Assessing the Morphological Composition and Energy Potential of MSW, the Case of the City of Johannesburg

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Abstract

The knowledge of the composition of a city's municipal solid waste and embedded resources is one of the pre-requisite for effective planning and implementation of sustainable strategies. A quantification exercise conducted towards estimating the composition and energy potential of the City of Johannesburg waste streams has been presented in this study. The waste quantification was conducted at Robinson deep landfill site and captured summer waste profile. The study showed that between 1.1 to 2.3 TWh/year can be generated from household collected refuse, also known as round collected refuse, depending on the degree of recycling implemented while waste from restaurants and eateries known as dailies can theoretically generate between 0.023 to 0.081 TWh/year of energy. The result also highlights the quantity of paper, plastic among other recyclables that can be diverted into other processes as secondary raw material. The energy potential of the non-recyclable energy potent materials was also presented.

Keywords
Municipal solid waste; waste quantification; calorific value; Energy

1 Introduction

Municipal solid waste (MSW) management is not a one-off planning, it is a dynamic evolution and planning has to cater for it. The quantity of MSW generated and their morphological composition form the basis for planning and management of MSW. However, for an effective MSW reduction policy to be implemented, the generated quantity of MSW is not sufficient alone for policy implementation but more of the variables affecting the generation rate and composition are critical (Grazhdani, 2016). Without an in-depth understanding of these variables, waste reduction policies may be ineffective and unsuccessful. Aside the recognition of these factors, the physicochemical characteristics and energetic potential of the MSW are needed for technology appropriation. This is the first step toward a sustainable long-term management policy formulation as regard minimisation, energy and resource recovery and eventual disposal (Vujic et al., 2010).

In many developing countries, researchers have highlighted lack of resources to monitor variables affecting MSW generation, incomplete or non-existence of MSW quantity data, composition and detailed knowledge of energy and secondary raw material resource potential are other limiting factors (Azadi and Karimi-Jashni, 2016; Dyson and Chang, 2005; Sukholthaman et al., 2015; Younes et al., 2015). The absence of these data has limited the exploitation of MSW as a resource for reducing the dependence on fossil fuel. Also, there has been increasing policy pressure from the international community for African countries to contribute toward the reduction of greenhouse gas emission. Such as the Rio convention of 1992 and more recently, the Conference of Parties (COP21) otherwise called 2015 Paris Climate Conference. In the COP21, a legally binding agreement was reached to keep global warming below 2 ℃ with South Africa being a signatory (COP21, 2015). To further emphasise the mandate for a reduction of greenhouse gas emission, the Polokwane declaration of 2001 came with a mandate for zero waste to landfill. Gradually major metropolitan cities have started driving this policy of zero waste to landfill. With the City of Johannesburg (CoJ) being the economic hub of South Africa and by virtue of such status, the population density in the CoJ is high so also the quantity of waste is expected to be high due to population and higher income level. Presently the CoJ is running out of landfill airspace thus increasing the need for an immediate interventive solution and fast tracking the policy implementation of zero waste to landfill. Within the waste management hierarchy, the CoJ is interested in energy recovery from it daily generated waste aside present effort on recycling and landfill gas recovery. However, the quantity of waste that can be used for energy generation is not known with certainty, thus technology appropriation and plant capacity cannot be accurately determined. Also, the MSW morphological composition is not known with certainty. Thus, this paper presents finding of a waste quantification study commissioned by the CoJ towards understanding the composition of MSW generated within the City and the theoretical energy potential. Fractions of recyclables, non-recyclables and organic waste were highlighted to emphasise the quantity of waste with energy potential that cannot be recycled hence will need to be diverted into energy recovery processes.

1.1 Waste Quantification

MSW quantification involves three phases, preparation, sampling and sorting, and assessment and reporting (Edjabou et al., 2015). There are several approaches reported in literature for conducting a waste quantification study (Capatina and Simonescu, 2008). The approach differs due to different classification systems used for streams and compositions of MSW. Also, different sample size applied, location of sampling, number sorting categories, randomisation of samples among others makes the comparison of results difficult. In a study in Rio De Janeiro, MSW was classified into 9 major categories (Borgatto, 2007) while in Serbia, MSW was classified into 16 categories (Vujic et al., 2010). According to the European commission report on methodology for analysis of solid waste, 13 compulsory primary categories and 35 secondary categories are required (European Commission, 2004). The ASTM approach also recommends a minimum of 13 categories with a procedure of load vehicle sampling, sample mixing, cone splitting, quartering and manual sorting. The different approaches quantification of MSW can be broadly classified into two. They are the direct approach which involves the sampling, sorting and weighing of waste stream composition either at generation source or at a central transfer location suitable for a regional or municipality scale quantification (Franklin Associates Ltd and Paraire Villages, 1998). While the second approach is an indirect analysis method that involves the overall material flow analysis assessing the quantity of input and output material into a system mainly applied for national scale quantification (Franklin Associates Ltd and Paraire Villages, 1998). In this study, the first approach has been implemented.

1.2 Description of Study Area

The CoJ is located in the Gauteng Province between latitude 26° 12' 08" S and longitude 28° 02' 37" E covering 1,644 km^2 and at an elevation of 1,767 m above sea level. The CoJ share boundaries with City of Tshwane on its north and Emfuleni Local Municipality on the South. It shares boundaries on the east with Ekurhuleni Municipality and on the western side with Mogale City Municipality. The 2011 census indicated the population of the CoJ was 4,434,827 and as at mid-2016, the population is at 4,865,117 and is projected to reach about 5.4 million by 2021 following a yearly average of 2.15%. The City's population is made up of young adult, age group 20-39 constitute 43% of the population with age 28 as the median (Wazimap, 2016). As at mid-2016, the number of households is 1,807,609 which is a 26% increase from 2011 census data. The number of households is projected to reach 2.16 million by 2021 (City of Johannesburg, 2016). At this rate of both population growth and household increase, the CoJ remains the biggest metropolitan by population size in South Africa and the fastest growing as well (Ahmad et al., 2010; City of Johannesburg, 2016; Mokgalaka, 2015).

The CoJ generates about 1.4 million tonne of waste per annum and Robinson deep, the largest operational landfill within the city with design air space capacity of $23x10^6\ (m^3)$. This landfill receives on average 40% of the waste generated within the city. Of the streams of waste discharged at this landfills, round collected refuse (RCR) which are waste collected from households once a week represents 53.11% of the total waste while dailies represent about 1.54%. These two waste streams are the waste stream of interest in this study due to their high degree of heterogeneity, a potential for biodegradable matter and somewhat complex nature to handle.

2 Methodology

In preparing the sampling procedure for the waste quantification study, careful consideration has been given to the available options for achieving a balanced, cost-effective and sufficiently accurate result. Since MSW generation rate varies on daily, weekly and monthly basis and sampling only provides a snapshot in time, random sampling procedure was taken over a duration of one week from 29 October 2015 to 7 November 2015 at Robinson Deep landfill site to capture as much of the variation in the municipality as possible. The choice of late October and early November has been recommended as the best time to capture a reliable summer waste quantification result. A team comprising of 16 students inclusive of the researcher carried out the waste sampling, sorting, and quantification at Robinson Deep landfill site. The procedures implemented were according to the three phases of Edjabou et al. (2015).

2.1 Planning

During the planning period, prior to the quantification and characterisation exercise, a site assessment study was undertaken to evaluate the terrain, study the existing procedure at Robinson Deep and promote cooperation with the staff of CoJ waste management company, Pikitup. Also, the planning period was used to collect historical data and site map for allocation of resources. During the planning period, waste classification categories were defined as shown in Table 1, sampling plan and schedule of activities were also developed.

2.2 Sampling and Sorting

Sampling and sorting were carried out at a demarcated section of the tipping plane of Robinson Deep landfill site. The demarcated section of the landfill was graded to ensure a level ground and a tarpaulin was laid for the waste sorting. Rear loading trucks were randomly selected during each day of sampling to discharge their content at the demarcated area. An earth-moving truck with a front bucket was used to mix the waste and about 1 m^3 of waste was set aside. Approximately 100 kg of waste was taken from the mixed waste as a representative sample and the rest were discarded. The sample was sorted manually into 41 fractions of the main 10 categories presented in Table 1. The percentage contribution was determined by weighing each fraction and dividing by the total amount of sample weight collected. Once this procedure is completed, another waste truck is randomly selected and the whole process is repeated.

Table 1. Main Categories and sub categories of RCR and Dailies

1. **Organic waste** (food waste, garden waste, composite organic waste).
2. **Paper and paperboard waste** (newspaper, cardboard & boxboard, books & magazines, office paper, corrugated paper, non-recyclable papers).
3. **Glass waste** (clear container/bottles, green containers/bottles, amber containers, non-packaging glass).
4. **Metal waste** (tin/steel containers, aluminium containers and packaging, scrap metals, other ferrous metal, non-ferrous metal).
5. **Plastic waste** (clear PET containers, green PET containers, amber PET containers, HDPE containers, film plastics, mixed plastic bags, non-recyclable/un-identifiable plastics).
6. **Fabric/Leather waste** (textile, non-textile based material, leather).
7. **Special care/Hazardous waste** (paint, waste electrical products, batteries, mineral oil and accessories, composite special care waste).
8. **Health care waste** (diapers/sanitary products, other biomedical waste).
9. **Miscellaneous Combustible waste** (tyre, furniture, wood, polyurethane foam).
10. **Miscellaneous Non-combustible waste** (Ceramics and rubble, other non-combustible materials).

2.3 Assessment and Reporting

At the end of each day of sorting, datasheets used were reviewed. The data collected from the site was computed into a developed excel spreadsheet. Other information collected were the waste depot area the truck served and any unusual observation in the waste sample received. The percentage and average of each fraction of waste were calculated for the duration of the sample period.

3 Results and Discussion

3.1 Size of samples

From the historical data collected, the CoJ dispose of 1.2 to 1.6 million tonnes on waste per annum with an average of 1.4 million tonnes. Round collected refuse contributed on average 54% of the total waste disposed of while dailies contributed about 1.54%. During the quantification exercise, a total of 25 trucks were sampled equivalent to 2500 kg of waste. On average, 4 trucks were sampled each day. Of the 25 sampled trucks, 15 were round collected refuse while 10 were dailies. Detailed observation of the results is provided in the following sections.

3.2 Round Collected Refuse

As earlier presented, round collected refuse are waste collected from household Figure 1. It was observed of the 41 fractions, food waste contributed 19.7% to the total RCR fraction of MSW. Corrugated paper contributed 5.1%, clear glass 6.1%, aluminium 3.5%, clear PET plastic 4.8%, Textile 1.8%, E-waste 1.8%, diaper and sanitary product 6.2%, tyre 2.5% and miscellaneous non-combustible materials 4.6% to the total RCR fraction of MSW as presented in Figure 2. Grouping the waste into 6 major categories for ease of comparison with the previous study, shows their contribution to the total waste. Figure 3 shows that organic main category contributed approximately 34% of the total RCR. A 2001 study reported 35% for organics, 17% for paper, 10% for plastic, 5% for glass and 3% for metal (Rod Ball and Associates, 2001). The composition for "others" was not clearly stated hence comparison is difficult to make.

Figure 1 RCR being discharged and waste sorting in progress

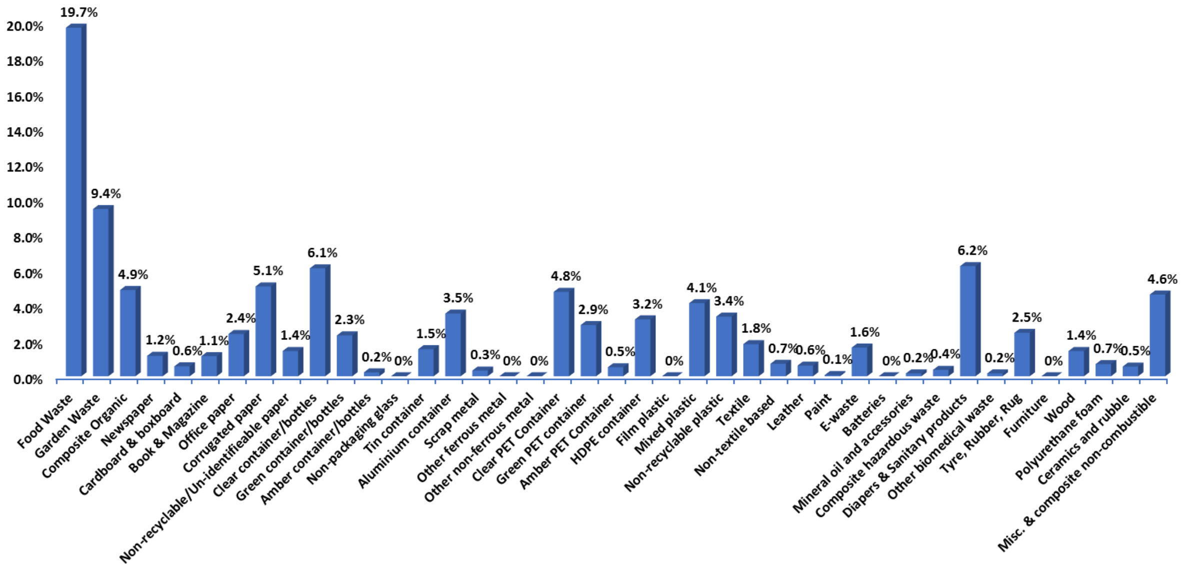

Figure 2 Percentage contribution of the fractions of RCR to MSW

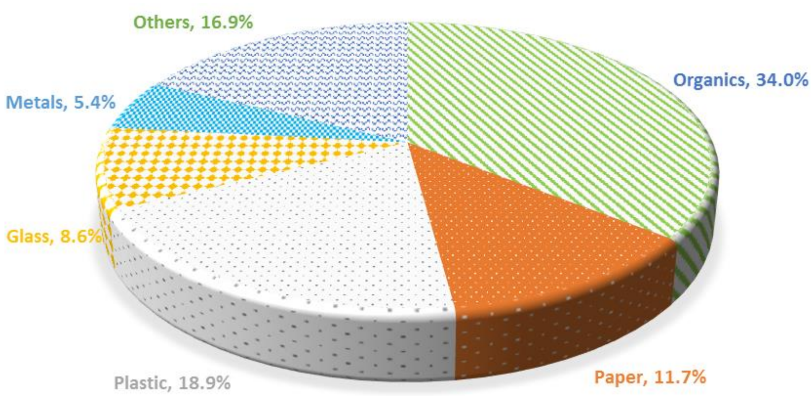

Figure 3 Percentage composition of RCR main categories to CoJ MSW

3.3 Dailies

Dailies are waste from restaurants and eateries (Figure 4). Food waste fraction contributed 13.9% of the total waste. The overall organic which is less than that of RCR is 14.45%. Plastic waste contributed the highest amount to the total dailies fraction of MSW when grouped into 6 main groups with 33.95% while paper came close with 17.03%. This is expected due to the quantity packaging material that goes with sale of food. Within the paper category, non-recyclable paper contributed 5.5% to the total waste due to them been soiled and wet. Other fractions observed were tin container contributing 4% to the total dailies fraction of MSW, HDPE container 9.5%, non-textile based material 4.3%, E-waste 1.2%, diapers and sanitary products 2%, polyurethane foam 0.2% and miscellaneous non-combustible 6.1%.

Figure 4 Dailies sorting in progress

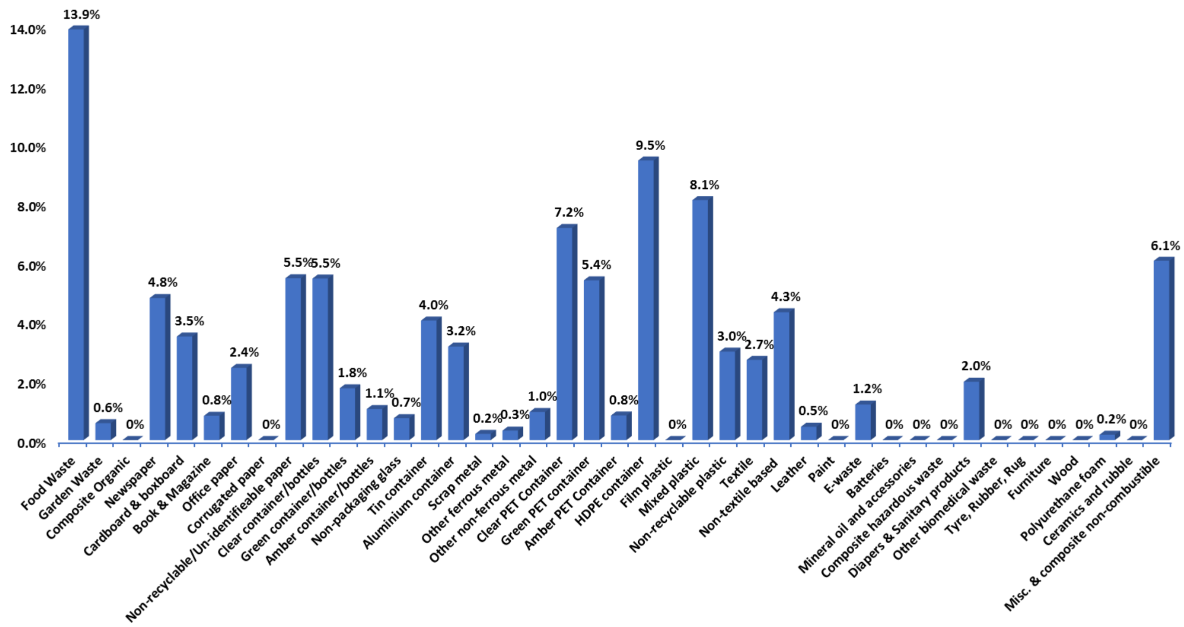

Figure 5 Percentage contribution of the fractions of dailies to MSW

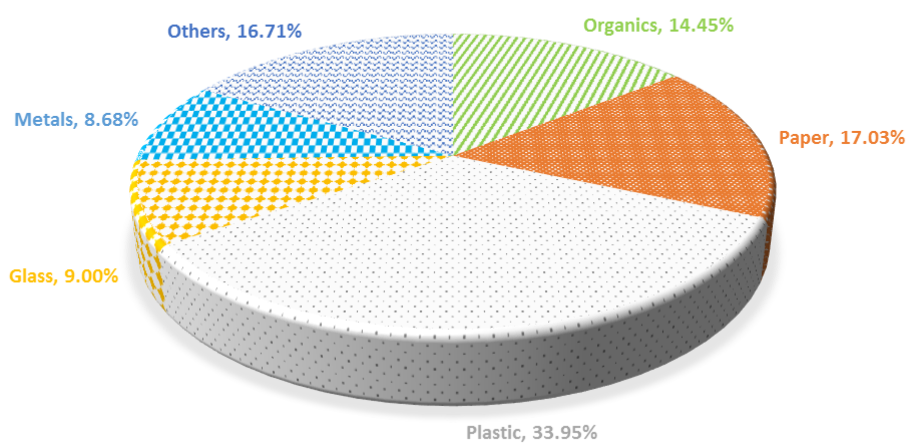

Figure 6 Percentage composition of dallies waste main categories to CoJ MSW

3.4 Energy and Resource Recovery Potential

The energy potential is calculated based on the gross calorific value of the major category. A combination of literature and laboratory analysis has been used for the calorific value. They values used are organic 9.4 MJ/kg, paper 11.9 MJ/kg, plastic 30 MJ/kg, textile 12.3 MJ/kg and miscellaneous combustible waste 8.25 MJ/kg (ECN Phyllis2, 2017). Table 2 shows that if all waste without recycling is diverted into an energy recovery process there is a theoretical potential of generating 2,276 GWh/year from RCR. On the other hand, when all recyclables have been extracted from the waste stream, the potential to generate about 1,062 GWh/year of energy is possible. Aside from energy recovery, the result shows that about 88% of paper waste and 82% of plastic waste presently discharged at Robinson Deep landfill can be recycled aside glass and metal which do not have any energy potential before diverting the non-recyclable energy potent waste to an energy recovery unit.

Table 2. Theoretical energy potential of RCR main waste categories

All Energy potential waste	Ton/yr	MJ	MWh/yr	Non-recyclables	Ton/yr	MJ	MWh/yr
Organics	252,804	2,381,409,912	661,503	**organic**	252,804	2,381,409,912	661,503
Paper	87,242	1,037,307,697	288,141	**Non-recyclable paper**	10,608	126,127,186	35,035
Plastic	140,331	4,209,923,480	1,169,423	**Non-recyclable plastic**	25,033	750,975,400	208,604
Textile	23,198	284,180,988	78,939	**Textile**	23,198	284,180,988	78,939
Miscellaneous Combustible	33,955	281,486,895	78,191	**Miscellaneous combustible**	33,955	281,486,895	78,191
	537,530	**8,194,308,972**	**2,276,197**		**345,597**	**3,824,180,381**	**1,062,272**

Considering dailies, diverting all waste from restaurants and eateries into an energy recovery unit, there is a potential of generating 81.4 GWh/year of energy but should the recyclables be recovered, the potential to theoretically generate 23 GWh/year do exist as shown in Table 3. Aside from the potential energy that can be recovered from the dailies waste stream, the result shows that 68% of paper waste and 91% of plastic waste can be recycled before diverting the non-recyclable waste to an energy recovery unit.

Table 3. Theoretical energy potential of dailies main waste categories

All Energy potential waste	Ton/yr	MJ	MWh/yr	Non-recyclables	Ton/yr	MJ	MWh/yr
Organics	3,115	29,347,256	8,152	**organic**	3,115	29,347,256	8,152
Paper	3,672	43,656,133	12,127	**Non-recyclable paper**	1,179	14,022,257	3,895
Plastic	7,320	219,588,600	60,997	**Non-recyclable plastic**	645	19,339,320	5,372
Textile	1,613	93,504	26	**Textile**	1,613	19,755,428	5,488
Miscellaneous Combustible	39	321,718	89	**Miscellaneous combustible**	39	321,718	89
	15,758	**293,007,212**	**81,391**		**6,591**	**82,785,980**	**22,996**

3.5 Conclusion

The result of this study highlights the energy potential of two major sources of the CoJ MSW, RCR and Dailies. The theoretical energy potential of the waste streams with and without recycling has been presented. The results also show the quantities of waste that are not eligible for recycling, particularly the organic fraction of MSW but are a potential candidate for energy recovery. Hence, there is a need to find an alternative, cost-effective, environmentally friendly and socially acceptable technology in dealing with such amount of wastes that cannot be recycled but are a good candidate for energy production.

Acknowledgements

The authors wish to acknowledge the City of Johannesburg, Environment and Infrastructural Service Department of the City of Johannesburg and the University of Johannesburg for providing grants for this research work.

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