Municipal Solid Waste – To - Energy For Mozambique

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ABSTRACT - The growing development nowadays on Mozambique is directly associated to the crescent industrialization and the increasing number of the population on enormous cities in Mozambique, special Maputo City the capital of the country: what needs more electrical energy to run them and produce more Municipal Solid Waste (MSW); uncontrolled and putting the City in a challenge to face these scenarios.

Maputo City is facing huge problem of the garbage, without the structure to deal with the Municipal Solid Waste (MSW), which deposited it in the landfill or open dumpsite out of normal conditions, contributing for many diseases and impact of the environment, harmful chemicals and greenhouse gases are released from rubbish in landfill sites when it is burnt or burns spontaneously, the subterranean water body is contaminated with leachate (methane); and proximately 72% of population or citizens have not electrical energy.

The purpose of this work is to use the municipal solid waste as source of energy in Maputo City, using waste-to-energy technology according to the composition of the garbage and increase the capacity of energy which is approximately to 20% in the Country reducing the impact of environment from the landfill and the dumpsites.

The motivations is to use the Municipal Solid Waste as other renewable source of energy, knowing that the country mainly hydropower and solar, wind, biomass in a small quantity, coal, fuel are vanishing; reduce the impact of environment, global warm and ailments caused by it.

The methodologies used to achieve the objectives are thermodynamics, heat transfer expressions and the COCO-OPEN simulation methodology to predate the energy generate from the composition and quantity of MSW.

The results illustrates that it is possible to use Municipal solid waste as source of energy or power according to the conditions of the track, as the calorific value of the waste is nearly equal to the calorific value of the coal which has been used to generate energy in many plants around the world.

Keywords: Composition, Cost, estimation of energy and power for Municipal Solid Waste Maputo City, Mozambique.

1. INTRODUCTION

Solid waste means any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded materials including **solid**, liquid, semi-**solid**, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operation

Energy is life and, if the development of the people keep growing day after day, what results in the need or huge use of the energy than before, turning less the scarce sources of it or increasing the impact on the environment by using Non Renewable sources , one of the harmful and responsible of the emission of green house gases. Because of its importance, many countries has been trying to find the solution for vanish of non renewable source.

Waste is death, Solid Waste is seen as the future alternative source of energy and manifold waste-to-energy technologies are in use around the world illustrating excellent result; They are finding solid waste as useful and are importing municipal solid waste to generate heat and electrical energy; what has been putting their economy stable in one way. The Population and Industrialization grow with generation of different kinds of waste accord to the type of country, whether is developed or developing; balancing the economy much time.

Many developing countries even as Mozambique use to expend tremendous amount of money with the municipal solid waste, and space, which should be resorted for other social infrastructure, like schools and hospitals to serve the needs of their citizens and the economics of these, instead of creating landfill or open dumpsites, answerable of different types of diseases, the most ailments which are very common in the population dwelling by the landfill and responsible of huge deaths in Mozambique are: cholera and malaria, associated to the breeding of mosquitoes, flies, rats, cockroach, and other pests principally in winter; and emission of green house gases, acid rain, global warming caused by the fire on them , and sometimes life is lost when landslides accidents occur, contamination of surface and ground water from leachate;

Table 1: Accident on improper waste disposal

Month and year	Country and City	Number of victims	Cause of accident on the landfill
February 2018	Mozambique, Maputo	16	collapse
August 2017	Guinea, Conacry	9	collapse
March 2017	Ethiopia , Addis Ababa	115	collapse
September 2016	Benin , Cotonou	Over 100	Fire

Source [82]

offensive odours and fires; methane, collapse of waste mountains leading to the loss of many lives; see table number 01, turning the sustainable development in risk; besides this, the countries have about 70% of their habitats without electricity.

Maputo is the capital of Mozambique and home to about 1.9 Million people. It is estimated that the population produces about 1.100 ton of waste per day. It costs between 10 to 25 USD1 per ton to just collect and remove this waste. This is an estimated 15.000 USD per day, 450.000 USD per month or 5,4 Million USD per year.[17] .

Thermal conversion, biochemical conversion and landfill gas are the Waste –to- energy technologies in use actually, which are subdivided by; incineration, gasification, plasma gasification, arc gasification, pyrolysis for thermal methods; aerobic, anaerobic digestion to biochemical method and landfill gas.

The incineration methods needs first a high calorific value, second huge money for maintained, problems of green house gases emission, corrosion of the furnace because of the presence of hydrogen sulphide (H_2S), and must be installed far the habit places, cost of transport to feed the plant with solid waste from long distance and big space for the waste to energy plant. The others processes do not require necessary the `high calorific value and use small area for the waste-to-energy plant, what turn them ideal for the city; less cost of transport, less or nearly zero green house gases emission and operated wet waste or plastic gasification and gasification plant; landfill gas plant uses huge space to collect methane by the protect wells just to not contaminant the water ground, pyrolysis, plasma and landfill gas plant; Landfill gas is a natural by product of the decomposition of organic material in landfills. LFG is composed of roughly 50 percent methane (the primary component of natural gas), 50 percent carbon dioxide (CO_2) and a small amount of non-methane organic compounds.

Anaerobic digestion, landfill gas, gasification, plasma gasification, arc plasma gasification, and pyrolysis technologies are suitable for municipal solid waste in Mozambique, according to the composition, calorific value and condition of the municipal solid waste. It is important to clarify that the best decision to select among these technologies requires further in-depth financial, technical and environmental analysis.

Waste is part of the economy; it is a by-product of economic activity, by businesses, government and households. Waste is also an input to economic activity; whether through material or energy recovery. Equally, costs can be reduced by optimising the management of waste which arises; avoiding also the emission of harmful pollutants to the atmosphere. Sustainable Development Goal, proper and Sustainable Municipal Solid Waste.

Energy that is produced in the form of electricity, heat or fuel using incineration, pyrolisation, gasification or anaerobic digestion is clean and renewable energy, with reduced carbon emissions and minimal environmental impact.

Several technologies have been developed that make the processing of MSW for energy generation cleaner and more economical than ever before; including landfill gas capture, combustion, pyrolysis, gasification, and plasma arc gasification. While older waste incineration plants emitted high levels of pollutants, recent regulatory changes and new technologies have significantly reduced this concern. Models are derived from physical composition and from ultimate analysis. They are determined through Boie, Dulong and Steuer's Model and lab calculations using calorimeters. Individual waste component energy content is used to determine composite energy content.

More studies have to be conducted just to find out the technology to be standardized to the Country and achieve

others sources of energy beside organic matter, papers, plastics, wood, agriculture waste, and However, the decision to select between the two scenarios requires further in-depth financial, technical and environmental analysis using life cycle assessment (LCA) tool.

Data about Municipal Solid Waste generated, collected, disposed and total cost from waste management have to be provided to the knowledge of the Public in general, as they do not exist.

1.1. Mozambique Profile

Mozambique is located on the South eastern region of Africa, coordinates 25.9500° S, 32.5833° E, with total area of 786,380 km², Maputo City is the capital. The country's eastern border lies along the Indian Ocean. Despite its large area, the country only has a Population of approximately 30.8 million (2019) where 64% are rural. The Nation's extensive border bounder land touches six neighbouring countries: Tanzania, Zambia, Malawi, South Africa, Swaziland, and Zimbabwe. It is a developing country with gross domestic production per capita 498.96 USD (2018), gross domestic production growth rate 3.7% annual change (2017) [77].

1.1.1. Maputo Profile

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Maputo City officially named Lourenco Marques until 1976 is the capital and most populous city of Mozambique. The city is named after chief Maputsu I of the Tembe clan, a subgroup of Tsonga people. Located near the southern end of the country, it is positioned within 120 km of the Eswatini and South Africa borders. The Population of Mozambique's capital city, Maputo, continues to grow at a rapid rate as the result of high birth rates and immigration. According to the National Statistics Institute (INE), Maputo City has the population of 1 908 078 (as of 2017)[68] distributed over a land area of 347.69 km²; posing enormous challenges to the local government in its efforts to deliver basic services; The Maputo metropolitan area includes the neighbouring city of Matola. Maputo is a port city, with an economy centred on commerce. It is also noted for its vibrant cultural scene and distinctive, eclectic architecture.[69][70]

The problems combined with the Municipal Solid waste in the capital city are numerous, from inner city to outer city, growing of the population, commerce, industrial and tourism industry are also intangibly linked to the aesthetic beauty and welfare of the town, Caused by the piled heap of garbage disturbs (the aesthetic view and create scavenging problems

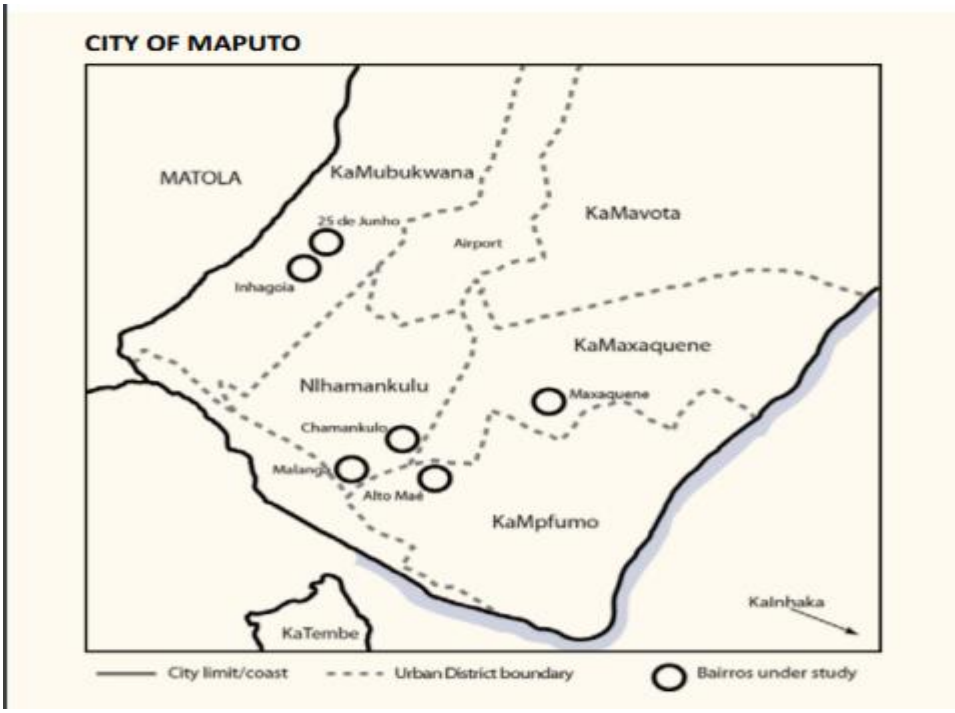


Figure 01: Map Maputo city

1.2. Generation and Disposal of Municipal Solid Waste in Maputo city

Municipal Solid Waste collection and disposal process are the huge challenge to the Developing Countries in the world not only in Africa, for instance Mozambique, which is facing difficult to manage the garbage at all, without any system or structure for that, the municipal solid waste and industrial waste are disposed in the dumpsites or open landfill.

Municipal Solid Waste in Mozambique is dumped in basic open-air dumpsites in all municipalities [6]. At waste dumpsites, waste is generally burnt, buried and compacted. As most dumpsites are situated within the city centre, burning of waste causes air pollution and may release toxic chemicals to the environment harming the nearby residential areas.[5][6][34].

The largest waste dump in country is Hulene site in Maputo City. It is situated in a suburb of the town, about 120 000 m² large, and the only legal dumpsite in the city. About 70% of the city's Municipal Solid Waste as well as industrial waste are dumped at Hulene[5][6][7][34][8].

It is built upon a former wetland in close proximity to the Hulene river which serves as the source of water for the city residents. The site is also threatened by a high water table. The underlying soil is sandy and hence highly permeable. With these conditions, it is very possible that the leachate from the dumpsite can enter and pollute the nearby river and groundwater.[1]

1.3. Composition Municipal Solid Waste in Maputo city

The composition of municipal solid waste varies greatly from municipality to municipality and, it changes significantly with social and economic factors, including population increases, consumption growth, consumption patterns and the technological development of the waste treatment systems during the time. In municipalities which

have a well developed waste recycling system, the waste stream mainly consists of intractable wastes such as plastic film and non-recyclable packaging materials; this is not the case of Maputo city.

The MSW composition depicts a clear difference between the city and the suburbs [3]

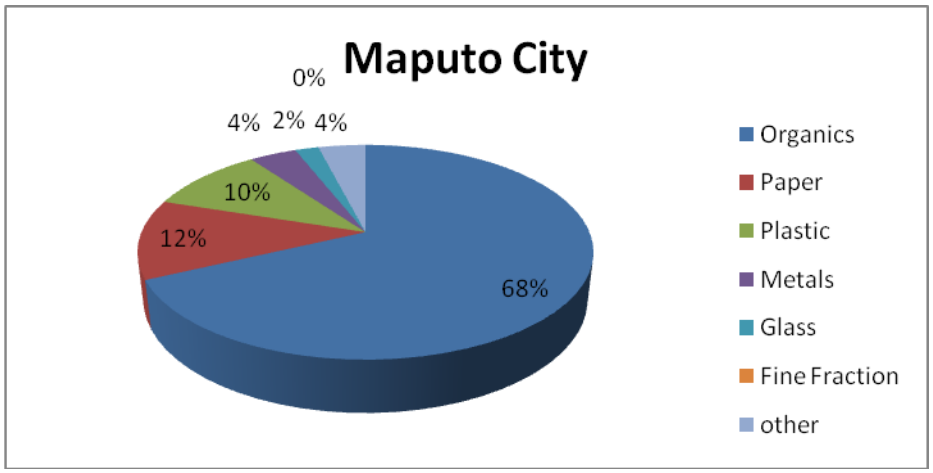


Figure 02: Genaral Composition of Municipal Solid Waste in maputo City [3]

1.4. Need of Waste to Energy Options in Mozambique

At the end of this century, the global energy demand is expected to be about six times more than that of the current demand [30]. The current available energy supply is much lower than the actual energy required for consumption in many of the developing countries. At present, one of the primary sources of energy throughout the world is fossil fuels that meet the demand of approximately 84% of the total electricity generation [25]. Due to rapid depletion of fossil fuel reserves, the world needs alternative sources of energy such as WTE for mitigating the future energy crisis [24]. The problem of disposal of huge quantity of generated MSW and the requirement of reliable source of renewable energy are common in many developing countries.[9] MSW causes serious environmental pollution, thus its use as a potential renewable energy source would serve the purpose of meeting increased energy demand as well as waste disposal.[9]

Technological advancement, improved pollution control systems, governmental incentives and stringent regulations have made WTE technology a potential alternative, especially for the developed countries. It not only provides a source of energy, but also reduces the potential harmful impacts of waste on the environment.[9]

1.5. Present Scenario of Waste to Energy at Global Level

The world population was 3 billion in 1960, which has increased to 7 billion in 2011 and it is expected to reach 8.1 billion by 2025[28]. The dramatic increase in global population coupled with economic development had led to rapid urbanisation and industrialisation, which changed the consumption pattern of the population that ultimately lead to the proliferation of MSW at an alarming rate. Many countries started adopting the WTE technologies for effective management of huge quantity of waste to produce energy. An estimate by the International Renewable Energy Agency, showed that the world has a potential of

generating approximately 13 Giga Watt of energy from WTE sector alone [29].

The results from the waste to energy technologies as well as Incineration and landfill gas illustrate that , an energy potential of all waste generated in Africa of 1125 PJ in 2012 and 2199 PJ in 2025. Nevertheless, if energy recovery through LFG is considered, about 155 PJ could be recovered in 2012 and 363 PJ in 2025 if waste actually collected, or projected to be collected, is considered. The electricity generation could reach 62.5 TWh in 2012 and 122.2 TWh in 2025, in ca

se of full waste collection, compared with electricity consumption in Africa of 661.5 TWh in 2010. If waste actually collected is considered, these estimates decrease respectively to 34.1 TWh in 2012 and 83.8 TWh in 2025. Apart from continental estimates, the study provides detailed information at the country level and a vision of the spatial distribution of energy from waste based on the city population in major African cities.

The European countries such as Netherlands, Belgium, Denmark, Germany, Austria, Sweden and Switzerland divert most of their wastes from landfill for recycling and composting facilities[27] In Asian countries, Singapore recycles 44% of their generated wastes, while in other countries (mostly developing), typically 8–11% wastes are recycled[32]. It has been reported that, some cities such as Hanoi, achieved recycling rate of 20–30%[33]. Many developing countries such as India, Vietnam, and Malaysia have started recovering

Along with domestic production, Sweden also imports trash from Norway and Britain each year to waste to energy power plants.

Most countries with very high recycling rates , such as Austria, Belgium, Germany and the Netherlands have high rates of waste to energy as a sink for pollutants and thereby have reduced landfill to almost zero.

2. METHODOLOGY

The literature review was used to attain the objectives of the work, where more than sixty papers, articles, journals and publication, sites as well as Google Scholar, Youtube, related to waste –to- energy and technologies of waste –to-energy, from 2015 to 2019 used, and to analyse composition, calorific value, characteristics, and to estimate the amount electrical energy generate or heat recovery and the environmental conditions parameters will be done by help of COCO (CAPE-OPEN TO CAPE –OPEN) Simulation Software. Technologies aim to exploit wastes in order to recover energy, decrease the depletion rate of fossil fuels, and reduce waste disposal [52][58][][59].

3. RESULTS AND DISCUSSION

Maputo City Municipal solid waste Facts; municipal solid waste generated in the inner city and suburban areas per person is estimate to approximately ; 1,0 kg/day and 0,56 kg/day respectively[16]. For the present work knowing the absence of the recent data, is assumed the average, which is 0.75 kg/pp/day to determine and forecast the quantity of Municipal solid waste. The tables above provide the evaluation of the population and the Municipal Solid waste in the last ten years and the forecast

The 1.7 million inhabitants in the city of Maputo produce a total of 676 000 kg/day of MSW and the total waste production is close to 980 000 kg/day when industrial waste is added. Material flow analysis for the city of Maputo revealed that waste generation increased from 397 million kilogram in 2007 to 437 million kilogram in 2014 [17]. ; 40 million kilogram in 7 year, approximately 160 million more up to 2050, total 897 million kilogram without place for disposal, will be huge challenge to anyone.

Table 03; Population development in Maputo City [70]

Year (census)	Population
1997	801 449*
2007	1 205 709*
2017	1 908 078*
2027	3 015 997**
2037	4 881 714**
2047	7 808 371**

***census**

** **Projection of Population in Maputo City.**

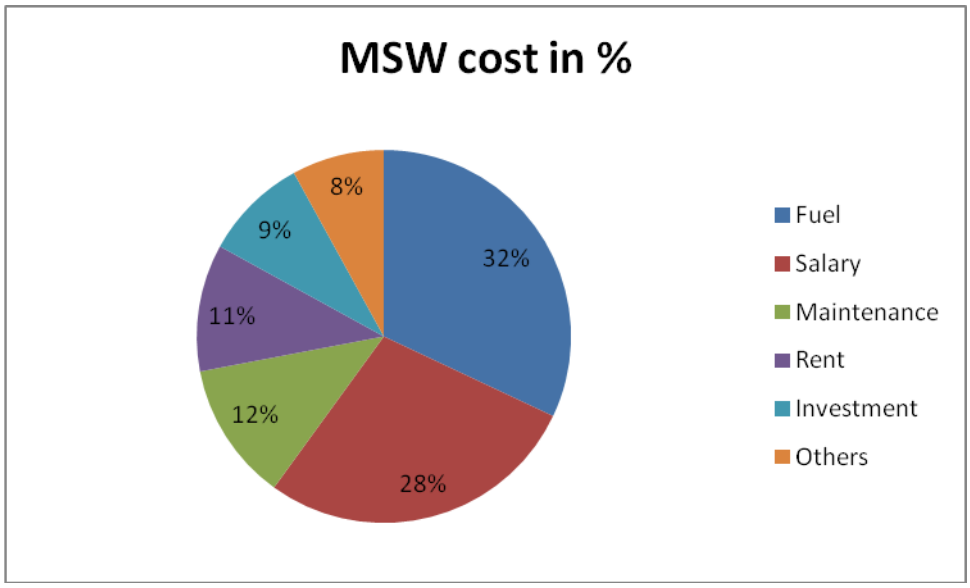
Table 05; Population growth and MSW generation in Maputo City and their projection

Year (census)	Population	MSW ton/day	MSW ton/month	MSW ton/year
1997	801 449	401	12 021	146 365
2007	1 205 709	603	18 086	220 095
2017	1 908 078	954	28 622	348 210
2027	3 015 997	1 508	45 240	550 420
2037	4 881 714	2 442	73 227	890 912
2047	7 808 371	3 904	117 125	1 425 028

The capital of the Nation, Maputo city is the mirror of the problem of MSW collection and disposal in the country, posing the aesthetic and welfare of it and the Citizens in risk;

Maputo city second the National Statistics Institute (NSI) has the population of about 1.9 million, and generate nearly 1 100 ton of solid waste per day, one average of 0, 50 kg/Person/day the Capital.

The municipality in Maputo spent more than US $600 000 per month on waste management system; the high percentage in transport for collection of solid waste and salary, 32% and 28% respectively; the Population are paying a tax for MSW since some years ago [7].



Graphic . 3. Cost of Municipal Solid Waste in Maputo City

Table 06; MSW cost (10 to 25 $ per ton) average value 17,5 $ per ton in Maputo City

Year	MSW ton/day	MSW ton/month	MSW ton/year	cost US per day	cost US per month	cost US per year
1997	401	12 021	146 365	7 017,5	210 525	76 841 625
2007	603	18 086	220 095	10 552,5	316 575	115 549 875
2017	954	28 622	348 210	16 695	500 850	182 810 250
2027	1 508	45 240	550 420	26 390	791 700	288 970 500
2037	2 442	73 227	890 912	42 735	1 282 050	467 948 250
2047	3 904	117 125	1 425 028	68 320	2 049 600	748 4 000

3.1. Calorific value of Municipal Solid waste in Maputo city

The calorific value is the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon or other organic molecule reacting with oxygen to form carbon dioxide and water and release heat.

Knowing the quantity of MSW and, the calorific value of it; we can design the size of the incinerator or any other technology of waste – to – energy and, flue gas treatment system. The calorific value of municipal waste must be approximately equal the value of CV coal, or more than this.

Glass, metal, rubber and inert material are recycled. These materials were neglected during the porportion of the

composite waste to determine the calorific value of the municipal Solid Waste of mozambique. The proportion consider for composite waste is as following considering components of composite municipal solid waste and percentage seen in the table 00.

The components do not refer to inert material, glass, metal and rubber those can be recycled or reused.

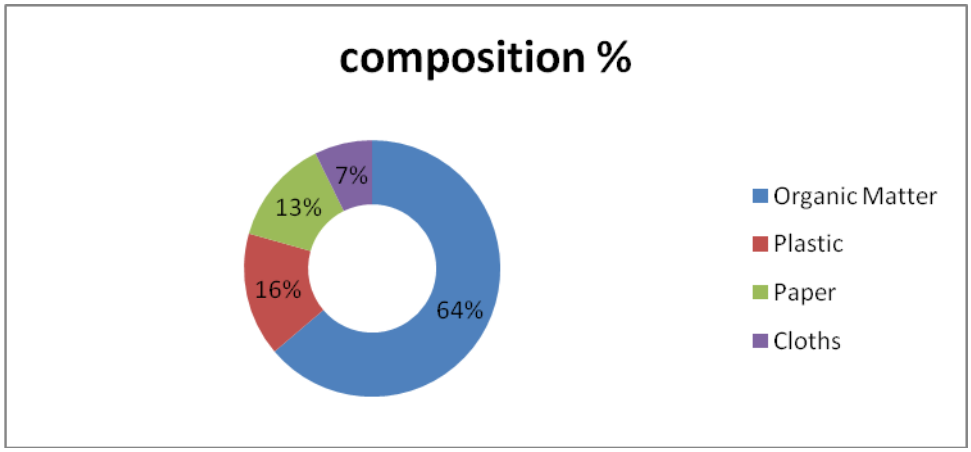


Figure 04: Composition of MSW to Energy in Maputo City

Table 07; Average calorific value of the MSW of Maputo City

	composition %	calorific value mj/kg		X*CV
Organic Matter	63,8	14	0,638	8,932
Plastic	15,6	35	0,156	5,46
Paper	13,3	13,5	0,133	1,7955
Cloths	7,3	30	0,073	2,19
avarege CV Mj/kg				18,3775

A material can burn without supporting fuel when it has a calorific value of min. 14,4 MJ/kg, this is approximately dry wood. To know the overall calorific value of the waste, you need to measure the calorific value or estimate by analyzing the composition.

If the amount of waste is known, and the calorific value of the waste is known, it is possible to design the size of the incinerator and flue gas treatment system.

The average heating value of municipal solid waste (MSW) is approximately 10 MJ/kg to 24.4 MJ/kg, it seems logical to use waste as a source of energy. Traditionally, waste-to-energy (WtE) has been associated with incineration. It indicates the amount of heat that is released when the coal is burned.

The Calorific Value varies on the geographical age, formation, ranking and location of the coal mines. It is expressed as kJ/kg in the SI unit system. Power plant coals

have a Calorific Value in the range of 9500 kJ/kg to 27000 kJ/ kg.

3.2. Appreciation of Energy potential, and Power grid from Municipal Solid waste in Maputo city

Knowing from some literature that 7 200 kWh per year can feed one house in the developed countries, the table 8 shows that more than 1000 house will be consuming energy generated by the MSW in Maputo city.

Literature says that one megawatt can power three hundred and sixty houses. The MSW plant of a capacity of 5 MW can generate power for at least 5% of the rural zone.

From the tables number 9 and 10 of the data from the grid and the population is illustrate that more than 5 % of the homes in the Maputo city can be feed by municipal solid waste plant; what will increase the number and the percentage of household linking to the electrical grid in the town as well as in the hole Country, providing a development of the economy and the welfare in the other hand.

Table 08;

Appreciation of Energy Potential from MSW in Maputo City

Year	MSW ton/day	MSW ton/month	MSW ton/year	MJ per day	MJ per month	MJ per year
1997	401	12 021	146 365	2045,64	61369,2	746658,6
2007	603	18 086	220 095	3077,49	92324,7	1123283,9
2017	954	28 622	348 210	4870,23	146106,9	1777634
2027	1 508	45 240	550 420	7698,12	230943,6	2809813,8
2037	2 442	73 227	890 912	12460,24	373807,2	4547987,6
2047	3 904	117 125	1 425 028	19930,32	597909,6	7274566,8

Table 09;

Forecasting of the electrical power potential from MSW in Maputo City

Year	MSW ton/day	MSW	MSW ton/year	kw per day	kW per	KW per year

		ton/month			month	
1997	401	12 021	146 365	25,57	767,1	9333,05
2007	603	18 086	220 095	38,47	1154,1	14041,55
2017	954	28 622	348 210	60,88	1826,4	22221,2
2027	1 508	45 240	550 420	96,23	2886,9	35123,95
2037	2 442	73 227	890 912	155,77	4673,1	56856,05
2047	3 904	117 125	1 425 028	249,15	7474,5	90939,75

Table 10;

Forecasting of the power grid form MSW in Maputo City

Year	MSW ton/day	MSW ton/month	MSW ton/year	kj per day	KJ per month	KJ per year
1997	401	12 021	146 365	17,72	531,6	6467,8
2007	603	18 086	220 095	26,66	799,8	9730,9
2017	954	28 622	348 210	42,19	1265,7	15399,35
2027	1 508	45 240	550 420	66,69	2000,7	24341,85
2037	2 442	73 227	890 912	107,95	3238,5	39401,75
2047	3 904	117 125	1 425 028	172,66	5179,8	63020,9

5. CONCLUSION AND RECOMMENDATION

The implementation of Solid Waste management structure will help to control the municipal solid waste in the source, before it arrive to the landfill and dumpsites what will reduce the impact of environment, acid rain and global warming and, avoiding many diseases, and the number of landfill and open dumpsites, the team of municipal solid waste will awareness the citizens about the importance of separation of the solid waste to the social and the country economy reducing the cost of collecting and deposit of garbage , as it comes with the new jobs to the population of that particular area.

The quantity of Municipal Solid Waste produced every day in Maputo City and the calorific value which is approximately equal to the coal, one of non renewable source used in thermal plant illustrate the possibility to use it as a source of energy or heat, using technologies like pyrolyse, incineration, gasification, with a good value of or capacity of electrical energy.

Anaerobic and landfill gas are most suitable technologies for the condition of the municipal solid waste of the Maputo city and as well as to the different area in Mozambique

The municipal solid waste plant will reduce the number of landfill or dumpsites and directly the impact of the environment use of non renewable source of energy

responsible of green house gas and global warming and job to the Population.

It is very urgent to separate the municipal solid waste, just to make a good management of it, and avoid the problem of landfills and dumpsites out of control as the process automatically reduce, recycle and reuse ; awareness the population about the risk and Benefits of the solid.

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