living in Addis Ababa on average produces over 1.3 kg of waste daily, however, only 0.46 kg of solid waste is collected per person per day. 3,978.31 m^3 per day, 1,312.78 tonnes/day, of solid waste is gathered and 70% is dumped at the biggest landfill in the country, Addis Ababa city at Reppi (Koshe). Out of the 30%: 5% is recycled, 5% is composted, and 20% is not collected and dumped in non-allowable spaces, for example, exposed areas, channels, drains, roads and other exposed areas in Addis Ababa(Cambridge Industries 2013). The volume of solid waste generated in Addis Ababa, Ethiopia is presented in figure 10 below.

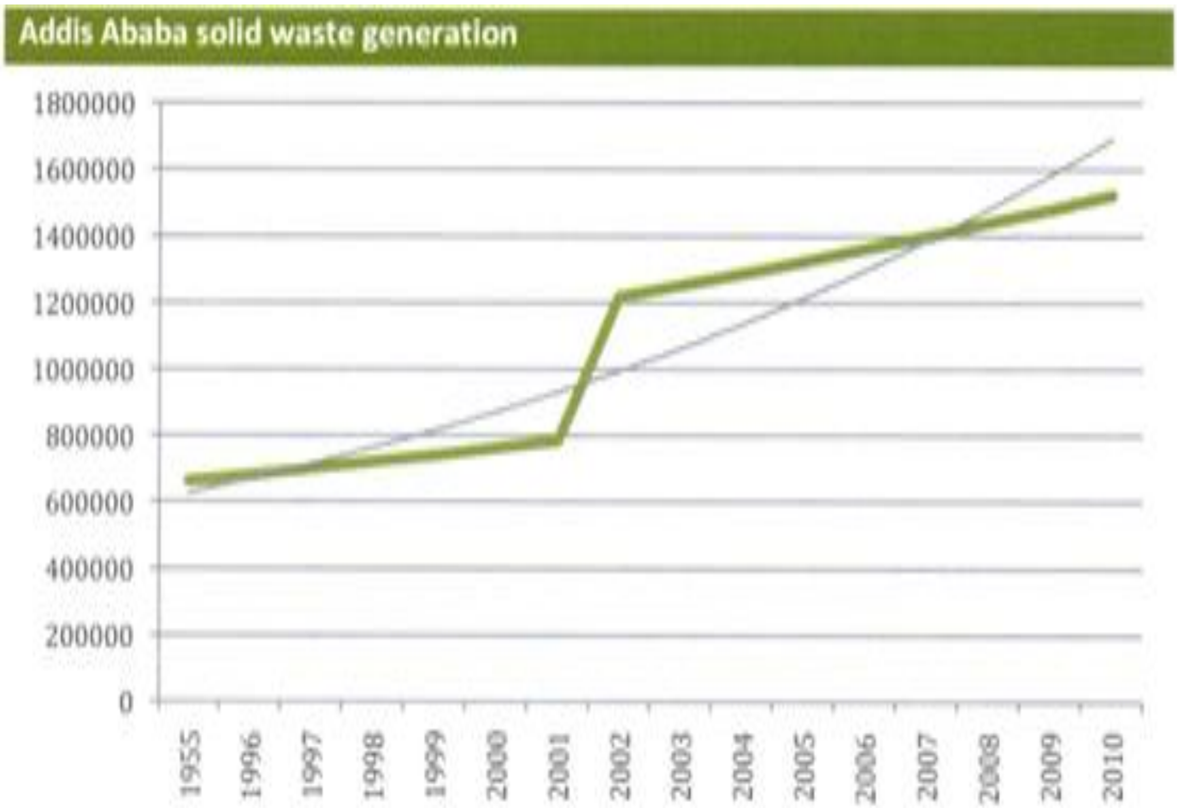

Figure 10: Addis Ababa solid waste generation in tonnes from year 1955 to 2010 (Cambridge Industries 2013).

Solid waste collection is currently managed on a municipal level in Ethiopia and Addis Ababa city. The city has augmented gathering level beginning 60% to 80% (Cambridge Industries 2013).

4.2 Sources and Composition of MSW

The sources of municipal solid waste generated in Addis Ababa city are street, residential, institutions, organizations and higher commercial centers. Street waste which amounts to 6% of the waste produced in Addis Ababa is collected from various corners of the city roads by street sweepers permanently employed by the city municipality. Residential waste is generated from residents of the city which amounts about 76% of the municipal solid waste generated in the city. Institutions, organizations and higher commercial centers (9% commercial, 5% industry, 3% hotels, and 1% hospitals) in total generate 18% of the municipal waste produced in Addis Ababa. Out of the total MSW generated 70% by weight and 50 by volume are organic wastes. Recyclable materials (metal, glass, plastics, paper, wood, rubber, etc.) are estimated to be 15% of the weight as well as volume of the municipal solid waste (Cambridge Industries 2013).

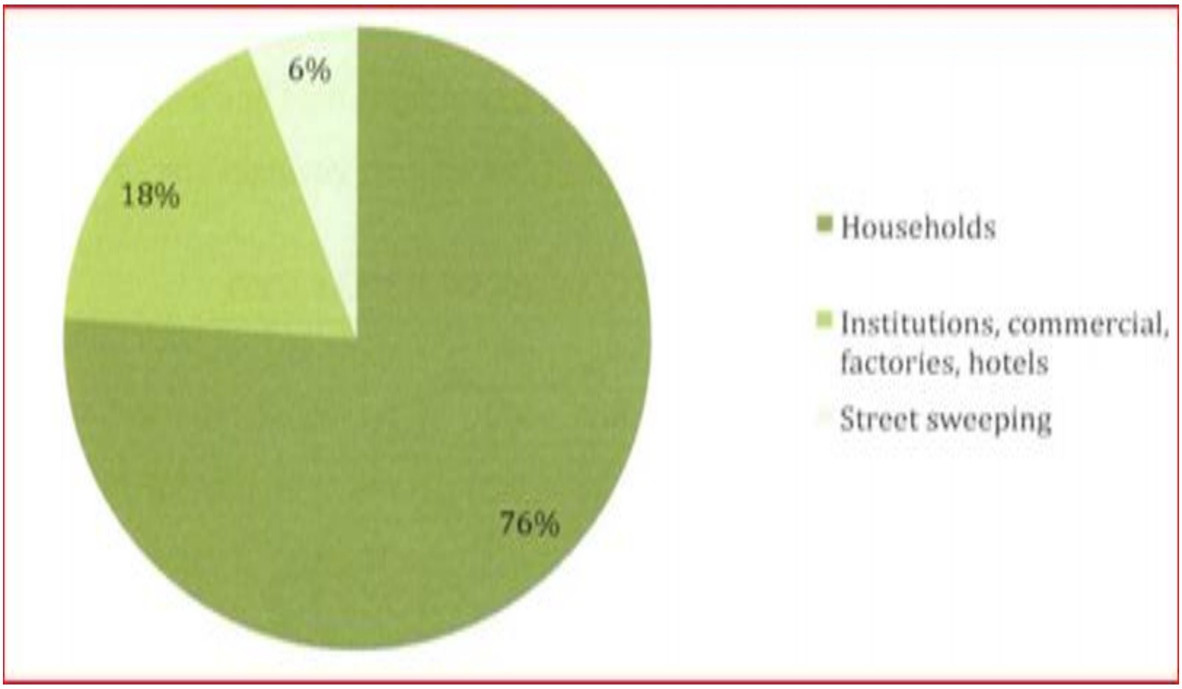

Figure 11: Sources of waste generated (Cambridge Industries 2013).

The physical composition of municipal solid waste has been estimated as: vegetables 4.2%, rubber/plastics 2.9%, paper 2.5%, bone 1.1%, wood 2.3%, textiles 2.4%, metals 0.9%, glass 0.5%, non-combustible 2.5%, combustible leaves 15.7%, and all fines 65%.

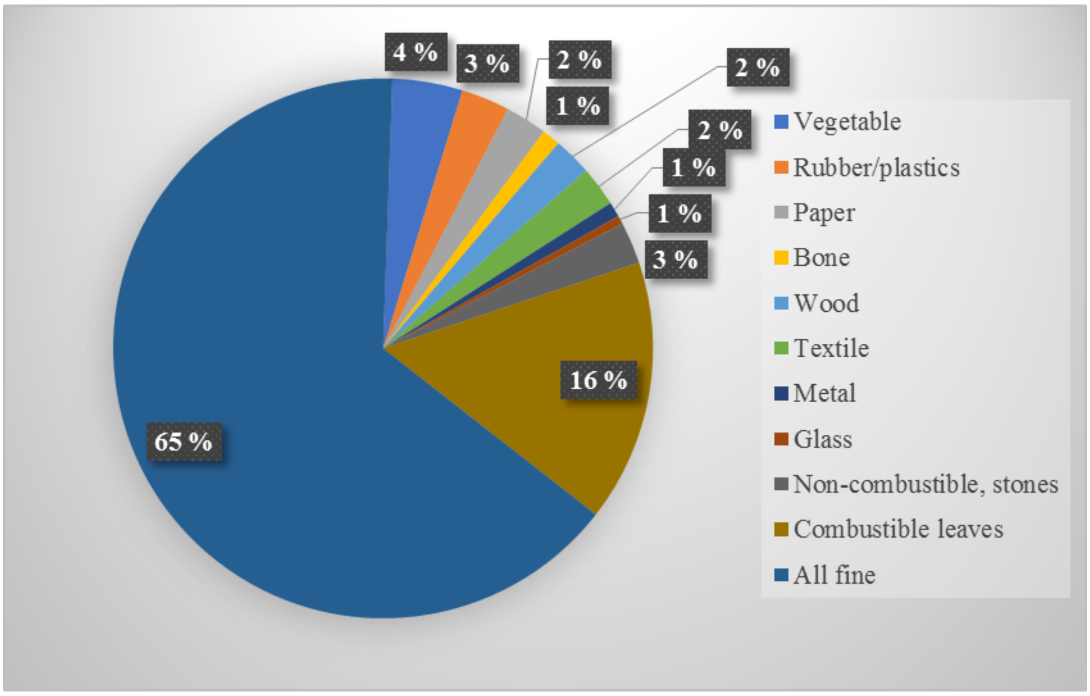

Figure 12: MSW composition of Addis Ababa by percentage (Cambridge Industries, 2013).

The waste composition of Addis Ababa is changing over time. For example, the share of organic waste is decreasing and the share of plastic waste is increasing. See the above waste composition of Cambridge 2013 and below waste composition of Fikreyesus 2011 for comparison, although the time gap is not significant.

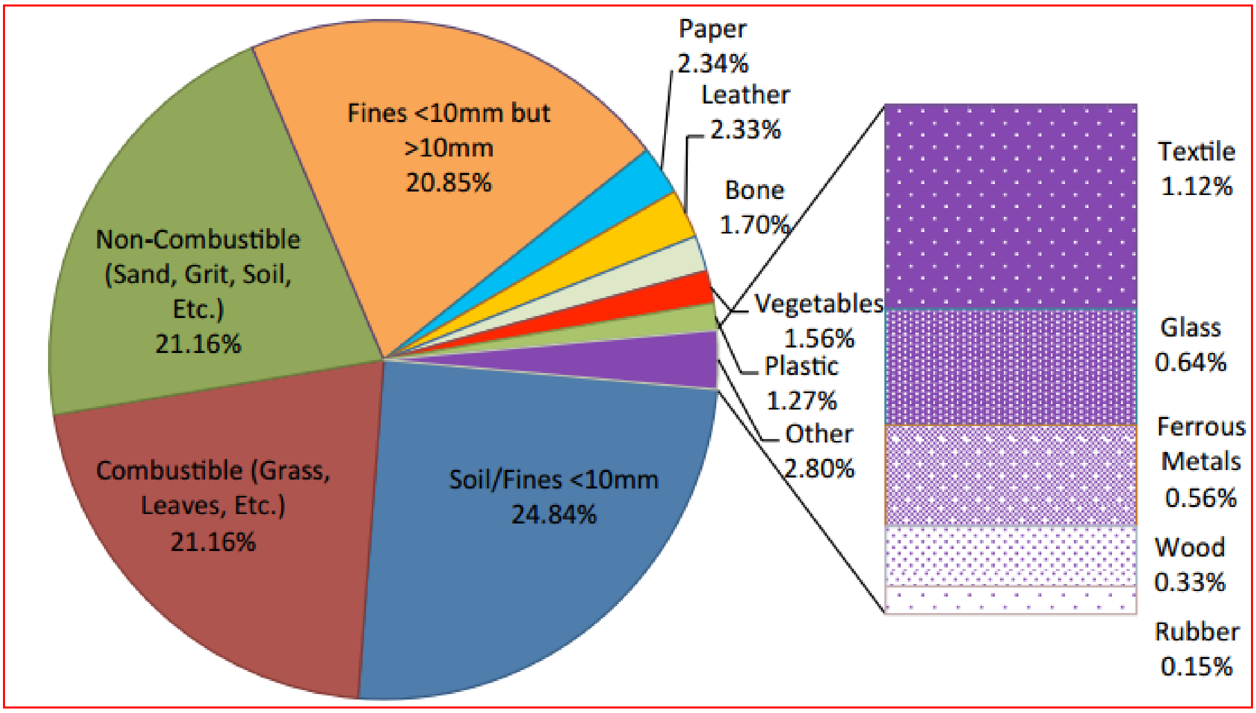

Figure 13: Composition of Waste in Addis Ababa, Ethiopia, (Fikreyesus, 2011).

4.3 Organization and Practices of MSW Management in Addis Ababa

The structure and practice of waste management in Addis Ababa city includes: Waste generation, collection, transportation, and disposal. The city expends big share of its annual money on gathering, transportation, and removal of dense leftover.

4.3.1 Collection

In Addis Ababa city municipality solid waste collection is separated to two levels: primary and secondary collection. Primary collection is implemented using micro and small organizations. There are around 750 micro and small enterprises that pre-collect waste door to door from households and organizations and dump them into designated container. These pre-collectors have a formal agreement with the municipality to do the activity and get payment for that. After the waste is pre-collected, it is dumped in containers then prepared to be taken by the municipality and to be dumped at the Reppi (Koshe) landfill.

Figure 14: Waste pre-collectors in Addis Ababa (Fikreyesus, 2011).

4.3.2 Transportation:

The municipality transports wastes from trash containers which are secondary collection to the final dumping site. Secondary collection is where 85 % of solid wastes are gathered from containers by municipality and conveyed to the final dumping site, Reppi (Koshe). Transportation of waste is conducted by 10 private companies and government using their own vehicles.

Figure 15: Secondary collection/storage containers in Addis Ababa (Fikreyesus, 2011).

4.3.3 Disposal of municipal solid waste

In Addis Ababa there are three common practices of waste disposal: landfill, open disposal, and incineration. Collected solid wastes from containers are disposed of into one landfill site, Reppi (Koshe) which has been established in 1964. Since the Reppi (Koshe) landfill disposal area is on full, enclosed with residential zones, nuisance and health risk for persons proximate, and has no fence; it has poor landfill site management. This can be seen in figure 15 above. The disposal system in the landfill site is rough and exposed which hauls the trashes using vehicle, spreads and levels using bulldozers and compacts using compressor. (Fikreyesus, 2011).

Figure 16: Reppi (Addis Ababa) open dumping site (Cambridge 2013).

Waste is sorted at different stage of the waste management process: the first sorting is made at household which sorts out plastic materials, glass, bottles for reuse and the second sorting is by many collectors, such as boys of the street, non-public division businesses, forgers at community landfill (Cambridge, 2013). This can be seen in figure 17.

Figure 17: Reppi Solid waste disposal site (Cambridge Industries, 2013).

4.4 Energy Recovery practices in Addis Ababa

In Addis Ababa and Ethiopia energy recovery practices from MSW is not practiced. Currently, however, a waste to energy plant is in the course of establishment. The waste to energy plant is under construction by the Cambridge Industries. The construction of the plant has been undertaken in Reppi (Koshe) landfill site in 2013 and was expected to be completed in 2016. However, the plant is not completed and started function. When the plant is completed, it is expected to produce 50 MW electricity power having a plant ability of 1400 tonnes of MSW/day to process which is close to three quarters of the typical waste produced in the Addis Ababa metro-area population of more than 4.6 million (Cambridge Industries, 2013).

5 MATERIAL AND METHODS

In this study, three scenarios were considered to evaluate and analyze the potential energy to be generated from MSW in the Addis Ababa city The amount of mixed MWS is 479165 t/a. The same amount of waste is considered in each scenario. These three scenarios were:

- Mechanical and Biological Treatment (MBT) of MSW which also includes incineration of the RDF (Scenario 1);
- Mass incineration in grate fired furnace (Scenario 2);
- Landfill gas production from MSW (Scenario 3).

Table 5: Summary of the three Scenarios and Associated Waste Treatment Options

1	Mechanical and Biological treatment (MBT):
	Refuse derived fuel (RDF)
	Anaerobic digestion (AD) of organic reject
	Separating recyclables
2	Mass incineration in grate fired furnace:
	All mixed mass solid waste
3	Landfill gas production:
	Landfill gas

Each of these scenarios is briefly explained and equations are used to calculate the amount of energy to be generated within the available MSW in the Addis Ababa city context. The Addis Ababa city current waste volume and composition of data collected, organized, and illustrated in chapter 4 and the process explained in methodology of the study in chapter 1, section 1.2 were used in calculating and describing the values of every MSW for each of the three scenarios.

5.1 Mechanical and Biological Treatment (MBT) of MSW (Scenario 1):

At its early stage, mechanical and biological treatments (MBT) aimed to lessen the quantity of waste sent to landfills. However, these days it is known for recovering fuel and other material portions by bringing together the mechanical and biological techniques. The mechanical technique which comprises of categorizing methods, for example screens, magnet separators, sieves and while biological usually observe anaerobic or composting technique (Anttila, 2013).

The mechanical and biological technique both are applied to estimate the energy potential from refuse derived fuel (RDF) and anaerobic digestion respectively in this scenario. The mixed MSW generated from household, industries, commercial and other institutions in Addis Ababa is assumed to go through mechanical treatment and produces different output streams. This process produces RDF for energy recovery, organic pre-rejects for anaerobic digestion and other rejects for land fill. Metal and glasses are recycled and sent for material production. Figure 19 below shows the schematic diagram of MTB in scenario 1.

5.1.1 Mechanical Treatment (MT) process to produce SRF from MSW

The mechanical treatment is one process within scenario 1 to produce RDF or SRF from MSW as shown in figure 18 below. The different output units of material in which the input waste unit divided into were SRF, ferrous and non-ferrous metal, discard material, heavy and fine fraction as indicated in figure 18 below. The basis and framework of MT is done using this process in figure 18.

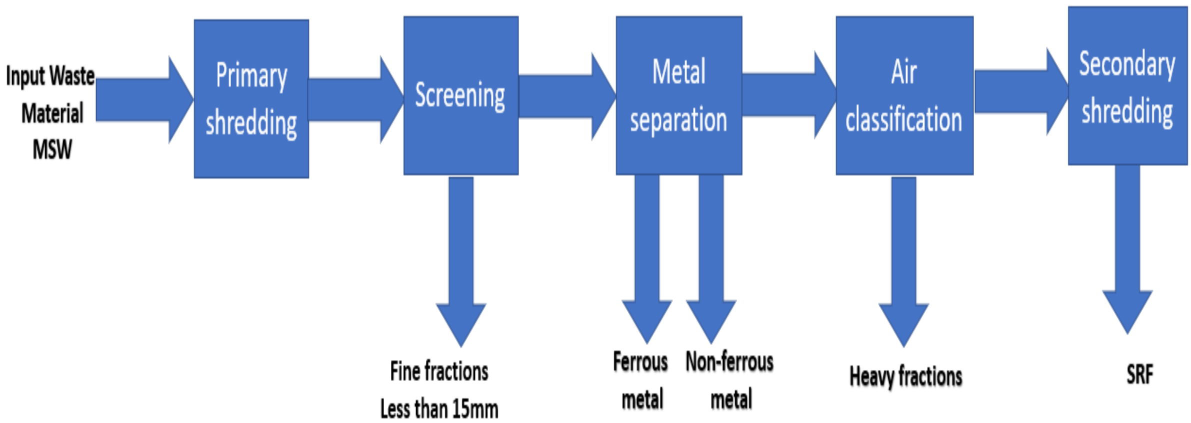

Figure 18: The mechanical treatment of mass solid waste (modified from Nasrullah et al., 2015).

The recovery rate of RDF line (calculated from Nasrullah et al., 2015) in table 6 below is used in the mechanical treatment process to produce SRF from MSW in Addis Ababa, Ethiopia in table 7. Those types of wastes of the Addis Ababa city which are same as or coincide with the types of wastes in table 6 are directly taken in the calculation of prescreen, ferrous metal, non- ferrous metal and air separation in table 7. However, those types of wastes which are not available in table 6 and available in table 7, their calculation of prescreen, ferrous metal, non-ferrous metal, and air separation percentage is assumed based on waste type and waste characterization. For example, from the types of wastes combustible leaves is not available in table 6 and does not coincide with the types of wastes in table 6.

To calculate the percentage of prescreen, ferrous metal, non-ferrous metal and air separation, of combustible leaves in table 7 of Addis Ababa, Ethiopia, assumption is considered and the same is applied for other types of wastes which are not available in table 6, too. It is assumed that the opening of the screen is wide enough to release all the fine and all fines are assumed to be 100% pre-screened as most of its composition is organic with the assumption that its particle diameter is less than 15 mm due to the primary shredding.

Combustible leaves are assumed to be 45% pre-screened by comparing to vegetable which is pre-screened 48% as both are organic and combustible leaves may have a bit coarse material than vegetable during primary shredding. Non-combustible are assumed to pre-screened 8% as pre-screened metal does. The comparison is made in such a way that both waste fractions are strong and compacted as a result only a few parts are pre-screened during shredding. Bones are assumed to be pre-screened same percentage as wood does which is 7%. The basic assumption is that both wood and bone have similar strength during primary shredding.

Table 6: Recovery rate of RDF line (calculated from Nasrullah et al., 2015).

	Pre-screen	ferrous metal	non-ferrous metal	Air separation
Food waste	48 %	0 %	0 %	0 %
Paper	3 %	0 %	0 %	0 %
Plastic	7 %	1 %	0 %	1 %
Textile	4 %	0 %	0 %	0 %
Wood and bambu	7 %	1 %	0 %	1 %
Metal	8 %	56 %	19 %	13 %
Glass	83 %	0 %	0 %	0 %
Mixed	12 %	0 %	0 %	0 %

The above table 6, is the basis for the calculation of percentage of prescreen, ferrous metal, non-ferrous metal, air separator, and RDF.

Table 7 below is formulated from the above table 6.

Table 7: MT process to produce SRF from MSW in Addis Ababa, Ethiopia based on the table 6.

Types of waste	pre-screen rejects (%)	Ferrou metal (%)	non-ferrous metal (%)	air separator (%)	RDF (%)
Vegetable	48	0 %	0	0 %	2.184
Rubber/plastics	7	1 %	0	1 %	2.639
Paper	3	0 %	0	0 %	2.425
Bone	7	0 %	0	1 %	1.012
Wood	7	1 %	0	1 %	2.093
Textile	4	0 %	0	0 %	2.304
Metal	8	56 %	19	13 %	0.108
Glass	83	0 %	0	0 %	0.085
Non-combustible. stones	8	0 %	0	0 %	2.3
Combustible leaves	45	0 %	0	0 %	8.635
All fine	100	0 %	0	0 %	
Total	75.4 (fine fractions)	0.58 %	0.19	0.16 %	23.678

Table 8: RDF composition and lower heating value as received LHVar.

Waste fraction	Share (%)	LHV of fractions MJ/kg	RDF (MJ/kg)
Vegetable	9.2	5.99	0.551
Rubber / plastic	11.1	29.3	3.252
Paper	10.2	14,2	1.448
Bone	4.2		
Wood	8.8	13.6	1.1968
Textile	9.7	13.6	1.319
Metal	0.0045		
Glass	0.0035		
Non-combustible,	9.7		
Combustible leaves	36.4	5.99	2.180
Total	100		9.95

Table 9: Composition of recyclable and reject flows

Waste fraction	Pre- screen reject (%)	RDF (%)
Vegetable	2.8	9.2
Rubber / plastic	0.27	11.1
Paper	0.1	10.2
Bone	0.1	4.2
Wood	0.21	8.8
Textile	0.13	7.9
Metal	0.09	0.0045
Glass	0.56	0.0035
Non-combustible	0.27	9.7
Combustible leaves	9.37	36.4
All fine	65	
Total	100	100

Table 10: Mass flow balance in the process stream in the RDF production

Composition	(%)	(t/a)
Fine fraction	75.4	361280
Ferrous meta	0.58	2779.2
Non-ferrous metal	0.19	910.4
Heavy fraction	0.16	761
RDF	23.678	113451
Total MSW (wet)	100	479165

The mas flow balance in the process stream in the RDF production is summarized in table 10 above.

The energy potential from RDF is calculated below from the above tables 8, 9 and other assumed values.

The lower heating value as received of the RDF produced from MSW was 9.95 MJ/kg and was calculated in table 8.
Annual gross thermal power (transfer loss is not included) for fluidized bed incinerator

Fuel energy of the waste $E_{MSW} = LHV_{ar} \times m\ RDF$, where (1)
LHV_{ar}= lower heating value on received basis
m RDF= masses of the refused drive fuel

The summary of initial value used for calculating energy derived from RDF and their sources are illustrated in table 11 below.

Table 11: Initial value used for calculating energy derived from RDF

Initial value used	**Sources**
LHV_{ar} of the RDF = 9.95 MJ/kg	Calculated value from table 8
Electricity efficiency = 0.27	(Anttila, 2013)
Plant availability= 7200 h/a Mass of RDF = 113451 t/a	(Cambridge industry, 2013) Calculated value from table 10

5.1.2 Biological Treatment (BT) of MSW to produce biogas using anaerobic digestion

The biological treatment is one process within scenario 1 to produce biogas from MSW by means of anaerobic digestion. Anaerobic treatment of organic waste is known as anaerobic digestion. Biogas and digestate is produced in the treatment process. Biogas is valuable gas having much methane that may be utilized by electricity generators, direct combustion, for turbine engine.

The energy potential of biological treatment (BT) of MSW to produce biogas using anaerobic digestion is calculated below from the Addis Ababa city MSW and the RDF results. The Addis Ababa MSW composition is 70 % organic by mass (Cambridge industry, 2013). Out of the organic component fractions paper accounts 2.5 % vegetable 4.2%, wood 2.3% and combustible leaves accounts 15.7%. This sum up to nearly to 25% organic matter. It is assumed that the rest 45% organic matter comes from the all fine. Hence 45% all fine is assumed to organic matter.

The MSW pre-reject fractions directed to the bio-digester for anaerobic digestion are paper, combustible leaves, wood, vegetables and 45% of the all fine fractions. The percentage of organic content which goes to the bio-digester is 38.58% by mass of the MSW, hence 184862 t/a = 184862000 kg/a.

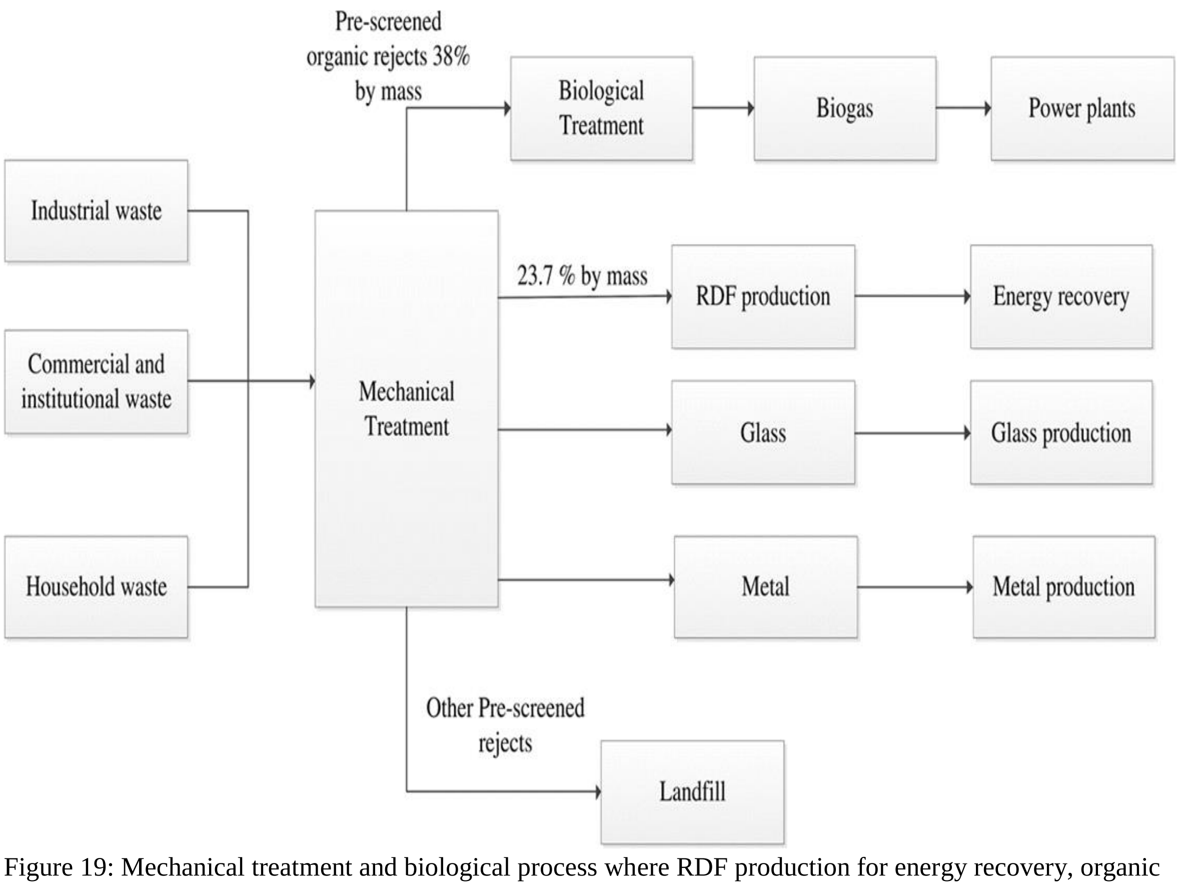

Figure 19: Mechanical treatment and biological process where RDF production for energy recovery, organic rejects for anaerobic digestion and other rejects for land fill.

The summary of initial value used in calculation of methane from biogas is presented in table 12 below.

Table 12: Initial value used in calculation of methane from biogas

Data used	**Sources**
CH_4 yield from bio-waste 0.34 m^3/VS	(Havukainen et al., 2014)
TS (% of FM) = 60%	(Balogun, 2017)
VS (% of TS) = 65 %	(Balogun, 2017)
Methane contains 10 kWh or 36 MJ/m^3	(Balogun, 2017)
Electricity conversion efficiency = 35%	(Banks, n.d.)

The equation below can be used to determine the methane content from biogas in Addis Ababa city MSW. TS (total solid) or dry mass, VS (volatile solid organic mass) and FM (fresh mass) are taken from table 13 below.

The volume of methane produced in biogas, V_{CH4} (m^3/a).

$$V_{CH4} = m\ bio \times TS\ \%bio \times VS\ \%bio \times Y_{CH4} \qquad (2)$$

Where,

m bio = mass of bio-waste (kg/a)

TS% bio = TS content of bio-waste (%)

VS% bio = VS content of TS (%)

Y_{CH4} = methane yield of bio-waste (m^3/kg VS)

Applying equation 1 above and putting all values,

The amount of methane produced from biogas is 24512661.4 m^3/a = 2798.2 m^3/h

Thermal energy content of methane, T_{CH4} (MW)

$$T_{CH4} = CH_4\ f\ (m^3/h) \times ME\ (MJ/m^3) \times CE \qquad (3)$$

Where,

CH_4 f = methane flow rate (m^3/h)

ME= methane energy content (MJ/m^3)

CE= combustion efficiency, in this case is assumed to be all the biodegradables are converted into biogas.

Table 13: Biogas yield sand composition of selected substrates (Balogun, 2017).

Substance	TS (%FM)	VS (%TS)	Biogas (m3/kg VS)	Methane % by Vol.
Biowaste	30-65	45-70	0.15-0.6	58-65
market waste	35-60	75-90	0.4-0.6	60-65
Grass	9-13	80-90	0.2-0.7	50-56

NB: TS total solid (dry mass), FM fresh mass, VS volatile solid (organic mass)

5.2 Mass incineration in grate fired furnace (Scenario 2)

Mass incineration is a method of direct combustion in the treatment of different leftover and pre-nominated waste management. Waste mass incineration is the burning of unprocessed and unsorted mixed MSW. The mass incineration process is commonly based on the grate technology. In addition to its technique as waste to energy in this scenario 2, it can reduce the size and load of the MSW highly. This technique is feasible to thermal action of large amounts of solid waste. In Addis Ababa city, Ethiopia a new waste to energy plan with a capacity to produce 50MW is under construction. It is not yet started production. It is expected to start production soon.

The waste features, for instance, LHV, moisture, and ash content are influential factors for the MSW incineration. Lower heating value (LHV_{ar}) is the best essential variable in shaping the MSW as fuel. Furthermore, LHV is the key factor in approximating if the MSW can endure the burning process with adding no auxiliary fuel (Anttila, 2013).

The energy potential of using mass incineration of MSW in grate fired furnace (scenario 2) is calculated below from the Addis Ababa city MSW data and estimated mass of the waste composition in ton per year.

Table 14: Estimated mass of the waste composition in ton per year

Types of wastes	Share (%)	Mass (t/a)
Vegetable	4.20	20125
Rubber/plastics	2.90	13896
Paper	2.50	11979
Bone	1.10	5271
Wood	2.30	11021
Textile	2.40	11500
Metal	0.90	4312
Glass	0.50	2395
None combustible stones	2.50	11979
Combustible leaves	15.70	75229
All fine	65	311457
Total	100	479165

The quantity of solid waste collected/person/day is 0.46kg and the entire quantity of waste gathered in Addis Ababa is 1313 t/d. (Cambridge industries, 2013)

The generation of waste per person depends on the economy of the country or the affluence of the population in a country which varies from place to place.

Total amount of waste collected per year is equal to 1313t/d ×365d = 479165 t/a

The total mixed mass MSW = 479165 t/a and all the share of the wastes fractions are going to the mass incinerator. Annual thermal (gross) power of the combustion plant for grate fire (transfer losses are not included)

The fuel energy of waste $E_{MSW} = m_{MSW} \times LHV_{ar\ MSW}$, where (4)

m MSW= total amount of collected waste (t/a)

$LHV_{ar\ MSW}$= lower heating value on received basis of MSW

Table 15: Initial values used to calculate for electricity production from grate fire.

Initial value used	Sources
LHV ar = 7.5MJ/kg	(Cambridge industry, 2013)
$\eta_{EEP} = 0.27$	(Cambridge industry, 2013)
$t_{APL} = 7200$h/a	(Cambridge industry, 2013)

Annual Electric production (transfer losses are not included) E_{EL}, for grate fire (GWh/a)

Annual electric production $E_{EL} = \eta_{EEP} \times E_{MSW}$, where (5)

η_{EEP} = Efficiency of the electricity production plant

E_{MSW}= fuel energy of the waste

Electricity output for ϕ_{EL} for (GF) in (MW) = $E_{EL}/t_{APL,}$ where

E_{EL}= annual electricity production

$t_{APL=}$ plant availability (annual peak load period)

5.3 Landfill gas production from MSW (Scenario 3)

Energy from landfill gas is prepared to lessen emissions and gas recovery from landfill activity. It contains process of pretreatment scheme, hygienic landfill activity, land gas gathering scheme, gas consumption scheme, and ecological control scheme which can help to the formation of landfill gas.

The anaerobic decomposition of recyclable portion is commonly a source of landfill gas (LFG). Landfill gas is constantly made because of the anaerobic degradation of the biodegradable portion of solid waste. Landfill gas is a combination of numerous gases methane and carbon dioxide as its key ingredients (Thesis 2013).

The energy potential of landfill gas production from MSW (scenario 3) is calculated below from the Addis Ababa city MSW data. The land fill gas calculation is made by assuming that the gas formed each year from the amount of waste land filled that year. This scenario is introduced to evaluate the volume of landfill gas produced and define the volume of power that could be produced.

Methane emission from a land fill can be calculated using the following formula.

$$m_{CH4} = (MSW_T \times MSW_F \times MCF \times DOC \times DOCF \times F \times 16/12 - R) \times (1 - OX) \quad \text{Where,} \quad (6)$$

m_{CH4}	The mass of methane emission (t/a)
MSW_T	The total amount of MSW (t/a)
MSW_F	Share of waste disposed into the land fill
MCF	Methane correction factor (depending on the type pf landfill)
DOC	Amount of degraded organic carbon in the waste (kgc/kgsw)

DOCF	Share of degrading organic carbon (%)
F	Share of methane in the land fill gas
16/12	Ratio between molar masses of methane and carbon
R	Amount of recovered methane (t/a)
OX	Oxidation degree

The total MSW collected in Addis Ababa per year is equal to 479165 t/a.

MCF the correction factor is taken as 0.6 general value taken from IPCC guideline value DOC assumed to be 0.2kgs/kgsw based on the waste composition of the country.

$DOCF = 0.014T + 0.28$

$0.014 * 22 + 0.28 = 0.588$

The average temperature of Addis Ababa, Ethiopia is estimated to be 22°C (world weather online, 2017). F is 0.5 the IPCC default value.

By applying the above equation, the total mass of methane produced is calculated when R is = 0 and OX= 0 as follows

$m_{CH4} = (MSW_T \times MSW_F \times MCF \times DOC \times DOCF \times F \times 16/12 - R) \times (1 - OX)$

$(479165\ t/a \times 0.75 \times 0.6 \times 0.2 \times 0.59 \times 0.5 \times 16/12 - 0) \times (1 - 0) = 16962.4 t/a$

Mass of the methane collected can obtained by multiplying m_{CH4} with the collection rate of the land fill gas

$R = m_{CH4} * 0.75 = 12721.8 t/a$ (7)

When methane is collected and when oxidation of methane (OX) in the upper level of the land fill is considered to be 0.1 based on the IPCC guide line value

m_{CH4} emission $= (m_{CH4} - R) \times (1 - OX) = (16962.4 t/a - 12721 t/a) \times (1 - 0.1) = 3816.56 t/a$ (8)

Now volume of the methane emission is 3816.5t/a×1000/ 0.717kg/m^3 = 5322873.082m^3/a =607.63m^3/h

The amount of thermal energy generated from the land fill can be calculated using the formula below:

Thermal energy E_{th} (MW) = $m_{CH4} \times LHV_{CH4} \times r$ (9)

Where r, rate of collection of methane

m_{CH4} = Flow rate of CH_4 (M^3/h)

LHV $_{CH4}$= Lower heating value of methane (MJ/M^3) = 36MJ/kg = 26.88MJ/$m^{3)}$

The amount of power can be calculated using electrical conversion factor by the following formula.

E_{ele} (kwh) = $m_{CH4} \times LHV_{CH4} \times r \times \mu$ ele (10)

μ ele = electrical efficiency in gas engine

Table 16: Initial value used for calculating electricity energy from land fill

Initial value used	sources
MCF= 0.6	(Jensen and Pipatti, n.d)
F=0.5	(Jensen and Pipatti, n.d)
DOC=0.2 kgs/kgsw	(Jensen and Pipatti, n.d)
DOCF= 0.588	calculated value
Ethiopia is estimated to be 22 °C	(world weather online, 2017)
rate of collection of methane = 75%	(Surroop and Mohee, 2011)
Density of methane= 0.717 kg/m^3	(Surroop and Mohee, 2011)
Electrical efficiency in gas engine = 33%	(Surroop and Mohee, 2011)
LHV of methane = 36 MJ/kg = 26.88 MJ/m^3	(Surroop and Mohee, 2011)

6 RESULTS ANALYSES

Based on the three scenarios description, calculation equation, and initial values in equations in chapter 5, results are presented in this chapter. Results of each of the scenarios are presented below.

6.1 Mechanical and Biological Treatment (MBT) of MSW: (Scenario 1)

6.1.1 Mechanical Treatment (MT) process to produce SRF from MSW

Based on equation 1 and the values assigned to it in chapter 5, mechanical treatment (MT) process to produce the potential energy to produce SRF is calculated. The result of the calculation produced an annual electricity output of 11.76 MW.

113451 t/a$\times \frac{9.95GJ/kg}{3600s/h}$= 313.6GWh/a

Annual electricity production is = $313.6GWh/a \times 0.27$=84.7GWh/a

Electricity output = $\frac{84.7GWh/a}{7200h/a}$= 11.76 MW

From the above output it can be concluded that the estimated energy potential to be produced from refuse derived (RDF) is 11.76 MW electricity.

6.1.2 Biological Treatment (BT) of MSW to produce biogas using anaerobic digestion

Putting values in equation 2 chapter 5, the amount of methane produced from biogas is 24512661.4 m3/a = 2798.2 m3/h.

Putting values in equation 3 in chapter 5, using anaerobic digestion (AD) thermal energy of methane from biogas =28 MW, the amount of power can be computed by using the conversion efficiency, 0.35× 28 =9.80 MW

From the above equation 3, anaerobic digestion thermal energy of methane produced from biogas is 28 MW and the amount of power computed using the conversion efficiency is 9.80 MW.

6.2 Mass incineration in grate fired furnace (Scenario 2)

Putting the values in equation 4, using mass incineration in grate fired furnace (Scenario 2)

The fuel energy of the waste produced is : $\frac{(479165\ \frac{t}{a}\times 7.5G/t)}{3600s/h} \approx$ 998.26 GWh/a

$\phi_{EL} = E_{EL} / t_{APL} = (269.35\ GWh/a) / (7200h/a) \approx 37.41\ MW$

Therefore, the estimated potential energy that can be produced using mass incineration of MSW in grate fired furnace (scenario 2) in the Addis Ababa city, Ethiopia is electricity of 37.41 MW. This 37.41MW of estimated potential energy in scenario 2 seems to be less than 50 MW which is planned to be produced by the newly under construction waste to energy plant using mass incineration technology in the Addis Ababa city, Ethiopia.

6.3 Landfill gas production from MSW (Scenario 3)

Putting value in equation 10, (607.63m3/h×26.88MJ/m3×0.75) = 12249.8MJ/h= 3.402MW
Putting value in equation 11 =3.4MW * 0.33= 1.12MW, the landfill gas production from MSW (Scenario 3) to produce a potential electricity of 1.12. Therefore, the estimated potential energy that can be produced from landfill gas production from MSW (scenario 3) in the Addis Ababa city, Ethiopia is 1.12 MW electricity.

6.4 Summary of the results

In summary, the potential energy derived from the three scenarios are illustrated in table 17 below. This summary in table 17 below shows derived electricity potential in MWh/a and the municipal solid waste (MSW) used to produce electricity (t/a).

Table 17: Summary of the Three Scenarios

Scenario	Derived electricity Potential in MWh/a	MSW used to produce electricity (t/a)
Mechanical and Biological Treatment (MBT) of MSW (Scenario 1)		
1.1 Refuse derived fuel (RDF)	11.76	113457
1.2 Anaerobic digestion (AD)	9.80	184862
Total	**21.56**	
Mass incineration in grate fired furnace (Scenario 2)	37.41	479165
Landfill gas production from MSW (Scenario 3)	1.12	479165

From the above table 17 which is the result of the analysis of the study, mass incineration in grate fired furnace (scenario 2) offered the highest potential of energy among the three scenarios with 37.41MW electricity. Mechanical and biological treatment (MBT) which is a combination of refuse derived fuel (RDF) and anaerobic digestion (AD) has the second highest potential energy (electricity) of the three scenarios for the city. Finally, Landfill gas production from MSW (scenario 3) has the least potential energy of the three scenarios

7 CONCLUSION AND RECOMMENDATIONS

Based on the literature review, data collected from the Addis Ababa city on MSW, Ethiopia, and the MSW to recovery of energy evaluation as well as analysis of the study, conclusion and recommendations are provided below.

7.1 Conclusion

Energy recovery from waste is the transformation of degradable and not- biodegradable leftover materials into serviceable heat, electricity, or fuel using different processes, comprising of incineration, mechanical and biological treatment, and landfill gas production which are the focus of this study. These waste to energy recovery techniques are reviewed from the literature. Data on municipal solid waste (MSW) are collected from the Addis Ababa, Ethiopia to be evaluated. The data collected were evaluated using three scenarios and estimated potential energy of each scenarios calculated using different equations. As a result of the calculation the scenarios and their corresponding potential energy was recorded as follows.

- Mass incineration in grate fired furnace (scenario 2) offered the highest potential energy (37.4MW) electricity out of the three scenarios for the Addis Ababa city MSW.

- Mechanical and biological treatment which is a combination of refuse derived fuel (RDF) is expected to produce 11.8 MW electricity and anaerobic digestion (AD) is expected to produce 7.34 MW of electricity. Anaerobic digestion is second highest potential energy, next to mass incineration, of the three scenarios for the city MSW.

- Landfill gas production from MSW (scenario 3) has the least potential energy 1.122 MW electricity.

7.2 Recommendations

As can be observed from the literature and the advantages and disadvantages section (6.1.1 and 6.4) in this study, incineration has greater elastic for waste, reduces greater mass and volume of waste, need take small period for removal, produces energy/calorific value, thermal energy recovery for straight heating or energy production generation, hygienic, and appropriate for small space.

All these advantages in addition to the highest potential energy of the three scenarios support the objective of the study and solves the waste challenge of the Addis Ababa city. Objective of the study was assessing the possibility of energy recovery from MSW and contribute to managing of MSW which is to lessen the quantity of solid waste and health associated problems in the city.

The only solid waste disposal site in the Addis Ababa city, Reppi/Koshe, is currently full and no other site prepared to replace it due to lack of land, the site is established 50 years back, surrounded by residential areas, proximate to people and causes nuisance and health hazards. As Addis Ababa, Ethiopia is in a tropical area, the waste site is not aqueous, no high moisture content except during the winter season from mid-June to mid-September every year. Even though nearly 70% of the waste produced in Addis Ababa are organic waste, emission control has to be taken properly as their might be high risk of toxic emission and particulates as in any other MSW.

Although incineration is high capital, operation and maintenance cost, the advantages weigh much more than its disadvantages. This coincides with the output of the scenarios to be chosen mass incineration with highest potential energy for the Addis Ababa city.
The second highest potential energy is scenario 2, refuse derived fuel (RDF) and anaerobic digestion (AD). In the potential power evaluation, the RDF and AD both together have electricity energy which is less than mass incineration.

However, both are clean technologies; use less area, appropriate for organic waste to have great digestion, uncomplicated operation and the advantages weigh over the disadvantages. The MBT which includes the RDF and the AD can be taken as second best option, next to mass incineration, for the Addis Ababa city as potential energy. Therefore, the study has recommended scenario 2 and scenario 1 respectively for implementation for the Addis Ababa city.

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