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Recycling and Thermal Treatment of MSW in a Developing Country

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Abstract: With the increase of the world population, urbanization and industrialization, the volume of generated municipal solid waste (MSW) has increased and creating a challenge problem for public authorities mainly in developing countries. Most of these countries are still disposing MSW in dumpsites. Without adequately treatment, MSW causes damage to the public health and to the ecosystem. One route to divert the MSW from dumpsite is recycling and incineration. Recycling economizes natural resources, water and energy and reduces emissions while incineration minimizes the need of big area for landfills, produces electricity, hot water, with minus emissions. In Brazil, for example, about of 95% of MSW is disposed in sanitary landfills and open e closed dumpsites. This paper highlights the importance of incineration and recycling activities in providing financial, energy, and ambient gains in Brazil. The investigated scenario is based on recycling 10% of the recyclables and incineration of the rest of MSW. The results show that the financial gain from commercializing only 10% of the potentially available recyclables amounts to about U$32,432,432 monthly or 122,729 minimum national salaries, while the electric energy generated from incineration is sufficient for supplying 16.5 million residences or nearly 25% of the Brazilian homes.
Keywords: *Energy, emissions, incineration, municipal solid waste, recycling*

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I. INTRODUCTION

The confusing concept formed around available thermal treatment technologies of municipal solid waste (MSW) together with the high cost of the equipments are among the major factors which impede a substitution of landfills and open dumps in the developing countries. The common belief is that emissions liberated during incineration even well neutralized still offer great risk for human health. In the past, the released emissions during incineration were not treated properly which provoked this general lack of confidence. This reality changed drastically during the last forty years due to the big and continuous investments in research and development of incinerators and systems for controlling and continuously monitoring emissions before they are released to the atmosphere. This turned incineration to be a viable option for treatment of MSW in many countries in European countries, Asia and North America [1, 2, 3, 4]. The lack of correct technical information and the degree of sophistication associated with the incineration process, control, monitoring and treatment of emissions allied with the lack of political will made many countries continue using the old practice of MSW dumping in any empty site. Analysis of the data published in the report of the European Union [2] shows that some countries gave high priorities in their public policies to adequate management of MSW establishing plans which include reuse and recycling of MSW together with incineration and biodigestion as shown in Table 1 and Fig. 1. The principal objective is to divert MSW from landfill and benefiting of its energy, economic and environmental potential. With this in focus, they establish plans and objectives, which are tackled and when achieved, other new plans and objectives are set for future management and so on. While this, the major part of the developing countries need to find adequate solutions to treat MSW [5, 6]. The global generation of MSW as estimated by the World Bank [7] is about 1.3 billion tons per year, and is expected to increase to approximately 2.2 billion tons per year in 2025. Adequate treatment of this daily generated huge amount of MSW is one the biggest challenges for public authorities in the 21st century.The disposition of MSW in inadequate open or closed dumpsites is a common practice used in many countries in the world. Dumping MSW is an eminent risk to public health and to the ecosystem. ONU estimated a loss of annual PIB of the municipalities of 3 to 7% due to the inadequate public sanitation, which affect principally poor population in developing countries [8, 9]. During the degradation process, the organic waste composed of rests of animal and vegetal matters decompose producing sub products highly offensive to the environment and human life such as greenhouse gases (GHG), methane (CH4) and carbon dioxide (CO2), leachate which contaminates the soil and underground water, harmful odors which attract insects, rats and other disease vectors. Non-degradable matter in MSW such glass, metal plastics usually takes years to decompose reducing in this way the useful life of the landfill [10, 11]. Brazil is composed of 5570 municipalities considered the fifth of the world in population, about 204 million of inhabitants in 2016, each generating around 1.05 kg of solid waste per day [12, 13] and has tremendous problems associated with the treatment and final disposition of MSW, which are still waiting for solutions. About 95% of MSW produced by the urban population, which represents about 85% of the total Brazilian population is disposed in about 4200 dumps (covered and open) and 1200 sanitary landfill [14]. Also because of the unplanned and irregular urbanization, dumps and landfills are becoming nearer to the residential areas, which presents eminent risk to public health. The closure of these open dumpsite in 2014 was postponed to 2022 because most of the municipalities could not reach these objectives due to a number of reasons including unavailable sites for planned landfills. Considering the energy, financial and ambient benefits of MSW and the quantities generated daily in Brazil, the adequate treatment following the tendencies in developed countries is essential to improve the basic sanitary aspects and benefit from MSW potential. In this context, the authors know that the incentives for recycling and thermal treatment by incineration of MSW depend exclusively on the political prioritization and public policies. The objective of this paper is to elaborate a scenario for the treatment of MSW in Brazil based on recycling 10% of the available recyclables, incinerate the rest of MSW, estimate the economic, energetic and environmental potential gains in an attempt to demonstrate that the scenario is a viable route for the treatment of MSW and demystify preconscious ideas about incineration.

II. GENERATION AND TREATMENT OF MSW

According to the World Bank [7], the average amount of MSW generated worldwide 0.35 kg/inhabitant/day. This means that thousands of tons of MSW are produced daily, need to be collected and adequately treated otherwise provokes irreparable environmental damage and impairment of the ecosystem. The destination of MSW in most countries, especially in developing ones is dumpsites [10, 15]. Waste treatment practices have improved considerably in the EU since 2000. Landfilling, the least environmentally friendly waste disposal method has been, gradually replaced by incineration, recycling and composting as can be observed in Table 1. In 2013, about 43% of the EU's generated MSW was recycled or composted. These improvements have been, to a large extent, driven by EU and national strategies prioritizing efficient waste management through various instruments [1, 16]. According to the estimates of the European Union [1] the EU-28 countries generated yearly in the period from 2010 to 2014 the respective amounts of 254,0; 251,0; 246,0; 242,1 million tons. In 2014 they treated about 236,2 tons. Table 1 shows generation and management of solid waste in these countries.

Table 1 Municipal waste, generation and treatment in 31 countries

Country/Year 2014	MSW Generated (Thousand tons)	Incineration with energy recovery (kt)	Total incinerated (kt)	Recycling (kt)	Landfill (kt)	Landfilling (%)	Recycling (%)	Incineration (%)
Austria	4833	1756	1756	1231	194	4.0	25.5	36.3
Belgium	4886	2131	2194	1663	47	1.0	34.0	44.9
Czech Rep.	3261	600	604	736	1827	56.0	22.6	18.5
Denmark	4279	2326	2326	1153	57	1.3	26.9	54.4
Estonia	470	222	222	125	30	6.4	26.6	47.2
Finland	2630	1316	1316	474	458	17.4	18.0	50.0
France	33703	11421	11794	7436	8691	25.8	22.1	35.0
Germany	50064	11594	16881	23323	137	0.3	46.6	33.7
Hungary	3795	373	373	923	2181	57.5	24.3	9.8
Iceland*	112	5	7	42	55	49.1	37.5	6.3
Israel	5034				4127	82.0	0.0	0.0
Italy	29655	5718	5718	7732	9332	31.5	26.1	19.3
Japan*	44874	31074	34803	9117	574	1.3	20.3	77.6
Korea*	17786	4200	4501	10432	2779	15.6	58.7	25.3
Latvia	648	0		107	515	79.5	16.5	0.0
Luxembourg	343	121	121	97	61	17.8	28.3	35.3
Netherlands	8890	4140	4239	2111	128	1.4	23.7	47.7
New Zealand	2931				2931	100.0	0.0	0.0
Norway	2175	1148	1148	567	60	2.8	26.1	52.8
Poland	10330	1162	1560	2180	5437	52.6	21.1	15.1
Portugal	4710	974	974	765	2307	49.0	16.2	20.7
Slovak Rep.	1742	186	190	88	1158	66.5	5.1	10.9
Slovenia	892	2	2	259	208	23.3	29.0	0.2

Spain	20217	2496	2496	3138	11138	55.1	15.5	12.3
Sweden	4246	2102	2102	1418	27	0.6	33.4	49.5
Switzerland	6006	2790	2790	1960	0	0.0	32.6	46.5
Turkey	31230	0	0	0	27864	89.2	0.0	0.0
UK	31131	8149	8263	8503	8656	27.8	27.3	26.5
Lithuania	1308	113	113	268	748	57.2	20.5	8.6
EUA	258000	33000	33000	66,4	136000	52.7	25.7	12.8
China	178602	53299	53299		107443	60.2		29.8

*Data of 2013.
Source: Elaborated with based on [2].

As can be seen, ten of the thirty-one countries landfilled less than 5% of MSW, in twelve countries, more than 50% of MSW is still landfilled, while in the two most populated countries (China and EUA) landfilling of MSW is still the most common method for handling MSW. With reference to incineration, only four countries burn over 50% of their MSW, five countries burn almost 40%. Japan leads the ranking with nearly 80% incineration of solid waste.

Brazil is a country with more than 4000 dumps (open and covered). The Brazilian National Policy for Solid Waste (PNRS) establishes the closure of the 2906 open dumpsites until last August 2014. This deadline was extended to 2022 because most of the municipalities had difficulty in honouring this determination. Also PNRS established the increase of recycling index from 2% to 20% but little progress was achieved in this direction [17].

2.1 Recycling

Recycling is the process that starts with the collection of solid waste at home and ends at the recycling industry. The return of the materials as paper, cardboard, plastics, glass and metals to the production chain saves energy, reduces emissions, avoid extraction natural resources and creates jobs and income necessary for the social inclusion of poor families [11]. Recycling and waste-to-energy projects are considered complementary waste treatment methods to divert waste from landfills and reduce GHG emissions. Waste-to-energy plants can incinerate all MSW including inadequate recyclables for reuse [18,1]. Table 2 shows that in the six listed countries the recycling rate increases year after year indicating the strengthening of the citizens' ambient conscience and the implementation of public policies focused on the treatment of MSW stressing the reuse of recyclables and hence reduce the dependence on landfills.

Table 2 Recycling rate of municipal solid waste

Country/Year	2010	2011	2012	2013	2014
Germany	62.5	63.0	65.2	63.8	63.8
Italy	31.0	35.5	38.4	39.4	42.5
Netherlands	49.2	49.1	49.4	49.8	50.9
Portugal	18.7	20.1	26.1	25.8	30.4
United Kingdom	40.2	42.0	42.6	43.3	43.7
EU -28 countries	38.3	39.6	41.4	42.2	43.5

Source: [2].

2.2 Treatment thermal of MSW

Technologies for thermal processing of MSW to produce energy include gasification, incineration, pyrolysis and treatment by plasma torch. Gasification differs from pyrolysis in that the quantity of oxygen is sufficient for complete combustion, operation at temperatures over 650 ^{o}C. Normally bulk MSW is not adequate for gasification, the principal product is syngas whose calorific value is around 4-10 MJ/Nm^3 [19, 20, 21]. Pyrolysis is the thermal degradation of matter in the absence of oxygen, depending on the calorific value can continually necessitate external heating source to maintain the temperature between 300 to 850 ^{o}C. The resulting product is syngas composed of a mixture of gases of calorific value varying from 10 to 20 MJ/Nm^3 [21].

In incineration, energy is released directly as heat while in the processes of pyrolysis and gasification liquid and gaseous fuels are produced which can be used to generate energy. Among the numerous advantages of incineration is the reduction of volume and mass by 90% and 75%, respectively; eliminating pathogens, and generating steam which can be transformed to electricity or used for water heating. Incinerators used for producing heat for general use can achieve efficiencies around 80 - 90% [19, 22, 23].

The first incineration plant for treating MSW was developed and operated in Manchester (UK) in 1876, and since then incineration is considered as an effective tool to treat dangerous and infectious material from hospitals and similar establishments. This process reduces the original volume of the material to about 10% and can be a viable option for municipalities where there are no suitable and cheap areas for constructing well engineered sanitary landfills [24, 15, 21].

Japan is considered the principal world leader for development and production of incinerators. The country has 1172 incinerators for the treatment of about 80% of the MSW of which approximately 24.5% with energy recovery generating 1770 MW [4]. The country average energy production rate from incineration of MSW is about 200 kWh/t, in Tokyo, electricity production rate corresponds to 390 kWh/t while Kobe produces 300 kWh/t. In Kobe, for example, 16.2% of the electricity demand and 25% of hot water demand is attended by incineration [25].

Singapore has 4 incineration plants where the biggest is composed of four incineration units, with total capacity to treat about 1700 t/day of household and industrial MSW of low calorific value (LCV), around 6MJ/kg. Each boiler generates 42 t/h of steam and 30 MW. The water used for generating steam for turbine is residual water from industrial processes treated before use [26]. Fig.1 shows an estimate of waste treatment in European Union-28 countries. As can be seen the amounts of incinerated waste are increasing reflecting the tendencies to eliminate dependence on landfills as a route for treating MSW.

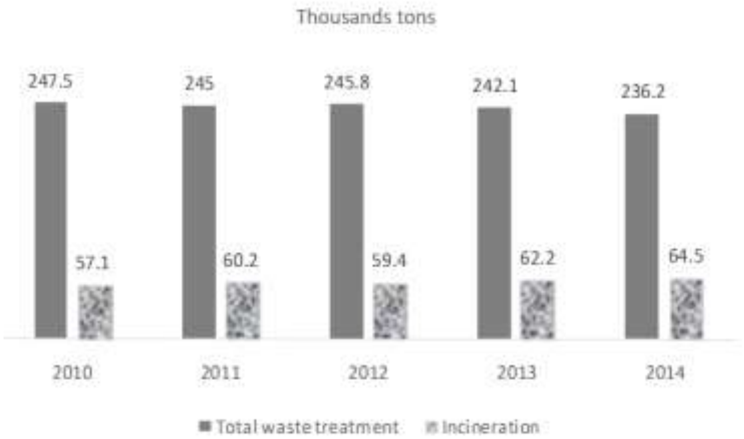

Figure 1 Estimated waste treatment in EU- 28 countries.
Source: [2].

EU-18 has 380 incineration plants of capacity sufficient to treat 85% of MSW. However, according to the Confederation of European Waste-to Energy Plants (CEWEP), 81 million ton of remaining MSW after reuse and recycling in waste–to-energy plants in Europe in 2013 could generate about 31 billion of kWh of electricity and 78 billion kWh of heat. Alternatively, these waste-to-energy plants can supply annually about 15 million inhabitants with electricity and 14 million inhabitants with heat [1]. According to Fazeli et al. [27] Malaysia generate 32000 ton/day of MSW, of which 80% is landfilled in an inert and unsanitary site and consequently losing its energy and ambient benefits. Alternatively, MSW can be incinerated to generate electricity at the rate of 8.9 MW per 1000 ton/day. China in 2012 generated 179.3 million tons of MSW and incinerated 35.8 million tons in 138 incineration plants [28]. Turkey has a capacity of generating about 230 GWh /year of electricity through of incineration of collected MSW [29], while Lebanon can generate 197.3 MW electricity by incinerating 2.6 million tons of MSW/year. Europe, for example can generate 31,000 GWh/year of electric power from their MSW, while EUA has a potential to generate 17,000 GWh/year. Russia on the other hand can generate about 26.6 MW from collected MSW [30].

2.4 Sub products of incineration: ash and emissions

Ash is sub product of the combustion of solid waste corresponding to 10% in volume or 20-30% in mass of MSW. There are two types of ash; solid ash and suspended ash. The suspended ash is usually collected and treated while the solid ash is inert and can be reused in manufacturing cement, construction material, ceramics etc. [20, 21]. Waste incinerators involve technologies that are more energy efficient and protective of human health and the environment. EU and USA established limits for emissions from incinerators in a way to protect human health and increase the society confidence in security measures adopted in these processes. Table 3 shows the limits adopted by EU, US and Brazil. As can be seen the limiting values adopted by the Brazilian standard is higher than those adopted by EU or USA.

Table 3 The limits adopted by EU, US and Brazil

Type of polluent	Limit/UE[1]	Limit/Brazil[2]	Limit/USA[3]
Dioxins and Furans	0.1ng/m³	0.50 ng/Nm³	0.13 ng/Nm³
Particulate matter	10 mg/m³	70 mg/Nm³	20 mg/Nm³
Organic substances in the vapor and gas	10 mg/m³		

states			
Hydrogen Chloride (HCl)	10 mg/m³	80mg/Nm³	29 mg/Nm³
Hydrogen Fluoride (HF)	1 mg/m³	5mg/Nm³	-
Sulphur dioxide (SO2)	50 mg/m³	280mg/Nm³	85 mg/Nm³
Nitrogen monoxide (NO) Nitrogen dioxide (NO2)	200 mg/m³	560mg/Nm³	305 mg/Nm³

[1] Directive 2000/1976/CE
[2] 40 CFR 60
[3] Emission limits according to Resolution CONAMA 316/2002
Source: [23, 31, 32].

III. MATERIALS AND METHODS

3.1 Materials

From the literature review, it is clear that recycling part of MSW together with incineration including energy recovery are possible treatment routes to ensure environmental sustainability, additional energy and financial gains. Due to the seasonality there are different consuming habits in Brazil. Data used refers to the MSW generated in urban areas. We also used global values obtained from reports for emission rates and fuel consumption in incineration. The parameters and data used in the calculations are presented in Table 4. The composition of solid waste in Brazil according to IPT/Cempre [33] is as follows: Organic matter 52.5%; Paper and cardboard 24.5%; Plastics 2.9%; Glass 1.6%; Metal 2.3%; Others 16.2%. We adopted in the calculation this data since there is no official recent data.

Table 4 Data used in the calculations.

Description	Reference Value	Adopted value	Reference
Specific mass of CO_2 (kg/m^3)		1.83	[34]
Emissions from incinerated MSW (tCO_2 TJ)	10 - 40	25	[35]
Avoided emissions in recycling (CO_2/t)		1.971	[11]
Avoided energy in recycling (GJ/t)		31.629	[11]
LCV of MSW incinerated (kJ/kg)	5250 – 10,264	6,130	[21]
Auxiliary fuel for incineration LPG (kg/t)[2]		8.0	[36]
Emissions due to combustion of LPG (kg CO_2/kg)		3.019	[36]
LCV of commercial LPG (MJ/kg)	40.05 - 46.05	40.05	[34]

[(1)] LCV = Lower calorific value; [(2)] LPG = Liquefied Petroleum Gas.
Source: Prepared by the authors.

3.2 Methods and calculations

This section presents the simplified diagrams used in the calculations and explanations of the procedures for the calculations. Usually MSW is collected in the country by contracted companies and public service or both. In small municipalities, the MSW collection is realized by the department of public of cleaning. The recyclables are usually collected by the department of public cleaning or private contracted companies where they usually pass over the recyclables to waste pickers association within the programs of creating jobs and income. The materials are separated according to type, compressed to reduce their volume, packed and transported to intermediate dealers or directly to the recycling industry where it enters again in the manufacturing chain. Recycling activities in Brazil are very intense driven by about a million informal waste pickers according to estimates of the National Movement of Recyclables Waste Pickers. Waste pickers usually collect recyclables from the streets in big Brazilian urban centers and sell to sustain themselves and their families. Fig. 2 shows the operational block diagram for the proposed scenario of solid waste treatment via recycling and incineration. In the collection process, the solid waste mix is collected and will be delivered to mass incineration system designed for energy recovery. The released heat is used to produce hot water and hot air for general use and electricity. Hot gases from incineration are cooled down, cleaned to remove soot particles and offensive gases before releasing to the atmosphere. The resulting ash from incineration is to be collected and mixed with other material to manufacture bricks, and road paving. With relation at recycling, the residents sort their recyclable waste and leave it outside residences to be collected. The collected recyclables are sorted by type, pressed, packed and delivered to intermediate dealers or sold directly to the recycling industry. Inadequate recyclables will be separated and forwarded for incineration.

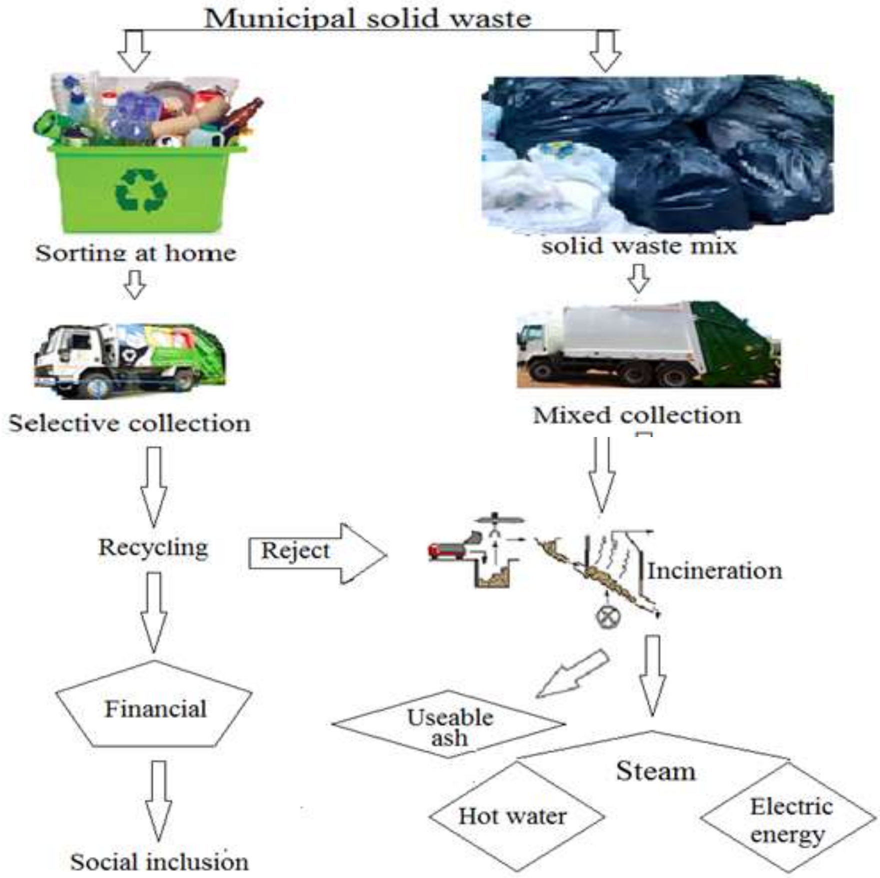

Fig. 2 Recycling and incineration of MSW.

IV. RESULTS AND DISCUSSION

4.1 Recycling

In an earlier work the authors calculated the amount of avoided emissions due to recycling a ton of Brazilian mixed recyclables as 1.971ton of CO_2/ton of recyclables and also calculated the amount of energy avoided due to reusing recyclables instead of raw material as 31.629 GJ/ton of recyclables [11]. Adopting these values in the calculations it is found that recycling 10% of available recyclables or 8000 t/day can avoid the emission of 5.84 M tons CO_2 per year and avoid consuming energy of about 256948 GJ/day. Recycling activities were implemented in Brazil in 1980. Until 2015, the official records [13] show that less than 4% of recyclables are selectively collected by the public sector. According to PNRS (National Policy for Solid Waste), the law number 12.305/2010 establishes achieving a recycling index of 20% by 2025 [17]. To revert the situation of recycling from less than 4% to 10 or 20% as requested by law, adequate public policies should be implemented, formalizing and organizing waste pickers associations and provide them with legal incentives and infrastructure helps, create awareness programs for the public and schools among other measures.

4.2 Incineration

The total mass of MSW of about 199,851 tons/days corresponding 80% of the mass of MSW generated and destined to incineration plants equipped with energy recovery systems and pollution control and monitoring equipment. In an earlier work realized by the authors, they calculated the average heat content of a ton of Brazilian MSW as classified earlier and this value is found to be 6130 kJ/kg [18, 11]. Mass incineration system will handle the amount of MSW producing heat which will be used to produce vapour for steam turbines coupled with electric generators to produce electricity with an efficiency of around 30%. Electric energy generated can reach 2902.6 GWh/month sufficient for the consumption of 16,476,663 residences or 25.4% of the Brazilian homes, considering an average domestic electricity consumption of 176 kWh/month. It is possible to increase the overall efficiency of the system by using heat exchangers to extract heat from the flue gases during the cleaning process before its release to the atmosphere. The price of U$ 0.20/kWh is practiced by the electric energy distributing company in the region of Campinas, SP in august 2016 [37]. We adopted this value as an average value for the price of electric energy for Brazil. Hence, the electric energy generated from incinerating 80% of MSW (combustible matter) corresponds to about U$ 580.5 x 10^9/ month.

4.3 Emission

As a result of incineration flue gases will be charged with particles and other gases responsible for greenhouse effects. Fly particles and gases will be removed by adequate and already available methods before it is released to the atmosphere. The amount of emissions produced as result of incineration amounts to 12.94 $MtCO_2$/year.

4.4 Ash

Ash is the final product from incineration can be used for paving roads, additive for manufacturing bricks and cement for construction services, and other applications. This process will eventually leave very little if any to be discarded, hence reducing the need for landfills [21]. From these results, it is possible to conclude that the energy and environment benefits from incineration are impressive. The thermal treatment leaves about 10% of ash which can be reused. It is important to mention that incineration is a viable option for handling MSW but must have adequate installations equipped with systems for monitoring, control and treatment of effluents to ensure safe and adequate operation such as used in European Union, Japan and EUA [19, 4, 32].

V. CONCLUSIONS

The results show that the treatment of the huge amount of MSW generated in the country contributes to improve basic sanitation and public health and ensure ambient sustainability. As can be observed, the energy and economic benefits from recycling and incineration cannot be ignored specially in a populated developing country as Brazil. The generated funds from commercializing only 10% of the potentially available recyclables represent ±123 thousand minimum national salaries. Considering that there are about one million informal waste pickers representing 0.5% of the Brazilian population, this financial gain is sufficient for about 10% of the informal waste pickers. This result can be augmented and the social inclusion can be increased by gradually increasing the recycling index by adopting adequate public policies and awareness programs to stimulate adherence to recycling activities. Another big contribution to the country is the energy generated as a result of incineration. Considering that Brazil is a developing country with urgent needs to diversify its energy resources and especially substitute the conventional ones by renewable energy resources to strengthen energy security. The electric energy generated from incinerating 80% of MSW is about 2902.6 GWh/month and this is enough for the consumption of nearly 25% of the Brazilian homes.

However, this huge amount of renewable energy is wasted since about 95% of generated MSW is destined to dumpsite provoking on national level strong negative impacts to the ecosystem.

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