Consideration of Emission Ratios in Integrated Sustainable Municipal Solid Waste Management Planning

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Key words: Process generated emissions, Emissions inventory, Emissions inventory model, Municipal solid waste management, Integrated sustainable municipal solid waste management.

SUMMARY

The treatment and disposal of Municipal Solid Waste (MSW) may cause environmental pollution and expose humanity to harmful substances and bacteria that affects human health and the ecosystem. Therefore, accurate quantification and detailed documentation of emissions data from Municipal Solid Waste Management (MSWM) will enables a city or region to demonstrate transparency and enhance the credibility of its corporate environmental and climate change strategy. Establishing a comprehensive corporate emissions inventory is an important first step in developing an environmental and climate change strategy. This is justified if adequate resource utilization and environmental implications are considered in planning the collection, transportation and treatment/disposal of MSW, hence developing a city wide, regional or national Integrated Sustainable MSWM system.

This paper presents a methodological approach for emissions inventory with case study in conducting a baseline emissions inventory using Life Cycle Assessment Model (LCAM).
The paper presents best practices in establishing the organizational and operational boundaries of a MSWM scenario emissions inventory in a sustainable city, region or national environment using three active landfills in Waikato Region of New Zealand. In this study, site-depended data for the landfills together with regional waste composition are used with associated collection, transportation and treatment/disposal data, to determine the emission levels associated with the landfills. Hence the environmental profile of the three MSW landfills were evaluated and compared in relation to their total waste intake over twenty years period (19720157.6 tonnes, 3533333.528 tonnes and 43538.452 tonnes for Hampton Downs, Tirohia and Taupo landfills respectively). Using the impact categories as classified in EASEWASTE, the emission ratios per tonne of waste are compared to assess the contributions of the landfills to the emissions associated with MSWM in the region.

Finally, the paper provides guidance on continuous improvement and maintenance of the emissions inventory in the MSWM sector to guide stake holders in reducing the impact of MSW through a Integrated Sustainable manner. The need for zoning MSW collection/transportation system using available disposal/treatment sites as focal points is therefore advocated. A modified generalized emissions inventory model for the MSW sector is suggested.

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1. INTRODUCTION

The health and environmental effects of MSWM have since been demonstrated (Aatamila et al., 2010; Aljaradin & Persson, 2012; Bandara &Hattiarachchi, 2003; Boadi &Kuitunen, 2005; Defra, 2011; El-Fadelf, Findikakis&Leckie, 1997; Forastiere et al., 2011; Kirkeby et al., 2006b; LaMar et al., 1978; Qdais, 2007; Rushton, 2003; Sankoh, Yan & Yen, 2013 and Zagozewski et al., 2011), and are often dramatic, warranting serious attention and actions. Still, it is often the visible (or "smell-able") and obvious obnoxious aspects of bad air quality that stimulate the most urgent demands for attention. The ability to begin putting numeric totals on what was being trashed into the air has played a key part in bringing fundamental attention to answering the question, "What is the problem?" From this fundamental need, things have gotten a lot more sophisticated but sometimes more obscure (Southerland, 1978).

Lee and Jones-Lee (1994) reported the potential adverse impacts of municipal solid waste (MSW) landfills on those who own or use properties near such facilities. Hirshfeld,Vesilind &Pas, (1992) reported that the property values near MSW landfills are adversely impacted by the landfill for distances of a mile or more from the area where waste deposition occurs. Adverse environmental impacts, public health and socioeconomic issues associated with MSW landfills have led to issuance of stricter regulations and increased public opposition to the sitting of such facilities (not in my back yard syndrome) (Qdais, 2007). As a result, the sitting of a new landfill has become one of the most difficult tasks faced by most communities involved in MSW management. (Tchobanoglous, Theisen&Vigil, 1993).

The understanding of the fact that waste management will ever be part of city management and part of human habitation; city managers have continually made waste management an integral part of city planning and management, especially in developed countries. It is normal to set targets of achievement. For example; targets on the expected level of disposal within a specified period, the percentage of recycling to be achieved and so on. Because of the understanding of the environmental threat from bio-waste and other biodegradable wastes (through the production of methane), accounting for about 3% of total greenhouse gas emission in the EU-15 in 1995, Landfill Directive (1999/31/EC) was promulgated by the EU Parliament which obliges Member States to reduce the amount of biodegradable municipal waste that they landfill to 35% of 1995 levels by 2016 (for some countries by 2020). This will significantly reduce this environmental problem (European Commission, 2012). To show the progress that is being made requires a regular monitoring of waste composition and emissions resulting from landfills.

This paper therefore, demonstrates the need to incorporate comprehensive emissions inventory as a step towards monitoring and showing the progress that are made in MSWM.

Results of analysis of results from the landfills revealed that the emission ratios (emissions associated with one tonne of waste) from the landfills differ significantly as a result of variations in the scenario created by significant difference in MSW transfer/transportation set up.

1.1 Emission Inventory

According to US EPA (2011), an emissions inventory is a database that lists, by source, the amount of air pollutants discharged into the atmosphere of a community during a given time period and the development of a complete emission inventory is an important step in an air quality management process. Emission inventories are used to help determine significant sources of air pollutants establish emission trends over time, target regulatory actions, and estimate air quality through computer dispersion modeling. An emission inventory includes estimates of the emissions from various pollution sources in a specific geographical area. A complete inventory typically contains all regulated pollutants.

Emissions and releases to the environment are the starting point of every environmental pollution problem. Information on emissions therefore is an absolute requirement in understanding environmental problems and in monitoring progress towards solving these. Emission inventories provide this type of information.

Emission inventories are developed for variety of purposes which can be categorised into two broad groups:

- Policy use, to track progress towards emission reduction targets and develop strategies and policies. The annual reporting of national total emissions of greenhouse gases and air pollutants in response to obligations under international conventions and protocols like UNFCC for GHG and regular emission reporting by individual industrial facilities in response to legal obligations are examples of this type of application.
- Scientific uses like inventories of natural and anthropogenic emissions are used by scientists as inputs to air quality models. Example of this is the Pollutant Release and Transfer Registers for air quality models.

This research falls under the first group as the purpose is the quantification of emissions from MSWM to help in monitoring progress being made in that sector as a step towards improving on the processes.

2. WHAT IS MUNICIPAL SOLID WASTE MANAGEMENT (MSWM)?

Municipal solid waste (MSW) reflects the culture that produces it. Effective waste management strategies depend on local waste characteristics, which vary with cultural, climatic, and socioeconomic variables, and institutional capacity (Vergara and Tchobanoglous, 2012). But generally, Municipal Solid Waste management is the collection, transport, processing or disposal, managing and monitoring of waste materials. The production and management of waste, affects air quality, water quality, and public health, and it contributes to climate change (Bogner et al, 2013).

The impact of waste management on the environment and human health depends on the management processes and procedures. On this base, the waste management hierarchy (Figure 1) evolved. The hierarchy gives priority to management strategy that is friendlier to the environment starting with reducing or preventing its generation through to reuse, recycling, recovery and finally residual management or disposal (Environmental Canterbury Regional Council, 2009 and European Union, 2008).

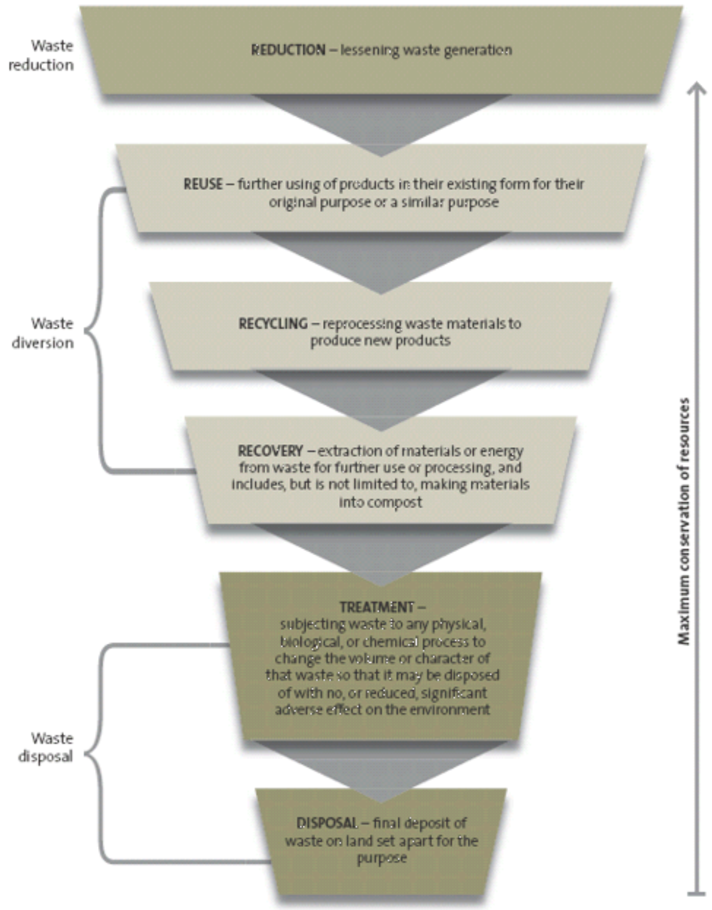


Figure 1: Waste management hierarchy (Source: Vergara and Tchobanoglous, 2012)

3. EMISSION FROM MSWM

According to World Bank (2012), about 1.3 billion tonnes of MSW is generated annually by urban settlers globally and this is expected to increase to 2.2 billion tonnes by 2025. Van de Klundert & Anschütz (2001) and UNEP (2009) agrees that waste management cannot be effectively managed without due consideration for issues such as the city's overall GHG emissions, labour market, land use planning, and myriad related concerns.

The estimated global annual emissions from solid waste disposal sites (SWDS) are in the range of 20 - 40 million tonnes of CH_4, of which the most comes from industrialized countries (so-called Annex I countries of the UNFCCC). This contribution is estimated to be approximately 5-20 percent of the global anthropogenic CH_4, which is equal to about 1 to 4 percent of the total anthropogenic greenhouse gas (GHG) emissions. The emissions from developing countries and countries with economies-in-transition will increase in the near future due to increased urban population, increased specific (pro capita) municipal solid waste (MSW) generation due to improved economy and improved SW management practices (Jensen & Pipatti, 2000).

Emissions from waste treatment centres may constitute a substantial nuisance for neighbouring residents. The emissions typically include microbes, particles, and odorous substances (Aatamila et al., 2010). Therefore, considering comprehensive emission inventory for waste management becomes critical.

Currently, emissions from waste management are considered based on the management procedure-landfill, incineration, composting, etc. The contributing process emissions are ignored or are part of a different emission source in Intergovernmental Panel on Climate Change (IPCC) report schedule or environmental report card of the city or nation. In that case, emissions from trucking of waste are reported under transportation while emissions from power consumption are part of the general emissions from the power sector as in IPCC (1997). Since it is not reported separately, there is no monitoring mechanism to know when there is an improved system.

But, for a better management of MSW considering the environment, better resource utilization and human health, it is important to understand the nature and rate of emission from all components of waste management – collection, transfer/transportation and treatment/disposal. This will help to improve best management practices for collection activities and provide more accurate metrics in life-cycle analyses of the environmental and economic impacts of solid waste management systems. Therefore, emissions from waste management system include emissions from the system itself plus emissions from internal and external processes. Hence solid waste disposal site total emissions will include emission from the site plus emissions from fossil fuel consumption and energy used in all activities and processes.

Painting the picture of the situation in the United States of America, EREF (n.d.) observed that over 500 million tons of MSW and construction and demolition (C&D) debris is generated each year in the United States. Proper disposal of this material in municipal solid waste and C&D landfills requires that this material be collected and transported from the point of generation to transfer stations or final disposal or processing sites such as landfills, materials recovery facilities or composting facilities. Due to the nature of solid waste collection, vehicles continuously start and stop, which creates a unique duty-cycle from an emissions standpoint. Additionally, air emissions resulting from solid waste collection activities are not well quantified and current data that exists is anecdotal at best. Emissions reductions measures implemented over the past decade, along with a large trend to utilize either dedicated or duel fuel liquefied or compressed natural gas vehicles, have fostered substantial reductions in emissions and have the potential to continue to result in environmental and economic benefits. In addition to local air quality impacts from solid waste collection, a better understanding of the contribution of the solid waste industry to carbon emissions is also of crucial importance".

In New Zealand, emissions from the waste sector in 2007 stood at 0.6 Mt CO2-e. This is a 25 per cent decrease from 1990 level of 2.4 Mt CO_2-e (Ministry for the Environment, 2009). This is however, including emissions from waste water treatment and excludes the process generated emissions.

4. WHAT IS INTEGRATED SUSTAINABLE MSWM (ISMSWM)?

SMSWM offers an unconventional way of thinking and looking at waste management, one that is designed to avoid and counterbalance the typical technology-centred approach, which has so often failed. It provides insights into the less obvious, but equally urgent planning aspects, including the environmental, socio-cultural, institutional, political and legal aspects. SMSWM puts all stakeholders into focus, in a matrix with the more traditionally recognised elements of the waste management system, such as prevention, reuse and recycling, collection, street sweeping and disposal (van de Klundert & Anschütz, 2001).

The ISMSWM thinking is that some of the waste management problems have to do with something other – or more – than money and equipment. Some problems have to do with the attitude and behaviour of citizens, waste management staff, private enterprises and waste pickers. According to van de Klundert & Anschütz (2001), "other problems are caused or made more serious by factors that are not technical or financial, but relate to managerial (in)capacities, the institutional framework, the environment, or the social or cultural context. In these cases, it is not money or equipment that provides solutions, but rather changing social, institutional, legal or political conditions".

The SMSWM concept was developed to reflect this reality, as a means to articulate a vision of waste management that would pay attention to all these various aspects. ISMSWM promotes technically appropriate, economically viable and socially acceptable solutions -- which do not degrade the environment. It promotes the development of a waste management system that best suits the society, economy and environment in a particular location. van de Klundert and Anschütz (2001) listed "equity, effectiveness, efficiency and sustainability" as the four basic principles:

Equity goes beyond a moral imperative because:

- Pollution in one part of the city ultimately affects the rest of the city, including its air and water supply. Pollution 'travels' in the form of communicable diseases, flies, insects, rats, air and water pollution.
- Polluted areas lead to poor living conditions, which in turn foster social unrest and anti-governmental activities. Abandoned waste is a symbol of a failed public service.

- Unclean neighbourhoods can affect the city's economy and inhibit development. Investors will not invest in a dirty place and sick labourers have low productivity.

The effectiveness of a service is the extent to which the objectives of the service have been met in practice. For example, a street sweeping service is effective if the streets are clean. Effectiveness for waste management in general means that all waste is removed, as planned and all recoverable materials are recovered. When effectiveness is limited to the city centre, tourist areas or business districts the overall waste management system is not fully effective. The less visible parts of the city are as important as – sometimes more important than – the visible ones.

The service is efficient when the benefits of clean streets are balanced by all beneficiaries paying a reasonable cost to keep them that way, using the optimal combination of labour, money, equipment, machinery and management.

Sustainability refers to the ways in which resources are used and how these fit into the local culture, context and society. These resources can be human (manpower), material (equipment) or natural resources - water, air, soil, even diesel, etc. It includes distinguishing between the use of renewable and non-renewable resources on the earth. It also refers to the interplay of all the aspects, such as social and political with technical and environmental. A system is considered sustainable when it can reproduce itself without reducing the possibilities open to the following generation of systems. "The entire concept is permeated by the notion of ecological justice and this requires a balancing of the interests involved. Development is important, but not at the expense of future generations who, under current legal systems, are unable to assert their rights and consequently remain voiceless when their rightful inheritance is being plundered by the present generation" (Bosselmann, 2008).

Waste management cuts across all socio-economic levels: household, neighbourhood, city, region and national. While at some level the most important level of waste management system is the city scale, but this does not necessarily mean that the system must be uniform. The 'dominant' system may not work in low-income areas or on hillsides, so that uniformity means these areas tend to be marginalized and receive little or no waste collection. In contrast to this, (van de Klundert &Anschütz, 2001) observed that an SMSWM approach promotes a variable, customised, decentralised and neighbourhood-oriented approach, looking at specific requirements and conditions as the basis for providing service to the various neighbourhoods and communities.

Therefore, among all other usefulness, SMSWM will assist in assessing existing system, designing of a new system and selecting of a new technology. A comprehensive emission inventory will assist in taking good decision in achieving these goals.

Waste generation increases with population expansion and economic development. Improperly managed solid waste poses a risk to human health and the environment. Uncontrolled dumping and improper waste handling causes a variety of problems, including contaminating water, attracting insects and rodents, and increasing flooding due to blocked drainage canals or gullies. In addition, it may result in safety hazards from fires or explosions. Improper waste management also increases greenhouse gas (GHG) emissions, which contribute to climate change. Planning for and implementing a comprehensive program for waste collection, transport, and disposal—along with activities to prevent or recycle waste—can eliminate these problems.

5. EMISSIONS AND INTEGRATED SUSTAINABLE MSWM

In the last few years, waste management have been very dynamic. Wilson (2007) observed that four imperatives drive the development of waste management plans: public health, environmental protection, resource recovery, and climate change. These factors have lead to emergence of stringent legislations targeting waste collections, transportation, treatment/recovery and disposal. Subsequently, visionaries came up with new technologies to fit into the new laws. Therefore, waste management have metamorphosed from 'end of pipe' concept of waste management, through the 'resource management' concept to the emerging concept which (Lee et al., 2013) refer to as 'closing the loop'. This principle is centred on integrated sustainability concept in MSWM, in which disposable wastes are reduced and as a result emissions are reduced equally. Also, through integration, material flow is simplified(Childerhouse & Towill, 2003). Therefore, integrated sustainability concept can solve what Deming (1982) referred to as "symptoms of complex material flow". Complex material flow contributes a good volume of emission through waste collection, transfer and transportation. It is therefore the opinion of this paper that emission inventory be used as one of the guides in MSWM planning.

6. METHODOLOGY

Three landfills (Hampton Downs, Tirohia and Taupo), located in Waikato Region of New Zealand are used in this case study. The landfills are chosen because of the similarities in design of Hampton Downs and Tirohia landfills, and the differences in the management scenarios of the three landfill, which affects the ways and level they impacts on the environment and human health (Table 1).

The objective is to demonstrate the relevance of emission inventory in proper planning and management of MSW.

There is no particular methodological approach for emission inventorying which is suitable for all purposes. All depends on the purpose, available data/tools and available fund for the task. An emission inventory for the modelling of air quality in a city is different from an emission inventory for GHG. For air quality modelling one needs the spatial distribution of the emissions and the dispersion parameters of the sources. For GHG, this is not needed. For air quality modelling in a city one generally needs data over a much larger area since air pollution is transported over long distances. This can be solved by nested models where a large scale model using for example a European emission inventory is used to calculated general concentrations. The local emission inventory can then be used to calculate the local contributions to be added to the large scale concentration field. In this case, care should be taken that (large) sources are not included twice. Emission inventory for GHG generally stick to the boundaries of the area concerned, though sometimes emissions in other areas are added to a cities total as indirect or shadow emissions.

The IPCC Guidelines give two methods for estimation of CH4 emissions from solid waste disposal (IPCC, 1996). The IPCC default method is a simple mass balance calculation which estimates the amount of CH4 emitted from the SWDS assuming that all CH4 is released the same year the waste is disposed of. The other method outlined in the IPCC Guidelines is the so-called First Order Decay (FOD) method. The FOD method takes the time factors of the degradation process into account, and produces annual emission estimates that reflect this process, which can take years, even decades.

A lot of computer models have been developed for emissions estimation, depending on the purpose and type of emission you are interested in. In their most basic form emission inventory contains the emissions in the area (and the associated spatial information and dispersion parameters in case of an emission inventory for air quality modelling. For practical purposes this suffices and often not more information is available at local level. The details of how the emissions were calculated and what statistics they are based upon are often only available at a national level. For example local traffic emissions could be available without having the exact knowledge of thelocal fleet composition (age/type), the associated emission factors, distances driven, etc. Likewise the total emission of a plant could be known or obtained for a national database without the total fuel use of the plant, the total output of product and the emission factor being locally known.

To compile an emission inventory, all sources of the pollutants must be identified and quantified. For each of the pollutants in the inventory emissions are typically estimated by multiplying the intensity of each relevant activity or activity rate in the geographical area and time span with a pollutant dependent proportionality constant known as emission factor. Therefore, the general model for emission calculation is:

$$\mathbf{E = AD \times EF} \qquad \mathbf{(1)}$$

Where E represents total emission, AD stand for activity data, while EF is emission factor.

In this case, LCAM using EASEWASTE software (Kirkeby et al., 2006a) was adopted. Therefore, an emission inventory was created based on available data for each of the landfills adopted in the study.

The results of the inventories created are represented in Figures 2-5. This implies the application of the integrated life cycle management concept, which presents a unique opportunity to reconcile the general management of MSW with environmental protection, good resource utilization and human health. Therefore, the inventory took into account, transportation data, collection processes, and the waste treatment plan at the landfills; hence the comprehensive expected emission inventory was created.

The inventory was analysed in relation with the quantity of MSW landfilled in each of the landfills, hence quantifying the ratio of each material released in form of emission, to the total waste disposed in the landfill, to get the ratios per tonne of MSW. Table 2 represents the categorization of the emission into the various impact category and the contributions from the MSWM processes.

The impact assessment ratio per tonne of waste landfilled in each of the landfills was calculated as in Tables 2 and 3. The values are normalized to facilitate comparisons.

The impact categories include; Global Warming (GW), Human Toxicity via water (HTw), Spoiled Groundwater Resources (SGR), Ecotoxicity via water (ETw), Stratospheric Ozone Depletion (SOD), Human Toxicity via air (HTa), Acidification (AC), Stored ecotoxicity in water (SETw), Human toxicity via air (HTs), Photochemical Ozone Formation, High NOx (PhOzF(HNOx)), Stored Ecotoxicity in soil (SETs), Nutrient Enrichment (NE), Photochemical Ozone Formation, low NOx (PhOzF(LNOx)), and Ecotoxicity in water, chronic (ETwc).

7. RESULTS AND DISCUSSION

The three landfills used in this study are all located within the boundaries of Waikato Regional Council of New Zealand. Therefore, it is under the jurisdiction of the Council to grant operational consent to them. This consent stipulates the operational guidelines which includes; the allowable volume of waste to be accepted and the number of years their operations will last, the category of waste to be accepted, gas management plan, landfill design (height, cover arrangement, leachate treatment, etc.), geographic areas to be serviced by the landfill, and so on.

One situation worthy of note is that Tirohia landfill in Paeroa and North Waikato Regional landfill near Hampton Downs receive significant quantities of waste from outside the region, including Auckland and Bay of Plenty regions, but also from places as far away as Gisborne (Waikato Regional Council, 2007). Gisborne is about 374km from Tirohia landfill. The nearest landfill to Gisborne is Taupo landfill, about 326km. A lot of emissions on trucking will be saved if the waste from Gisborne is diverted to Taupo landfill.

From Tables 2 and 3, it is obvious that transportation have a major contribution to making waste dumped in Tirohia landfill to have a higher emission ratio than the one dumped in Hampton Downs, considering that the two landfills have gas flaring system in place.

Generally, transportation and collection contributed a good percentage of emission in all cases, as demonstrated in Table 4. Transportation contributed about 706,000kg of Sodium [Na], about 78 per cent of total value from Tirohia landfill. Other emissions where transportation represent source of high percentage include NMVOC (69.47%), VOC (64.3%), CO_2 (fossil) (55%), Particles-PM 10 (73.73%), etc.

Considering the effects of these pollutants will help in seeing reasons to why authorities and other stake holders should think of how to reduce these figures. Subsequent inventories will show the progress that is being made in this direction or the increase as the case may be.

8. RECOMMENDATION

Equation (1) represents the general principle for compilation of emission inventory. To adopt the recommendation to include emissions from solid waste management processes in planning and management will require modifications in the model to include emissions that are generated from those processes. Therefore, total emission will include emissions from transportation system within the management process. This will include emission from collection sub-system, emissions from transportation of the waste from collection point to disposal facility and emissions from the use of machineries and tools (which are operated using fossil fuel). This can be represented by factor E (Tr)

Depending on the design and management plan of the disposal facility, there may be emissions E (En) as a result of the use of other type of energy like electricity.

Therefore, the sum total of emission as a result of the waste management system will be represented by a general model:

$$\textbf{Emission (Total)} = \left\{ [AD * EF] + [E\ (Tr) * EF] + [E\ (En) * EF] + \text{---} \right\} \qquad (2)$$

8.1 Activity Data and Uncertainties

Because of the complexities in the activities that are associated in E (Tr) and E (En), it may be difficult to collect activity data that may relate distinctively to each of the activities. Ensuring the quality of the inventory will be an important activity. According to (IPCCa, 1996), "the most important aspect of quality assurance and quality control is thorough and transparent documentation of the emissions calculation steps, including all activity data and emission factor values".

Estimation of emissions from road transport requires data for a range of parameters including:
• Fuel consumed, quality of each fuel type;
• Emission controls fitted to vehicle in the fleet;
• Operating characteristics (e.g. average vehicle speeds or types of roads;
• Maintenance;
• Fleet age distribution
• Distance driven, and
• Climate.

All of these data may not be available. For example, total fuel consumption may be known but not how it is used by different types of vehicles (e.g. total petrol sales, but not petrol consumption by cars, light duty trucks and motorcycles separately). Thus the simplest methodology is based on fuel consumption alone (IPCC, 1996).

Therefore, results will still be uncertain from:

- Emission factors whose values are laboratory-based hence may not represent real road driven conditions.
- The activity rates are, like any statistical data, uncertain. In addition as they are not collected specifically for use in emission inventories they may not be exactly the data required by the estimation methodology.
- The methodology used to estimate emissions may not accurately reflect the true emission processes.

Road transport emits mainly CO2, NOx, CO and NMVOCs; however it is also a small source of N2O, CH4 and NH3. Therefore the only major direct greenhouse gas emission is CO2. Emissions of CO2 are directly related to the amount of fuel used. Emissions of the remaining gases depend on the amount of fuel used but are also affected by the way the vehicle is driven (e.g. the speed, acceleration and load on the vehicle), the vehicle type, the fuel used and technology used to control emissions (e.g. catalysts). Thus the simplest way to estimate the emissions of the other gases is to use fuel based emission factors; this is only appropriate where there is insufficient data to use the more complete methods available (IPCCb, 1996).

In general, the methodology in the IPCC Guidelines (1996) recommends that emissions from transportation be estimated by multiplying the amount of fuel consumed by an appropriate emission factor. Although some default emission factors are presented, it is recommended that country-specific factors be used if possible. Therefore, the uncertainty in activity data will depend upon the reliability of the data collection agent and the degree to which all fuelconsumed is captured. If actual fuel consumption data is not available and instead proxy data such as fuel expenditures is used, then the overall uncertainty in the emissions estimate would be expected to be greater.

IPCC Guidelines (1996) also noted that engine characteristics and technology affects emissions, especially non-CO2 gases. In the case of SO2, the sulphur content of the fuel is the primary factor. The general assumption during the estimation is therefore another uncertainty factor.

The emission from power consumption is a factor in the source of the energy. Therefore, if it is fossil generated energy, the amount of energy as recorded by the installed meter in the facility is used with the agreed factor to determine the total emissions.

There may be other emissions like use of oil, gas, etc. These are included to sum up the total emissions as the case may be.

The identification of the emission sources is very crucial towards a successful completion of a reliable emission inventory that will serve this purpose.

9. CONCLUSION

Private haulers and solid waste collection agencies are constantly challenged by the need to reduce emissions to the atmosphere, reduce cost, and at the same time increase collection efficiency and equipment optimization. Having the knowledge of their emission contribution will be a good impetus towards achieving these goals, as they will not plan to reduce their pollution if they are not aware of them and the sources.

To make good use of emission inventory in taking vital decision in MSWM, some other information will be needed. These include:

- Mapping all waste management activities in the city, region or nation.
- Knowledge of the physical infrastructure of the areas covered like roads and traffic conditions, lay-out of neighbourhoods, etc.

Putting the three factors together will help in producing seamless MSWM plan that will stand the taste of time, saving the environment, health and resources. The final map will be a zoned map that will attach all generated waste to a particular facility through a zoning policy.

Table 1: Summary of Landfill scenario data

Name of landfill	Hampton Downs	Tirohia	Taupo
Average annual intake (tonnes)	986007.88	176666,68	2176922.6
Expected total intake (tonnes)	19720157.6	3533333.53	43538.45
Average distance from source of waste (km)	34	142	18
Gas management plan	Flare (energy recovery in view)	Flare (energy recovery in view)	vent
Landfill design	Modern Engineered	Modern Engineered	Modern Engineered
Waste composition	Regional	Regional	Regional
Landfill design height (metre)	10	10	8
Density (t/m3)	1.8	1.8	1.8

Table 2: Compared impact assessment ratio per tonne of waste in each of the waste management processes in the landfills

	Waste management processes	Tirohia Landfill [PE]	Hampton Downs Landfill [PE]	Taupo Landfill [PE]
HTw	Collection	7.00E-05	7.00E-05	7.00E-05
	Transportation	6.98E-05	3.70E-05	2.92E-04
	Treatment & Disposal	1.65E-03	2.50E-03	1.65E-03
SGR	Collection	0.00E+00	0.00E+00	0.00E+00
	Transportation	0.00E+00	0.00E+00	0.00E+00
	Treatment & Disposal	1.20E-01	1.50E-01	1.20E-01
ETw	Collection	6.29E-08	6.29E-08	6.29E-08
	Transportation	6.27E-08	3.32E-08	2.62E-07
	Treatment & Disposal	4.49E-05	1.59E-04	4.49E-05
SOD	Collection	0.00E+00	0.00E+00	0.00E+00
	Transportation	0.00E+00	0.00E+00	0.00E+00
	Treatment & Disposal	1.43E-02	9.67E-02	1.43E-02
HTa	Collection	1.62E-03	1.62E-03	1.62E-03
	Transportation	1.62E-03	8.56E-04	6.75E-03
	Treatment & Disposal	2.22E-03	2.18E-03	2.22E-03
AC	Collection	1.17E-03	1.17E-03	1.17E-03
	Transportation	1.17E-03	6.19E-04	4.88E-03
	Treatment & Disposal	4.29E-03	2.33E-03	4.29E-03
SETw	Collection	0.00E+00	0.00E+00	0.00E+00
	Transportation	0.00E+00	0.00E+00	0.00E+00
	Treatment & Disposal	2.57E-02	2.57E-01	2.57E-01
HTs	Collection	1.76E-06	1.76E-06	1.76E-06
	Transportation	1.75E-06	9.28E-07	7.32E-06
	Treatment & Disposal	1.26E-04	5.73E-04	1.26E-04
PhOzF(HNOx)	Collection	9.32E-04	9.31E-04	9.31E-04
	Transportation	9.28E-04	4.92E-04	3.88E-03
	Treatment & Disposal	2.77E-03	1.62E-02	2.77E-03
SETs	Collection	0.00E+00	0.00E+00	0.00E+00
	Transportation	0.00E+00	0.00E+00	0.00E+00
	Treatment & Disposal	2.04E-02	2.04E-02	2.05E-02
NE	Collection	2.44E-03	2.44E-03	2.44E-03
	Transportation	2.43E-03	1.29E-03	1.01E-02
	Treatment & Disposal	9.33E-03	9.19E-03	9.33E-03

PhOzF(LNOx)	Collection	7.63E-04	7.63E-04	7.63E-04
	Transportation	7.61E-04	4.03E-04	3.18E-03
	Treatment & Disposal	2.35E-03	1.36E-02	2.35E-03
ETwc	Collection	9.93E-03	9.93E-03	9.93E-03
	Transportation	9.90E-03	5.24E-03	4.13E-02
	Treatment & Disposal	1.54E-02	1.79E-02	1.54E-02

Table 3: Compared emission ratio per tonne of waste by contributing gases to global warming

Substances	**Hampton Downs Landfill (PE)**	**Tirohia Landfill (PE)**	**Taupo Landfill (PE)**
Methane (CH4)	8.01E-03	9.07E-03	8.20E-02
Carbon Dioxide CO2	5.27E-03	8.12E-03	5.01E-03
CFC 12	3.63E-04	3.63E-04	2.02E-03
Carbon Monoxide (CO)	3.72E-05	4.79E-05	3.86E-04
CFC 11	2.64E-05	2.64E-05	1.97E-04
HCFC 22	2.41E-05	2.41E-05	6.83E-05
CFC 113	2.14E-05	2.14E-05	2.15E-05
Nitrous Oxide (N2O)	1.33E-05	1.70E-05	1.34E-05
HCFC 21	1.79E-06	1.79E-06	2.78E-10
Dichloromethane	1.17E-06	1.17E-06	5.07E-06
Hydrocarbons (HC)	6.69E-07	9.34E-07	6.99E-07
Carbon Tetrachloride	1.93E-07	1.93E-07	6.15E-07
1,1,1-Trichloroethane	1.64E-07	1.64E-07	1.90E-07
HFC 134a	6.63E-10	6.63E-10	7.67E-10

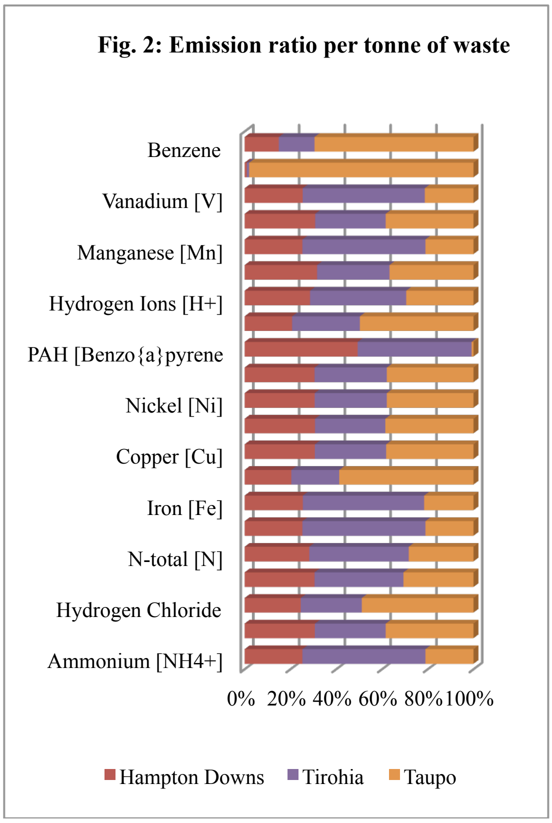


Fig. 2: Emission ratio per tonne of waste
Benzene
Vanadium [V]
Manganese [Mn]
Hydrogen Ions [H+]
PAH [Benzo{a}pyrene
Nickel [Ni]
Copper [Cu]
Iron [Fe]
N-total [N]
Hydrogen Chloride
Ammonium [NH4+]
0% 20% 40% 60% 80% 100%
Hampton Downs
Tirohia
Taupo

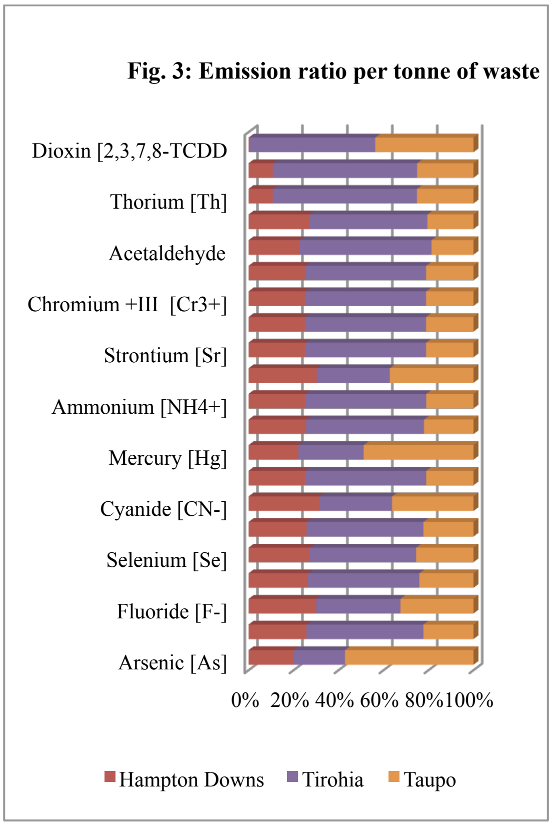


Fig. 3: Emission ratio per tonne of waste
Dioxin [2,3,7,8-TCDD
Thorium [Th]
Acetaldehyde
Chromium +III [Cr3+]
Strontium [Sr]
Ammonium [NH4+]
Mercury [Hg]
Cyanide [CN-]
Selenium [Se]
Fluoride [F-]
Arsenic [As]
0% 20% 40% 60% 80% 100%
Hampton Downs
Tirohia
Taupo

Fig. 4: Emission ratio per tonne of waste

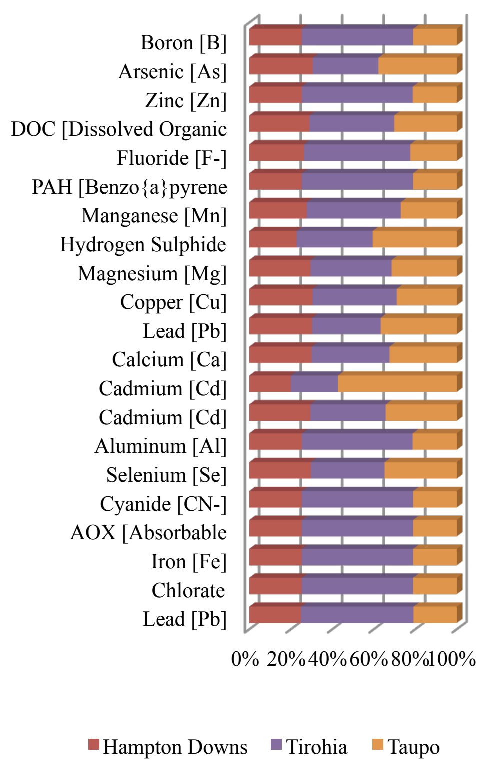


Fig. 5: Emission ratio per tonne of waste

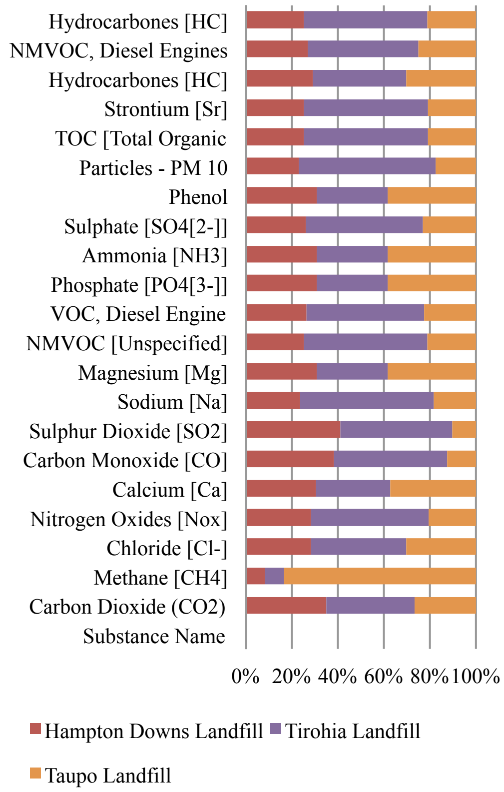
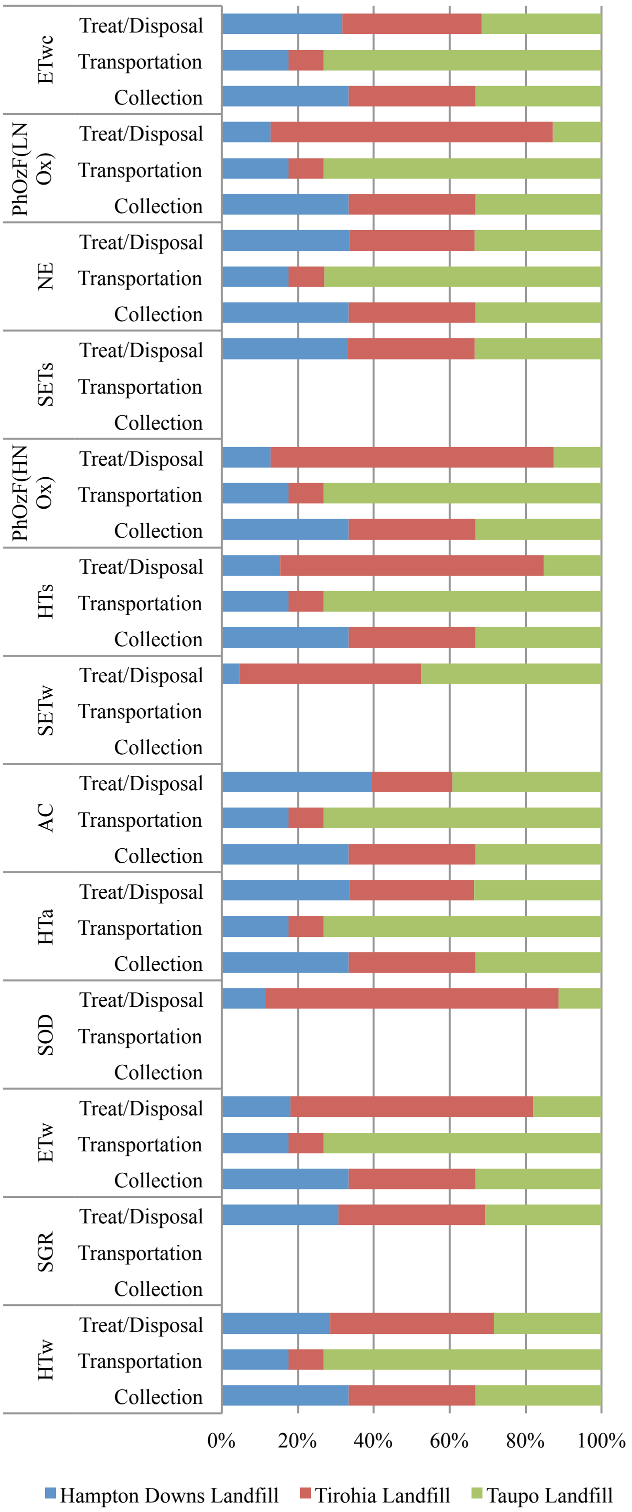


Fig 6: Compared impact assessment ratio of waste management processes in eache of the landfills



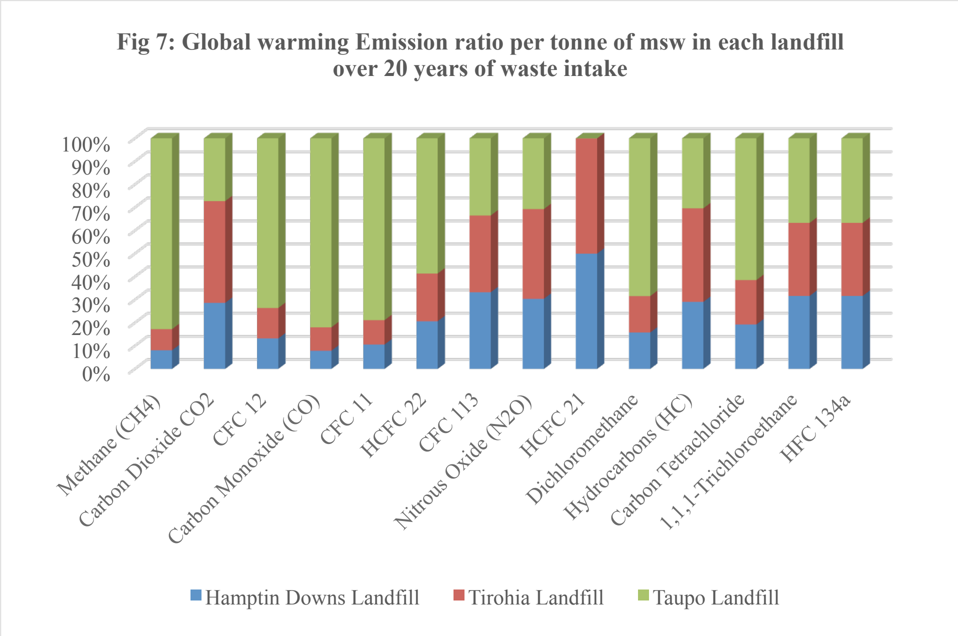


Table 4: Percentage contributions of the process sectors to selected emissions (Tirohia landfill)

Substances	Total (kg)	Collection System		Transportation System		Treatment/disposal	
		Value	%	Value	%	Value	%
Carbon Dioxide [CO2](Fossil Fuel)*	2.48E+08	3.27E+07	13.21	1.36E+08	55.01	7.87E+07	31.80
Methane [CH4]	9.64E+06	3.91E+04	0.41	1.63E+05	1.69	9.44E+06	97.90
Chloride [Cl-]*	2.80E+06	2.82E+05	10.05	1.17E+06	41.83	1.35E+06	48.11
Nitrogen Oxide [Nox]*	2.03E+06	2.91E+05	14.30	1.21E+06	59.57	5.32E+05	26.14
Calcium [Ca]	9.02E+05	1.82E+04	2.02	7.58E+04	8.41	8.08E+05	89.58
Sodium [Na]*	9.01E+05	1.70E+05	18.82	7.06E+05	78.35	2.55E+04	2.83
Carbon Monoxide [CO]	6.55E+05	4.63E+04	7.07	1.93E+05	29.43	4.16E+05	63.50
Sulphur Dioxide [SO2]	4.77E+05	2.32E+04	4.86	9.66E+04	20.24	3.58E+05	74.88
NMVOC*	4.68E+05	78038.54	16.68	324903.87	69.47	64863.455	13.87
Magnesium [Mg]	2.43E+05	791.9	0.33	3296	1.36	238500	98.31
VOC*	1.18E+05	18245	15.45	75946.1	64.31	23933.7	20.27
Sulphate [SO4(2-)]*	6.09E+04	9355	15.36	3.90E+04	63.97	12580	20.66
Ammonia [NH3]	5.16E+04	1.106	0.00	4.605024	0.01	51563.57	99.99
Particles-PM 10*	5.24E+04	9147	17.47	38075	72.73	5132	9.80

Total Organic Carbon [TOC]*	2.67E+04	4471	16.76	18610	69.78	3586	13.45
Hydrocarbon [HC]*	1.48E+04	1818.9	12.26	7572	51.04	5442.6	36.69
Ammonium [NH4+]*	4854	813.7	16.76	3387	69.78	653.4	13.46
Nitrates-N [NO3-N]*	1959	328.3	16.76	1367	69.78	264.1	13.48
Iron [Fe]*	1858.66	305.219	16.42	1270.742	68.37	282.799	15.22
Hydrogen Chloride [HCl]	1607	41.95	2.61	174.6	10.86	139.1	8.66
Nitrous Oxide [N2O]	1566	106.1	6.78	441.8	28.21	1018	65.01
Manganese [Mn]*	203	32.716	16.12	136.25	67.12	34.07	16.78
Nickel [Ni]	168.3	15.92	9.46	66.26	39.37	86.07	51.14
Vanadium [V]*	161.6	26.79	16.58	111.5	69.00	23.29	14.41
Hydrogen Ion [H+]*	124.3	12.54	10.09	52.19	41.99	59.53	47.89
Boron [B]*	92.05	15.43	16.76	64.24	69.79	12.38	13.45
Zinc [zn]*	58.05	9.66	16.64	40.22	69.29	8.172	14.08
PAH	174.57	7.178	4.11	29.876	17.11	137.436	78.73
Fluoride [F-]*	37.44	5.889	15.73	24.52	65.49	7.03	18.78
Hydrogen Sulphide [H2S]*	28.55	3.43	12.01	14.28	50.02	10.84	37.97
Cupper [Cu]	18.49	1.471	7.96	6.124	33.12	10.89	58.90
Aluminum [Al]*	14.3	2.373	16.59	9.89	69.16	2.04	14.27
Cyanide [CN-]*	12.07	2.024	16.77	8.426	69.81	1.623	13.45
Lead [Pb]*	8.967	1.537	17.14	6.399	71.36	1.032	11.51
Chlorate [ClO3]*	8.844	1.483	16.77	6.172	69.79	1.189	13.44

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BIOGRAPHICAL NOTES

Macbeda Uche MICHAEL-AGWUOKEwas born in Serti-Baruwa in Northern Nigeria. His educational carrier started at Federal Polytechnic Idah in then Benue State also in Nigeria, where he read surveying (National Diploma). After a short working experience in a construction company, Macbeda enrolled for Higher National Diploma (HND) in Land Surveying at Federal Polytechnic Bauchi. After a brilliant surgeon at Federal Polytechnic Bauchi, he took up appointment with the institution in 1990.

In 2001/2002 session, Macbeda was admitted at University of Lagos, Akoka Yaba, where he graduated with MSc degree in Surveying and Geoinformatics. Before this period, Macbeda was at Enugu State University of Science and Technology (ESUT) in South Eastern Nigeria, for a BSc degree in Surveying and Photogrammetry.

Meanwhile, Macbeda continued his working carrier at Federal Polytechnic Bauchi, from where he consults in Land Surveying, GIS and Environmental Planning/Engineering. Macbeda is currently a PhD candidate at Auckland University of Technology with special interest in **Sustainable Urban Environment**.

Macbeda is members of Nigerian Institution of Surveyors (NIS), International Solid Waste Association (ISWA) and WASTEMINZ- New Zealand.

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