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DIFFERENT APPROACHES TO MUNICIPAL SOLID WASTE MANAGEMENT IN BRAZIL: CASE STUDY RIO DE JANEIRO

Examiners: Professor, D.Sc. Tech. Mika Horttanainen
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ABSTRACT

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Inadequate final disposal of municipal solid waste (MSW) is associated with significant greenhouse gas (GHG) emission, environmental, health and safety issues, space consumption, public health and developmental issues in general. The environmental impact of waste is mostly felt in developing countries, inadequate waste management and treatment solution, inadequate policies and outdated practices are some of the factors leading to the significantly high final disposal of waste in dumps in developing countries. Brazil and other developing countries are changing the status quo by adopting polices that will adequately address this problem of inadequate waste management and disposal. Life cycle analysis (LCA) identifies the potential environmental impact of a product though environmental impact assessment, International Organization for Standardization (ISO) created the ISO 14040 and ISO 14044 to serve as principle guidelines for conducting LCA. Various waste treatment solution was applied to identify the waste management solution with the least Global warming potential (GWP) for treating the MSW generated from the city of Rio de Janerio, while reducing significantly final waste disposed in landfill.

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LIST OF ABBREVIATIONS

GHG	Greenhouse Gas Emissions
IPCC	Intergovernmental Panel on Climate Change
EU	European Union
WB	World Bank
MSWM	Municipal Solid waste Management
MSW	Municipal solid waste
LFG	landfill gas
LCA	Life Cycle Assessment
ISO	International Organization for Standardization
LCI	Life Cycle Inventory
LCIA	Impact Assessment
GWP	Global warming potential
ISWM	Integrated Solid Waste Management

1. INTRODUCTION

Over the years rapid economic growth based on economic development, technological development, mass production of goods in Europe, United States, were linked with growing consumption habits that rapidly spread worldwide (Leme et la, 2014;lino and Ismail,2013).The 1980s ushered in the era of increased consumption and disposability, leading to the manufacturing of disposable durable goods that required packaging. Packaging materials used for foods, hygiene packaging were manufactured from non-biodegradable materials, generating millions of tons of Municipal Solid Waste (MSW) worldwide that required collection, sorting, treatment and appropriate final disposal. (Lino and Ismail, 2013).

Urbanization is a leading factor in the increasing amount of MSW generated worldwide, increasing the accumulation of waste through concentrated development and population growth, especially in developing countries with limited waste management knowledge (Ferri,et al,2015). Significant pressure is constantly placed on the environment from increase deposal of MSW in landfills, increasing land contamination, air pollution from the emission of nitrogen, Sulphur and other air pollutants, in addition, to methane (CH_4), carbon dioxide (CO_2) and other greenhouse gasses (GHGs). Landfilling, especially indiscriminate dumping of waste is responsible for polluting ground and surface water. More factors leading to the increase in MSW generation includes, population growth, changes in consumption habits, and patterns of development. (Leme et la, 2014)

MSW is generated from residential, industrial and commercial that resembles waste generated from household, and other human activities, MSW are generally composed of organic degradable matter including, bio-wastes, papers and similar waste, in addition, to non-degradable organic waste including, plastic, and non-degradable inorganic matter including, glass, metal, ceramics and others(Chandrapp,R and Das,D,2013;Lino ,Ismail,2011). Disposal of non-degradable inorganic matter in the Ambient is a major waste accumulator due to the slow decomposable rate of such waste, leading to reduced life span of landfill. (Lino and Ismail, 2011)

Emissions from Landfill gas(LFG) contributes in the accumulation of GHG in the atmosphere globally. According to IPCC 2007, “landfill generates CH_4; CH_4 emission from landfill constitutes the highest emission of GHG from the waste sector”. GHGs emitted into atmosphere traps heat from the sun leading to global warming, resulting to changes in the global climate with a rippling effect on food production, weather pattern, human health, and water supply. (EU, 2001)

Solid waste is primarily disposed in Landfills in developing countries including; Brazil, Nigeria, Mexico, and Turkey, with approximately 90% of the final disposal in landfills (Lino and Ismail, 2011). Municipal solid wastes in developing countries are mostly disposed in non-regulated landfills, majority of waste that are finally disposed in landfills are organic wastes which are considered high emitters of Methane (CH_4), Carbon dioxide (CO_2) to the atmosphere. Emission from CO_2 is biogenic, consequently, emission from CO_2 is unaccounted for in landfill, only emissions from CH_4 and other insignificant gases are accounted for in landfill (leme et al 2014)

Currently, in some developed countries the share index of material and energy recovery from MSW is over 90% (Lino and Ismail, 2013). Germany incinerated 37% of its waste in 2010, 62% of waste was recycled, almost 0% was sent to landfill. Sweden and Denmark had only 1%, and 4% of the total waste sent to landfills in 2010. Finland landfilled 42% of its final waste in 2012 (EEA, 2013). According to Statistics Finland (2015) the final disposal of waste to landfill was drastically reduced to an estimated 17% in 2014. Many factors are responsible for this reduced waste to landfills in the EU including, directives from the EU on the disposal of hazardous waste, non-hazardous waste, and inert waste to landfills. Other factors driving the reduction of final waste disposed in landfills includes, the need to reduce emission of GHGs, environmental health and safety and public health issues.(Horttanainen,M et al,2013)

To mitigate the problems associated with landfilling of MWS in some developed countries waste legislation and policy were enacted, implemented, enforced to reduce the amount of final disposal of wastes to landfills, such legislation and policy includes the EU Directive 2008/98/EC on waste which imbeds the principles of waste management hierarchy of, prevention, recovery, recycling. Prevention of waste tops the priority of waste management with reduction of packaging material, reuse of material. Material recovery of waste ensures that material is recycled for the purpose of prolonging the life cycle of material. Energy recovery is employed when prevention and material recovery is not applicable, energy recovery eliminates any possibilities of material recovery, chemical energy from the material is recovered in form of power, heat or combined heat and power (CHP) (EU, 2008).

In developing countries including, Brazil, similar waste management principles exists and is reinforced by the laws. The ineffectiveness of the system in enforcing, implementing, monitoring the laws is a major impediment in the development of an effective waste management system (Leme et al, 2014).The government of Brazil is trying to change the way final waste is disposed through developing, utilizing alternative waste management systems.

1.1 Background

Brazil is the largest country in South America and is divided into five geographic regions Midwest, Northeast, North, South, and Southeast (loureiro et al,2013).Brazil is a developing country, with approximately 200.4 million people World Bank(WB,2015).Brazil is mostly urban concentrated with 84% of the population living in urban areas, the southeast region dominates the other regions in urbanization and development, with an estimated 56% of the 84% of the total urban population of the country. (Souza et al, 2014) Additionally, Brazil had GDP growth rate of 3.4% per year from 2010 to 2013(WB,2015), increasing the demand for durable and non-durable goods and significantly increasing the growth in municipal solid waste disposal in landfills in the large urban cities in Brazil, including, Sao Paulo, Rio de Janeiro and Curitiba. (Souza et al, 2014)

Brazil economy grew from 2003 to 2013 lifting approximately 26 million people from poverty, reducing inequality significantly. However, GDP slowed in 2011 to 2.1% and 0.1% in 2014 0.1% while ending with a high inflation at 6.4% (WB,2015). There is no immediate threat of an external economy crisis for Brazil despite the poor economic performance, the country has about $360 billion in reserves which is estimated to be 17% of the GDP and the country is backed up with a solid finance sector (WB2 2015)

Population growth in Brazil has remained modest with an increase of 0.9% from 2010 to 2011, the MSW generation has increased by 1.8% in the same period (Souza et al, 2014). Due to the lack of adequate policies over the years 60% of Brazilian cities still dump their waste in open dumps (ferri et al 2015;Leme et al ,2014).The generation of waste per capital in Brazil was 381.6 kg person^{-1} year^{-1}. In 2011 an estimated 55.5 million tons of urban waste was collected with the southeast region contributing a total 53% of the collected MSW. 42% of the waste was treated appropriately in sanitary landfill facilities, while 58% were treated in inappropriate non sanitary landfills and disposed on land (Souza et al,2014) , representing a serious environmental , social problem.

In Brazil, the primary means of discarding MSW with no economic benefit is through landfill (M., Soto. et al 2013; Loureiro.et al, 2013). Utilization of landfills for waste treatment in municipalities in Brazil is mainly due to economic and technological factors, consequences attributed to landfill of waste in Brazil includes, emission of GHGs, land pollution, ground , surface water pollution, public health issues, space depletion. The Brazilian government is seeking alternatives waste treatment solution. Hence, the enactments of laws to monitor, regulate, and develop alternative options for waste management in Brazil. (Souza et al, 2014)

National Solid Waste Act 12,305/2010; the law mandates all MSW with no economic benefits to be disposed in sanitary landfill, this law encourages the use of alternative waste treatment methods before final disposal of waste to landfill such waste treatment includes incineration of waste. (Lino and Ismail, 2013)

The state of Rio de Janeiro is the third most populous state in Brazil and is located in the southeast region of the country. (loureiro et al 2013).Rio de Janeiro city is the capital of the state and second largest city in the state with a population of 6.5million inhabitants. MSW management in the city is managed by the Urban Cleaning Company of the city COMLURB (Carvalho. Et al 2011; Rio de Janeiro 2015) .Significant amount of waste generated in the city is disposed in a landfill, similar to other cities in the country(S Maier; L Oliveira; Carvalho. Et al 2011; loureiro et al 2013), city has a Municipal Plan for Solid Waste Management (PMGIRS) which the city is presently implementing to ensure that it achieves a reduction of GHG in compliance with the Municipal Act of climate change (Act nº 5.248/2011) which targets reduction GHG as follows 2012 8%, 2016 16%and 2020 20%. (RIO, 2012)

Finland has a population of 5.5million inhabitants, (Statistic Finland 2015), an industrialized country in the Northern part of Europe. According to OECD (2015), Finland has used economic incentives, especially taxation, to promote green growth leading to considerably reduction in the intensity of GHG emission since 1990. Further ambitious emission reduction target are been implemented including the EU directive on reduction of biodegradable waste to landfill (OECD 2015).

In Finland the total GHG emission from waste management sector decreased 48% since 1990, most of the reductions emanates from the reduction of landfilling of waste in Finland (Hupponen et al 2015; EEA, 2014).However, landfilling of waste still produces 84% GHG from waste which is considerable high, since municipal waste in Finland is approximately 3% of the total waste (Horttanainen et al 2013).

Finland is still reducing the final waste disposed in landfills to fulfill its own target of 50% recycling by 2016. (EEA, 2013). Currently, Finland is still a long way from achieving its set target on the EU waste hierarchy; Finland is still mostly in the stage of waste to energy recovery with approximately42 % of MSW recovered through incineration. (Statistic Finland 2014) However, Finland has developed and is utilizing efficient waste treatment technology which could be beneficial to some developing countries, that are developing a waste management system with the purpose of utilizing alternative waste treatment solution (sokka et al, 2007)

Finland made strides to meet the target of 20% for landfill disposal of waste by 2016, with almost 20% of MSW disposed in landfills in 2013, compared to 42 % deposited a year earlier (Statistic Finland 2014). According to Statistic Finland, incineration of waste is on the increase with eight plants running, 14 waste co incineration plants. Material recovery from Finnish waste is still slightly constant, however, energy recovery increased significantly, accounting for 75% recovery rate from Finnish waste. (Statistic Finland 2014)

This thesis, analyzed and made comparison to the waste management legislations and policies in Brazil and Finland, for the purpose of adopting MSW treatment solutions that were utilization in the second part of this thesis for modeling alternative MSW treatment solutions for the city of Rio de Janeiro, similar to the systems utilized in Finland. The main purpose for this thesis is described below.

- Analyze the possible potential for reducing GWP through material recovery and energy recovery from MSW while reducing final waste to landfill in Rio De Janeiro, Brazil.

1.2 Motivations for the research

The share of population of the world living in urban city was 54% in 2014 according to the United Nations ,(2015) and by 2050 this number is expected to grow to 66%.Brazil has a total urban population of 85% and other developing countries are moving in the similar direction with Brazil. (United Nations, 2015) Without a sustainable MSW management system that would sustain the enormous waste that will be generated by the massive growth in population, the potential for public health and environmental disaster is very real especially in the developing countries. Brazil and Rio de Janeiro city are perfect case studies with current high urban population. Developing a sustainable MSW management solution to solve the increasing MSW problems in Brazil may encourage other emerging countries to develop similar systems.

2. OVERVIEW OF MUNICIPAL SOLID WASTE MAGENMENT

Municipal solid waste definition varies in different countries reflecting the diverse waste management practices between countries, regions or continents. (EEA 2013) From the analysis of various materials utilized for this report. MSW management was found to be most diverse between industrialized countries and developing countries.

Industrialized countries generate more waste than developing nations, however, waste management is better organized in industrialized nations reducing the amount of waste disposed in landfills (H Campos 2013), material recovery and energy recovery is emphasized in developed nations. Waste is constantly treated as a commodity leading to the introduction of waste management policies. The strict enforcement of such waste policies enacted by governments, regional blocks in developed countries are major priorities for most of the countries. Policies including the EU legislation and directives on the reduction of final waste to landfill, the directive on recycling from waste, the directive on the limits of emission to air of pollutants from incineration of waste. (EEA 2013).

Developing countries are moving towards developing sustainable MSW management systems, waste management in most developing countries are strongly connected to economic, and health issue (Munnich, et al 2005) Landfilling of waste is the most wildly used waste management system in developing countries, wastes are disposed in open dumps due to, the high cost of using other forms of waste treatment solution ,inadequate technological knowledge, lack of awareness on the potential dangers associated with the exposure to waste and the harm to the environment. This uncontrolled dumping of MSW constitutes a seriously public health issue and has been linked to direct effects on child health, water borne diseases and widespread flooding in many developing countries, developing countries may find it expensive to use other form of waste treatment solutions without subsidies from government or funding from developed countries, (Wilson et al 2014)

A major factor leading to the increasing MSW issue in developing countries is the recent growth in urbanization of cities in developing countries, leading to increase in waste generation and with limited resources and only basic technology in the treatment and final disposal of waste. MSW is becoming a serious environmental issue; deficient enforcement of regulations, policies on waste is another challenge facing MSW management in developing countries (Chen et al., 2010; Couth and Trois, 2010).

2.3 Solid waste management policies in Finland

Waste legislation in Finland is mostly based on EU legislation, the Finnish legislation on waste are stricter on standard and limits in some areas compared to the EU legislation on waste. According to the Environment Ministry of Finland (2015) the Government of Finland adopted a waste plan in 2008, the plan known as The National Waste Plan for 2016, highlight the aims of waste management in Finland. The objectives of this plan includes

- Preventing waste generation
- Promoting biological recovery of material and recycling of material
- Increase incineration of waste unsuitable for recycling
- Reduction of harmful effect from waste treatment and final disposal
- Reduction of GHG emission generation from waste by reducing the amount of biodegradable material disposed in landfills and the recovery of CH_4 emitted from the treatment of waste in landfills.

The plan is aimed at achieving a decline in the amount of municipal waste by the year end of 2016,the plan targets a 50% MSW material recovery and recycling, 30% energy recovery and a maximum of 20% waste treatment in landfills. (Helda; ministry of environment 14/2009 ;SYKE.2009).Waste management in Finland is covered by various acts and decree that covers all types of waste with exception to radioactive waste which are covered by separate waste law (Environment Ministry of Finland 2015)

In Finland, issue connected to the negative impact of waste to the environment is addressed in the legislation on the environmental protection ACT 527/2014, the environmental protection Decree 713/2014. However, General waste in Finland is covered by the waste Act 646/2011, and the waste decree 179/2012 (finlex 2013). Waste treatment and recovery is covered by the government decree on waste incineration 151/2013, the recovery of waste in the earth construction is covered by decree 591/2006 (finlex,2014).

Waste Act 646/2011 with amendments up to 528/2014 defines waste as "any object which the holders discards, intends to discard or is required to discard" the same act states that an object is not a waste but a byproduct if it results from a production process, whose primary aim is not the production of the object, including

I. further use of the substance or object is certain;
II. the substance or object can be used directly as is, or without any further processing other than normal industrial practice;
III. the substance or object is produced as an integral part of a production process; and
IV. the substance or object fulfills all relevant product requirements and requirements for the protection of the environment and human health for the specific use thereof and, when assessed overall, its use would pose no hazard or harm to human health or the environment.

The purpose of the act is to prevent hazard and harm to human and the environment posed by waste and waste management, reduce harmfulness of waste and the reduction of waste in general. Furthermore, the act promotes sustainable use of natural sources, ensuring a sustainable waste management and prevention of littering due to waste.

The decree on waste (179/2012) defines the purpose of different waste separation and collection, the decree contains a list of operations that constitutes recovery and final disposal of waste (Finlex, 2014).In Finland municipalities are responsible for MSW management, including transportation recovery and disposal. However the producers of waste are responsible for the cost of recovery or disposal of waste (Finlex, 2014; SYKE, 2014)

Municipal solid waste management in Finland is typically based on the directive from the EU, some of the directives includes, the directive 2008/98/EC that establishes the legal framework for waste treatment in EU, setting the definition and waste management principles for all EU legislation on waste management including the Finnish waste legislations, including the terms "polluter pays principle" and the "waste hierarchy”. Furthermore, directive 1999/31/EC on the landfill of waste which obliges Member states including Finland to minimize biodegradable waste to landfills to 75% by 2006, 50% by 2009 and 35% by 2016, and to treat it before disposal, the directive similarly describes system of operating landfill and waste accepted in any landfill. Other directives on waste management includes directive 2000/76/EC on the Incineration of Waste, Waste Incineration Directive (WID) enforces strict operating conditions and technical requirement imposed on waste incineration plants and co incinerating plants to reduce limits of emission to air ,water, soil from pollutants. (Municipal waste Europe 2015)

2.1 Solid waste management policies in Brazil

In August 2, 2010, the federal government of Brazil Institutionalized law No.12.305, this lead to the establishment of National Policy on Solid Waste (PNRS), amending Law No 9605 of 12 February 1998. The law is regulated by decree 7.404/2010 (PNRS2010; Rio de Janerio, 2015; S.Maier, L.Oliveira, 2014). According to the law No.12.305, establishing PNRS provides the set of principles, objectives, instruments and guidelines, for integrated management of solid waste in Brazil. Furthermore, the policy subjects every stakeholder to comply with the Act, and provides directives for stakeholder’s responsibilities in waste management, including delegating of responsibility of waste management to stakeholders, according to their involvement in waste generation “producers pay”. (S.Maier, L, Oliveira, 2014; PNRS, 2011). The law does not apply to radioactive waste, radioactive waste is regulating by specific law. (PNRS, 2010; COMLURB, 2011).Apart from PNRS, other federal laws applies to solid waste management, such laws includes; 11.445/2007(National policy on Sanitation), law 9.974/2000(law of pesticide and its related components), and law 9.966/2000(law of oils and other harmful and dangerous substances in waters), finally law 6,938/1981(National Policy on the Environment). (S.Maier,L.Oliveira, 2014; COMLURB, 2011)

According to Act 3 of PNRS, 2010, Municipal Solid waste Management (MSWM) refers to a set of exercises that shares directly or indirectly, in the stages of waste collection, transport, transshipment, treatment and disposal, the act, emphases the appropriate environmental disposal of MSW, and environmentally sound disposal of tailings. Municipalities are required to adopt an integrated solid waste management plan that utilizes a waste management solution that incorporates; political, economic, environmental, cultural and social control, under the principle of sustainable development. (PNRS, 2010)

PNRS is aimed at an environmental sound MSWM, that subjects every stakeholder to comply with the law of waste management in Brazil, including individual and public entities, and the proper delegation of responsibility to stakeholders, including producers, public authorities, and individual responsible for generating waste both directly or indirectly. (PNRS, 2010; .Maier,L.Oliveira) Furthermore, the policy is aimed at avoiding risk to public health and safety, and minimizes adverse environmental impact from waste generation and disposal. (PNRS, 2010)

The process of facilitating the collection of MSW for the purpose of recycling, material recovery or for environmental sound disposal of waste, from consumers to the business sector is referred to as Reverse logistic in the Brazilian waste act. The procedure utilized by producers has to ensure that waste Reverse logistic serves as a tool for economic and social development (G.L, Ferri, 2015; PNRS,) The waste act also emphasizes that environmental sound waste disposal to landfills, this should be an orderly distribution of waste in landfill in accordance with specific operational rules, that avoids risks to public health and safety, at the same time minimizing adverse environmental impact. (PNRS, 2010)

In Brazil, it is the responsibility of federal government to establish laws and guidelines for urban development, policies that covers housing, sanitation and urban transport (Carvalho2011, S.Maier, L, Oliveira, 2014; COMLURB, 2015) However, it is the responsibilities of individual states to integrate, organize, plan and execute public services that relates to MSW management. (COMLURB, 2011; S. Maier, L, Oliveira, 2014)

2.3 Comparison of waste management polices between Brazil and Finland

Brazil and Finland share many similarities in MSW management policies, both countries have general laws that serve as guidelines for the management of MSW. In Brazil the Law No. 12.305, Established the National policy on solid waste (PRNS) this law was the tool used in defining MSW, the objective of waste management, and scope of waste management. While, the National Waste Plan for 2016 was the tool used in outlining the aims of waste management in Finland, Finland has general legislation on waste. Waste Act 646/2011 and the Government decree on waste (179/2012)

Waste management responsibility in Finland belongs to the municipalities including the proper collection of waste, treatment of waste. In Brazil the same principal applies, municipalities in both countries outsource the management of waste to companies. The responsibility for the cost of waste management in both countries belongs to the producers of waste. In Finland waste management is influenced by the EU legislation on waste, through a number of directives and binding target set by the regional block, EU, influences waste management in Finland.

In Brazil the waste management is based on the national legislation, the Brazilian waste legislation has no binding targets on the reduction of biodegradable waste to landfill; some targets exist for municipalities for the reduction of GHG generated from waste. However, targets are not binding.

Waste pickers are recognized by the waste management law of Brazil, under Art 40 of PRN, pickers are included as legitimate participants in collection of reusable, recyclable materials under associations. Pickers have contributed immensely in material recovery especially scarp metals all over Brazil, the practice provides a source of income for the poorest in the society pickers are forming groups to better their way of life. However, this practice could be harmful to human health and wellbeing, considering that most of the pickers generally conduct their picking from open dumps and waste bins without proper equipment or training exposing them to all sorts of diseases, the monetary rewards may not be sufficient to improve the standard of living of pickers, hence, keeping them below acceptable standard of living.

In Finland, waste management is a strictly done by waste management companies, with very advance waste management solution, the Finnish law on waste does not recognize picking by individuals as a waste management solution. However, individual are encouraged as pickers for monetary rewards, and for environmental protection purposes.

In Brazil, sanitary landfilling of all waste is fully acceptable as a waste treatment solution for all waste; Brazil has provisions for recovery and recycling. However, there are no targets set on recovery limits. In Finland, directive from the EU plus national legislations have binding targets to reduce waste generation, disposal. In Finland energy recovery and material recovery from waste is highly practiced. In Brazil treatment of landfill gas (LFG) before flaring is practiced, energy recovery is gradually been practiced in some cities in Brazil including Sao Paulo (Mendes et al 2004).

Brazil is a developing country, while Finland is an industrialized country. Finland produces more waste per capital than Brazil the generation of waste in Finland is 500kg per capital in 2004-2012 (EEA 2, 2015).In Brazil the generation of waste was 382 kg per capital in 2011-2012(ABRELPE,2012). Generation of waste in Brazil may grow still in the future if the country continues to develop and the population keeps moving to the urban cities.

According to Statistic Finland (2014) bio-waste share of the waste fraction in Finland was 15 percent; portal (2015) listed the share of bio-waste in the Brazilian MSW fraction at 55 percent. Bio-waste in landfill is highest emitter of GHGs; the significant composition of organic in the Brazilian waste may lead to a higher emission of GHG from the waste compared to the Finnish waste. Enforcing the EU directive on the reduction of final organic in landfill, would further reduce the GHG produced from Finnish waste in landfills

Prudence demands the development of more sustainable ways of treating and reducing the final disposal of waste to landfills, to support a rapid urbanizing country like Brazil, while reducing the potential for future environmental and health problems from unsanitary waste disposal. The second part of this thesis analyzes the utilization of alternative waste treatment solutions using the city of Rio de Janeiro Brazil as a case study.

2.4 Alternative MSW treatment system

The thermochemical treatment of solid waste or conversion to gas for the purpose of utilizing the chemical energy of waste for heat, electricity or chemical fuel is referred to as waste to energy. (Arena et al 2015) Thermochemical conversion can be grouped into two categories, combustion and gasification based thermal treatments.

Combustion is the oxidation of combustible waste residue usually in the presence of oxygen, energy recovery from combustion allows for significant recovery of energy and a significant reduction in the volume of solid residue to be sent for final disposal. While gasification, is the process of converting the volatile compounds under controlled oxygen flow with significant low oxygen needed for complete combustion into gasses the dominant gases are CO_2, CO, H_2, CH_4 the process of gasification allows for a dramatic reduction of the waste volume .(Arafat 2013)

The waste to energy treatment solution adopted as an alternative to landfill in this report was waste incineration. Incineration of waste for purpose of energy recovery is defined by IPCC (2006), as the combustion of solid waste and liquid waste in controlled incineration facilities, incineration types includes; MSW, industrial waste, hazardous waste, clinical waste and sewage sludge.

Composting another waste treatment utilized as an alternative for landfill in this report, is an aerobic biological process of biodegradable organic matter conversion to compost. (Hrad et al 2014).During composting, biodegradable material is mineralized by the microbial communities present in the waste. (Anderson,et al2010).

3. MSW POLICIES AND MANAGEMENT IN RIO DE JANEIRO CITY

In Brazil, management of MSW in each municipality is the responsibility of authorities in charge of governing that municipality; each municipality may decide to delegate the services of waste collection, processing and final disposal to another party. (Ferri, 2015; Maier, and L, Oliveira, 2014) In Rio de Janeiro city, the service of MSW management is delegated to the "Municipal Urban Waste cleaning company" (COMLURB). The majority shareholder in the company is the municipality of Rio de Janeiro; the company was formed in accordance with Law No 102/1975. The company is delegated with the responsibility of collecting, transporting, storing, recycling, recovery and the disposal of the waste generated from the City (COMLURB, 2011)

The waste management company of Rio de Janeiro state, COMLURB is subject to both federal and state legislation on MSW management, including PNRS, and the state policy on solid waste 4.191/2003.The company is required to function under the Municipal law on cleaning 3.273/2001 and the regulating decree n 21.305/2002, and the Municipal law on the integrated management of solid waste under Law n 4.969/2008.(.Maier,and L. Oliveira,2014)

In 2003 the state of Rio de Janeiro established the Law no 4191 State Policy on Solid Waste, in an attempt curtail inadequate waste disposal. The law was a state policy for solid residues, selective waste separation, and proper waste disposal to sanitary landfill was the aim of the policy, which targeted the 92 province of the state.(S.M,Loureiro 2013; .Maier, L. Oliveira, COMLURB)

Wastes generated in Rio de Janeiro city are transferred to seven transfer station, Caju stations functions as recycling plants.(S.M, Loureiro,2013;S.Maier,L.Oliveira,2014,Ciclus 2015).
Recycling of metal in Rio de Janeiro like most cities Brazil is mainly driven by waste pickers. Picking is centered towards scrap metal for financial gains, in Rio city pickers are estimated to have increased recycling of metal by 3%.Brazil recycling of aluminum cans, in 2010 it reached a rate of 98% recovery rate.(M,Soto and F, Zamberlan 2013)
Caju has the highest capacity for storing waste with an estimated total capacity of 3000t/d. (Ciclus, 2013) All the wastes generated from the city are presently disposed in one landfill, the Seropédica landfill. According to Ciclus (2014) the landfill has the most secured, modern and

efficient solution for landfill waste treatment. The design features of Seropédica consist of a bioenergetics landfill leachate treatment, and a biogas capture and treatment station. (Ciclus 2014).

Table 1 Rio de Janeiro Transfer stations, capacities and distances to Seropédica landfill

Transfer stations	Capacities t/day	Distance to Seropédica landfill in km	sources
Santa Cruz	1100	37,5	Ciclus 2015 COMLURB 2014 Google map
Jacarepaguá	730	57,1	
Bangu	1800	36,2	
Marechal Hermes	730	45,4	
Penha	1500	56,5	
Taquara	730	51,2	
Caju	3300	66,8	
Total	9900		

Waste from the various transfer stations are sent to one landfill, the Seropédica landfill

3.1 Current municipal waste treatment in the city of Rio de Janeiro

3.1.1Controlled landfill

According to Brazilian Technical Norms Association (ABNT)" *a controlled landfill is a method for disposing of MSW in the ground without causing hazards or risks to public health and safety, minimizing environmental impacts. This method employs engineering principles in order to restrict the waste to the smallest area possible and to reduce it to the lowest permissible volume, thereafter covering it with a layer of earth at the end of each working day or at shorter intervals if necessary…"*(ABNT NBR 8419, 1984).

MSW treatment in controlled landfill is based on anaerobic digestion (without oxygen) of organic material present through bacteriological processes leading to decomposition, the product from anaerobic digestion of waste is a mixture of biogases including, CH_4, carbon dioxide (CO_2), hydrogen (H_2) and sulphuric acid (H_2S) The average composition of biogas is CH_4 41%, CO_2 34%, $N_2$2% and O_2 2%(U.S.EPA, 2008). The biogas composition is dependent on the amount of air infiltration. However, it is assumed that 50% of the carbon degrades in the landfilled is converted to CH_4 and the rest is converted to CO_2 50 %(IPCC3, 2006)

3.1.2Technology used in Seropedica landfill

The Seropedica landfill is currently the only landfill used by COMLURB to dispose the waste generated from the city of Rio de Janeiro, a controlled landfill that utilizes a triple soil seal layer made with reinforced webs of high density polyethylene (HDPE), and sensors connected to software that indicates any abnormality in the soil. The soil around the landfill is protected by a complete waterproof system, several protective layer exist between the soil and the waste residue, which is referred to as cell. a meter of clay, one blanket of HDPE 1,5 millimeters,30cm sand, geotextile fabric,15cm clay, HDPE blanket 2mm,and finally ,over 50 cm clay. Waste depositing is done in layers the ground gets 30cm of clay after each deposit of waste. (COMLURB, 2012)

Placing a layer of sand and a layer of compacted clay which practically prevents the seepage of liquid in the soil is the first stage of sealing, above this seal, a layer of HDPE material is placed, it is expected to have a useful life span of 700 years. A layer of sand and clay is applied on which the electrodes are placed. Every 20 meters a network of sensors will be deployed, totaling about 200 in the first cell, which is approximately 140 thousand square meters. The sensors are used in detecting any spill between layers. In case of any breakage in the web, the electricity current flows and the circuit between the poles are closed; the information generated goes to the control boxes. The data is analyzed by specific computer software that generates drafts and reports based on the results of monitoring (COMLURB, 2012)

4 METHOD AND MATERIAL

4.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is a methodology developed to enable manufactures and service providers analyze the environmental impacts and effect of their products and services, through collation and assessment of the inputs and outputs of the potential environmental impacts of their product and services during the lifecycle. The framework for conducting LCA was released by the International Organization for Standardization (ISO) from the period of 1997 to 2000, resulting in the standards ISO 14040, 14041, 14042 and 14043. The standards were updated in 2006, amalgamating previous standards to ISO 14040 and ISO 14044 (J.Pryshlakivsky and C .Searcy, 2013)

Inputs are the products, material resources or energy that are required or that enters a unite process, while outputs are the products, material, emission to diverse departments such as air, water and soil, or energy flow that leaves the system. According to W. Klopffer (2013) two constitutive unique features distinguishes LCA from other environmental assessment methods, the two features includes analysis from cradle to grave, Functional unit. Application of both futures allows for comparison of product system with similar purpose or that serve the same purpose. In cradle-to-grave analysis, product defined as goods and services is analyzed from origin to the end of life or reuse, recycling to material recovery. (W. Klopffer and G, Birgit2013)

LCA addresses the potential environmental impact of a product throughout the products life cycle, from raw material acquisition, production of the goods, use, end of life treatment, recycling, the final disposal of the product (cradle to grave).This process allows for strategic environmental planning by leaders of industry, product, and processes comparison, compliance to environmental laws can be supported with LCA. LCA is one of several environmental management techniques it might not be appropriate techniques for all situations. Typically, LCA does not address economic and social aspects of a product. (GABI 2015, ISO 14040 and ISO 14044)

4.2 life cycle assessment phases

The ISO created the ISO 14044 to serve as a principle guideline for conducting LCA.LCA comprises of four phases:

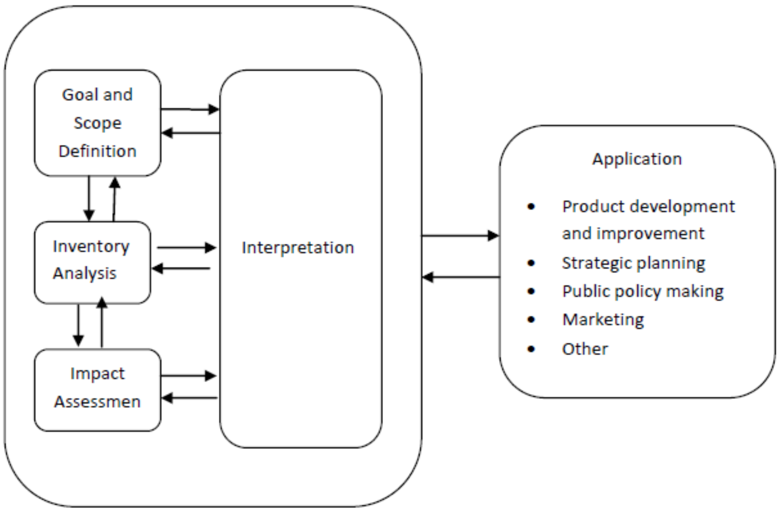

Figure 1 LCA framework (ISO 14040, 2006)

4.1.1Goal and scope definition

General decisions for setting up the LCA are made in Goal and Scope phases. Goal and scope should be defined clearly and shall be consistence with intended application. Goal defines the reason and overall objectives for the study, additionally, the target audiences are defined. The use LCA to make comparison between alternative waste systems in this report will be determined at this stage.

The scope, describes the product system. The entire assumptions made are described in the scope including, system boundaries, selected impact categories for analysis, data quality requirement, allocation procedures. In the scope definition it is important that the actual system boundary is used in order to determine if the LCA takes account of part of the life cycle or the entire life cycle. The method used in setting the product system is described in the scope phase. Description of the product requires function description

The function of the product has to be defined when describing the product, including the demand the product is meant to fulfill, this is vital when comparisons are to be made between two or more product with different ranges of functionalities, for this a functional unit is defined. A functional unit is the quantified definition of the product system with a physical unit, and a functional unit shall be consistence with the goal and scope of the study. A reference to which input and output data are normalized which is one of the primary purposes of the functional unit has to be defined. A reference flow is the measure of the product unit and material required to fulfill the function as defined by the functional unit. To determine the structure of the life cycle system, the system boundaries are determined

The system boundary are defined by cut off criteria, the cut off criteria allows for the definition of the unit processes included in the system, hence are taken into account in the life cycle assessment, and the excluded are cut off from the system. To ensure relevant processes are taken into account, application of cut off criteria is usually applied in combination. In comparative LCA, processes used in both product systems are usually cut off since comparison will make no difference in the overall result, this process was applied in this comparative LCA. Common system boundary types includes; cradle to grave, cradle to gate, gate to gate and gate to grave. The boundary type that was utilized for this analysis was the cradle to grave analysis.

Additional aspect of LCA to be taken into account includes allocation. When more than one product is produced from a process the input and output data are partitioned according to the relative contribution to each product this is referred to as allocation. Allocation can be calculated based on mass, energy value and when not avoidable should be made on a physical property, ISO 14044, advices that allocation be avoided since it is difficult process. However, if allocation cannot be avoided, the inputs and outputs of various products and by product can be apportioned to replicate various contributions based on certain characteristics. Two methods may also be utilized, substitution, system expansion when avoiding allocation, system expansion was utilized in this report since different output was compared

4.1.2The inventory analysis

This phase involves the modeling of all the processes essential in the system in order to calculate the Life Cycle Inventory (LCI). Typically modeling involves a number of stages including the collection of data, the data collected are typically quantitative, qualitative data for every process in the system, this may be done by collecting primary data or through the collection of secondary data. For this report secondary data was used for this inventory analysis. The data collected must be connected to the functional unit and validated, after data collection is done a model of the system product may be built. LCI is essentially the table listing all the material and energy input and output, the LCI result allows for the calculation of the Life Cycle Impact Assessment (LCIA).

4.1.3 impact assessment

LCIA is used to identify and evaluate the amount, significant potential environment impact of a product system, the LCIA can be calculated using four steps. Two are mandatory classification and characterization, while normalization and evaluation are optional steps. Classification is a process of assigning each resource and emission to one or more impact categories. Impact categories are scientific definition linking specific substances to specific environmental issue including, Global warming potential (GWP), acidification, eutrophication.

Any emission to air that contributes to Global warming potential (GWP) impact category such are CO_2 and CH_4 are classified as contributors, substances may contribute to more than one impact category such contributors are classified as contributors to all relevant impact categories, for this report only GWP impact category was considered and the contributes are CO_2, CH_4 and N_2O.

Characterization is the conversion of the result of the LCI into reference unit of the impact category, every quantity is multiplied by a characterization factor, characterization factors are determined by different scientific groups based on different methodology and philosophical view on environmental issues, the most widely used methodology methods are Traci in the United States and CML in Europe. For this report the analysis of the GWP was carried out using the Life Cycle methodology in Accordance with the ISO 14040 and the ISO 140440 Standard. LCIA was determined in compliance with the Centre of Environmental science at Leiden University, (CML 2001-APRIL.2013).

4.3 application of method

Currently, the city of Rio de Janeiro disposes and treats MSW in the Seropédica landfill. The CH_4 from the landfill waste is treated before flared to the atmosphere as CO_2 in accordance to the specification provided by law. Alternative waste treatments solutions were compared to the status quo, to determine the most sustainable waste treatment solution; the niche system with the least GWP compared to the regime system was considered the most sustainable waste treatment solution for Rio de Janeiro city. Four alternative scenario were modelled and compared to the currently regime, alternatives waste treatment solution were integrated in compliance with the waste management of policy Brazil, a cradle to grave analysis was done using the GABI 6 life cycle assessment simulation software for the modelling of the scenarios.

The same data sources for waste generated from the city was used for all the scenarios to determine the GWP for the various treatment solution, this report does not suggest the best means of waste treatment for Rio de Janeiro city, since it only estimates the treatment system with the least GWP. Several assumptions were made since some important data were not available. The treatment solutions used in the various scenarios were discussed in chapter 2 of this report.

4.1.4Scope and Goal

The goal of this LCA is the utilization of Integrated Solid Waste Management (ISWM) to determine the aim of this thesis as stated in the Background. The alternative waste treatment solutions are compared to control landfilling of waste, the treatment solutions that were compared to landfill includes, incineration of waste residue, composting of recovered organic waste, dumping of waste in landfill without flaring. Three significant emission contributors to GWP were analyzed for emissions in this LCA, the contributors includes, CH_4, CO_2 and N_2O

4.1.5 Functional unit

An estimated total of 2.8million tonnes (t) y^1 of waste is sent in 2013 year to the landfill from the seven transfer stations listed in (table 2) from Rio de Janeiro city. The total waste generated was approximately 3.5million tonnes. This thesis assumes loses for each waste fraction, loses are assumed to come from improper source separation, material handling.

The population of the city is estimated at 6.5 million inhabitants, the waste generated per person daily is 1, 5kg/day (Ciclus, 2015; COMLURB, 2015; Rio PMGRIRS, 2012).Using the mass of waste disposed daily, the Global warming potential (GWP) from MSW sent to landfill, and waste treated through other alternatives was determined for the year 2014, the emissions was compared in (t) CO_2-Equiv.

4.1.6 System boundary

A cradle to grave analysis was done for this LCA analysis; this analysis excluded the waste collection process within the city, waste inside the city is collected by trucks, data was not found on waste collected from the different areas of the city, the waste collected inside the city are distributed to seven transfer stations in the city. Data on the waste transferred from the seven transfer stations to the landfill was collected from various sources. The cradle of this analysis starts from the transfer stations due to the availability of data, which gives this analysis a realistic result. Since this is a comparative LCA the flow and process in the various MSW treatment systems were expanded to avoid allocation.

The system boundary for MSW treatment is divided into different stages including; waste transportation to and from the transfer stations where the waste residue are stored, the next stage is the transfer of waste to treatment facilities. The actual processes involved in the various waste treatment solution was taken into consideration but not analyzed in detail.

4.1.7 Data collection

The data used for conducting this LCA, were mostly secondary data obtained from academic articles obtained through the Lappeenranta University Technology (LUT) library Database, some data were collected from open sources, and vital data were obtained from the Gabi software during the simulation of the model. Additionally, data were collected from various sources in the internet.

The lack of data material from the city of Rio de Janeiro, lead to the utilization of some open data material for this study and some assumptions were made. However, the overall input of data reflects a considerable percentage of waste management in Rio de Janeiro, Brazil. Simulation and calculate of relevant information was achieved with the aid of the Gabi 6 software

For the purpose of utilizing different scenario in this study, source separation of waste was assumed for some waste fraction, source separation efficiency of 45% was assumed for the city, sources separation was only done for organic waste, metal, and paper waste. This report will assume a 95% recovery efficiency of metal for Rio de Janeiro city 3% below the recovery level in Brazil.

The data utilized for every scenario was listed in tables on that scenario page, for easy understanding, only general data used was indicated here

Table 2 Estimated MSW percentage gravimetric composition for Rio de Janeiro (2013)

Inputs		
Waste fraction	Percentage	sources
Organic waste	52,%	(GEO Portal, 2014) (COMLURB Municipal Company of Urban Cleaning 2014)
paper	17,5%	
plastic	16,%	
glass	6,7%	
metal	1,7%	
Inertia waste	6,1%	
Total waste generated per day	10,000,000 kg/day	
Total waste collected and sent to landfills per day	9,900,000kg/day	
Population estimation for 2015	6,5million	IBGE 2015

5 SCENARIO

5.1Reference Scenario

The current waste management situation in Rio de Janeiro city represents the reference scenario in this thesis, the treatment processes in the landfill was analyzed in detail in chapter 3 of this thesis. The landfill is a conventional landfill, where leachate and gas generated are managed before been discharged. Leachate handling involves side and bottom liners, the collection system and treatment of the leachate prior to discharge to surface water. (Manfredi et al 2009). Gas is collected treated and then flared in Seropedia landfill, the top soil is covered for mitigation of uncollected gas.

The landfill gas (LFG) is generated through the decomposition of organic component in the waste the primary gases produced from this degradation in significant amount are CH_4 and biogenic CO_2. Other gas produced in small amount includes nitrous oxide N_2O, nitrogen oxides NO_X and carbon monoxide CO.

CO_2 released from decomposition of waste was not included in the calculation, according to IPCC 2006, CO_2 emission is biogenic in origin and net emission is counted under the Agriculture, Forestry and Other Land Use (AFLOU). Additionally, according to Manfredi (2009) Biogenic CO_2 is considered neutral with respect to GW in landfill.

Data used in the calculation of CH_4 emission were obtained from articles and sources with similar characteristics and properties to the current landfill situation in Rio de Janeiro,data were obtained from articles that conducted similar studies in Brazil, Europe, in addition to default parameters obtained from IPCC 2006 waste data.

Table 3 Data on default parameter for CH4 emission calculation

parameter	used values	sources
Collection efficiency	ε =50%	mendes et al (2004)
methane is oxidized into (biogenic) carbon dioxide with an efficiency	η =99%.	Manfredi & Christensen 2009
oxidation in the top cover and, with respect to methane, the oxidation efficiency i	β = 30%	Manfredi et al 2009
Dissimilation factor of biogenic carbon as LFG (*D*LFG	0,5	Manfredi & Christensen 2009;IPCC2006;Barlaz 2005
Biogenic carbon content (kg C tonne–1 ww)	75	Manfredi *et al*. 2009

The table above shows data and some default parameters used in the emission calculation of CH4 in the landfill.

To determine the GWP of the landfill, the global warming factor (GWF), LFG emission were determined in tonnes(t) CO_2-eq. Equation (1) was used to estimate the GCH_4 generation from landfill, the biogenic carbon C content used was 75kg C/ tonne of MSW, while dissimilation coefficients of biogenic carbon LFG of 0.50 was used for the calculation.

The report assumes 55% of the mass base of C becomes CH_4, 45% oxidized to CO_2, 1.40 specific volume (m^3) occupied by 1 kg CH_4 at standard temperature and pressure (STP: T = 0 °C, P =101.3 kPa). GCH_4 is the generated methane from landfill gas, when managed and treated CH_4 emission is less than the amount generated, the molecular weight of methane to carbon ratio is obtained from dividing the molar mass of methane by carbon molar mass.

$$GCH_4=C\times D_{LFG} \times 0,55\times 16/12\times 1.40 \qquad (1)$$

The overall emission of CH_4 ($CH_{4\text{Emitted}}$) was calculated from the dispersed CH_4 emission from the landfill surface ($CH_{4\text{Dispersive}}$), emission of unoxidized CH_4 was calculated from flares ($CH_{4\text{Flares}}$). $CH_{4\text{Dispersive}}$ and $CH_{4\text{Flares}}$ depends on oxidation efficiency provided on the top cover of the landfill and is defined by the parameter β, The LFG collection efficiency parameter is defined by parameter ε. while the efficiency of the flare is defined by the parameter η

$CH_{4Dispersive} = GCH_4 \times (1 - \varepsilon) \times (1 - \beta)$ (2)

$CH_{4Flares} = GCH_4 \times \varepsilon \times (1 - \eta)$ (3)

The dispersed and flared gas are summed up to get the total emission

$CH_{4emitted} = CH_{4Dispersive} + CH_{4Flares}$ (4)

The landfill gas produced from the references scenario was estimated to be 950 000t CO_2-Eq

5.2 dumping scenario

The uncontrolled dumping of waste in open landfill characterizes dumping of waste. CH_4 generation from degradation of organic matter from this sort of landfill is not treated or flared before emitted to the atmosphere, CH_4 that escapes to the atmosphere is deprived of any oxidation, the waste disposed in dumps are considered mixed waste without any waste handling. GWP, is determined in the dumping scenario using the same initial parameter applied in the reference scenario. However, the emission to leachate is 4% ($D_{Leachate}$ = 0.04), equation (1) is the only equation that applies to the dumping scenario since no form of recovery is done and oxidation is deprived.

5.3 Compost Low carbon Scenario

In this scenario, organic waste is treated in an aerobic process known as composting in a composting plant, degradation of organic waste occurs during composting releasing gasses. Several factors affected emission of CH_2 during the composting process, for this report the factors considered includes, technology employed for the process, the efficiency of emission control process, composting types, all these factors affects the emission to air (Boldrin,et al 2009).this report considered all these factors during the emission estimation.

Degradable organic carbon (DOC) of the waste is mostly converted to biogenic CO_2; CO_2 emission is not counted as a waste sector emission. The formation of CH_4 is in the anaerobic section of the compost, CH_4 is largely oxidized in the aerobic section of the composting process. According to (IPCC,2006) CH_4 release to the environment is less than 1 % of the initial carbon content of organic waste. (IPCC,2006)

For this scenario it is assumed that organic waste source separation efficiency is 70%, organic waste is collected and sent to the composting plant for material recovery, other waste residue are treated in the landfill with the same processes employed in reference scenario.

In- vessel composting was employed for composting in this scenario. In vessel composting, takes place in enclosed building with the exhaust gases treated before being released to the environment .(Boldrin,2009) In this process organic waste are fed into a silo or the composting equipment were environmental conditions are controlled, environmental conditions including temperature, moisture and aeration. 9 kWh/tonne of electricity from the Brazilian hydropower electricity grid mix was utilized in the composting plant.

To determine the GWP from composting, the primary GHGs CH_4 and N_2O, were calculated using the total mass of organic composted and the emission factors provided in table 4, both emissions factors were provided in wet basis, hence both emissions were estimated directly on a wet basis using the equations below:

$$CH_4 \text{ Emission} = M\textit{i}*EF\textit{i} \qquad (5)$$

CH_4 Emissions = total CH_4 emissions in inventory year
M*i* = mass of organic waste treated by biological treatment type *i*,
EF = emission factor for treatment *i*, g CH_4/kg waste treated
i = composting or anaerobic digestion

$$N_2O \text{ Emission} = M\textit{i}*EF\textit{i}*1- R \qquad (6)$$

N_2O Emissions = total N_2O emissions in inventory year
M*i* = mass of organic waste treated by biological treatment type *i*,
EF = emission factor for treatment *i*, g N_2O /kg waste treated
i = composting
R = efficiency of bio filter to remove N_2O

Table 4 Default emission factor for composting organic waste and input parameters

Parameter	Value	source
Composting		
CH4 emission factor	4gCH_4 / kg of waste treated (wet basis)	IPCC4 2006
N_2O emission factor	0.3 g N2O / kg of waste treated (wet basis	IPCC4 2006
Electricity use	9 kWh/tonne	Boldrin et al 2009
N2O R removal efficiency	removal in the bio filter 90%	Dalemo et al.(1997)

The compost material will be used as bio-cover and bio-filter for the landfill, landfill covers are the environmental interface between the deposed waste and the atmosphere (He et al 2015). The compost cover oxidizes CH_4 that is not captured by the LFG collection system (M.Erfan et al 2012). According to He (2015) compost has good porous structure, large surface area, and high cation exchange capacity, and has demonstrated a high CH4 oxidation capacity and is therefore a good material to mitigate CH4 emission from landfills.

Table 5 low carbon landfill input parameters

Low-organic landfill		Sources
biogenic carbon content C	35kg tonne–1 ww	Manfredi et al 2009
dissimilated DLFG	33%	Manfredi et al 2009

The rest of the waste fractions was sent to landfill and the process of GHG accounting follows the same procedures that were employed in the references scenario. Organic waste which constitutes 51% of the total waste was mostly sent to the composting plant; reducing moderately the high carbon content of the waste, the presence organic waste from inefficient sources separation, paper, other carbon waste, are responsible for the landfill waste generating a moderately high carbon emission.

Input parameters used for calculating emission of $CH_{4,}$ biogenic carbon content , dissimilation are shown in (table 5) the parameters were estimated using sources that conducted research on similar landfill. Degradation of landfill waste is reduced by the elimination of organic waste in the landfill waste, emissions to air is estimated with the assuming that this landfill is a low-organic waste landfill (Manfredi et al. 2009).

5.4 Energy recovery scenario

The energy recovery scenario involves the incinerating of the entire waste fraction in waste to energy (WTE) facility, designed with the capacity to burn 1,000,000 kg/day of mixed waste. The waste collected from the city is sent to the plant from the transfer stations. The plant is equipped with the air pollution control equipment.

The process of incineration or thermal conversion of waste is characterized by close to complete oxidation of the organic matter to CO_2,CO may be emitted due to incomplete oxidation, in addition to the presence of various hydrocarbons. N_2O may be emitted depending on the gas cleaning system (Astrup et al 2009)

In waste incineration, carbon is present as biogenic or fossil carbon according to Fellner (2007); Staber (2008). Fossil carbon has a GWP of 1, biogenic carbon is considered neutral with a GWP accounting of 0. T Astrup et al (2009). GHG accounting is done for all waste collected in the city and treated in the plant with a grate fired incinerator.

The grate incinerator is the most widely used incineration technology for waste burning according to Themelis, (2008); Astrup (2009). The waste is incinerated on a moving grate, the waste is received directly there is no shredding for the purpose of this report so waste handling is very minimal. Grates generally treats most kind of mixed waste, energy efficiency for grate varies depending on the recovery form, electricity recovery to heat recovery in some case combined heat and power (CHP) recovery. The recovery for this report is for electricity used in the plant, the excess electricity may be utilized in the city of Rio.

The CO_2 generated in the incineration facility was estimated using the IPCC(2006) methodology. CO_2 emission was estimated from the fossil carbon content in the waste combusted, multiplied by oxidation factor, converting the amount of fossil carbon oxidized to CO_2.The waste input into the grate serves as the activity data, while the emission factors data is generated from the oxidized carbon content of the waste that is of fossil origin. Dry matter content, total carbon content, fossil carbon fraction, oxidation factor are all relevant data included in estimating CO_2

emission. Other data includes, amount, composition of waste. According to IPCC (2006) Carbon in the waste C is converted into CO_2 by applying the factor 44/12 based on the molar masses of oxygen and carbon. CO_2 emission from waste incineration was estimated using equation 7

$$CO_2\ \text{emission}_{\text{(kg/yr)}} = \Sigma i(IWi * CCWi * FCFi * EFi)*44/12 \quad (7)$$

CO_2 Emissions = CO_2 emissions in inventory year, Kg/yr
i = MSW: municipal solid waste
IWi = Amount of incinerated waste of type i
CCWi = Fraction of carbon content in waste of type i
FCFi = Fraction of fossil carbon in waste of type i
EFi = Burn out efficiency of combustion of incinerators for waste of type i (fraction)
44/12 = conversion factor from C to CO2

$$N_2O = \Sigma i(IW i * EF i) * 10^{-6} \quad (8)$$

N_2O Emissions = N_2O emissions in inventory year, kg/yr
IW*i* = amount of incinerated/open-burned waste of type *i* , kg/yr
EF*i* = N_2O emission factor (kg N_2O/kg of waste) for waste of type. The continuous and semi-continuous incinerators Emission factor 50 (g N_2O / t) waste was used for this report
10^{-6} = conversion from kilogram to gigagram

The estimation of CH_4 in waste incineration is dependent on factors including; continuity of the incineration process, the technology and management practices (Gio 2004). For this study, continues incineration without daily shutdown or startup was employed. According to IPCC5,(2006) CH_4 was observed to be low at the exhaust gas furnace, lower than the concentration gas intake of the incinerator. Consequently, it is good practice to apply emission factor of zero for CH_4 considering the low concentration and the high uncertainty. The waste incinerating net efficiency of 18% Mendes et al, (2004), the incinerator consumes electricity produced by the plant, the excess energy generated by the plant may be sold to the surrounding vicinity.

The high content of the wet organic fraction decreases the Lower Heating Value (LHV) of the waste from Brazil to 5 MJ kg-1, with the organic fraction reaching 51.5% of the total waste fraction. Souza et al, (2014).The research and design institutes in China, has developed measures to improve usability of the stoker grate technology to make it adaptable to the Chinese waste. The LHV of the Chinese waste is 3-5 MJ kg^{-1} owing to the very high organic waste fractions. To obtain a smooth combustion during the treatment of waste, when utilizing the stoker grate technology, waste is held for 5-7 days instead of 2-3 days by an enlarged bunkers, enabling 20% of the water contents of the waste to be collected as leachate, other modifications includes, use of hot air from the combustion which is led through the waste inlet, combustion time is longer, the stocker grate is extended in length (Dorn et al., 2012). The same technology may be applicable to waste incineration in Rio de Janeiro since the organic fractions of the waste is similar to that of China.

6 SCENARIO RESULTS

The outcome of the various outputs results were taken from the Gabi 6 software. The result considered the major contributors CH_4, N_2O and CO_2 emitted during waste treatment. The impact category was strictly focused on the environmental impact assessment of GWP non biogenic emission, for each scenario the emission from contributors was determined separately, the emission was characterized into tonne(t) of CO_2 equivalent for one year.

Table 6 shows the output results for the three significant contributors to impact categories for each of the scenario; the result was obtained using the CML 2001 method for GWP excluding biogenic carbon from GABI absolute values

Table 6 Output emission to air of GHGs from all scenarios CML 2001 (t) CO2-Equiv for one year

Output	GHGs (t)			
contributors	Reference scenario	Dumping scenario	Low carbon scenario	Energy recovery scenario
Carbon dioxide	8000	8000	9800	2020
Nitrous oxide	60	60	2800	-900
Methane	940 000	2 600 000	661 000	-2100
Total emission	950 000	2600 000	670 000	-980

Table 7 shows the emission to air from the relevant contributors from the entire scenario, GWP for the elementary output flows for the process were obtained from Gabi using the CML 2001 method, the impact categories were presented in (t) CO_2-Equiv y[1]

The minus for electricity for the energy recovery indicates that energy was recovered

Table 7 Input and output flow for the treatment of 2.8million tones y1 of MSW from the city of Rio de Janeiro

Inputs	Reference scenario	Dumping Scenario	low carbon scenario	energy recovery scenario
Energy				
Electricity(GWh y^1)Energy(net calorific value	10		9 kWh/tonne	18%
crude oil(m^3)	3000	3000	20000	-3000
Natural gas(m^3)	2400	2400	22000	5000
Output flows CML 2001 (t)CO_2-Equiv				
diesel emission Carbon dioxide Nitrous oxide Methane	820 40 240	820 40 240	2 300 2700 850	820 40 200
electricity emission Carbon dioxide Nitrous oxide Methane	-		5500 30 60	-14 000 -1 000 -2 300
truck emission Carbon dioxide Nitrous oxide Methane	7300 20 2	7300 20 2	2000 56 5	7000 19 1.4
emission from landfill Carbon dioxide Nitrous oxide Methane	- - 940 000	- - 2 600 000	- - 660 000	- - -
emission from composting Carbon dioxide Nitrous oxide Methane			- - 2	
emission from incineration Carbon dioxide Nitrous oxide Methane				82 00 41 -
Total emission	950 000	2 600 000	670 000	-980
Recovered material and energy			Compost Bio cover	electricity

Interpretation

The GWP from the sanitary landfill was very significant, emitting 950 000 (t) CO2-Eq, The high GHG from the landfill is due to the high percentage of organic waste disposed in the landfill, this is easily deduced from the fact that landfill waste emitted significantly higher GHG compared to the other processes in the plan. The emission came from CH_4 emitted from the landfill as observed from the relative contribution from the CML 2001result, without the flaring of CH4 the GWP of the landfill would be much higher. Flaring of methane to oxygen significantly reduced the GWP of the LFG, methane when released to the environment has the potential to warm the globe 21 time more than CO_2,flaring reduces the environmental effect by oxidizing CH to CO_2 which is a less harmful GHG.

The open dumping of waste with no collection and flaring of LFG showed the highest GWP as shown in table 7, emission of CH_4 without oxidation GHG emission twice the amount emitted from the reference scenario (sanitary landfill) with a total 2 600 000(t) CO_2-Eq. Akin to the reference scenario CH_4 emission was significantly higher combined to other contributors in the dumping scenario, without flaring emission to air increased, increasing the potential for GWP.

The low carbon scenario utilized more processes and flows compared to the references scenario, electricity consumed in the composting process produced low emission to air, emitting 5600 (t) CO_2 equivalent, landfill emitted approximately 660 000(t) CO_2 equivalent, a total of 98% of the emission to air, emission from landfill was mainly from other carbon fractions especially 70% organic waste resulting from inefficient source separation, paper, and other carbon waste faction. Emission from the Brazilian hydropower and the landfill processes had a lower GWP in the plan compared to the reference scenario.

In the energy recovery scenario the treatment of waste by incineration consumed energy during the process of burning emitting 8200(t) CO_2 equivalent, the highest emitting process from the energy recovery scenario was the burning process. The electricity generated from the waste displacing emission from the burning process to air by -14 000(t) CO_2 equivalent, leading to a negative emission of -980. (t) CO_2 equivalent. The emission from the incineration which was 82 00(t) CO_2 equivalent was offset easily from the electricity generation.

An interpretation of the result was done after life cycle inventory, life cycle impact assessment was conducted, GWP of the alternative scenarios were compared to the reference scenario. The cumulative GHG emissions to air from all the elementary flow in the alternative scenarios were compared to the reference scenario.

From the figure below the comparison was made for the cumulative emissions from the entire scenario, the reference scenario GWP was compared to all scenario significant differences in emission to air was detected. Emission from energy recovery scenario showed significantly higher differences in emissions, energy scenario emitted less than 1% of GHG compared to the references scenario. From the analysis result the environmental hot spot for reference scenario was the emission from the LFG, LFG constituted over 90% of the emission from landfilling of waste.

Open waste dumping without collecting of LFG as shown in the second scenario has a far higher GWP compared to the reference scenario. The emission of GHG from dumping was significantly higher than the emissions from the reference scenario combined with all alternatives scenarios.

In low carbon scenario, material recovery from composting and the landfilling of low carbon waste was compared to the reference scenario, The GHG emission was only 71% of the emission compared to the reference scenario. Compost was utilized for bio cover and bio filter for the landfill, further reducing the GWP of the low carbon scenario. The landfilling of low carbon waste generated a lower emission of GHG gas compared to the emission from the conventional landfill. The hot spot for the low carbon scenario was the landfilling of the waste, generating a total of 98% of the emission to air from this low carbon scenario.

Energy recovery scenario was the only scenario that involved waste incineration with energy recovery only; there was a significant production of CO_2 from the incineration process. However, energy recovery from the process offset the produced GHGs significantly recovery of electricity utilized in the plant for waste treatment offset the emission to air of GHGs to 1% compared to the reference emission

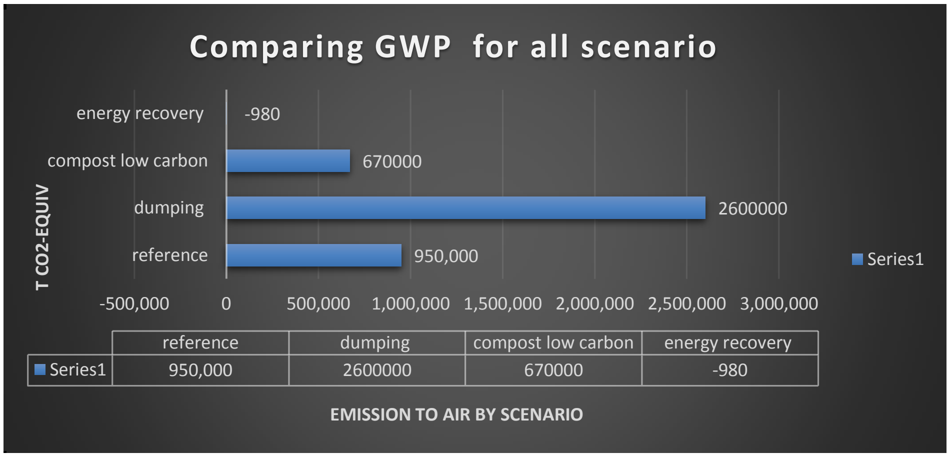

Figure 2 the comparison of the GWP of the different scenario

7.DISCUSSIONS AND CONCLUSIONS

This study utilized four MSW treatment scenarios that integrated different waste treatment solution, the cradle to grave analysis was essential to this study due to the different flows and processes utilized in the scenarios during different stages of the processes, hence, all the indirect and direct emission from the different flows and processes were accounted for.

The reference scenario, consist of solely landfilling of waste; this produced the significantly high GWP mainly due to the high composition of organic waste. The biological degradation of this waste generates high amount of CH_4.CH_4 was flared to reduce the GWP of the gas, flaring of CH_4 which is a highly flammable gas is done to produce CO_2 to reduce the GWP of the LFG. unoxidized CH_4 dispersed to the atmosphere producing significant amount of emission to air in addition to the flared CO_2.

The flaring of CH_4 from the Rio de Janerio landfill reduces the GWP from landfill, the emission is still significantly high, utilization of the LFG for power, heat, would further upset the emission.

However, emission of GHGs from the landfilling of waste from Rio city will reduce further with the utilization of energy recovery of waste, a more sustainable treatment solution that will eliminate the potential for pathogens responsible for diseases in waste, reduce the volume, mass of final waste to landfill, improving human and environmental health. Energy recovery will better offset the GHGs generated from MSW.

The low carbon scenario, consist of low carbon landfill, composting of organic waste. In this scenario the highly degradable organic waste was reduced from landfill, organic waste was used for producing compost for landfill covering. The emission from flaring CH_4 from landfill and the dispersive CH_4 produced 72 % of the GHGs compared to the landfilling done in the references scenario, low carbon landfill an effective means of reducing the MSW sent to landfill.

The low carbon scenario would be an Ideal scenario for the Brazilian waste management solution, the waste are utilized for other purposes through material and energy recovery from LFG without incineration, allowing for the possibilities of landfill mining in the future for further material recovery. The world raw resources is constantly been depleted, landfill mining may be a major source of generating for future resources

The compositing of organic waste was done in a closed system this involves the utilization of air pollution solution which impacts on the reduction of the GWP from composting immensely, reducing air pollution gases impacts on the reduction of GHGs as well. The electricity utilized was obtained from hydropower the environmental impact was very insignificant, direct emission from landfill was the main emitter to air the high emission to air shows the high GWP of landfills even in low carbon landfill. The employment of compost for bio cover in landfill may mitigate the emission of CH_4 from landfills, utilization of composting greatly reduces the final waste to landfill, reducing the volume of final waste disposed in landfill, in addition to reducing the impact from GWP the use of compost recovered from organic waste as biocover for landfill further reduces the GWP of composting.

Composting could serve as a means of advancing technology, increasing employment, while reducing the emission of GHGs from the waste in Rio city, composting of the waste reduces the GW, diseases contracted from waste sorting, making waste picking by pickers less hazardous. This will allow for better storage of other waste fractions increasing the potential for material recovery from Rio MSW

The energy recovery scenario incinerates MSW in a grate firing plant, produced CO_2 emission to air. The energy recovered is utilized for electricity in the plant offsetting the earlier emission from incineration of waste; the electricity recovered could be utilized for the city of Rio de Janeiro, reducing the demand for the use of other sources of electricity for the city.

The incineration of waste reduces the space used for waste disposal significantly compared to composting, energy recovered from the waste could also reduce the need for raw material extraction in energy production, with the constant rise and drop in water levels incineration of waste may serve as a better alternative for power in parts of the city, most importantly for this thesis waste to energy reduces significantly the GWP from waste treatment.

Dumping is highly inefficient and the least sustainable way of treating waste, no material recovery or energy recovery is done, and this form of waste disposal consumes vast space, in addition to reducing the life span of infrastructure, increasing the potential for public health problem. GWP is highest with dumping even higher than the reference scenario. This shows why legislation on waste management and enforcement of such laws are important in achieving, reducing significantly impact of waste disposal to the environment.

The outcome of the analysis clearly shows the problem of improper disposal of waste to the environment, public health and economic development. Achieving a sustainable development requires sustainable waste management solutions that integrate various waste management solutions. This LCA demonstrates that no single solution can adequately provide the solution needed to achieve a sustainable solution. Hence, the authorities in Rio de Janeiro city may need to utilize different solutions that will adequately solve the waste problem reduce the volume of waste disposed in landfill, improve technologic development while increasing economic growth in the city.

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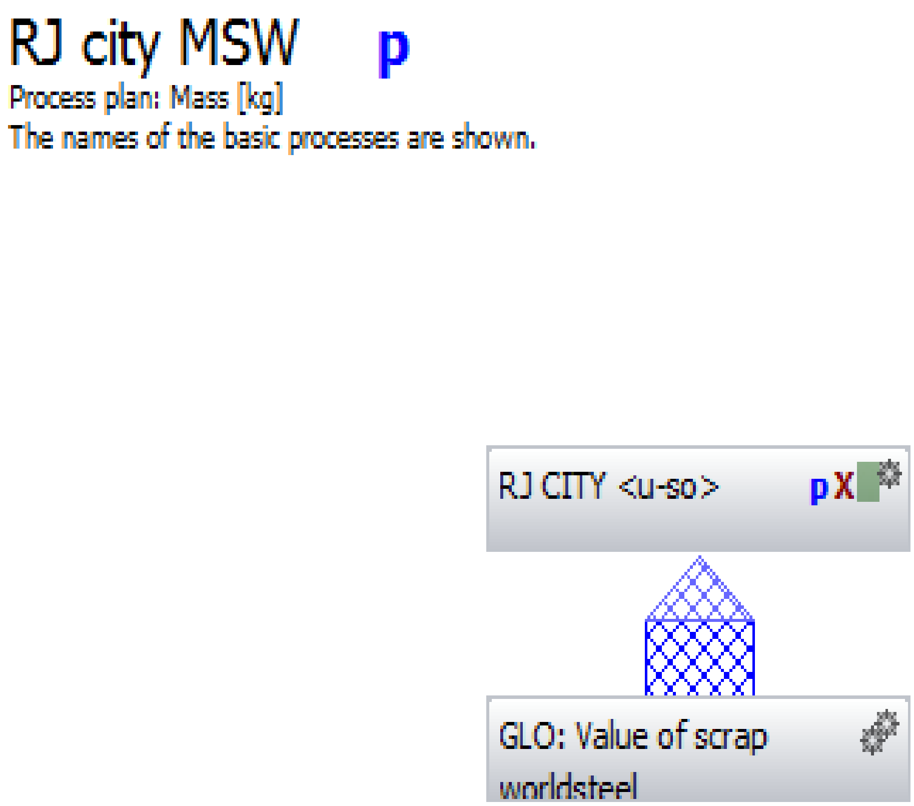
9. APPENDICES



RJ city Transfer stations and Utilization (second level plan)

Process plan:Reference quantities

The names of the basic processes are shown.