Evaluating the Municipal Solid Waste Management Approach of a City using Material Flow Analysis

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Abstract

Towards an efficient utilisation of resources, waste minimisation and reuse through recycling and energy recovery is becoming as important as energy efficiency. Knowledge of municipal solid waste flow provides the starting point for evaluating management efficiency measures implemented. This study aims at applying material flow analysis towards evaluating the existing waste management approach within the City of Johannesburg to highlight the degree of recycling activities at each point within the waste flow pathway. Also, to identify the drivers and quantify the amount of valuable resources presently being lost to due to landfilling. The result obtained showed that about 4.41% of 1,400,000 tonne/year of waste generated is being recycled/recovered. Of the recycled fraction, about 60% is contributed by informal recyclers. Approximately 300,000 tonne/year of recyclable material is presently being discarded at landfills within the city and 252,000 tonne/year of organic waste is available for energy recovery.

1 Introduction

The amount of material and energy consumed within a system is similar to the consumption of resources within that system (Shafie et al., 2016). Increasing economic activities and human population will further invigorate the consumption of resources. As a result of consumption, depletion of resources occurs, products are formed while waste is generated which impact pressure on the environmental sinks (Hartlieb et al., 2005). The type of waste and the physicochemical characteristic of the waste is a function of the input resource and the transformation process involved. Waste is categorised in three forms; gas, liquid or solid (Igoni et al., 2007). The latter generated by communities-Municipal Solid Waste (MSW) is the broad waste of interest in this study. MSW has been defined by several authors in different ways though with confusing context such as MSW being referred to a domicile solid waste, urban solid waste or residential solid waste thus giving a rise to ambiguity in the boundary of what is considered in MSW classification (Buenrostro et al., 2001). The summarised definition is given here highlights, the emphasised phrase in most of the definitions encountered. MSW is thus defined as wastes emanating from households, institutional, commercial and industrial entities based within a community to which by their nature and composition are similar to wastes from household and that such waste is collected by the community waste collection authority, its agent or technology acting on its behalf (EPA, 2016; Igoni et al., 2007; Kolekar et al., 2016; Read, 1999). MSW once believed to be a societal burden is now being approached as a potential resource for the creation of new materials and as an alternative energy source. The change in attitude can be related to the fast depletion of primary natural resources and better understanding of the impacts of greenhouse gas emissions which includes but not limited to biodiversity loss, increase air, water and soil pollution, deforestation and shortages of resources and materials, all of which is as a consequences of over-consumption and unsustainable production processes (Lehmann, 2010). Recently, discussion about resource efficiency and resource recovery are becoming as intense as energy efficiency. However, to fully capture the degree of such efficiency in resource use and recovery of secondary resources from waste, the flow of material into and out of a system is important.

Material flow analysis (MFA) is a system assessment tool that provides an approach for energy and material flow connections into and out of a defined system within a time frame. MFA can be applied in evaluating the whole waste management hierarchy or a single waste stream towards identifying sources of MSW generation, sources for minimising waste, internal material flows, potential opportunities for reuse, recycling and accounting for hidden flows and sinks that may be unexplainable in a more traditional method of MSW analysis (Owens, 2008; Owens et al., 2011). Using MFA, it is possible to objectively evaluate an existing MSW management technology, identify the deficiency and assess the potential efficiency-improvement approach and make a decision on the most preferred process (Muchangos et al., 2016). The MFA model is based on the first law of thermodynamics on the conservation of matter that is within a system boundary, all inputs, stocks and transformation processes must be accounted in output or accumulation. MFA has been applied in the field of MSW management extensively. Shafie et al. (2016) applied MFA approach for three cities in Malaysia with a recommendation of approach on effective MSW management and planning. Giang et al. (2013) used MFA for analysis of MSW management system in the City of Hanoi, Vietnam. The MFA analysis indicated that 70% CH_4 emission and 53% CO_2 can be avoided by diverting organic waste from landfill and 75% GHG can be avoided by incorporating landfill gas recovery system. Muchangos et al. (2016) implemented MFA for MSW management in Maputo City, the capital of Mozambique. The model was used to identify and quantify the main inflows and outflows of MSW management system between 2007 and 2014. The results showed the missing gap is waste collection and disposal, highlighted practical waste reduction strategies, explore the potential for material recovery, quantify the growing trends of illegal dumping and recommended the urgent need to phase out the existing practice of open disposal of waste. For single element tracing, MFA has also been applied. (Hartlieb et al., 2005) applied MFA to trace cadmium from its production through various application processes to the recycling and disposal of developed products. Agamuthu et al. (2011) applied MFA for assessment of the elemental transfer of aluminium waste at a sanitary landfill. Achinas (2014) evaluated olive oil waste management processes in the agricultural and environmental sector of southern Europe using MFA. Annisa (2016) applied MFA to assess the potential of different scenarios to recycle, material and energy recovery from MSW discharged at a landfill towards reducing quantity discharged and extending the service life of the landfill. Zaccariello et al. (2015) also, investigated material recycling potential and waste to energy opportunities with MFA.

As presented, MFA has been widely used as an assessment tool for finding fundamental information for the discussion of sustainable resource management. Through the implementation of MFA, many developed countries have a better understanding of their resources by monitoring of their flows and thus are able to measure the degree of efficiency in their processing and utilisation. The knowledge gained has been applied in efficient product design and waste minimisation. In-depth understanding of MSW flows within the City of Johannesburg is needed to identify process routes, factors, locations, inefficiencies, problems and opportunities within existing waste management approach. Also, since the City is interested in investing in new technologies with a focus on resource recovery through recycling and energy recovery, MFA can be used to evaluate the overall material and energy flows for different pathways as well as their impact on the environment. Although MFA is a data-oriented analytical technique, it holds a huge potential of providing the needed knowledge toward other detailed studies in the decision-making process. In this study, MFA has been applied to evaluate the flows of material within the existing waste management framework of the City of Johannesburg. The study also presented the role of informal recyclers in waste management.

2 Methodology

2.1 Field site and system boundaries

A waste quantification and characterisation studies were conducted at Robinson Deep landfill site and Johannesburg fresh produce market in the City of Johannesburg. The streams of waste quantified were the household collected waste called round collected refuse, waste from restaurants and eateries called dailies and waste from the City's fruit and vegetable market. The quantification exercise was conducted between October 29th and November 20th 2015. The system boundaries considered in this study are the waste disposal, transportation to the landfill sites, recovery of recyclables and final disposal of rejected MSW.

2.2 Data collection

The waste quantification and characterisation exercise provided the primary data used in this research. Secondary data of the total waste generated within the city and fractions of garden waste were retrieved from the annual publications of the waste management company of the city, Pikitup. Assumptions on quantity of waste recycled by informal recyclers were made at this stage of the study based on the observed activities at both sites during the waste quantification.

2.3 Material flow analysis

MFA was modelled using the STAN (subSTance flow ANalysis) tool, a freeware for material flow investigation developed by the Vienna University of Technology (Institute for Water Quality, Resources and Waste Management) (Cencic and Rechberger, 2008). Using the STAN tool, each block represents a process or a sub-system included in the system boundaries, while each flow arrow is related to the mass flowrate of waste or material. The width of the flow arrow is proportional to their values, that is the flows are graphically represented with Sankey diagrams. Four types of mathematical models are used in STAN (Cencic and Rechberger, 2008). They are balance equation, transfer coefficient equation, stock equation and concentration equation.

Balance equation:

$$\sum inputs = \sum outputs + change\ in\ stock$$

Transfer coefficient equation:

$$Output_x = transfer\ coefficient_{to\ output\ x} * \sum inputs$$

Stock equation:

$$stock_{Period\ i+1} = stocked_{period\ i} + change\ in\ stock_{period\ i}$$

Concentration equation:

$$mass_{substance} = mass_{goods} * concentration_{substance}$$

These equations could contain known constants, measured values and unknown variables. Detail description of the software is presented by (Brunner and Rechberger, 2005; Cencic and Rechberger, 2008)

3 Results and Discussions

3.1 Waste quantification

The waste quantification result is summarised in Table 1. The detailed procedure for the quantification can be found (University of Johannesburg, 2016). The quantification result shows that organic waste contributed the highest fraction for RCR and JFPM streams of waste while plastic contributed the highest fraction for dailies.

Table 1 Waste quantification for the three streams

Waste group	RCR	Dailies	JFPM
Organics	33.98%	14.45%	93%
Paper	11.73%	17.03%	3.08%
Plastic	18.86%	33.95%	1.19%
Glass	8.62%	9.00%	0%
Metals	5.38%	8.68%	0.43%
Fabric & leather	3.12%	7.48%	0%
Special Care/hazardous	2.21%	1.20%	0%
Health Care	6.38%	1.97%	0%
Misc. Combustible	4.56%	0.18%	0.58%
Misc. Non-combustible	5.16%	6.06%	0.14% (others)

3.2 Material Flow Analysis

Towards implementing the material flow analysis, the assumption taken for informal recycler based on the observation of the authors during the period of quantification is presented in Table 2.

Table 2 Assumptions for secondary data

Waste group	RCR	Dailies	JFPM
Organics	0%	0%	0%
Paper	8%	4%	5%
Plastic	3%	2%	0%

Glass	5%	15%	0%
Metals	25%	40%	0%
Fabric & leather	0%	2%	0%
Special Care/hazardous	0%	0%	0%
Health Care	0%	0%	0%
Misc. Combustible	0.4%	0%	0%
Misc. Non-combustible	0%	0%	0% (others)

During the quantification exercise, the waste stream of interest to the informer recycler is the metal waste. Other waste streams which are also of interest are the unsoiled paper waste, HDPE plastic and unbroken glass bottles. The low fraction allocated to metal in RCR is due to the compaction of the waste and the mixed organic dirt when discharged. Also, the compactor trucks at the landfill site for compacting the waste works continuously irrespective the activities of the recyclers, thus only a limited time is available for searching for such metals. However, for dailies, the waste is not compacted and not as dense as RCR, thus making the process of searching for metals much easier. The major drawback is the high amount of plastics and polystyrenes in the waste as shown in Figure 1. For the three major streams of interest, the organic waste is not being recycled nor diverted into composting process. Garden waste from city parks was included in the study, the average annual amount generated is 61,345 tonnes per year. The City has a composting process for parts of its garden waste. It is assumed that only 40% of the annual garden waste is composted and the rest is discarded at the landfills. Inputting all the above parameters and assumptions, the material flow model was developed and the result of the MFA is presented in Figure 2.

Figure 1 Activities of informal recyclers at the landfill site

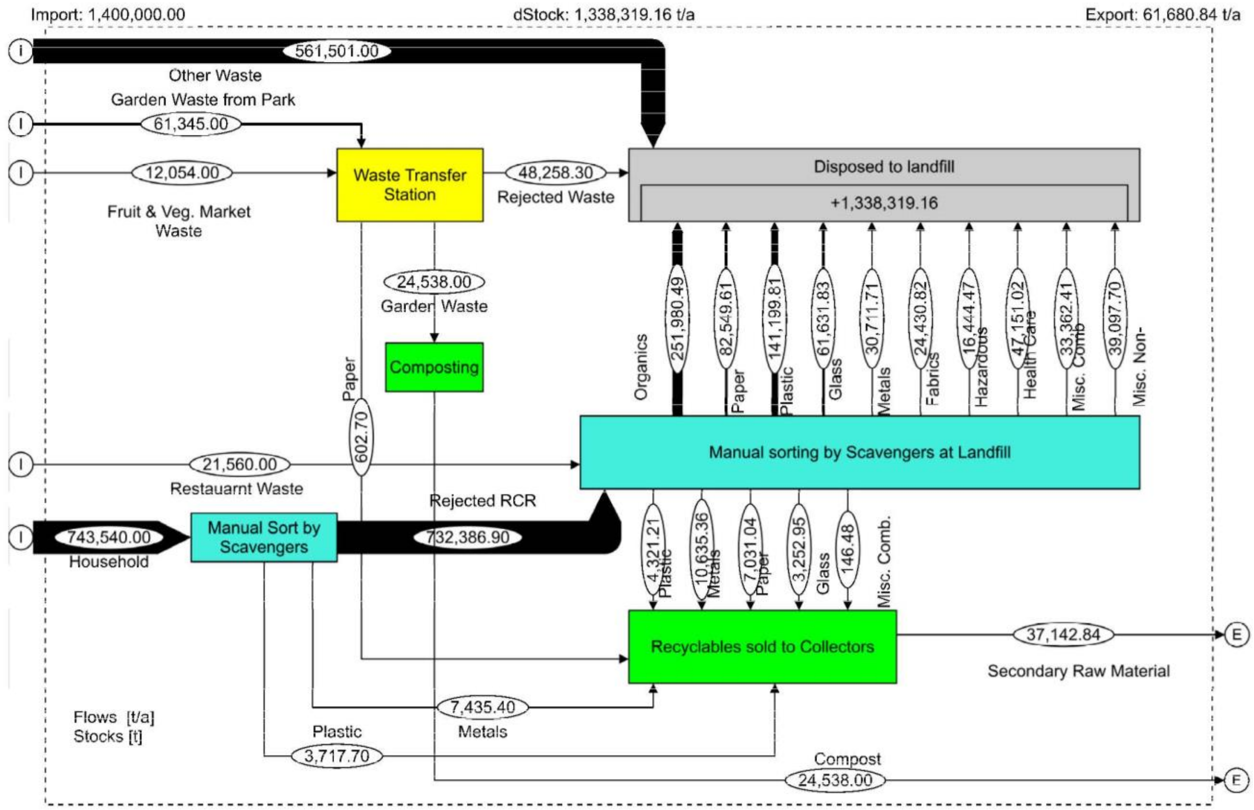

Figure 2 Material flow of existing waste management strategy

It can be observed that only about 61,681 tonne/year of waste is recovered/recycled of the 1,400,000 tonne/year of waste discarded at the landfill sites within the City of Johannesburg. The "manual sort by scavengers" process from the household waste streams are the informal recyclers that pick up recyclables from waste bins just before the city waste management company, Pikitup, empties the bins from each household. It is estimated that about 7,435 tonne of metals and 3,717 tonnes of plastics is recycled by this group of informal recyclers. From the fruit and vegetable market waste transfer station, there is a group of paid recyclers who picks out only packaging cardboard from the waste discharged. It is estimated that about 602 tonne/year of paper waste is recycled since 93% of the waste is organic and any soiled paper is also discarded. The core of recycling activity occurs at the tipping plan of the landfill site as shown in Figure 1. Based on the assumed parameters, about 25,387 tonne/year of waste is recovered/recycled at the tipping plane of the landfill. Of the total recycled/recovered material, of 61,681, about 60% is contributed by informal recyclers. Though this is based on the logical assumptions of the authors, it shows the role of this unrecognised group of people within the waste management process. From the results obtained with the MFA, there is a huge potential to recover more than 300,000 tonne/year of recyclables through a material recovery facility and also the non-recyclable such as the organic waste which is about 251,980 tonne/year can be diverted into a mechanical biological treatment (MBT) facility for both resource recovery ad energy extraction. Also, the MFA shows that no interventive measure exit for pre-sorting of waste from restaurants (dailies) before discharging them at the landfill. The high plastic content in dailies and the quantity of it in RCR, which are not biodegradable, is a threat to the ecosystem.

4 Conclusion

In this study, MFA has been applied to graphically present the flows of materials within the City of Johannesburg waste management strategy. Though the study has been based on primary data from a quantification study and secondary data based on logical assumptions of the authors. However, the study highlights the quantity of waste being recycled and the waste stream with a high recycling rate, garden waste and metal waste. It also shows the quantity of resource discharge at the landfill sites are potentially available for recovery should appropriate technologies be implemented. Aside the quantity and type of waste presented, this study shows how informal recyclers are playing a key role in the material recovery process, though mainly in exchange for money to meet their basic needs. The formal integration of informal recyclers at the first point of the waste collection might increase the quantity of material presently recycled, reduce the energy intensiveness of transporting waste to landfills and reduce the eventual waste disposed at the landfill as a short-term measure. Basic application of MFA has been presented in this study. A detailed study with scenarios analysis of different waste management approaches in comparison to the existing approach, quantifying not only the quantity of waste but also the energy potential and intensity, process efficiency, inherent by-products and environmental impact of applicable waste management technologies is being developed.

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References

Achinas S (2014) Material flow analysis (MFA) for waste management in olive oil industries sector in South Europe. *Journal of Sustainable Development Studies* **5**:11.

Agamuthu P, S. MM and Mohd Afzanizam M (2011) Material flow analysis of Aluminium in a dynamic system: Jeram sanitary landfill. *Malaysian Journal of Science* **30**:12.

Annisa B (2016) Scenarios tackling municipal solid waste (MSW) flow into landfill based on MFA-STAN integrative method towards building sustainable city in Indonesia. *ARPN Journal of Engineering and Applied Science* **11**:12.

Brunner PH and Rechberger H (2005) *Practical handbook of material flow analysis*, Lewis Publishers.

Buenrostro O, CBocco G and Cram S (2001) Classification of sources of municipal solid waste in developing countries. *Resources, Conservation and Recycling* **32**:13.

Cencic O and Rechberger H (2008) Material flow analysis with software STAN. *Journal of Environmental Engineering Management* **18**:5.

EPA (2016) Municipal solid waste. *Waste-non-hazardous waste* **2016**.

Giang HM, Luong ND and Huong LTM (2013) Assessment of potential greenhouse gas mitigation of available household solid waste treatment technologies. *Waste Technology* **1**:7.

Hartlieb N, Brautigam KR, Achternbosch M, Kupsch C and Sardemann G (2005) Use of material flow analysis for assessing solid waste management in Germany regarding sustainable solutions. *Transactions on Ecology and the Environment* **81**:11.

Igoni AH, Ayotamuno MJ, Ogaji SOT and Probert SD (2007) Municipal solid-waste in Port Harcourt, Nigeria. *Applied Energy* **84**:664-670.

Kolekar KA, Hazra T and Chakrabarty SN (2016) A Review on Prediction of Municipal Solid Waste Generation Models. *Procedia Environmental Sciences* **35**:238-244.

Lehmann S (2010) Resource recovery and materials flow in the city: Zero waste and sustainable consumption as paradigms in urban development. *Sustainable Development Law and Policy* **11**:15.

Muchangos LSd, Tokai A and Hanashima A (2016) Application of material flow analysis to municipal solid waste in Maputo City, Mozambique. *Waste Management & Research*:15.

Owens EL (2008) Material flow analysis for Kayangel State, Republic of Palau: Solid waste management on a small pacific island, in *Department of Civil and Environmental Engineering* p 97, Michigan Technological university, United States of America.

Owens EL, Zhang Q and Mihelcic JR (2011) Material flow analysis applied to household solid waste and marine litter on a small island developing state. *Journal of Environmental Engineering* **137**:8.

Read AD (1999) Making waste work: making UK national solid waste strategy work at the local scale. *Resources, Conservation and Recycling* **26**:259-285.

Shafie FA, Omar D, Karuppannan S and Ismail N (2016) Urban-scale material flow analysis: Malaysian cities case study. *International Journal of Environment and Sustainbility* **5**:9.

University of Johannesburg (2016) Feasibility study: Implementation of a pilot biogas plant at Robinson deep landfill, in *Waste to Energy* (Masebinu SO ed) p 178, University of Johannesburg, Johannesburg.

Zaccariello L, Cremiato R and Mastellone ML (2015) Evaluation of municipal solid waste managment performance by material flow analysis: Theoretical approach and case study. *Waste Management & Research* **33**:15.