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Application of IWM-1 modeling technique in solid wastes inventory analysis and impact assessment of Lagos state, Nigeria

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In urban centres, pollution effects of solid wastes range from objectionable odour and groundwater contamination, to emission of toxic gases. This paper investigates the impact of solid wastes generated from four selected local government areas viz: Mushin, Agege, Ifako-Ijaye and Ikeja of Lagos State, Nigeria. Fifteen households in each of the areas were selected and daily samples of solid wastes were collected from each household over a period of 2 weeks. Wastes compositions were determined and four model scenarios viz: landfilling (the existing practice), material recovery, composting and incineration formed. Integrated Waste Management-1 (IWM-1) tool was applied for inventory analysis and determination of wastes pollution impacts on air and water. Measured impact categories include: global warming potential, acidification potential, eutrophication, and photochemical ozone depletion. CO_2, CH_4, NO_X, SO_X, volatile organic compounds, particulate matters, Pb, Cd and organic matters were the examined impact parameters. Mean percentage wastes composition are: organic matter 74.8, paper 6.1, nylon 1.6, plastic 3.4, textile 2.9, glass 3.7, metal 5.3, silt 1.4 and ash 0.8. Landfilling Scenario has highest carbon equivalent of 2618 while incineration has lowest of 167 tonnnes, with CH_4 impact being the most threatening on climate change. The respective greenhouse gases emitted are: (94.8 and 5.1% of CO_2 and CH_4); Smog precursors (0.02 and 0.007% of particulate matters and volatile organic compounds); heavy metal (0.43 and 1.3kg of Pb and Cd); and organic matters (16729kg of BOD). The existing total landfilling system is ineffective in curtailing the negative impacts of the wastes on air and water. It is recommended to be preceded by waste recycling and controlled incineration.

Key words: Integrated Waste Management-1, inventory analysis, landfilling, impact assessment.

INTRODUCTION

Solid wastes comprises all discarded and left-over items such as garbage, refuse and trash awaiting reuse or disposal (Tchobanoglous et al., 1977; Hoornweg, 1999; Davis and Masten, 2004; Audu, 2007). According to the Lagos Waste Management Authority, solid waste is the general term used to describe non-liquid waste materials in a human setting that pose environmental health risks. Pollution effects of solid wastes on human beings and the environment range from objectionable odour to groundwater contamination and emission of toxic gases. The impact is felt more form wastes generated in urban centres due to various attendant commercial and industrial activities of such locations.

The complexity of issues required for effective Integrated Municipal Solid Waste Management (IMSWM) gave rise to development of various computer-aided approaches helping decision makers in identifying the best management methods (Mendes *et al.,* 2004). Any computer-based system supporting decision making is a Decision Support System, DSS (Finlay, 1989). DSS incorporate computer-based models of real life biophysical and economic systems. Since the early 21st century, there has been a major shift towards Life Cycle Assessment (LCA) computer-aided tools (White *et al.,* 1997). LCA is a holistic approach that is increasingly utilized for solid waste management especially in the decision-making process and in planning strategies. LCA can be categorized as a hybrid approach since it utilizes equations for inventory analysis and recycling loops on the one hand, while on the other it requires expertise input for impact assessment and characterization (White, 1995).

LCA is being used in solid waste inventory analysis to assess the environmental impacts of products from cradle to grave and evaluation of waste when a material is discarded into the waste stream (Ojoawo and Gbadamosi, 2013). ISWM involves evaluating local needs and conditions, and then selecting and combining the most appropriate waste management activities for those conditions. Each activity such as waste prevention, recycling, composting etc, requires careful planning, financing, collection and transport of solid waste. Integrated Waste Management (IWM)-1 modeling tool applies the principle of LCA for solid waste inventory analysis and identify the attendant pollution effects on air and water, and has thus been chosen for this study. The integrated waste management model-1 was designed to evaluate the MSW in its entirety. It was developed based on Visual Basic Programming and with an interactive interface. It is a dynamic model which enhances the application of collected data and generation of fresh ones (White, 1997). It is a tool which seems to meet all the necessary requirements of the present study. A typical input screen shot of the IWM-1 modeling tool is shown in Figure 1 while the generally relationship between the climate change and solid wastes (USEPA, 2002) is captured in Figure 2.

LCA is an environmental management tool used to aid understanding and compare the impacts of a product or service from cradle to grave. The technique examines every stage of the life cycle, from raw materials acquisitions, through manufacture, distribution, use, possible reuse/recycling to final disposal (Olawoore et al., 2012). Every operation or unit process within a stage is included and for each operation within a stage, the inputs (raw materials, resources and energy) and outputs (emissions to air, water and solid waste) are calculated (the Life Cycle Inventory). These inventory inputs and outputs are then aggregated over the life cycle and environmental issues associated with these inputs and outputs can be evaluated further by Life Cycle Impact Assessment. Other decision-making tools can then be combined with this information to interpret the results.

The key stages in the LCA are: goal and scope definition; life cycle inventory (LCI); life cycle impact assessment (LCIA); and Interpretation. The LCIA phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. Impact assessment should address ecological and human health effects; it should also address resource depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. The main steps of an LCIA are: selection and definition of impact categories; classification; characterization; normalization; grouping; weighing; evaluating; and reporting the results. In mathematical models introduction of one or two environmental goals, as is done in goal programming, is not enough. Implementation of LCA as a tool of model development and evaluation seemed to be the proper answer to this challenge. This has been applied in this study to analyze the components of solid wastes in the study area.

In LCIA the emissions which occur in the life cycle of a product are translated into their potential impacts on the environment ranging from local impacts from land use over regional impacts due to e.g. toxic substances, acidification or photochemical oxidants to global climate change. For each category of impact (like global warming or photochemical ozone formation), the impact assessment applies substance-specific characterization factors which represent the substance's potency. LCIA identifies and evaluates the amount and significance of the potential environmental impacts arising from the LCI. The inputs and outputs are first assigned to impact categories and their potential impacts quantified according to characterization factors (PE-International, 2011).

The attendant issue of air and water pollution arising from solid wastes disposal is becoming more pronounced in developing countries. This paper therefore focuses on solid waste management in four (4) selected Local Government Areas of Lagos State Nigeria viz: Mushin, Agege, Ifako-Ijaye and Ikeja. The aim is to analyze the municipal solid waste management system in Lagos metropolis. The objectives are to investigate the material composition of each waste; determine their impacts on air and water through the formulated management scenarios of landfilling, material recovery, composting and incineration; and to identify the most environmental friendly waste disposal scenario.

MATERIALS AND METHODS

Study area

The selected Local Government Areas of Lagos State which constitute the study area includes Mushin, Agege, Ifako-Ijaye and Ikeja. Lagos State is located on the Southwestern part of Nigeria, on the narrow plain of the Bight of Benin. Figures 3 and 4 show the Maps of Lagos, and the selected LGAs respectively. Lagos lies approximately on longitude 2^0 E and latitude 6^0N. Lagos State is bounded in the North and East by Ogun State of Nigeria, in the West by Republic of Benin, and stretches over 180 kilometers along the Guinea Coast of the Bight of Benin on the Atlantic Ocean. Governmental establishments that are responsible for environment management are the Lagos State Waste Management Agency (LAWMA), Lagos State Environmental Protection Agency (LASEPA), the Local Government Councils, (LGCs) and the Ministry of Environment and Physical Planning (MEPP). Treatment of waste in this urban centre currently by landfilling complements the two (2) under-utilized incineration plants located along Oshodi-Apapa expressway and at Ebute–Meta. The prominent

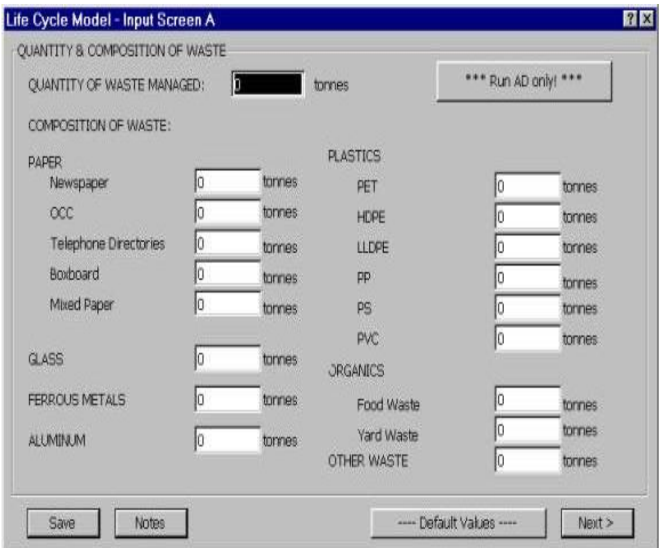

Figure 1. A typical input screen shot of the IMW-1 tool.

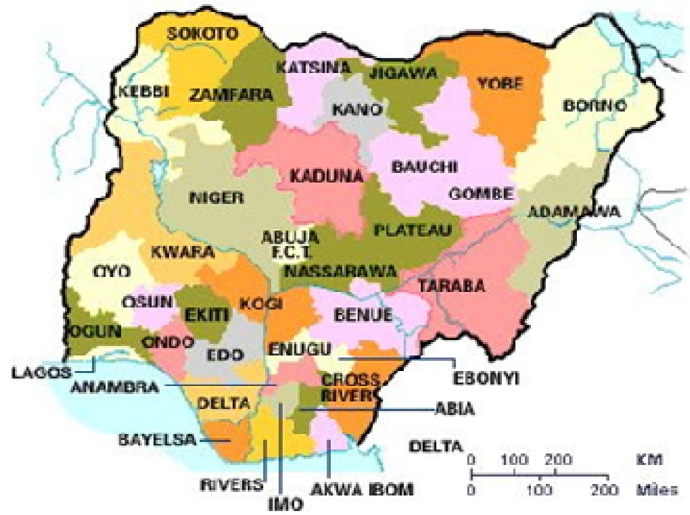

Figure 3. Administration States in Nigeria.
Source: Shell Petroleum Development Company, Nigeria

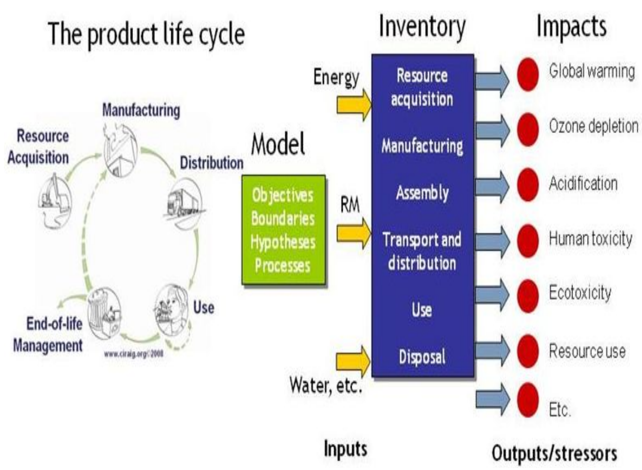

Figure 2. Relationship between climate change and solid waste.
Source: Solid waste and Energy Response, United State Environmental Protection Agency, USEPA, 2002

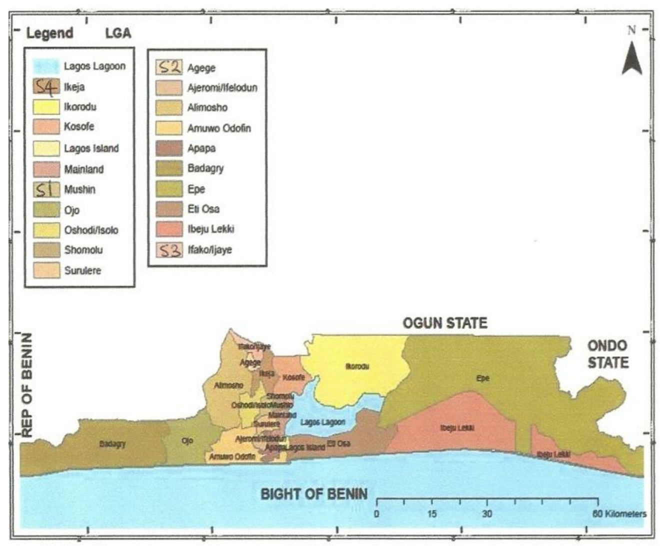

Figure 4. Location Map of the study Area.
KEY – S1: Mushin LGA, S2: Agege LGA,S3: Ifako Ijaye LGA, S4: Ikeja LGA

landfill sites in the study area are at Oloshosun, Agege and Iyana-Iba. The waste is collected and transported by the various agencies, to the designated landfill sites, and occasionally openly burnt at the points of generation to reduce its volume. This may create pollution problems for the environment through the release of particulate matter and harmful gases into the atmosphere.

The LCA scenarios

Consideration

Four Scenarios were considered in this paper, these are Landfilling; Material Recovery Facilities (MRF); Composting and Recycling. The percentage compositions of wastes in the study area for these Scenarios are as reported in an earlier work of these authors (Babatunde, 2014) and are as shown in Figures 5 to 8.

Flowchart description

The percentages represent the proportion of the total

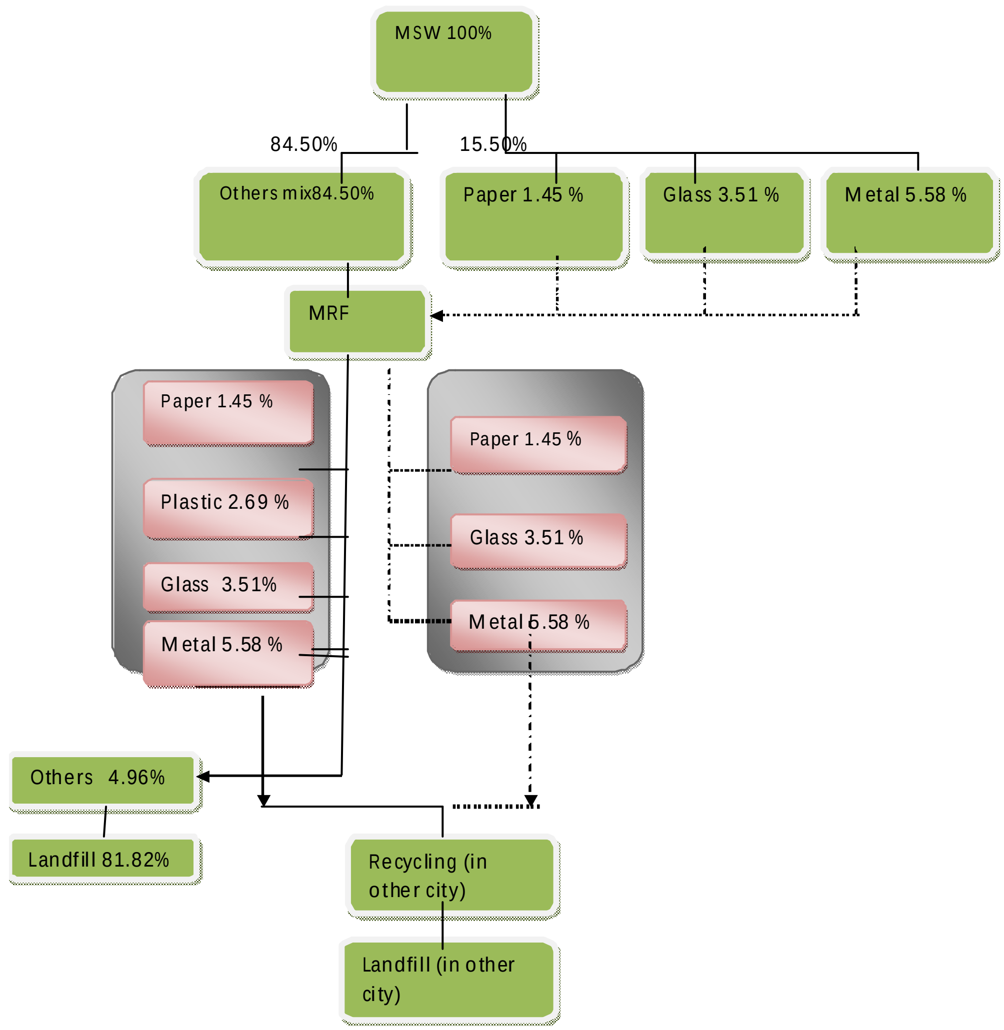

Figure 5. Scenario 1 (Mushin Local Government Area).

municipal solid waste stream (Babatunde, 2014).

(a) Scenario One, S1: 18.18% recycling 81.82% landfilling

(b) Scenario Two, S2: 20.08% recycling and 79.92% landfilling

(c) Scenario Three, S3: 22.84% recycling, 76.23% composting and 1.16% landfilling

(d) Scenario Four, S4:31.34% incineration and 68.66% landfilling

Formulation

Scenario 1: This was based on the current waste management system of Mushin Local Government Area, incorporating some improvements. In this scenario, a material recovery facility (MRF) and a landfill were added to the system. The recyclable fraction (84.5%) collected by scavengers was sent to the MRF, which was located on the landfill site. The rest of the recyclables was separated in the MRF into rubbers, steel, aluminum, glass, and plastics. After separation, these recyclable materials were sent to the recycling facilities for processing into fresh items. Recycling efficiencies for these materials are for the materials brought by scavengers and those separated in the MRF, respectively (Babatunde, 2014). The residuals after the recycling process were subjected to landfilling where the recycling was undertaken.

Scenario 2: In this scenario depicting the management system in Agege Local Government Area an incineration process was added to system instead of a composting facility. In this case, all organic waste and the wastes from the separated recyclables were transported to the incinerator.

Scenario 3: This scenario emphasizes the recovery of

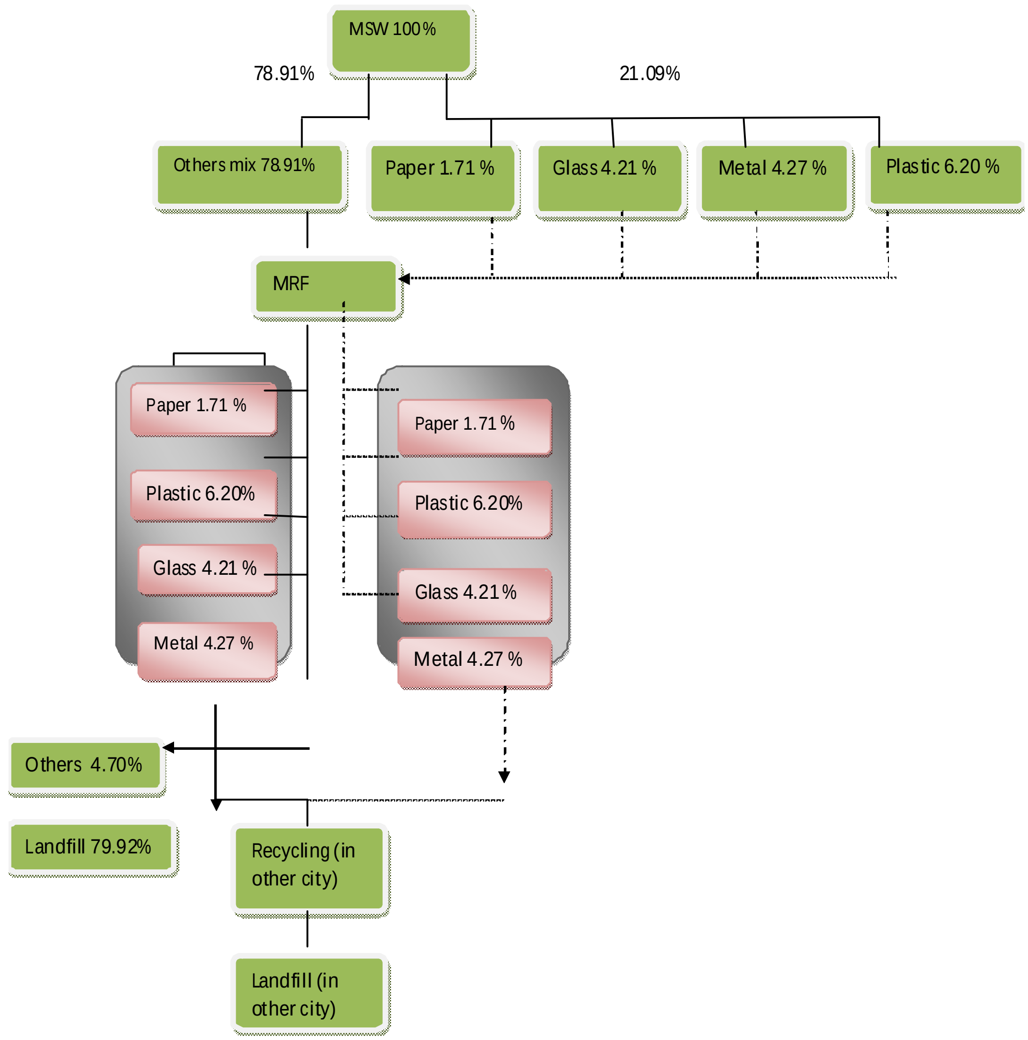

Figure 6. Scenario 2 (Agege Local Government Area).

the biologically degradable fraction. The flow of the system is similar to scenario 2 for recyclable materials while organic fractions from the MRF were transported to the composting facility. The residues from the MRF were sent to the landfill.

Scenario 4: In this scenario, a source separation system with efficiency was added as an improvement to scenario 1. The recyclables obtained from source separation were sent to the MRF, and after processing they were sent to the recycling facilities. The recyclables mixed in organic waste were also processed and sent to the recycling facility with efficiency. After the recycling process, residuals are sent to the landfills.

Running the IWM-1 model

On the starting page of the EPIC/CSR Integrated Waste Management tool (Release 2.0.0, 2004), a brief description of the scenario is typed into the provided window. The quantities and composition of wastes are fed into the Input Screen A on the next interface. Then on the Waste Flow Screen, input the corresponding quantities of wastes into each of the provided flow options like Recycling, Composting, Anaerobic Digestion, Land Application, Energy from waste, and landfill. Input screen C has waste collection data, haulage distance, truck types with fuel efficiencies and transfer station information, all filled into appropriate slots. Recycling Recovery Amounts interface is fed with total amount of wastes available for recycling and the various components like paper, steel, aluminum, and plastics. It also has a provision for determining if forest sequestration is necessary or otherwise. Input Screen F is about Energy consumption (electricity or natural gas), residue, residue management and distance to re-processor. The last interface is fed with landfilling details

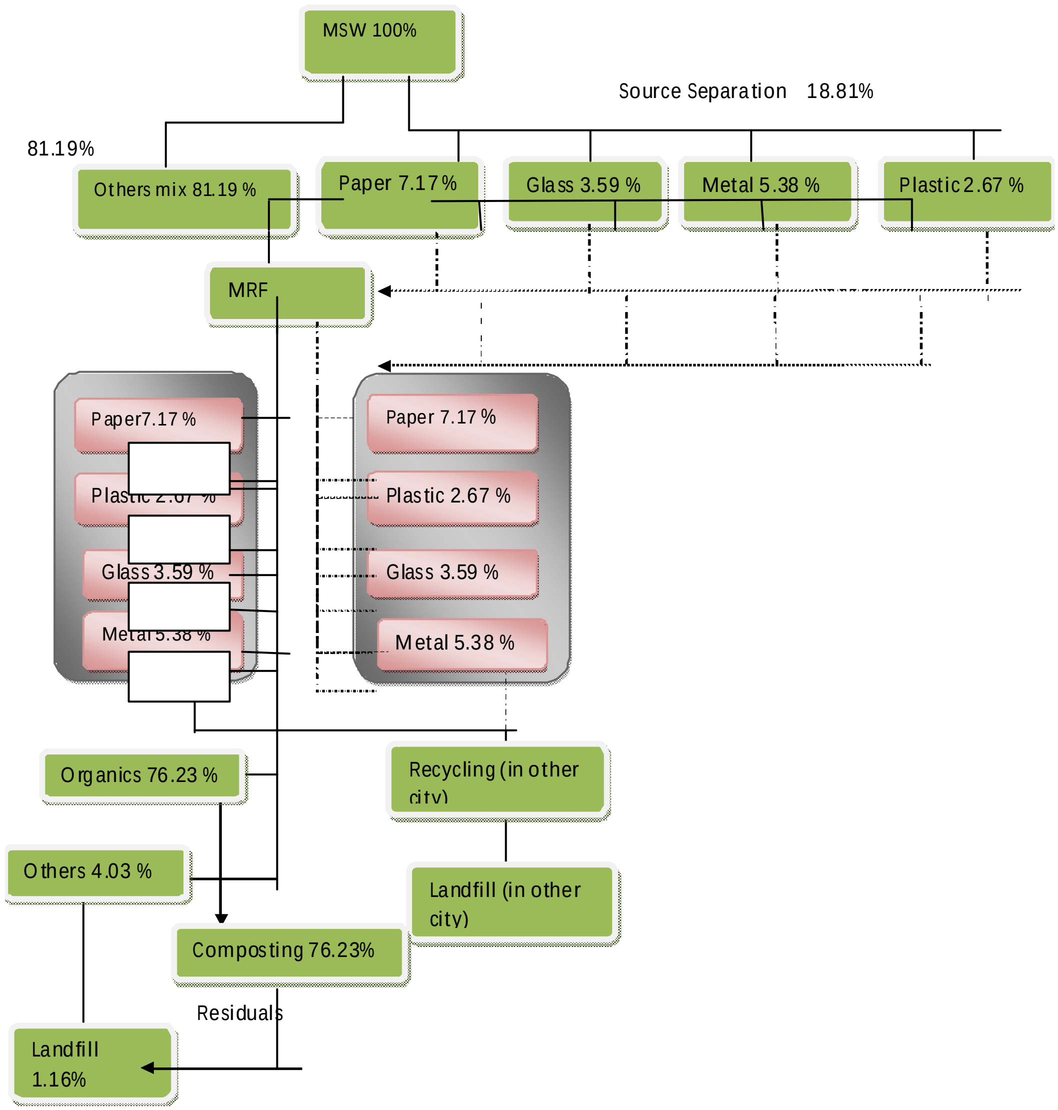

Figure 7. Scenario 3 (Ifako Ijaye Local Government Area).

of gas/energy recovery and their efficiencies, annual precipitation value, leachate collection efficiencies, landfill sequestration and energy consumed by landfill operation.

RESULTS AND DISCUSSION

The key outputs from IWM-1 modeling tools after feeding with the inputs above are: Environmental Inventory, net LCI, and LCIA. Others are the total waste management system, virgin material displacement credit, and reprocessing of recycled materials.

Environmental inventory

Tables 1 to 3 summarize the environmental inventory of the scenarios. Model result shows that Scenario 1 (Mushin Local Government Area) has the highest residual wastes (of 2714 tonnes, CO_2 51 tonnes, CH_4 + NO_X 143 tonnes, CO_2 Equivalents 3182 tonnes, NO_X 0.42 tonnes, SO_X 0.01 tonnes, HCL 0.01 tonnes, VOCs 0.20 tonnes, Pb 0.89kg, Hg 0.013kg, Cd 1.29kg, BOD 16,725kg).

This is followed by Agege LGA (with the residual wastes of 1825 tonnes, CO_2 37tonnes, CH_4 + NO_X 101 tonnes, CO_2 Equivalents 2241 tonnes, NO_X 0.29 tonnes, SO_X 0.00 tonnes, HCl 0.01 toness, VOCs 0.20 tonnes, Pb 0.60kg, Hg 0.009kg, Cd 0.87kg, BOD 11,250kg). Ifako Ijaye LGA is next (with the residual waste of 1787 tonnes, CO_2 39 tonnes, CH_4 + NO_X 91 tonnes, CO_2 Equivalents 2035 tonnes, NO_X 0.27 tonnes, SO_X 0.00 tonnes, HCL 0.00 tonnes, VOCs 0.10 tonnes, Pb 0.59kg, Hg 0.009kg, Cd 1.85kg, BOD 11060kg), while Ikeja LGA has the least

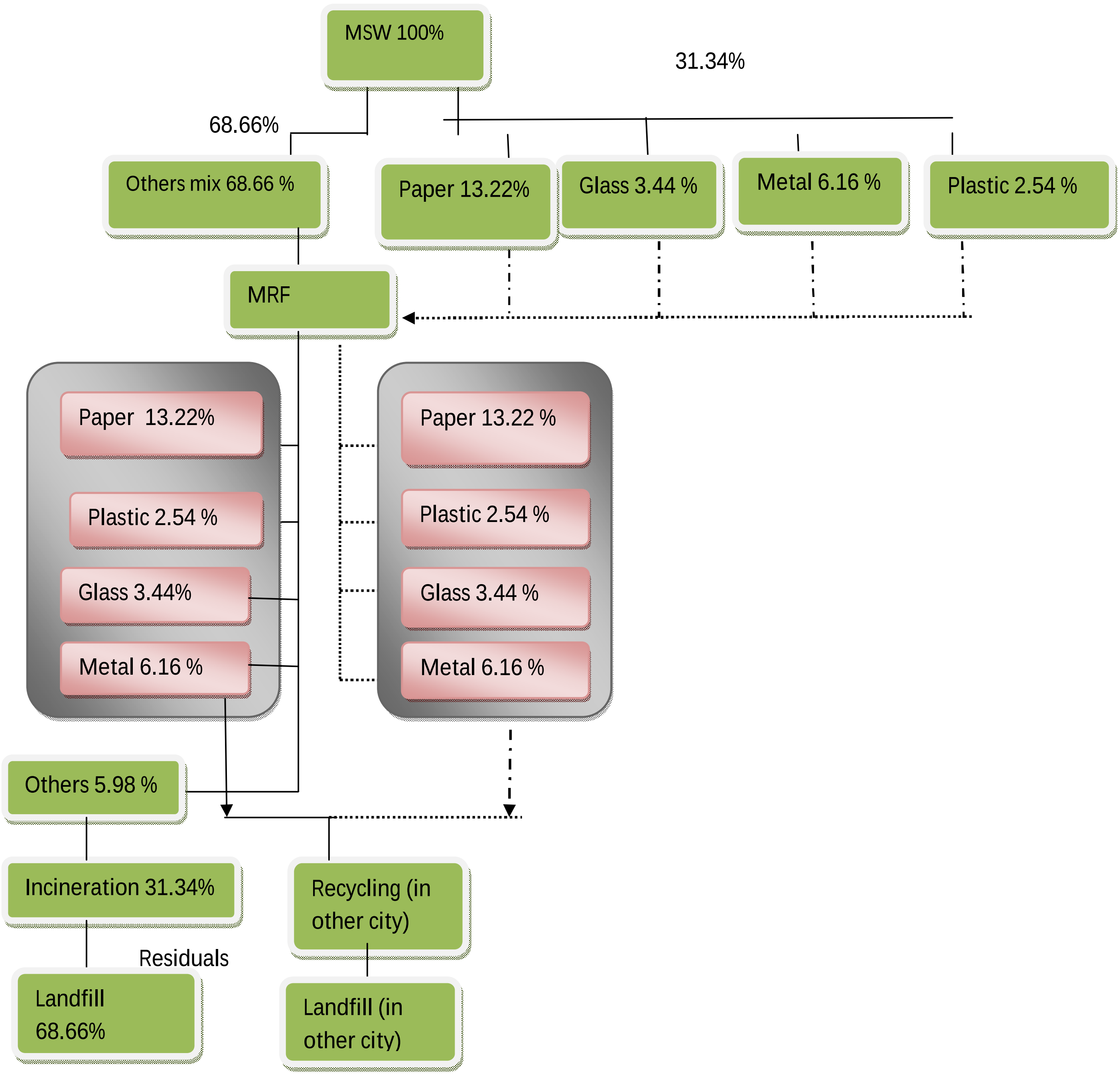

Figure 8. Scenario 4 (Ikeja Local Government Area).

the residual wastes (of 1499 tonnes, CO_2 38 tonnes, CH_4 + NO_X 84 tonnes, CO_2 Equivalents 1864 tonnes, NO_X 0.20 tonnes, SO_X 0.00 tonnes, HCL 0.00 tonnes, VOCs 0.10 tonnes, Pb 0.50kg, Hg 0.007kg, Cd 0.72kg, BOD 9299kg). Scenario 1 has highest carbon equivalent of 2618 tons and scenario 4 has lowest carbon equivalent of 167 tonnes.

Life Cycle Inventory (LCI)

In Figures 9 to 12 the distribution of respective pollutant gases and particles are represented in histograms. As shown in Figure 9, CO_2 equivalent has the highest quantity generated in all the scenarios with the highest being from Mushin area where nearly 4/5th of the wastes

Table 1. Net life cycle inventory of the scenarios.

	S1 MUSHIN LGA	S2 AGEGE LGA	S3 IFAKO IJAYE LGA	S4 IKEJA LGA
GREENHOUSE GASES				
CO_2 (tonnes)	-167	-106	-74	-95
$CH_4 + NO_X$	142	100	91	83
CO_2 Eq. (tonnes)	2618	1872	1745	1518
ACID GASES				
NO_X (tonnes)	-0.70	-0.40	-0.30	-0.40
SO_X (tonnes)	-2.30	-1.50	-1.20	-1.40
HCL (tonnes)	-18.60	-12.30	- 9.90	-11.20
SMOG PRECURSORS				
NO_X (tonnes)	-0.70	-0.40	-0.30	-0.40
PM (tonnes)	0.70	0.50	0.50	0.40
VOCs (tonnes)	0.20	0.20	0.10	0.10
HEAVY METAL & ORGANIC MATTERS				
Pb (kg)	0.43	0.30	0.36	0.21
Hg (kg)	0.013	0.009	0.009	0.007
Cd (kg)	1.279	0.860	0.846	0.710
BOD (kg)	16,729	11,250	11,060	9,299
Dioxins (TEQ) (g)	0.00017	0.00011	0.00011	0.0009
Residual Waste (tonnes)	2,714	1,825	1,795	1,509

Table 2. Comparison of Net Life Cycle Inventory of S1 and S4.

	SCENARIO 1 MUSHIN LGA	SCENARIO 4 IKEJA LGA	NET CHANGE
GREENHOUSE GASES			
CO_2 (tonnes)	-167	-95	72
$CH_4 + NO_X$	142	83	59
CO_2 Eq. (tonnes)	2618	1518	1100
ACID GASES			
NO_X (tonnes)	-0.70	-0.40	0.30
SO_X (tonnes)	-2.30	-1.40	0.90
HCL (tonnes)	-18.60	-11.20	7.40
SMOG PRECURSORS			
NO_X (tonnes)	-0.70	-0.40	0.30
PM (tonnes)	0.70	0.40	0.30
VOCs (tonnes)	0.20	0.10	0.10
HEAVY METAL & ORGANIC MATTERS			
Pb (kg)	0.43	0.21	0.22
Hg (kg)	0.013	0.007	0.006
Cd (kg)	1.279	0.710	0.569
BOD (kg)	16,729	9,299	7,430
Dioxins (TEQ) (g)	0.00017	0.0009	0.00073
Residual Waste (tonnes)	2,714	1,509	1,205

are biodegradable. Methane was generated in a minimal quantity in all the scenarios while CO_2 produced was inconsequential. From Figure 10, none of the acidic gases produced in the entire study area appeared significant. The acidification potential/threat of the wastes in study area is therefore negligible.

Particulate matters and Volatile Organic Compounds have significant effects in all the scenarios, the impact is however mostly felt from the Mushin area of scenario one (Figure 11). Smog emission from Ikeja wastes was found to be of the least quantities as manifested in form of Particulate Matters and Volatile Organic Compounds. Oxides of nitrogen generated in all selected cases were negligible. As shown in Figure 12, the Pb, Mg and Cd were of marginal quantities from all the scenarios. The organic matters as measured in form of BOD have the highest influence on wastes from Mushin area. This could be traced to the predominance biodegradable wastes in

Table 3. Comparison of Net Life Cycle Inventory of S2 and S3.

	SCENARIO 2 AGEGE LGA	SCENARIO 3 IFAKO IJAYE LGA	NET CHANGE
GREENHOUSE GASES			
CO_2 (tonnes)	-106	-74	32
CH_4 + NO_X	100	91	9
CO_2 Eq. (tonnes)	1872	1745	127
ACID GASES			
NO_X (tonnes)	-0.40	-0.30	0.10
SO_X (tonnes)	-1.50	-1.20	0.30
HCL (tonnes)	-12.30	- 9.90	2.40
SMOG PRECURSORS			
NO_X (tonnes)	-0.40	-0.30	0.10
PM (tonnes)	0.50	0.50	0.00
VOCs (tonnes)	0.20	0.10	0.10
HEAVY METAL & ORGANIC MATTERS			
Pb (kg)	0.30	0.36	0.06
Hg (kg)	0.009	0.009	0.000
Cd (kg)	0.860	0.846	0.014
BOD (kg)	11,250	11,060	190
Dioxins (TEQ) (g)	0.00011	0.00011	0.00000
Residual Waste (tonnes)	1,825	1,795	30

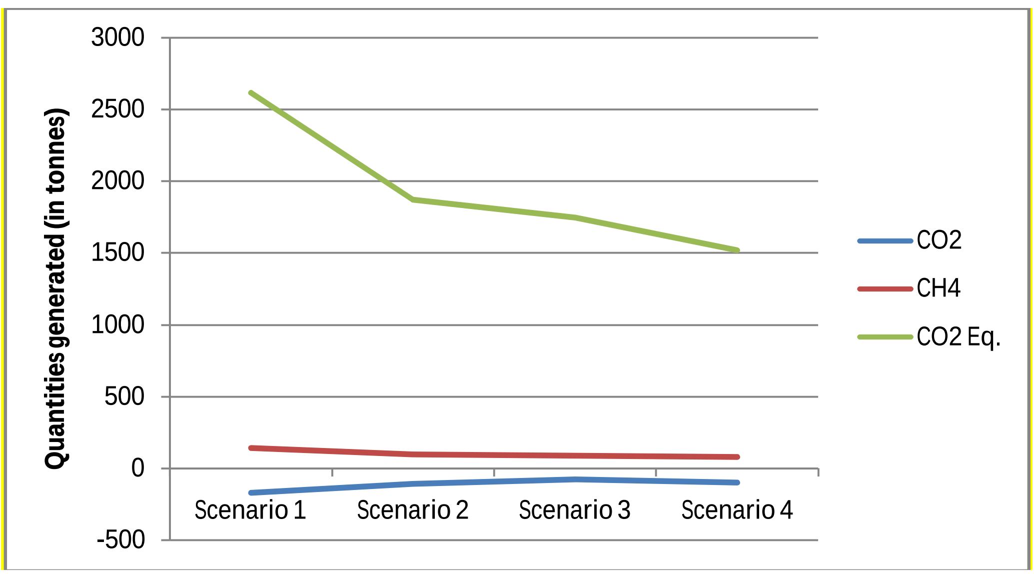

Figure 9. Quantities of green house gases generated from the scenarios.

the area. On the other hand the least quantity of BOD was measured from the wastes of Ikeja area. The standard of living reflected as being high here as the components of waste include higher quantities of cartons, plastics, packaging materials, cans etc.

Life cycle impact assessment

Four impact categories that were investigated are: global warming potential, acidification potential, eutrophication and photochemical ozone depletion.

Global warming potential

The climate change factors are expressed as global warming potential for time horizon of 100 years(GWP100), in kg CO_2/kg emission. CH_4 is of the most important impact for landfill Scenario (S1). The global warming effect for S2 and S3 mostly results from CO_2. S4 is the best scenario for climate change with the

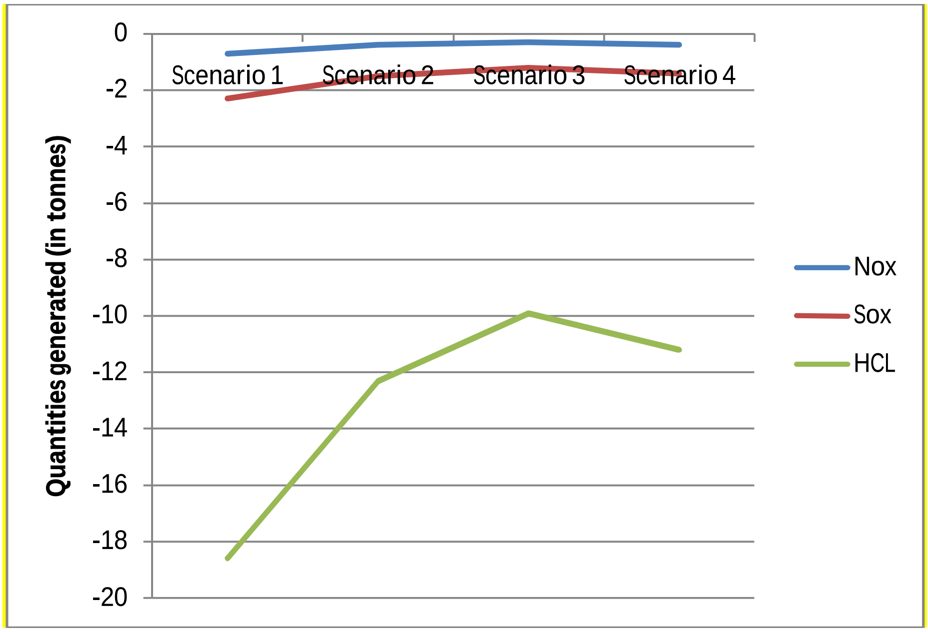

Figure 10. Quantities of acidic gases generated from the scenarios.

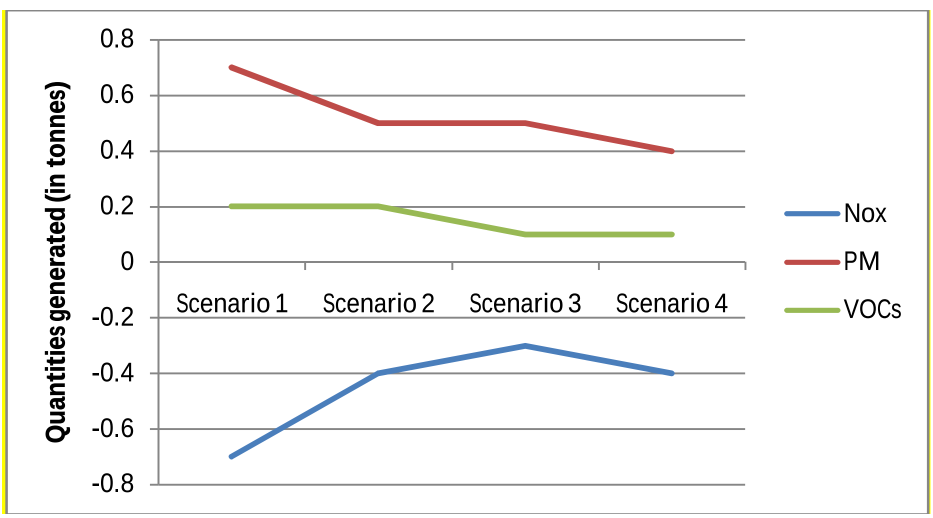

Figure 11. Quantities of smog precursors in the scenarios.

least CO_2 value of 1518 tonnes.

Acidification potential

The major acidifying pollutants are SO_2, NO_X, HCL and NH_3 (PE International, 2011). All of the scenarios except S4 show approximately same tread for acidification from ammonia and nitrogen dioxide in the air, the values were all negligible as shown in Table 1. S4 is the best scenario for this impact category because of the recycling process involved.

Eutrophication potential

Eutrophication is a phenomenon generally known to influence terrestrials as well as aquatic ecosystems. Biochemical Oxygen Demand (BOD) and ammonia are both contributory factors to eutrophication as they both aid the depletion of phosphate in circulation. Nitrogen dioxide is the dominant substance for the eutrophication

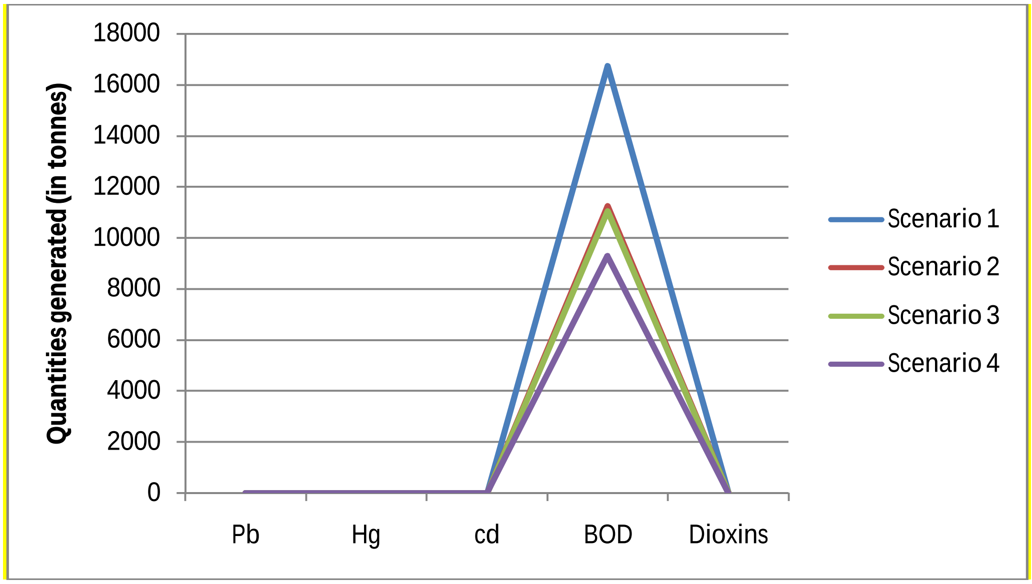

Figure 12. Quantities of heavy metals and organic matters in the scenarios.

Table 4. Impact characterization of the scenarios.

SCENARIOS	S1	S2	S3	S4
Abiotic depletion	0.013	0.009	0.009	0.007
	(kg Hg eq/ton waste managed)			
Global warming (GWP100)	3182	2241	2035	1864
	(kg CO_2 eq/ton waste managed)			
Acidification	0.01	0.01	0.00	0.00
	(kg HCL eq/ton waste managed)			
Eutrophication	0.42	0.29	0.27	0.24
	(kg NO_X eq/ton waste managed)			
Photochemical oxidation	0.20	0.20	0.10	0.10
	(kg VOCs eq/ton waste managed)			

effect of S2 and S3. As shown in Table 1, S4 has the lowest value for this impact category due to ammonia in the air and also the least BOD value of 9,299kg.

Photochemical ozone depletion

This impact indicator defines substances with the potential to contribute to photochemical ozone formation as volatile organic compounds (VOCs), which contain hydrogen or its depletion. Scenario 4 (S4) is the best scenario in this impact category. Photochemical ozone depletion effect for S3 and S4 results from methane. S1 and S2 have higher values of VOCs (0.20 tonnes) than S3 and S4 with 0.10 tonnes perhaps due to NO_2 emissions. Table 4 shows the results of the characterized impacts of the Scenarios. These orders of LCIA show that the S4 Scenario is the most environmentally preferable.

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