MSc Program
Environmental Technology & International Affairs

Waste Management - Municipal Solid Waste Management in Emerging Economies with the Waste-Management Planning Software WaPla

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Affidavit

I, **SUMAN LEDERER, BBA, MAIS**, hereby declare

1. that I am the sole author of the present Master's Thesis, "WASTE MANAGEMENT - MUNICIPAL SOLID WASTE MANAGEMENT IN EMERGING ECONOMIES WITH THE WASTE-MANAGEMENT PLANNING SOFTWARE WAPLA", 115 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

As incomes rise, people consume more and produce more waste. The current rate of waste generation is estimated to be 2.01 billion tons per year, with a rising trend. It is expected to reach 3.4 billion tons by 2050 if the current rate of waste generation continues. This rising trend has an adverse effect on the environment and climate in terms of greenhouse gas emissions, which are estimated at 1.6 billion tons CO2eq in 2016 from solid waste, which is around 5% of the total CO2eq emissions. This quantity is expected to rise to 2.6 billion tons CO2eq in 2050. Challenges in waste management are faced due to several factors, including the lack of standardized definition of municipal solid waste and lack of data collection of waste-related data.

The objective of the Master Thesis is to get familiar with, and present, different types of waste, different types of waste disposal methods, challenges of, and to, appropriate waste management in emerging economies, and finally to make suggestions for appropriate waste management of MSW in emerging economies, based on literature review and mainly on the results of the analysis of waste data in the waste-management planning software, WaPla, which has been developed by the Institute of Water Quality and Resource Management at the Technical University of Vienna. It provides an overview of waste flows in a city or a country and can identify the most affected waste disposal methods and the sources of highest emissions of unintended persistent organic pollutants and greenhouse gas.

Using the WaPla software, the MT has presented 4 scenarios of waste-management planning based on the examples of the Chongwe District in Zambia and the Giza Governorate, the 6th of October City and the Sheikh Zayed City, in Egypt. The Master Thesis concludes that emerging economies should improve data collection of waste-related data, as well as the coverage of waste collection and rather than increasing the usage of land as landfills/dumpsites, emerging economies should consider establishing waste-to-energy facilities to transform waste to resource.

Key words: Municipal solid waste, MSW, waste, waste management, emerging economies, landfilling, open burning, circular economy, waste management planning software, waste planning, WaPla, Chongwe District, Giza Governorate, waste to energy, WTE.

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List of Abbreviations

BMW	Bio-medical waste	NDC	Nationally determined contribution
BR	Open burning	PCB	Polychlorinated biphenyls
CEI	Circular Economy Institute	PCDD	Polychlorinated dibenzodioxins
CO2	Carbon dioxide	PCDF	Polychlorinated dibenzofurans
CP	Composting	PET	Polyethylene terephthalate
DMP	Informal dumping	POPs	Persistent Organic Pollutants
eq	(Carbon dioxide) equivalent	PPE	Personal protective equipment
ETIA	Environmental Technology and International Affairs	RDF	Refuse derived fuel
EU	European Union	Rec	Recycling
FLD	Fire at landfills and dumpsites	SC	Stockholm Convention
GDP	Gross domestic product	SDG	Sustainable Development Goal
GHG	Greenhouse gas	t/yr	Tons per year
GIS	Geographic information system	TERI	The Energy Research Institute
GWMO	Global Waste Management Outlook	TU	Technical University
HIC	High-income country	ucW	Uncollected waste
Inc	Incineration	UMIC	Upper-middle-income country
IPCC	Intergovernmental Panel on Climate Change	UNEP	United Nations Environment Programme
IWM	Integrated waste management	UN-Habitat	United Nations Human Settlement Programme
IWM	Integrated waste management	UNIDO	United Nations Industrial Development Organization
LIC	Low-income country	uPOPs	Unintended persistent organic pollutants
LF	Landfill	USD	United States Dollar

LMIC	Lower-middle-income country	WaPla	Solid Waste Management Plan Tool 2.0 - MSW
Mg	Milligram	WB	World Bank
MRF	Material Recovery Facility	WC	Waste collection
MSW	Municipal Solid Waste	WG	Waste generation
MT	Master Thesis	WHO	World Health Organization
		WTE	Waste-to-energy

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The Institute of Water Quality and Resource Management at the Technical University of Vienna developed the WaPla software ‘Solid Waste Management Plan (WaPla) Tool 2.0 – MSW’ and I would like to thank the Institute for enabling its usage for the Master Thesis.

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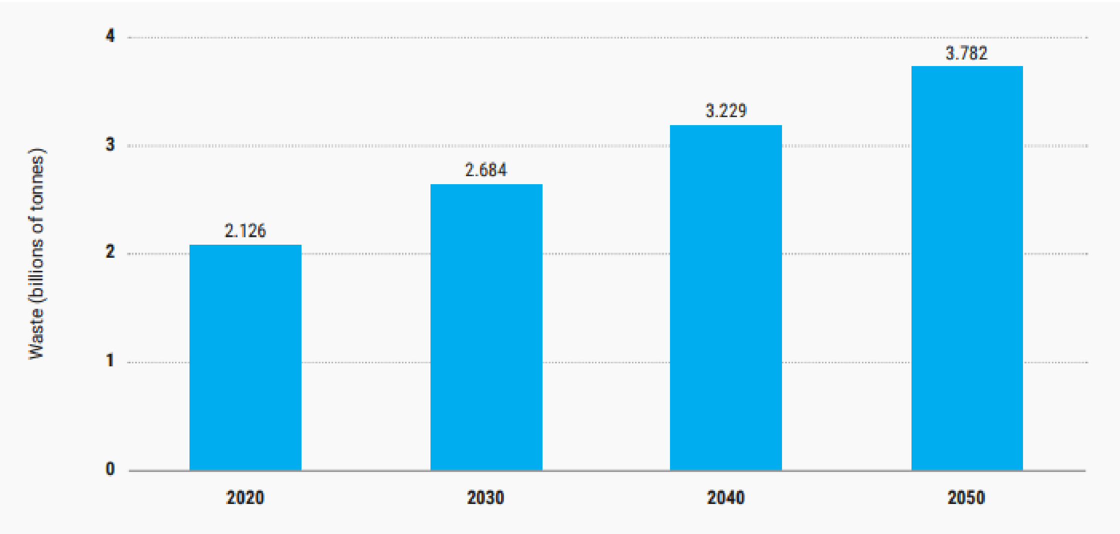
Thank you!

1 Introduction

1.1 Introduction and background

> *"The world is on a trajectory where waste generation will drastically outpace population growth by more than double by 2050".* (World Bank (WB), 2018, p. xi).
> *"Every year across the globe more than two billion tonnes of municipal solid waste (MSW) is generated. If packed into standard shipping containers and placed end-to-end, this waste would wrap around the Earth's equator 25 times, or further than traveling to the moon and back."* (UNEP, 2024, p.9).

Waste, as explained by Tchobanoglous & Kreith (2002, p.1.1) is produced by human activities via disposal when the material is not considered to be useful anymore. The form of this waste is usually solid[1], and the discarded material is considered to be of no use and is not wanted anymore, and hence the word 'waste' is used to describe it.
The WB (2018, p.3) has reported the quantity of municipal solid waste[2] (MSW) generated each year to be 2.01 billion tons. This quantity is estimated to reach 3.4 billion tons by 2050. The quantity of total waste generated per capita per day is 0.74 kilogram. The following figure shows the current waste production and the projected waste generation in 2050, if waste production continues in the current[3] manner.



Source: UNEP (2024, p.18).

Figure 1: Waste production from 2020-2050

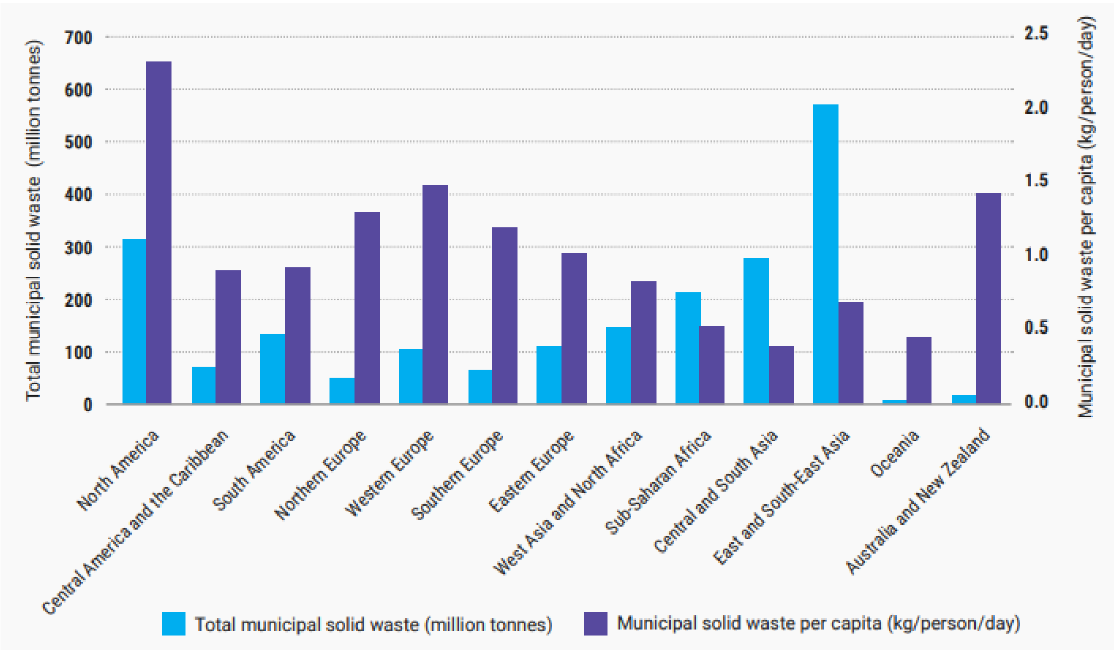
[1] Wastewater is not considered within the context of household or municipal solid waste, as the flow of wastewater is considered and treated differently and separately.
[2] Defined and explained in chapter 2.1.1.
[3] Often referred to as 'business as usual' scenario.

As incomes rise, people consume more and produce more waste. A reduction in the production of waste, as well as the toxicity of waste is necessary to mitigate the problem of waste.

This increasing waste quantity has repercussions for the environment and climate, in terms of greenhouse gas (GHG) emissions. The WB (2018, p.5) reported that in 2016, around 1.6 billion tonnes of GHG[4] are estimated to have originated from solid waste, which amounted to 5% of the total GHG. According to estimates, this quantity is expected to rise to 2.6 billion tonnes of GHG in 2050.

According to the WB (2018, p.3), the amount of waste produced depends on different factors, including the economy of a country, and depending on whether it is low-income country (LIC), lower-middle-income country (LMIC), upper-middle-income country (UMIC), high-income country (HIC), this quantity varies between 0.11 kilogram to 4.54 kilogram per capita per day. According to the report, at least one-third of the total quantity generated is not disposed off in an adequate manner. And one-third of the total waste is generated in HICs.

The following figure shows the total MSW generation by region and the MSW per capita per day.



Source: UNEP (2024, p.16).

Figure 2: Total MSW generation by region and MSW per capita by region

The above figure 2 shows clearly the critical situation regarding the quantities of waste, and the current high amount of waste production in East and South-East Asia.

[4] Carbon dioxide equivalent (CO2eq.).

The population of the world is increasing, and people are consuming more and more, and in relation to that, waste quantities are also increasing, also in emerging economies (Nanda & Berruti, 2020, p.1438). As the Master Thesis (MT) will present in the following sections, an awareness of this critical increase in the quantities of waste does not seem to be given in all the countries, as several countries, mostly emerging economies, do not manage waste in an adequate manner, and in many cases, do not even collect waste-related data. Inadequate waste disposal inevitably leads to pollution of the surrounding environment, which has a critical adverse effect on the health of the population. It is even estimated that in low-income countries, percentage of deaths due to adverse health impact of environmental pollution can be up to 90% (Siddiqua, 2022, p.58515).

Having grown up and spent my childhood in India, an emerging economy, visited a few countries for work purposes, mostly emerging economies, worked on a few project and programme evaluations with a focus on waste management[5] and witnessed inadequate waste management in several emerging economies, including waste dumping anywhere and everywhere, as well as open burning of waste, I wanted to delve into the topic of waste and waste management, and use this opportunity of writing the MT to look at existing issues related to waste and waste management, challenges faced by the countries, ways of appropriate waste management and requirements of appropriate waste management in emerging economies.

1.2 Objective and Research Questions

The objective of the MT is to get familiar with, and present, different types of waste, different types of waste disposal methods, challenges of, and to, appropriate waste management in emerging economies, and finally to make suggestions for appropriate waste management of MSW in emerging economies, based on literature review and mainly on the results of the analysis of waste data in the waste-management planning software, WaPla[6]. In line with this, the main research question and two sub-questions are as follows:

[5] Team member in the terminal evaluation of the portfolio of 3 projects: 'Global Waste Management Outlook' (GWMO); 'Secretariat Support to the Global Partnership on Waste Management'; and 'Delivering Integrated Waste Solutions at the National and Local Level'. https://wedocs.unep.org/handle/20.500.11822/35925?show=full [Accessed on 05 May 2024] and Lead Consultant for the mid-term review of the project 'Promotion and Delivery of Environmentally Sound Waste Management Technologies and Methods and in-Country Technical and Advisory Support'.

[6] Elaborated in chapter 3.1.

Table 1: Research questions and methodology for analysis

Research questions	Methodology for analysis
Main research question	
How can the WaPla software be used for waste management planning in emerging economies?	Literature review Data analysis in WaPla software
Research sub-question 1	
What is the situation of municipal solid waste in emerging economies, including challenges faced, if any?	Literature review
Research sub-question 2	
What are the results of waste management planning in WaPla software for the selected emerging economies?	Data analysis in WaPla software

The author of the MT hopes that:

i. Countries, especially emerging economies, will recognize the critical situation of increasing waste and start using supporting software, for example, the WaPla software, to analyse data and plan their waste management system in an adequate manner;

ii. In order to analyse data in the WaPla software, or any other waste-management planning software, they will recognize the significance of waste-related data and start/enhance collection of such data;

iii. Emerging economies will implement programmes to design and establish well-thought and well-planned waste management systems; and

iv. Adverse effects of lack of, or inadequate, waste management on health, environment and climate can be reduced or even eliminated.

1.3 Methodology

The methodology to arrive at the conclusions and suggestions for waste management for emerging economies is based on:

i. Literature review;

ii. Planning of waste management carried out in the waste management planning software, WaPla.

As such, the categorization of waste into the different types, MSW, e-waste, plastic waste, etc., explained in the following chapter 2.1, has not changed over the years; similarly, the meaning of the different waste-disposal technologies has also not changed over the years, for example, the technologies may have changed and/or improved, but incineration in an incinerator still has the same meaning. Therefore, for an understanding of the definitions in chapters 2, about the different types of waste and waste-disposal methods, the *'Handbook of Solid Waste Management'* second edition, by George Tchobanoglous and Frank Kreith (2002) was referred to.

Moreover, since data on waste, for example, waste generated and/or collected, is not always compiled, waste-related data from the World Bank's *'What a Waste 2.0', 2019,* was referred to.

UNEP has released a number of publications on waste-related issues; therefore, a few relevant UNEP reports were referred to.

For the rest of the literature mentioned in the MT, in order to gain an understanding of waste-related issues all over the world, within or related to the topics mentioned in the MT, the author made efforts to consult peer-reviewed articles from authors from different regions and countries of the world and examples of waste-related research in different regions of the world.

The MT has made efforts to provide an overview of different types of waste, including the current state of affairs, that is, the estimated quantities existing in the world, not to just provide definitions, but firstly, to present the different types of wastes as each type of waste requires to be disposed off in an individual manner which is more-or-less tailor-made for that type of waste; secondly, to present the fact that the quantities of different types of waste change over time, even though most of them have an increasing tendency; thirdly, to present that the quantities of waste are different in different countries, depending, amongst others, on the size of population, the main economic sectors and income of the country.

After providing an overview of the different types of waste, the MT continues with providing a short overview of different types of waste disposal methods. In this sub-chapter 2.2 however, it does not delve into the depth of the design and construction of the different types of waste collection and disposal methods, firstly, because the intent of the MT is to review possible waste management options and make recommendations based on the analysis in the WaPla software of waste data in the Chongwe District in Zambia and the 6th of October City and Sheikh Zayed City in the Giza-Governorate in Egypt; and secondly, each component in waste collection and disposal comes with its own technical and cost specifications, parameters and considerations and it is beyond the scope of the MT to delve into each one of them.

Thereafter, the MT briefly defines waste management and reviews and compiles other topics pertinent to waste and waste management, namely, the reasons for the development of waste management in industrialized countries, the relation between waste generation and the gross domestic product (GDP) of a country, waste and the sustainable development goals (SDGs), the role of waste management in emerging economies, challenges in waste management, the role of social attitude and behavior, gender, vulnerable groups and waste management, sustainable consumption and production and the circular economy, as well as introduces recent waste-management related topics such as remote sensing in waste management.

The chapter thereafter starts with an introduction of the waste-management planning software 'WaPla' and then presents waste-management planning carried out in the WaPla software for 2 cities in emerging economies.

The last chapter entails the summary and conclusions, based on the analysis done in the WaPla software and the definitions and aspects stemming out of the literature review, as well as presents a few possible topics[7] for further research.

As explained above, after chapter 1 – Introduction, chapter 2 – Waste management – elaborates the different types of waste, waste disposal methods and other waste-related topics based on pertinent waste literature. Chapter 3 introduces the WaPla software. With the help of the Institute for Water Quality and Resource Management at the Technical University (TU) of Vienna, waste-related data was requested and received from the University of Zambia and Waste Management Department of Chemonics Egypt Consultants based in Giza, Egypt. This data was then entered and analysed in the waste-management planning software WaPla. Results are presented in chapter 3. Chapter 4 presents the conclusions and suggestions for waste-management planning after taking into account the results from the WaPla software and information from different literature.

Limitations: Waste and waste management are really vast topics, and it is not possible to elaborate each definition, type, requirements and specifications of each and every type of waste, waste-collection and disposal methods and waste-disposal technologies. Moreover, waste management is specific to each city, country and respective waste situation. Therefore, the MT does not claim to have reviewed and assessed everything related to waste and waste management. Rather, it has made efforts to present an overview of the different types of waste, a few waste-disposal methods, other waste (management) related topics, and finally the waste-management analysis in the WaPla software to make suggestions for waste management in

[7] The thematic area of 'waste management' is vast and there are innumerable topics of research in waste management. Therefore, only a few possible topics are mentioned in the sub-section.

emerging economies based on 2 examples, which demonstrate the usage and usefulness of the WaPla software for waste-management planning of MSW in emerging economies.

It is worth mentioning that costs have not been taken into consideration. Costs are an important factor in the decision-making process of any city (and country) for any specific waste-disposal technology. However, as shown in chapter 3, several options exist for waste-management planning and it is beyond the scope of the MT to delve into the details of the cost of each option.

While conducting literature search, over 100,000 peer-reviewed article titles were returned as search results for several waste-related topics searched for, within the time period of 10 years. This also goes to show the broadness of topics related to 'waste management', and it is beyond the scope of the MT to even introduce each topic, inter alia, the emissions, health effects.

2 Waste Management

2.1 Types of waste

2.1.1 Municipal Solid Waste

According to Tchobanoglous & Kreith (2002, p.1.1), in a community, although there might be different ways to classify the sources of waste, one way is to categorize into: i) residential, ii) commercial, iii) institutional, iv) Construction and demolition, v) municipal services, vi) treatment plant sites, vii) industrial, and viii) agricultural.

Although there is no homogenous definition of MSW (Edjabou et al., 2015, p.4), in essence, the definitions available in literature are similar to the definition of MSW in Tchobanoglous & Kreith (2002, pp.1.1-1.2), who have defined MSW as "all community wastes, …" including "wastes from residential, commercial, institutional, and some industrial sources …", "with the exception of wastes generated[8] by municipal services, water and waste-water treatment plants, industrial processes, and agricultural operations". MSW has been defined along the same lines by the UNEP (2024, p.5) and encompasses "all residential and commercial waste but excludes industrial waste". The WB (2018, p.9) has defined MSW as "residential, commercial, and institutional waste. Industrial, medical, hazardous, electronic, and construction and demolition waste are reported separately from total national waste generation to the extent possible".

Normally, in order to find out more about what the MSW in different countries consists of in reality, a waste analysis is carried out, that is, samples of MSW are taken, separated, and a datasheet filled out with information such as names, categories and

[8] Produced by and in households.

weight (WB, 2018, p. 29; Edjabou et al., 2015, p.4). The composition of the MSW is considered to be an important factor for waste management planning (Edjabou et al., 2015, p.4; Abylkhani et al., 2020, p.6), as the disposal methods may differ depending on the type of waste.

Tchobanoglous & Kreith (2002, p.1.3): MSW normally comes from the following sources:

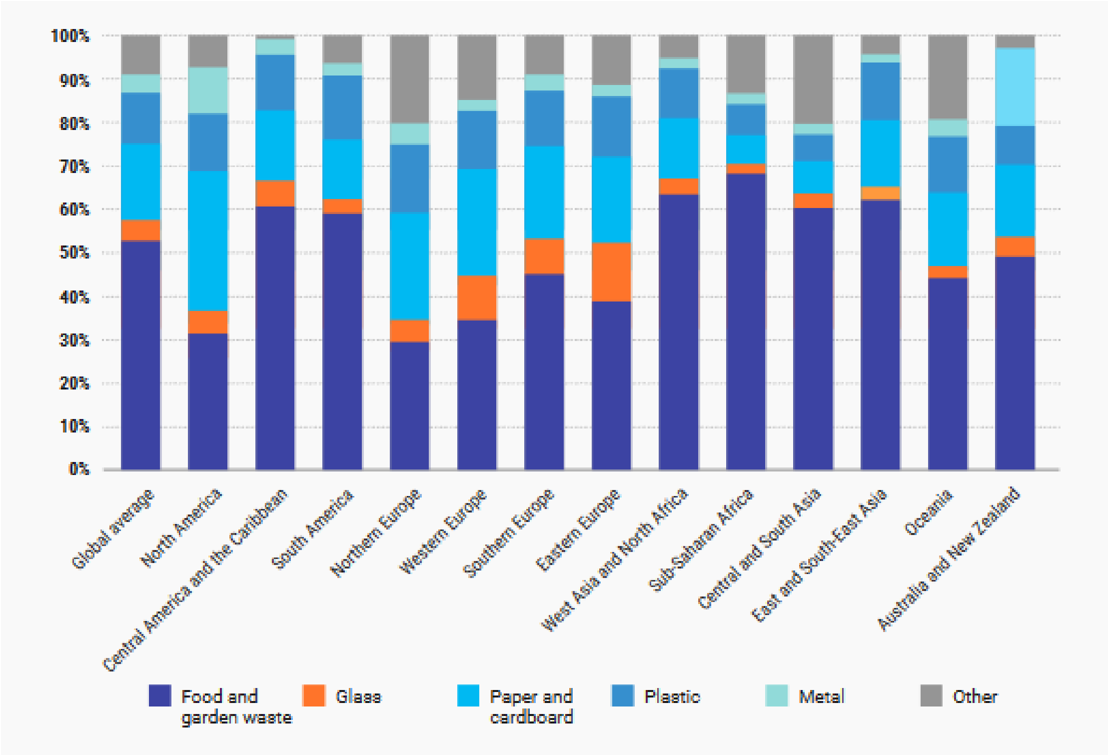
Table 2: Sources of MSW

Source	Examples
Residential	Family homes, houses, apartments, etc.
Commercial	Office buildings, shopping malls, warehouses, hotels, airports, restaurants
Institutional	Schools, medical facilities, prisons
Industrial	Packaging of components, office wastes, lunchroom and restroom wastes (industrial process waste not included)

Source: Tchobanoglous & Kreith, 2002, p.1.3, Table 1.1.

According to the WB (2018, p.30), a difference in the composition of waste exists depending on the income of the country; for example, recyclable dry waste – plastic, paper, cardboard, metal and glass, is dominant in HICs, reaching upto 51% of the MSW than food and green waste, which is around 32%; the situation is different in emerging economies, where upto around 56% of the MSW entails food and green waste, and only an estimated 16% of the total waste may be made of recyclable materials. The reasons for this high amount of food waste are diverse, inter alia, high production, non-saleability due to any damage, too high quantities of purchases by customers (Nanda & Berruti, 2020, p. 1439). The issue of high quantities of food waste and related issues have been explored in various literature, with different approaches proposed to reduce the quantities of food waste, or to at least use it as a renewable resource (Cecchi & Cavinato, 2019, p.11). Figure 85 in Annex 6.2 shows the composition of global waste in HICs, UMICs, LMICs and LICs.

Regional differences exist in the composition of MSW as shown in the following figure:



Source: UNEP (2024, p.20).

Figure 3: Composition of MSW according to region

The above figure is relevant for the MT as it shows the composition of MSW according to region. The Republic of Zambia is an LIC, located in Sub-Saharan Africa, and the Arab Republic of Egypt is a LMIC and located in the region West Asia and North Africa.

2.1.2 Industrial waste including hazardous waste

Industrial waste is categorized into hazardous waste and non-hazardous waste. According to TERI (2014, p.5), hazardous waste is characterized by its toxic nature, due to which it cannot be disposed off in the normal way other MSW is disposed off; it requires special consideration for disposal. In most countries, including in several emerging economies, special legislation regulates the disposal of hazardous waste, which is delineated in different categories. Some waste materials can be considered to be hazardous waste if they are ignitable, corrosive, reactive and/or toxic. Examples of hazardous waste are waste from specific industries, from chemical products, from different processes production and in industries, waste oils[9], solvents, battery acid, corrosive metal containers, explosives, materials entailing mercury, lead, pesticides,

[9] Waste oil, for example from old transformers may contain persistent organic pollutants (POPs) – Polychlorinated biphenyls (PCBs). https://chm.pops.int/Implementation/PCBs/Overview/tabid/273 [Accessed on 16 April 2024].

bulbs, waste containing prohibited materials, radioactive waste, etc. (TERI, 2014, pp. 5-6).

Non-hazardous industrial waste can be recyclable or non-recyclable and is produced via activities in industries. Its constituents may sometimes be considered to be MSW, for example, glass, cardboard, other packaging material, metal, lime sludge, etc. It does not require being treated in a special manner as the aforementioned hazardous waste, and can be disposed off or recycled according to existing disposal systems which can handle the larger quantities of such waste and operate in compliance with existing rules and regulations. (TERI, 2014, p.7).

2.1.3 E-waste

Electronic waste (e-waste) includes waste from electrical and/or electronic equipment when it is disposed off (TERI, 2014, p.8). Electronic items are used all over the world and due to enhanced usage, production is also growing at an enhanced pace, resulting in increased waste of electronic equipment or e-waste (Fowler, 2015, p.1).

Especially since the expansion of the usage of computers, laptops, and mobile phones, as well as television, refrigerators, air conditioners, washing machines, etc., the quantity of e-waste has increased exponentially, and is creating huge challenges in terms of adequate disposal. The adverse impact of inadequate disposal on the environment and the health of human beings is also a critical aspect. The issue is particularly prominent in emerging economies, as they are still struggling even with introducing adequate waste management systems for MSW. (TERI, 2014, p.8; Fowler, 2015, pp. 2-5).

Figures 86 and 87 in Annex 6.2 show the percentage of e-waste in total waste generated. Although the share of e-waste is the smallest at 0.02%, it is estimated to be at least a few million tons per year (Fowler, 2015, p.1).

2.1.4 Plastic waste

According to Walker & Fequet (2023, p.116983), altogether a production of 9,200 million tons of plastic is estimated to have been produced in the form of plastics for single use, from which over 6,900 million tons of plastic has landed in landfills, and contributed to polluting the environment.

Estimated 242 million tons of plastic waste was produced in 2016, mainly in the regions East Asia and Pacific, Europe and Central Asia and North America (WB, 2018, p.117), and in 2019, 368 million tons of plastic was produced in the world (Walker & Fequet, 2023, p.116983). Walker & Fequet (2023, p. 116983) estimate that only 9% of the plastic produced altogether so far has undergone recycling.

Plastic waste makes its way to the water bodies. Although technologies have been developed for plastic removal from the water, it is again a question of cost, despite the very critical impact plastics are having on the marine environment (Schmaltz et al., 2020, p.12).

Gradually, countries are becoming aware of the risks associated with plastic waste, and have started initiatives to create awareness about the need to reduce plastic waste. Pathak (2023, p.169-170) gives the example of awareness of plastics wastes in India, especially in Mumbai, where the city government carried out awareness-raising in the population, which is seen to be in line with the Prime Minister's 'Clean India Mission'. She goes on to explain that it is not an isolated case and that awareness is rising.

Increasingly, countries are introducing measures to eliminate or reduce plastic waste, inter alia, prohibiting providing plastic bags for shopping free of cost, prohibiting the use of plastic straw, creating awareness for moving away from disposable or one-time usage plastic consumer goods to other multiple-use and sustainable materials. Gokdemir et al. (2024, p.2) have mentioned a few questions[10] which might prove to be helpful for people when thinking about plastics and their usage in order to increase individual awareness and responsibility about the usage of plastics.

2.1.5 Bio-medical waste

Bio-medical waste (BMW) is waste from healthcare institutions, that is, clinics and hospitals (TERI, 2014, p.8). In its Guide *'Management of Solid Health-Care Waste at Primary Health-Care Centres – A Decision-Making Guide'*, the World Health Organization (WHO) defines it in a similar way (2005, p. 2) as "the total waste stream from a health-care facility that includes both potential infectious[11] waste and non-infectious[12] waste materials".

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[10] "1. What is your country's annual plastic garbage import? Is it necessary to import plastic garbage from other countries? What is the total amount of imported plastic garbage? 2. Has the imported plastic garbage been subjected to any customs control and inspection to determine whether it is dangerous or toxic waste? Could plastic debris containing phthalates, bisphenol, or other poisonous compounds enter your country during this process? If so, how much does it contribute to the pollution of land water and air? 3. How much plastic garbage enters your country without any control or inspection, if the processes relies solely on the importer company's discretion, and how much of the imported plastic garbage is recycled, rather than simply dumped? 4. How is non-recyclable plastic waste evaluated and assessed?" (Gokdemir et al., 2024, p.2).

[11] "Infectious waste includes infectious sharps and infectious non-sharp materials. Infectious sharps consist of syringe or other needles, blades, infusion sets, broken glass or other items that can cause direct injury. Infectious non-sharps include materials that have been in contact with human blood, or its derivatives, bandages, swabs or items soaked with blood, isolation wastes from highly infectious patients (including food residues), used and obsolete vaccine vials, bedding and other contaminated materials infected with human pathogens. Human excreta from patients are also included in this category. … If no

Around 20% of the BMW is deemed to be infectious and therefore, needs to be separated at source, and stored, transported and disposed off separately. Moreover, all persons who might come in contact with BMW have to take the infectious character of BMW into consideration and wear personal protective equipment (PPE) while handling BMW. The appropriate disposal of BMW takes place in special facilities which are equipped for BWM disposal (TERI, 2014, p.8).

The issue of appropriate disposal of BMW[13] exists to a great extent in emerging economies, although many of them have realized the significance of proper management of BMW and have drafted and incorporated corresponding regulation (Ali et al., 2017, pp.6-7).

Emissions from uncontrolled dumping and burning of BMW contain different substances, amongst others, unintended persistent organic pollutants (uPOPs), mainly polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Zhang et al. (2019, pp. 237-246) conducted epidemiological assessments in Central China with over 600 individuals, which included persons who worked in incineration facilities, foundry and persons who lived at a distance of more than 5 km from these facilities, as well as food samples. They found higher concentration of PCDD/DF in the incinerator than in the residential areas, and also found adverse effects on the health of the workers, thus confirming that uPOPs also bioaccumulate.

2.1.6 Other types of waste

According to UNEP (2015, p. 53), other types of waste include construction and demolition waste, agricultural and forestry waste, and mining and quarrying residues and waste. Efforts are made, almost everywhere, to dispose off agricultural and forestry waste where it is generated, that is, by returning it to the earth, or by using it as biomass fuel. Similarly, waste produced during mining and quarrying is normally disposed off at the same site, and not really transported anywhere else. Construction and demolition waste contributes with around 36% to the total waste (UNEP, 2015, p. 54). Other waste materials which need to be disposed off in an appropriate manner are inter alia, batteries, used oil, tires, just to name a few.

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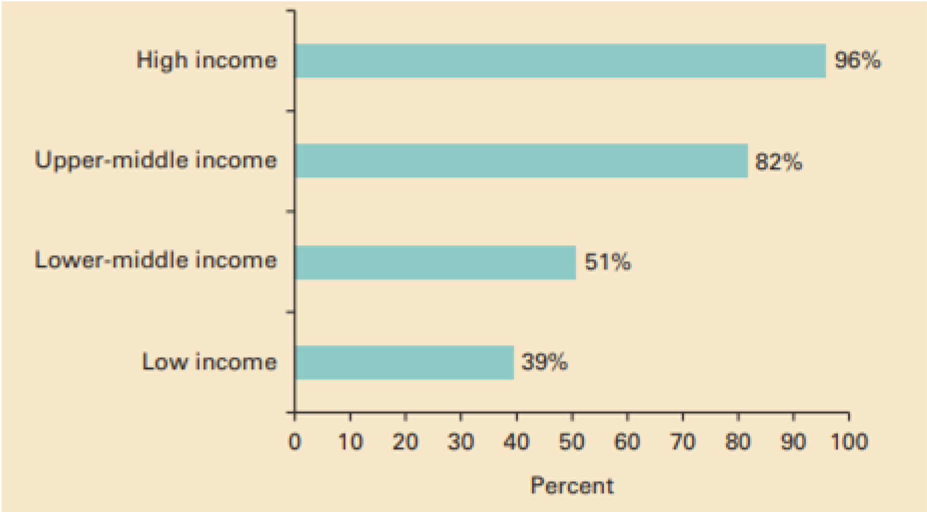
separation of wastes takes place, the whole mixed volume of health-care waste needs to be considered as being infectious." (WHO, 2005, p.2.).

[12] "Non-infectious wastes may include materials that have not been in contact with patients such as paper and plastic packaging, metal, glass or other wastes which are similar to household wastes." Ibid.

[13] The author of the MT has worked on the evaluation of a project related to BMW 'Environmentally Sound Management of Medical Wastes in India'. Without going into the details of the evaluation, the author would only like to note that BMW is also a crucial issue in emerging economies.

2.2 Waste disposal methods for MSW

Normally, municipalities are responsible for collecting waste from households, which is carried out in different ways[14]. The percentage of waste collected, as shown in the following figure, differs according to the economy of the country (WB, 2018, p.32); for example, the rate of waste collection in HICs is around 100%, in UMICs 82%, LMICs, around 51%, and in LICs, around 39%, the rest of which lands in dumpsites or is disposed off by open burning[15].



Source: WB, 2018, p.32.

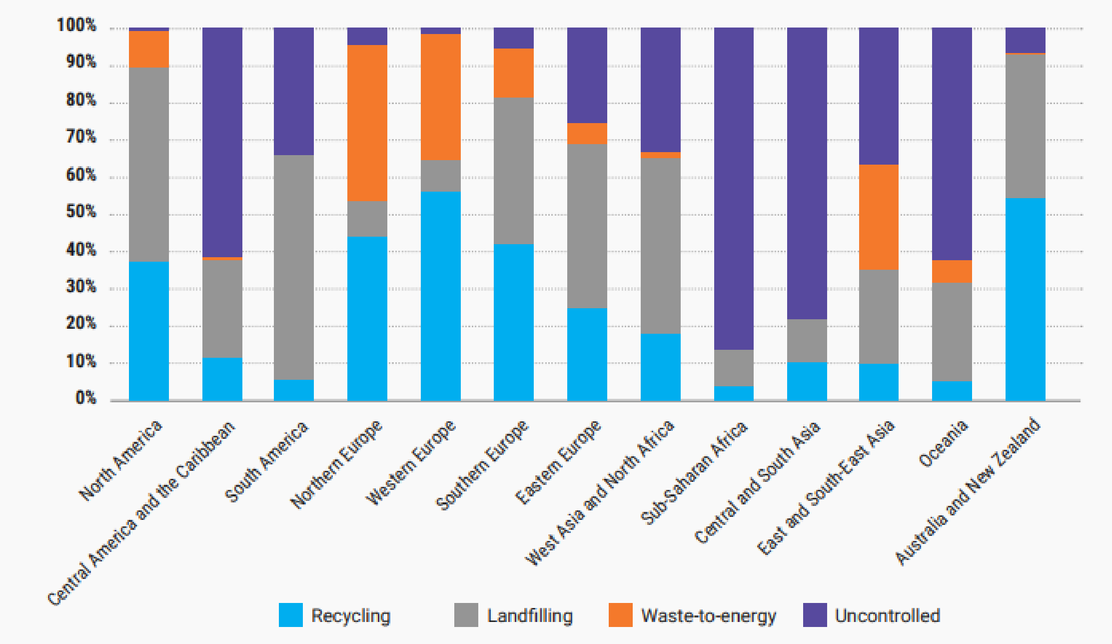
Figure 4: Rate of waste collection according to income level

Waste is normally treated or disposed off by the following methods, namely, composting, incineration, controlled landfill, unspecified/informal landfill, sanitary landfill, open dumpsites, recycling, and other. The global average percentages of the different waste disposal methods are illustrated in figure 88 in the Annex.

Regional differences exist in the waste disposal method followed. The following figure shows the waste disposal methods prevalent in the different regions:

[14] There are different ways of collecting waste from households, and each way has its advantages and disadvantages in terms of resources needed. Since waste collection is not a focus of the MT, it is not elaborated in a detailed manner in the MT.

[15] Explained briefly in chapter 2.2.2.



Source: UNEP (2024, p.22).

Figure 5: MSW treatment and disposal according to region

As seen in the above figure, in Sub-Saharan Africa, where the Republic of Zambia is located, ‘uncontrolled’ disposal, that is, waste disposal via informal dumpsites and burning, constitutes an absolute maximum of almost 90% compared to other waste disposal methods, in this case ‘recycling’ and ‘landfilling’. In West Asia and North Africa, where Egypt is located, ‘landfilling’ is more prevalent, followed by ‘uncontrolled’ disposal and then ‘recycling’. The same is actually also reflected in the data received from both countries, elaborated under chapter 4 of this MT.

The different waste disposal methods - landfilling, informal and formal incineration, recycling, Material Recovery Facility (MRF), composting, source reduction and other informal methods - are defined and explained briefly in the following sub-sections, as some of these methods are taken into consideration for the analysis in the waste-management planning software WaPla.

2.2.1 Landfilling

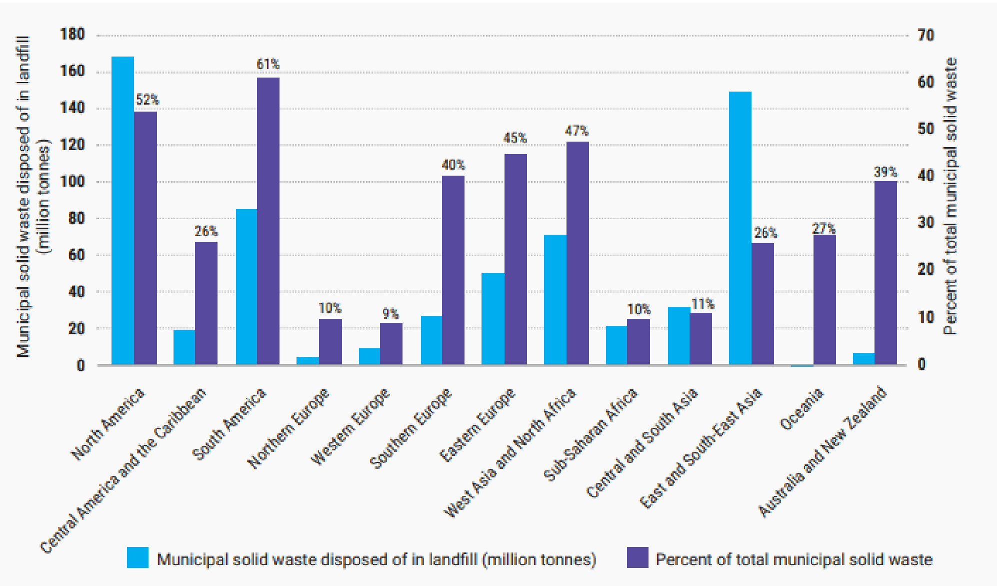
“Landfill is the term used to describe the physical facilities used for the disposal of solid wastes and solid waste residuals in the surface soils of the earth” (Tchobanoglous & Kreith, 2002, p.14.1).

In earlier times, landfills mainly consisted of ‘dumps’. ‘Dumps’, ‘dumpsites’, ‘waste dumps’ are also called ‘uncontrolled land disposal sites’, where waste is brought and dumped without any organization (Tchobanoglous & Kreith, 2002, p.14.2). UNEP (2024, p.5) has defined dumpsites as “places where collected waste has been deposited in a central location and where waste is not controlled through daily, intermediate or final cover, thus leaving the top layer free to escape into the natural environment through wind and surface water". According to the WB (2018, p.5), in emerging economies, and especially in LICs, around 93% of the waste is disposed off on dumpsites. The situation is different in HICs, where only around 2% of the waste is dumped.

Hafeez et al. (2016, p.954) tested samples of air, soil, dust and water from close vicinity of a dumpsite in Lahore City, Pakistan, and tested them for persistent organic pollutants (POPs) and found quantities of polychlorinated biphenyls (PCBs), polybrominated diphenyl (PBDEs) and dichloran plus (DP) in all media with the highest concentrations in the air, followed by water, then dust and then soil, thus presenting a risk to the population in close vicinity of the dumpsite.

Solid wastes brought to assigned land which is used as landfills can be the MSW without treatment, but after removal of recyclables, or solid waste residuals after processing of solid waste. Earlier, landfills were constructed, even in developed countries, without due consideration to human health and environment. In the course of time, landfills started being covered by a layer of soil, to prevent waste from drifting away with wind, reduce odor and to keep a check on uncontrolled entry of water into the landfill. (Tchobanoglous & Kreith, 2002, p.14.1-14.2).

Landfills seem to be the most prevalent form of waste disposal existing in UMICs catering to 54% of the total waste (WB, 2019, p.35). Again, regional differences exist in the amount of MSW sent to the landfill. This is illustrated in the following figure together with the actual quantity of MSW in million tons which is sent to the landfill:



Source: UNEP (2024, p.27).

Figure 6: Rate of landfilling of MSW according to region

In recent years, landfills have been developed further, and different steps have been incorporated in the management of landfills, which includes "planning, design, operation, environmental monitoring, closure, and post-closure control of landfills", and establishing engineered 'sanitary landfills' (Tchobanoglous & Kreith, 2002, p.14.1). According to UNEP (2024, p.27), a sanitary landfill is "an engineered facility for the disposal of solid waste on and in a controlled manner".

Sanitary landfills have a liner at the bottom and sides of the landfill to prevent seepage of leachate[16] and gases[17] into the ground (Siddiqua et al., 2022, p.58536); the liners are made of layers of soil, mostly clay[18], or a geosynthetic material. Daily covers consist of a few centimeters – normally 15-30 centimeters – of soil, or compost, or shredder fluff. After filling the landfill to its full capacity, it is covered with the final cover, to prevent the entry of gases into the atmosphere and the entry of water from outside into the landfill. Equipment is installed at the landfill to collect the landfill gas, that is, methane, as well as leachate. (Tchobanoglous & Kreith, 2002, pp.14.2, 14.10).

According to Siddiqua et al. (2022, p. 58517), there are separate landfills for MSW, industrial waste and hazardous waste.

Hazardous waste is not landfilled together with non-hazardous waste. How the landfill is designed[19] depends on several factors, including the type of waste it is expected to receive; for example, design and construction of the landfill for hazardous waste would be different from that of non-hazardous waste, and from non-hazardous MSW, etc. Depending on the design and construction of the landfill, that is, if constructed and operated in an appropriate manner, including monitoring, it contributes to the protection of human health and environment. In some countries, the landfills have integrated gas-control systems, liners, leachate collection systems and monitoring systems for ground-water. Resource recovery can also take place at landfills, for example, methane gas can be collected; moreover, considerations are ongoing for capturing of carbon dioxide. If constructed properly, the landfill, after closure, can be used for recreational purposes,

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16 "The liquid that forms at the bottom of a landfill is known as leachate. It is a result of the percolation of precipitation, uncontrolled runoff, and irrigation water into the landfill, and also contains water which was initially contained in the waste or the liquid produced from the decomposition of waste." Tchobanoglous & Kreith, 2002, pp.14.2, 14.30.

17 "Landfill gas is the term applied to the mixture of gases found within a landfill, and consists mainly of methane and carbon dioxide." Tchobanoglous & Kreith, 2002, p.14.4.

18 Clay is selected due to "its ability to absorb and retain many of the chemical constituents found in leachate and for its resistance to the flow of leachate". Tchobanoglous & Kreith, 2002, p.14.35.

19 Several aspects are taken into consideration, as follows, i) Layout of landfill site; ii) Types of wastes that must be handled; iii) The need for a convenience transfer station; iv) Estimation of landfill capacity; v) Evaluation of the local geology and hydrogeology of the site; vi) Selection of leachate management facilities; vii) Selection of landfill cover; viii) Selection of landfill gas control facilities; ix) Surface water management; x) Aesthetic design considerations; xi) Development of landfill operation plan; xii) Determination of equipment requirements; xiii) Environmental monitoring; xiv) Public participation; xv) Closure and post-closure care. Tchobanoglous & Kreith, 2002, Chap.14.

for example, as parks. On the other hand, if not constructed and protected properly, the negative environmental impact can be very high, in the form of leachate seeping into aquifers, uncaptured methane emissions into the air, as well as emission of other gases, spread of disease vectors, other adverse health and environmental effects. (Tchobanoglous & Kreith, 2002, pp. 14.1-14.84).

The emissions and potential contaminations have been mentioned also by Siddiqua et al. (2022, p.58520); firstly, that landfills contribute to GHG emissions by releasing methane, due to decomposition of organic matter, into the air; secondly, by potentially contaminating groundwater with leachate; and other surface and groundwater with chemicals; thirdly, by releasing odors into the air; by flowing matter together with rainwater to nearby soil and areas; fourthly, by causing infections in human beings; and lastly, by possibly attracting rodents and other bacteria, also leading to adverse health effects on human beings.

2.2.2 Informal incineration – open burning

According to the UNEP (2024, p.6), open burning of waste is "waste that is combusted without emissions cleaning". According to UNEP (2005, p.13), PCDD/PCDF are formed and released in open burning[20]; and depending on the content of constituents of the MSW, their emissions might be even higher.

Open burning is considered to be a huge challenge in several countries, especially in emerging economies, because the practice exists since probably decades, and is used by the population in the absence of any other waste management method.

Kumari et al. (2019) have also assumed that the quantity of MSW is expected to rise in India in the coming years and therefore, have made efforts to estimate the quantities of ten constituents of the emissions during open burning, namely, amongst others, dioxins and furans, as open burning used to be a normal practice in India. They have used an emission factor of 40 microgram TEQ/MT for burning of MSW in the open and 300 microgram TEQ/MT for burning of MSW in landfills. They have concluded that India will be surpassing the maximum value of PCDD/DFs per day, and adverse health impacts can also be expected to increase. They have pointed out waste-to-energy (WTE), explained in the following sub-section 2.2.3.3, as a better option for MSW management.

[20] Besides, amongst others, via inadequate combustion (UNEP, 2005, p.13).

2.2.3 Formal incineration

2.2.3.1 Burning in an incinerator

Waste is collected and brought to an incineration facility and burnt. Tchobanoglous & Kreith (2002, p.13.4) have defined it as “the destruction of a waste material by the application of heat”. UNEP (2015, p.76) has also explained that the materials being used as fuel need to fulfill simple requirements, for example, being dry and non-hazardous, and special requirements, for example with respect to their residues after burning, namely, bottom ash and fly ash, which has been described by Huang et al. (2020, pp. 1-9); firstly, this may contain toxic substances, depending on the materials that were incinerated; and secondly, the residues also require appropriate disposal.

Tchobanoglous & Kreith (2002, 13.7) have mentioned that the type of waste expected to be received by the incinerator should be clear before designing, because there would be differences depending on whether they are planned to receive MSW or industrial or hazardous waste.

Incineration has the advantage that the amount of waste in terms of weight, 80-85%, and volume, 95-96%, are reduced considerably (Nanda & Berruti, 2020, p.1435). It is also a preferred option in some countries due to, amongst others, the space required for, or occupied by, landfills (Nanda & Berruti, 2020, p.1436).

Extensive research has been carried out on the health impact of incinerators on persons working in the incinerator and those living nearby. Tait et al. (2018) carried out a literature review and found that there was plenty of research confirming the negative health impacts of working in incinerators. Therefore, it is crucial that the incinerators are constructed and operated in such a manner that firstly, the workers in the incinerators are not affected; and secondly, that the emissions do not adversely affect people living in close vicinity of the incinerator.

2.2.3.2 Incineration in cement kiln

UNEP (2015, p.76) has mentioned cement kilns to present a good final destination for several hazardous substances, for example, liquid hazardous wastes, which are mixed with other fuel. As the companies which own the cement kilns are not so numerous all over the world, they are normally multinationals, which have the resources – financial, technical and technological – necessary for the burning of hazardous substances in cement kilns. Nowadays, cement kilns are also used for huge quantities of processed non-hazardous waste - refuse derived fuels (RDF) from MRF[21].

[21] MRF is explained briefly in section 2.2.5.

2.2.3.3 Waste-to-energy

According to Zhao et al. (2016, p. 606), the functioning and physical structure of a WTE facility can be compared to that of any power plant which uses traditional fuel with few differences, but regulations underlying WTE are very strict.

The basic principle behind a WTE facility is that waste is converted to energy, which can be used for different purposes, mainly, to generate electricity and to produce heat Tchobanoglous & Kreith (2002, p.13.4). According to Nanda & Berruti (2020, p.1435), MSW has considerable potential in WTE facilities, to be put to use to satisfy energy requirements, which are continuously increasing.

According to Tchobanoglous & Kreith (2002, p.13.4), WTE facilities, albeit connected with high initial investment costs, have many important benefits; i) the amount of material is considerably reduced, up to ten times; ii) this contributes to the second benefit, namely, elimination of space for disposal, for example, via landfilling, or even storage anywhere, for example, holding pond; iii) energy recovery in the form of steam (heat) and electricity; iv) bottom ash from incinerators has the potential to be used as construction material, together with cement or concrete; v) if constructed properly, including all environmental standards and regulations, emissions can be minimal and with minimal impact on the environment; vi) if constructed properly, emission of particulate matter can be reduced; and vii) similar to previous, if constructed and operated properly, it can eliminate all harmful/hazardous materials.

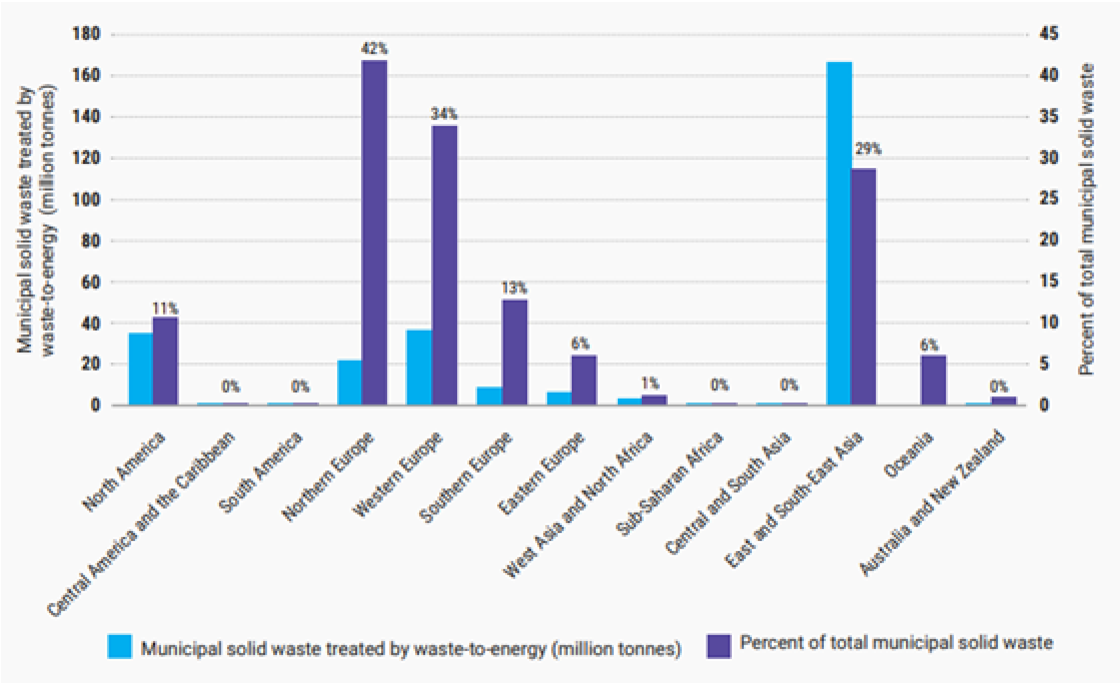
WTE also comes with some challenges (Tchobanoglous & Kreith, 2002, p.13.4): i) one challenge in WTE facilities is related to the initial high investment costs; ii) another issue is related to the expertise required for the operation of the incinerator, in a safe and economical manner; iii) some materials are non-combustible, for example, waste from construction and demolition; iv) additional fuel is necessary to commence and sometimes, even to continue the process of combustion; v) in case of wet waste, a higher quantity of fuel will be necessary to dispose off the waste; and lastly, vis) if not constructed in a proper manner according to established environmental standards, higher and more toxic emissions might take place, and the ash might be toxic too, thus not contributing to the environment in a positive way, and rather contributing to the negative impacts on the environment.

According to UNEP (2015, p. 76), incineration with energy production is in use since several years, and has reported that around 65% of the MSW from industrialized countries is used for this purpose. At the same time, this may prove to be challenging for emerging economies as this requires high level of technical expertise, in additional to financial resources, infrastructure and technology, to adhere to environmentally sound management, especially taking into account the resulting emissions and disposal of residues.

Schwarzboeck et al. (2016, p.415) have assessed the share of carbon dioxide (CO2) emissions at WTE plants in Austria, and concluded that as the material which goes into the WTE plants as inputs consists to a great extent of paper, wood, food waste, and plastics, energy recovery via combustion does not contribute to CO2 emissions in the context of climate.

However, the above may not always be the case in all WTE plants, as this depends on the technology used and maintained.

The following figure shows the regional differences in the disposal of MSW in WTE incinerators:



Source: UNEP (2024, p.25).

Figure 7: Disposal of MSW via WTE according to region

Interestingly, Zhao et al. (2016, p.606) have pointed out that WTE facilities may not be so popular with the wider population in other [non-EU] countries, and people might even be suspicious of the WTE facilities and might not wish to live near them.

The picture seems to be different in Europe. As seen in the above figure, WTE incinerators[22] are more prevalent in Europe, followed by East and South-East Asia, and North America. In Europe, it is also seen as one of the instruments of a circular

[22] A good example of a waste-to-energy facility is the Spittelau incinerator in Vienna, Austria. https://positionen.wienenergie.at/en/projects/spittelau-waste-incineration-plant/ [Accessed on 05 May 2024].

economy by using waste to create energy (Malinauskaite et al., 2017, p.2014). Bajic et al. (2015, p.1438) have also confirmed this, adding that WTE has high potential as energy produced at WTE also contributes to energy security of the country.

2.2.4 Recycling

According to Tchobanoglous & Kreith (2002, p.1.9), recycling may be the option perceived mostly in a more positive way than other methods of waste management. They share the opinion that recycling has a number of benefits, for example, it is resource-saving; reduces the necessity for mining; reduces the amount of waste going to the landfills; removes recyclable materials, such as metals or glass, from other waste materials.

At the same time, Tchobanoglous & Kreith (2002, p.10) mention the issues which may arise in recycling, namely, issues may arise if recycling is not carried out in an environmentally-appropriate manner. Further, they mention that too much recycling may over-burden a good existing recycling system, and that recycling cannot be the only way of waste management.

2.2.5 Material Recovery Facility

In some cases, the collected mixed waste, separated or not, is brought to another facility, the MRF, where it is separated into individual components – glass, metals, plastics, cardboards, sacks, etc. The MRF is constructed and equipment established taking into account the type of waste expected to be received there, that is, whether waste separated at source is expected to be received at the MRF or whether it will have to separate recyclable waste from mixed MSW. Besides sending the segregated material to other facilities for recycling, two main functions of the MRF include removing contaminants from waste and i) enabling it to be used as fuel in incineration facilities; ii) removing recyclable materials from waste, and using the remaining waste for producing compost, which finds usage as landfill coverings. In some of the MRFs, waste materials are also processed. (Tchobanoglous & Kreith, 2002, pp.8.10, 8.13, 8.14).

Further, they explain (Ibid, p.8.14) that contaminants are removed, and after removal of materials such as glass and metals, which are non-combustible, and bio-degradable materials, which can be used for the production of compost, the remaining material is used as fuel for incineration facilities, called RDF. Oftentimes, this remaining waste material, RDF, is pelletized for easy storage and transport, and used in cement kilns. For purposes of definition, sometimes, the MRF is seen as a part of recycling (Ibid, p.8.18).

Although the MRF presents a good possibility for recovery of different individual recyclable and non-recyclable components, from the sorted or unsorted mixed MSW, and can provide material for recycling, composting and as RDF, according to Tchobanoglous & Kreith (2002, p.8.31), it may not always be economically viable.

2.2.6 Composting

UNEP (2015, p. 74) has defined composting as “the output of a biological process that converts biodegradable waste to a humus-like-material. The main use is to improve soil quality, as compost improves its biological and physical properties, … it also has some value as fertilizer.” Ayilara et al. (2020, p. 16) have expressed the same opinion that compost is important as a fertilizer, and a move away from fertilizers with chemicals to compost may be possible, thus contributing to protecting the environment from potentially toxic chemicals.

Tchobanoglous & Kreith (2002, p.12.1) have explained that composting[23] can be carried out on easily degradable organic waste, for example, plant and animal tissue, and that it is not really for organic waste that cannot be degraded easily, including synthetic organic waste, for example, wood, leather, polymers, and cannot be used for inorganic waste, such as dirt, glass, ceramics, and metals. Moreover, it can be carried out inside a vessel or in the open (p.12.1). Via different lay out methods, supply of ample air needs to be ensured, either naturally or with additional equipment; appropriate moisture, temperature, oxygen[24] and pH levels – different pH levels for the different micro-organisms – are also necessary, for the growth of the different micro-organisms. Further, for composting, waste can be separately collected, namely, garden waste, or it can be separated from mixed MSW. It helps in reducing the volume of waste up to fifty percent, and takes up around 50 percent, by dry weight, of organic mass (p.12.1).

Composting is carried out to some extent even in developed countries, for example, the US, where recovery for composting has been increasing steadily, since the end of the 1980s till 2005, the total quantity of composting was then maintained with the increase being minimal in the last 10 years (Tchobanoglous & Kreith, 2002, p.5.25).

[23] Since the past few years, composting is considered to be an aerobic process, during which organic matter is broken down by some bacteria, actinomycetes, fungi, protozoa, worms and some larvae. The micro-organisms consume sugars, starches, simple celluloses and amino acids from the organic waste as nutrients, if available in a form which they can consume, and grow, until the nutrient, also called substrate in literature, supply reduces. Key elements consumed by the micro-organisms are carbon, nitrogen, phosphorus and potassium, besides smaller amounts of cobalt, manganese, magnesium, copper and calcium. (Tchobanoglous & Kreith, 2002, p.12.3).

[24] Optimum oxygen level is considered to be 14-17 percent. (Tchobanoglous & Kreith, 2002).

Challenges with composting might be with operating the technology, costs, maintaining appropriate oxygen, temperature, moisture and pH-levels, odor and possible pollutants in the compost, for example, heavy metals, toxic organic compounds, glass, and other pathogenic organisms (Cerda et al., 2018, pp.57-67).
UNEP (2015, p. 74) has also pointed out that compost can even be contaminated due to hazardous waste stemming out of households, if the households have not separated such waste from other household waste. Therefore, in industrialized countries, regulations exist on the use of compost which has been produced with waste as input.

2.2.7 Source reduction

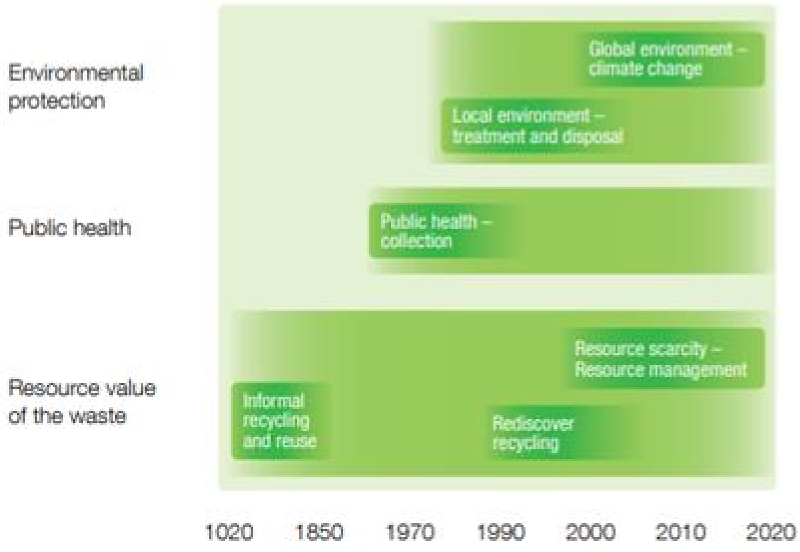
According to Tchobanoglous & Kreith (2002, p.1.8), "source reduction focuses on reducing the volume and/or toxicity of generated waste. It includes the switch to reusable products and packaging, for example, returnable bottles." This can be implemented at all levels – national, state and city. It is a challenging and tedious task, involving several actors and institutions, resources, a shift in production patterns in terms of packaging, and most importantly, a shift in the mindsets of the population. Source reduction is in line with the concept of 'sustainable consumption and production' which is elaborated in chapter 2.11.

2.3 Development of waste disposal methods in developed countries

According to UNEP (2015, p.27), major concerns which led to the development of appropriate waste disposal, and appropriate waste management systems were firstly, health of the population; and secondly, health of the environment.
The concern for the health of the population emerged as early as in the first half of the 19th century[25], as countries in Europe and North America were confronted with the cholera epidemics[26]. People realized the linkage between the decomposition of organic waste and the cholera epidemics, and countries started introducing ways to collect MSW. However, till the 1960s and 1970s, it was still not disposed off in an appropriate manner, when environmental considerations started to emerge. Until then, damage had been caused to the environment in the form of pollution of air, water – both surface and groundwater, and including seas and oceans, and land; for example, by not stopping the flow of waste and waste water into seas and groundwater and by dumping all waste on dumpsites, without taking into consideration if it is hazardous waste or not. And in recent years, the reason for enhanced acknowledgement for the need for appropriate

[25] After the cholera epidemics around 1830 (UNEP, 2015, p. 27).
[26] UNEP (2015, p.27, footnote 14) also mentions in the footnote that this is an over-simplification of the discussion on this topic.

waste management lies in the adverse impact of climate change influenced by human beings[27], as inadequate waste management also contributes to the environment with, inter alia, carbon emissions and other uPOPs. This also led to the recognition of the need to stop dumping of waste and open burning, and reduce the use of landfills, as well as other aspects such as the idea of sustainable production and consumption and the concept of the 'circular economy[28]' to eliminate or at least reduce waste, and to dispose if off in an appropriate manner. As an approximate differentiation, health concerns may have led to the development of waste collection and environmental concerns may have led to the development of waste disposal systems. The approximate timelines of the reasons for the development of the waste management system in Europe and North America is shown in the figure below:

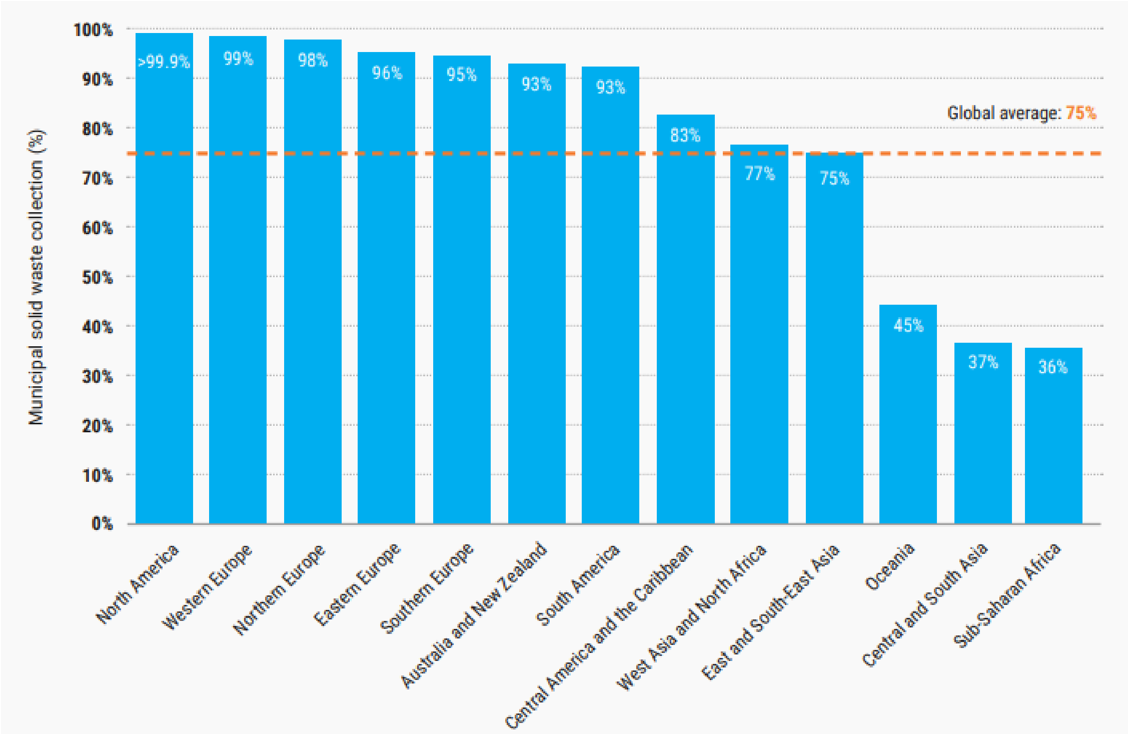


Source: UNEP (2015, p.28).

Figure 8: Approximate timeline of the reasons for the development of waste management system in Europe and North America

Formal disposal of waste depends on formal waste collection, whether organized by the country or by any private service. Waste collection rates are different in different regions. The following figure illustrates the rate of waste collection according to region:

[27] Anthropogenic climate change, as it is termed in climate-change related literature.
[28] Explained briefly in chapter 2.12.



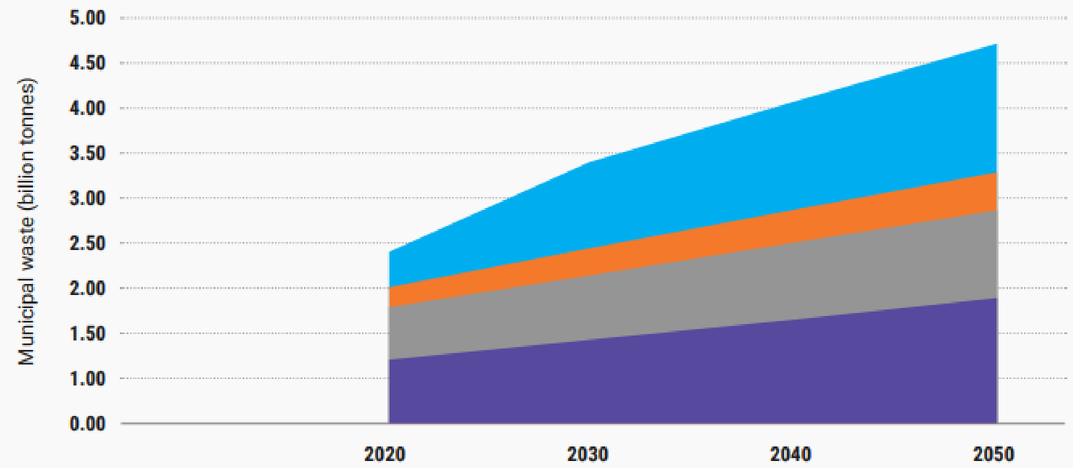
Source: UNEP (2024, p.23).

Figure 9: MSW collection according to region

As seen in the above figure, waste collection rates are above 90% in Europe, North and South America and Australia and New Zealand. Central America and the Caribbean, West Asia and North Africa and East and South-East Asia are estimated to have waste collection rates above 75%, and Oceania, Central and South Asia and Sub-Saharan Africa have yet to catch up in terms of rates of waste collection with below 45% of MSW collection rates. It is clear that only waste collected (formally) will be disposed off in designated areas and by designated methods[29]. Uncollected waste lands normally in (informal) dumpsites and landfills, and is oftentimes, burned – this has already been elaborated under landfills and open burning.

The following figure shows the current world waste-management scenario which has been projected upto 2050:

[29] Although these may still not always correspond to 'environmentally sound management of waste'.



	2020	2030	2040	2050
Recycled	0.40	1.05	1.31	1.57
Waste-to-energy	0.27	0.35	0.41	0.47
Landfilled	0.64	0.79	0.94	1.09
Uncontrolled	0.81	1.05	1.31	1.57

Source: UNEP (2024, p.34).

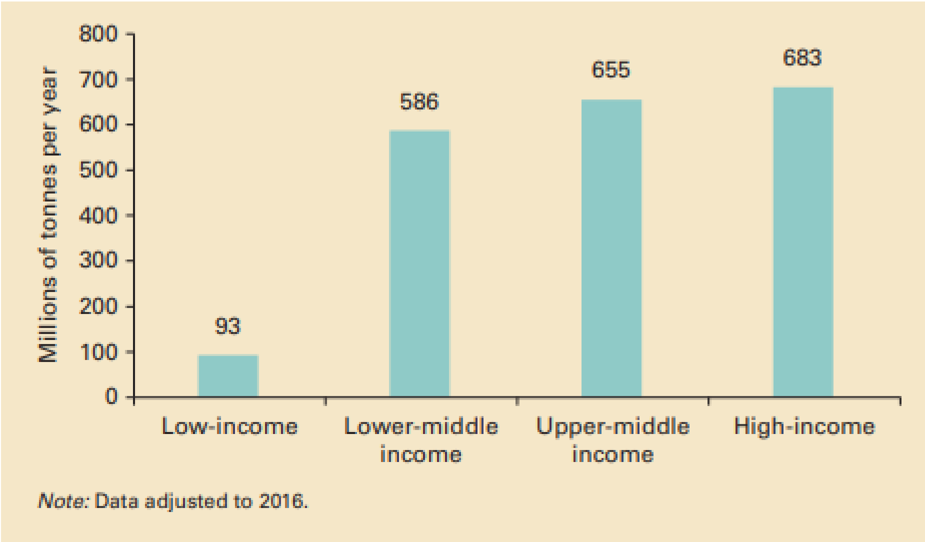
Figure 10: Scenario 1 – Waste management as usual 2020-2050

Whereas currently 0.81 billion tons of waste are not collected, should this scenario continue, often referred to as 'business-as-usual' or 'waste-management-as-usual' scenario, this quantity is expected to rise to 1.57 billion tons of waste which is not collected, that is, disposed off in (informal) landfills and dumpsites, and burned, thus contributing to polluting land, water and air, the latter with both uPOPs and GHG emissions.

The 'waste-management-as-usual' scenario with respect to landfills is also alarming. With currently 0.64 billion tons of waste going to (formal) landfills, this quantity is expected to rise to 1.09 billion tons of waste going to (formal) landfills in 2050. With the population of the earth increasing, space is also needed to meet increasing need for food, amongst others.

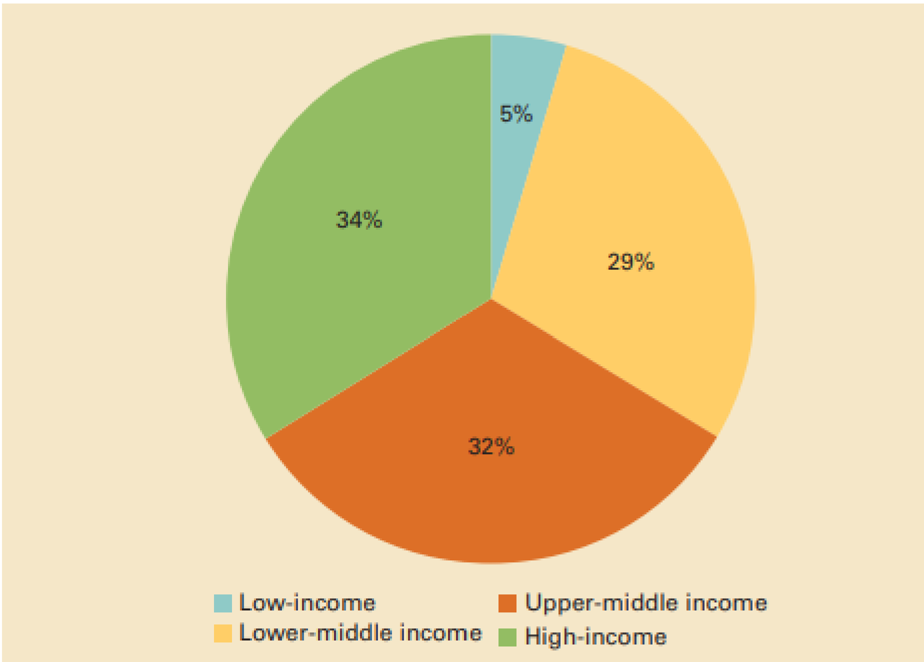
2.4 Waste generation and GDP of a country

As mentioned earlier, according to the WB (2018, p.20), the quantity of waste generated is in the range of 0.11 kilogram – 4.54 kilogram per capita per day. The growth rate of waste is faster for LICs than for HICs. Moreover, the rate of urbanization is a factor in the quantity of waste produced; this relation is also positive, that is, urban areas within countries, and countries with higher rate of urbanization produce higher quantity of waste per capita and in total than other countries. The following graphs present the quantity of waste produced according to income level, as well the shares of each with respect to waste produced.



Source: WB, 2018, p.21.

Figure 11: Quantity of waste production according to income level

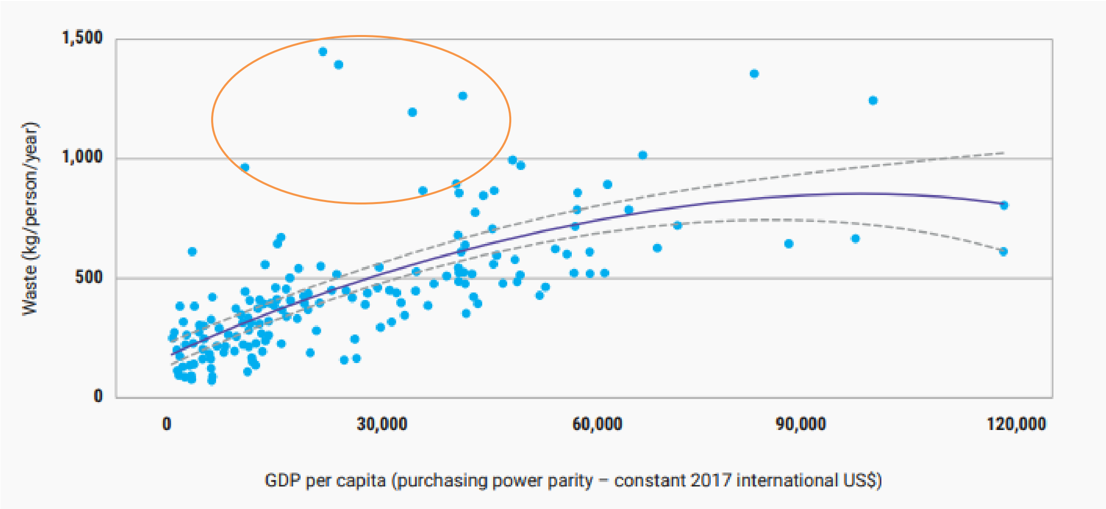


Source: WB, 2018, p.21.

Figure 12: Share of waste production according to income level

The above graphs show clearly that the quantity of waste produced by HIC is the highest, followed by UMIC, then LMIC and finally LIC, which is still a smaller quantity and share compared with the others.

The quantity of waste produced is also found to be positively related to the economy of a country (WB, 2018, p.18). This is illustrated in the following chart:



Source: UNEP (2024, p.15).

Figure 13: Waste generation and GDP per capita

The above chart illustrates the countries, shown as dots, and the relationship between the economy of a country, represented by its GDP per capita, and the waste produced in kilogram per capita per year. With the exception of a few outliers, shown in the brown marked portion, whereby the quantity of waste produced is higher than other countries, or at least as high as other countries, but with lower GDP per capita, an increase in both GDP per capita and quantity of waste produced can be seen. The trend-line is shown in purple colour.

2.5 Waste management

According to Tchobanoglous & Kreith (2002, p.1.1), "Waste management is related to the evolution of a technological society." They have defined integrated waste management (IWM) as "the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals" (Ibid, p.1.8).

UNEP (2015, p. 29) has defined waste management[30] as "All the physical elements (infrastructure) of the system, from waste generation through storage, collection, transport, transfer, recycling, recovery, treatment and disposal". Interestingly and not incorrectly, UNEP (2015, p. 29) has also used the analogy of the function of kidneys for waste management, as both extract polluting materials which pass through, put them together and then pass them on for removal, in the case of waste management, ideally in an environmentally sound manner. Important aspects to be considered while

[30] Although the MT has followed UNEP's definition and explanation of waste management and Tchobanoglous & Kreith's definition of IWM, it has not delved into aspects of waste management related to collection, storage, transport, transfer, recycling and recovery.

planning a waste management system are the stakeholders or all the actors involved directly and indirectly, and all strategic characteristics of the country.

2.6 Waste and the SDGs[31]

The 17 Sustainable Development Goals[32] (SDGs) deal with various thematic areas crucial to development. Waste (and waste management) is one of the crucial aspects included in the targets, and therefore indicators, of the 'Global Indicator Framework'[33]. 'Waste' is included in the following SDGs and the respective corresponding indicators:

Table 3: Waste and the SDGs

Goals and targets	Indicators	Related to
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, …	6.3.1 Proportion of domestic and industrial wastewater flows safely treated	Wastewater
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes,		Wastewater
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities	Municipal solid waste and other waste management
12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	12.3.1 (a) Food loss index and (b) food waste index	Food waste
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with	12.4.1 Number of parties to international multilateral environmental agreements on hazardous waste, and other	Chemicals and hazardous waste

[31] A part of this sub-section was submitted as an assignment by the MT author within the framework of the lecture 'Global Environmental Monitoring - Remote Sensing', ETIA, 2024, and has been only slightly adapted and included in this sub-section.
[32] https://sdgs.un.org/goals https://www.un.org/millenniumgoals/ https://sdgs.un.org/goals https://sdgs.un.org/2030agenda https://sustainabledevelopment.un.org/post2015/summit [Accessed on 11 April 2024].
[33] https://unstats.un.org/sdgs/indicators/indicators-list/

agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement	
	12.4.2 (a) Hazardous waste generated per capita; and (b) proportion of hazardous waste treated, by type of treatment	Hazardous waste
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse		Solid waste – including plastics, textile, etc.
12.c Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, …		

Source: SDG Indicators - Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development.

In emerging economies, waste management, as understood under Goals 11.6 (municipal solid waste) and 12.5 (solid waste – plastics, textiles, etc.) normally consists of either burning the waste, called 'open burning', or dumping the waste somewhere, at a formal or informal dumpsite or landfill; all of these waste disposal methods have been briefly elaborated in earlier sub-sections.

2.7 The role of waste management in emerging economies

If not managed in an adequate manner, waste impacts human health adversely (Nanda & Berruti, 2020, p.1438).

As mentioned earlier, the WB (2018, p.18-28) has reported the quantity of MSW generated each year to be around 2.01 billion tons. This quantity is estimated to reach around 3.4 billion tons by 2050. According to the report, at least one-third of the quantity generated is not disposed off in an adequate manner. And one-third of the waste is generated in HICs. Whereas the increase in waste generation in HICs is estimated to be around 20% by 2050, in emerging economies, waste generation is expected to increase by at least 40% in the same time period. Regional differences are expected to exist and the regions Sub-Saharan Africa, South Asia, the Middle East and North Africa are expected to have the fastest growth in waste, between doubling and tripling their waste. In these regions, according to estimates, at least 50% of MSW, if not more, is inadequately disposed off, via dumping and open burning. In-country situation is also not uniform in emerging economies. In emerging economies, a maximum of around 48% of waste might be collected in urban localities, but only around 26% in other regions of the same country. This is very different in Europe, Central Asia and North America, where around 90% of waste is collected. This also shows the need for adequate waste management, especially in emerging economies.

According to the WB (2018, p.101), although around 20% of the district budget[34] is spent for waste management by district authorities in emerging economies, especially in LICs, around 90% of the waste is estimated to be still thrown in dumpsites and/or burned. This speaks for inadequate waste management system and lack of awareness by the population.

In MICs, this portion is estimated to be around 10% of the budget of the district authorities or municipalities; and in HICs, this is around 4% of the municipality budget. (WB, 2018, p.101).

UNEP's GWMO-I (2015, p. 49) entails a very interesting case study on the introduction of waste management and shift in waste disposal in Mauritius, an island country, *'Moving away from dumpsites to sanitary landfill and then towards recycling in Mauritius'*, where waste management till the 1980s consisted mainly of dumpsites. In the 1990s, the country moved from dumpsites to landfills, and then introduced sanitary landfills in the late 1990s. Effectiveness and efficiency in transporting waste were enhanced by the establishment of transfer stations, and waste collection quantities were enhanced, gradually covering the whole country[35]. Further, in view of social behaviour and mindset of the population in the context of waste, awareness-raising activities were carried out to increase awareness of the population about waste management. The waste management system has been adapted over time, according to rising requirements. Composting was also introduced via the establishment of a composting facility, as well as recycling.

The same report (UNEP, 2015, p. 50) also contains the example of collection of plastic polyethylene terephthalate (PET) bottles and aluminium cans for recycling in the Republic of Kiribati, also an island country. Moreover, bags were introduced for collecting waste which cannot be recycled or composted, with the result that waste going to the landfill was decreased by 60%.

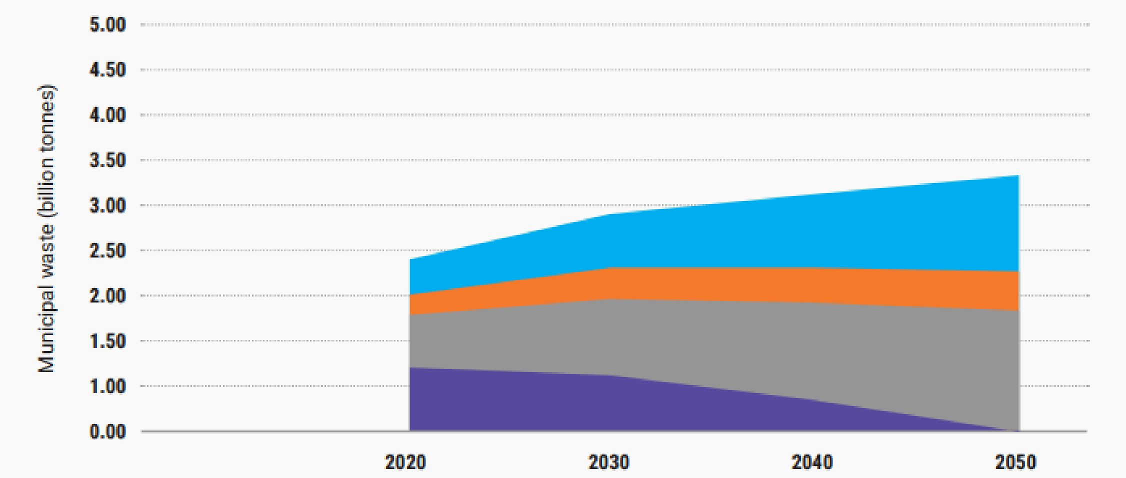
[34] 20% is a considerable portion, nevertheless, it cannot be understood that this is the case in all municipalities in all emerging LICs, as this may vary depending on the country and its priorities.
[35] Mauritius is not a very big country in terms of size, and ranks 178 in the world according to its area.

The above examples might prove to be interesting, realistic and feasible for emerging economies – those that already have an incinerator or a cement kiln may consider using it for waste disposal. In other cases, it may well be a good consideration to introduce or enhance recycling, introduce composting, establish transfer stations, establish sanitary landfills to the extent possible, and otherwise, at least specified areas as landfills to avoid illegal dumpsites and above all illegal open burning, and most importantly, enhance waste collection to gradually cover the whole country. In parallel, awareness-raising activities for the general population are also crucial, in order for the people to get familiar with, and accept, the "new" waste management system in the country. The aspect about the population's attitude and behaviour is explained briefly in chapter 2.9.

Brunner & Fellner (2007, p.240) have reached the same conclusion that while economically well-off countries can afford to focus on waste as resource via recycling and other high-cost technologies, emerging economies, especially those with lower GDPs, are still struggling with establishing an initial appropriate waste-management system.

The following figure presents the end destination of MSW in 2020 and entails projections upto 2050 if waste collection is enhanced to full coverage. It shows that uncontrolled waste[36], that is waste which is not collected, and normally lands in dumpsites and/or is burnt in an uncontrolled manner, is reduced to zero, thus eliminating (or at least reducing) health, environmental and climate change risks via leakages and emissions.

[36] "Controlled waste is collected and then either recycled or disposed of in a controlled facility. Uncontrolled waste is either not collected, and so by necessity dumped or burned in the open by the waste generation, or collected and then dumped or burned at its final destination." (UNEP, 2024, p. 21).



	2020	2030	2040	2050
Recycled	0.40	0.66	0.89	1.16
Waste-to-energy	0.27	0.39	0.44	0.47
Landfilled	0.64	0.94	1.19	1.51
Uncontrolled	0.81	0.70	0.40	0.00

Source: GWMO-II (2024, p.35).

Figure 14: Scenario 2 – Waste under control 2020-2050

The above figure shows the projection of waste with two differences to scenario 1; firstly, waste production is reduced, possibly with increased awareness and corresponding programmes in all the countries; and secondly, all the waste is collected. In the above figure, it should be alarming that the quantity of waste going to landfills has still increased from 1.09 to 1.51 billion tons compared to scenario 1, even though the quantity of waste generated is reduced. Interestingly, the quantity of waste going to WTE incinerators has remained the same, 0.47 billion tons. This shows that even in future projections, investment of countries in WTE plants is not expected.
[Note of the author: this is actually a very unfortunate situation, that although countries have enhanced coverage of waste collection to 100%, they are not investing in WTE scenarios, which albeit very expensive, might be a good solution in terms of waste disposal, as it would dispose off waste and additionally bring in benefits and revenue at the same time, although the revenue might still not cover all costs, that is, the initial investment and the running costs].

2.8 Challenges in MSW management

The lack of a **standardized definition of what constitutes MSW** has been pointed out by several researchers, as well as the inadequacy or total **lack of data collection on waste-related data**, amongst others, waste generated and waste collected. UNEP

(2024, pp.43-59) identifies these and the following further challenges which it has termed "barriers to change"[37]:

i. **Waste as a complex problem:** Several factors play a role in waste management and are interdependent, involving diverse stakeholders, investments by different actors, costs of different resources, products and services which are used in waste management, cost of recycling, and existing social dynamics in a country, especially with regard to waste generation;

ii. **Lack of recognition of the urgency of the waste challenge:** Whilst pictures of inadequate waste management are frequent, the problem of waste and waste management have not really been recognized as being urgent, and the problem of increasing waste still exists, with the quantity and even types of waste increasing, and many countries, especially emerging economies not taking adequate action towards appropriate disposal;

iii. **Data on pollution and health risks is lacking:** As mentioned earlier, a homogenous definition of waste at the international level is not given. And it is very challenging to compile good-quality data on waste-disposal methods such as open-burning. Due to this reason, it is also difficult to compile data on emissions, for example, uPOPs, namely PCDD, PCDFs, from such waste-disposal activities;

iv. **Climate impacts are underestimated and mitigation opportunities are underexploited:** Due to an underestimation of the impact of lack of or inadequate waste management on climate change, it has not [yet] been seen as one of the mitigation measures contributing to climate change;

v. **Lack of inclusion:** There is a tendency to favour opinions of technical persons than taking the opinions and experiences of local population[38] into consideration, which might also lead to a failure of policies and measures;

vi. **Gendered aspects of waste are not recognized:** Gender role stereotypes play an important role in many countries and are also relevant in waste management – gender and waste management is elaborated further in chapter 2.10 of the MT;

[37] The aim here is to shortly inform about the challenges to waste management existing in the different countries rather than going into the detail of each challenge.

[38] A main reason being that oftentimes, their knowledge, experience and opinions are considered to be subjective; this may well be true, but it does not mean that they are necessarily wrong.

vii. **The informal sector is undervalued:** In several countries, especially emerging economies, the informal sector plays an important role in many sectors, also in waste management, namely, waste collection, transportation, sorting for recycling, disposal and also repair and/or reuse. A majority of persons in waste management are working in the informal market, but similar to the local population mentioned above, they also have a vast knowledge about all aspects of waste in the areas of their work;

viii. **Legislation is frequently inadequate and ineffective:** Firstly, the issue of lack of homogenous definition of waste at the international level plays a role here; and secondly the existence and wording of in-country legislation pertinent to waste management as well as implementation thereof plays a crucial role in waste management;

- Lack of an enabling environment: Several aspects can favour effective waste management, including the aforementioned in-country legislation, infrastructure, investments, resources – human, financial and technical;
- Weak enforcement, sanctions and penalties: Even if the aforementioned in-country legislation was given, effective implementation thereof would be necessary for adequate waste management;

ix. **Technical barriers:** Barriers are differentiated into universal and contextual barriers; the former stemming from existing products which are not recyclable, which can only be disposed off properly either in a landfill or in an incinerator; the latter depends on the country-context;

x. **Persistent market and financial barriers:** These exist due to the continuous increase in urbanization and the quantity of waste, and the inadequate or complete lack of a proper and structured market for waste management, including the corresponding initial and running need for finances, that is, investment required to establish a proper waste management system;

- Financing mechanisms not always fit-for-purpose: A large portion of the running costs of a proper waste-management system is made up of the costs for waste collection; however, the investors or aid-providers wish to focus on the actual waste disposal system while providing finance; this poses a challenge for the authority or company for carrying out the whole cycle of waste management;

- Polluters are not paying or changing: Firstly, this may not be included in the legislation of several countries, especially emerging economies and secondly, several countries may lack resources for an effective execution of the principle, even if it should exist.

2.9 Social attitude and behavior

Social attitude and behaviour of the population towards waste also impact the outcome of any waste-management system. For example, cost of waste disposal to be borne by the population determines to what extent they might be willing to participate.

Cai et al. (2020) carried out a survey of residents in Zhuhai city in China to assess their attitude and behaviour towards e-waste management, and found that whereas the majority realizes that e-waste management is crucial, only a minority was actually ready to pay an amount for e-waste disposal, as waste management is considered to be the responsibility of the government.

Similarly, Alhassan et al. (2020, p.3) carried out a survey in Ghana on social attitude, mindset and behaviour with respect to waste management and found that socio-economic factors also influence the persons' attitude and behavior towards waste management.

Further, other factors may also have an impact on waste generation in households. Mattar et al. (2018, p.1221) carried out a survey of 1264 households in five Governorates in Lebanon on factors related to socio-demographics, attitudes and behaviour and their impact on food waste produced in the households and concluded that, amongst others, food waste was lesser in rural areas than in urban areas; further, factors such as type of employment, level of education, number of persons in households and place of meal consumption also influenced the quantity of food waste.

UNEP (2024, p.43) has also noted that "for waste management systems to be effective and efficient, behavioural change may be required in hundreds of thousands of households."

2.10 Gender, vulnerable groups and waste

"*Gender is the result of socially constructed ideas about the different roles, behaviours, rights and responsibilities of men and women, and the relations between them. … As a result, the understanding of gender and gender relations differs between cultures and societies, and also changes over time. Gender difference is usually connected to unequal power and access to choices and resources. The different positions of women* *and men are influenced by many aspects, such as historical, religious, economic and cultural realities, as well as the environment*". (UNEP, 2019, p.11).

UNEP's (2019) report 'Gender and waste nexus – Experiences from Bhutan, Mongolia and Nepal' has reviewed gender roles and stereotypes and their implications on waste management or work in the waste sector based on case studies carried out in 3 countries, namely, Bhutan, Mongolia and Nepal, as they are relevant in the context of waste-related jobs, both formal and mostly informal, as well as impact on health and waste management itself.

Findings of the report pertinent to gender are as follows:

i. A traditional distribution of roles of women and men is prevalent;
ii. A pay gap depending on the gender exists;
iii. Household waste makes up a large portion of the total solid waste;
iv. Women are normally the main responsible persons for households, and therefore also for household waste;
v. Women are mainly responsible for cooking in the households, thus making them also the main responsible persons for organic food waste;
vi. In some regions, women also work as waste pickers;
vii. Waste-related jobs in several countries are in the informal sector, thus increasing the vulnerability of the persons, including women and young population;
viii. Landfill operators and waste collecting truck-drivers are mostly men;
ix. Inequalities are deemed to exist with respect to gender roles, and influence also all aspects related to waste management;
x. Gender-disaggregated data in the waste sector is not compiled in any of the 3 countries.

In Ulaanbaatar, a few women own recycling enterprises, which speaks for the role of women in entrepreneurship.

In Nepal, women are also engaged in small-scale composting enterprises, and contrary to Ulaanbaatar, it is very rare to find women involved in the recycling business. Further, scrap business, which, albeit mostly in the informal sector, is considered to be economically profitable, is at the same time considered to be very dangerous, which might explain the lack of women in this business.

In Bhutan, recycling and second-hand/repair shops are operated mainly by men and mostly social entrepreneurs in the waste sector are also men.

Dias (2016, p.376) points out that waste pickers are still not recognized as providing a service, or as actors in the economic system, or as livelihood earners.

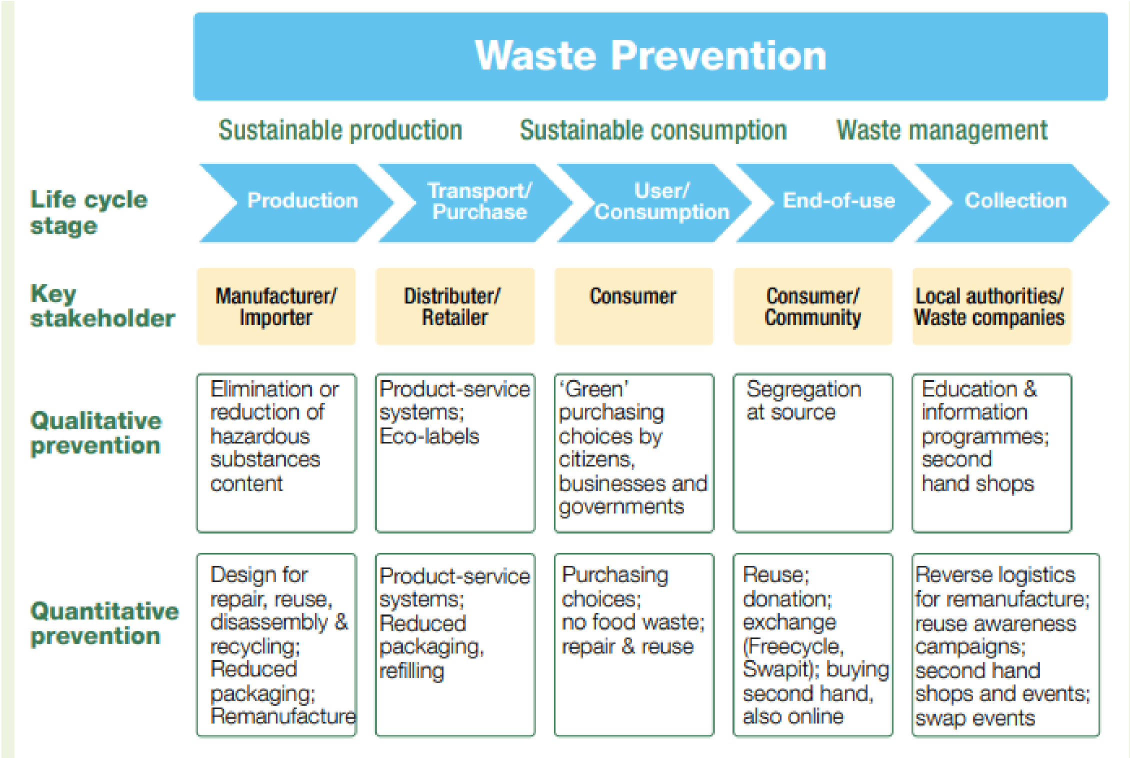
Further, according to the WB (2018, p. xi), vulnerable people working in the informal sector and/or living in vulnerable conditions near waste-related work or sites, for example landfills, face the risk of losing their inadequately constructed living places in case of landslides at the larger and higher landfills, and face the risk of adverse health conditions as well.

In conclusion, although the waste sector is referred to as being gender-neutral, from the above it is clear that for any improved waste-management system, interventions, especially in emerging economies, would need to include women as key target group, as they are responsible for households, for the families, for cooking, for organic food waste, and for household waste, besides also presenting a majority of waste pickers, including at landfills. It is necessary to compile gender-disaggregated data and eliminate the gender pay gap, especially in waste-related jobs. It is also necessary to provide information on risks, including to health, in waste-related jobs, and to adequately equip them to reduce the risk. Finally, it is necessary to transform the informal sector into a formal sector, thus reducing their vulnerability.

2.11 Sustainable Consumption and Production

[UNEP, 2015, p.40] Consumption is deemed to be directly proportional to several environmental problems, including the production of waste. This has led to the realization that high rate of consumption, especially in industrialized countries, and with emerging countries considered to be on the same path, is a global challenge, and therefore, its inclusion in the SDGs – SDG 12 – Sustainable Consumption and Production. On the one hand, international organizations have engaged in this topic, research has been done, and reports published. On the other hand, it is also the mindset of the population, explained briefly under chapter 2.9 in the context of waste generation, collection and disposal, which influences consumption and therefore, also production to a great extent. In the context of sustainable consumption, the concept of 'honorable harvest' has been explained well by Kimmerer (2020) who talks about firstly, respecting all sources of provision, whether plant or animal; secondly, about taking only what is needed and not take – that is consume – excessively; thirdly, about replenishing what has been taken, again whether plant or animal, so as to ensure sustainability for all; and lastly, about the responsibility of each individual in consumption.

The following figure illustrates the pathway of waste production, and therefore, the pathway to be taken for waste prevention, in a simplified manner:



Source: UNEP, 2015, p.44.

Figure 15: Pathway of waste prevention

The principle and pathway in the above illustration are clear – reducing consumption would lead to reducing waste[39].

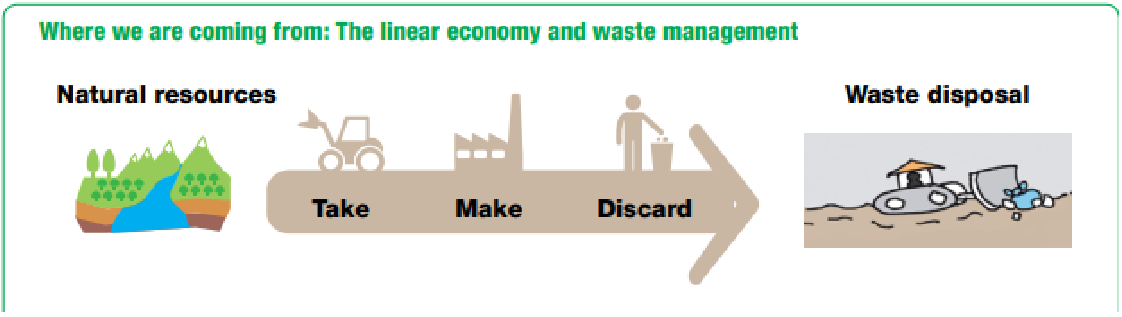
Sustainable production, as the term suggests, is about the production of goods, and therefore, can integrate, sustainable methods and materials in the design of the product itself, as well as production methods with the integration of the environment and pollution and climate change, resource consumption during production, that is, water, electricity, raw materials, procure raw materials from suppliers which also adhere to set standards, biodiversity to the extent realistic, and the conditions for and impact on people working in the production, and the waste disposal method into account during the design phase, including the concept of circular economy. (UNEP, 2015, pp.40-41).

2.12 Circular economy

Waste as resource is the idea underlying recycling, an MRF and also circular economy, that is, material recovery, material reuse, material recycling and waste as fuel in incinerators or cement kilns. In view of the high cost for establishing and operating waste disposal facilities, emerging economies in the meantime would do well to start

[39] At least household waste produced via individual consumption which, in emerging economies, normally lands in landfills, dumpsites and open burning.

considering waste as resource and introduce or enhance material recovery and material recycling, and integrate circular economy considerations in the design phase of the products as well as in the waste management system.
Till the introduction of the circular economy concept, the dominating way of living was the production of goods from the raw materials, consumption of goods and then disposal of goods, that is, the traditional linear economy, which generates waste, when the goods are disposed off. (UNEP, 2015, p.7).
This is shown in the following figure:



Source: UNEP, 2015, p.24.

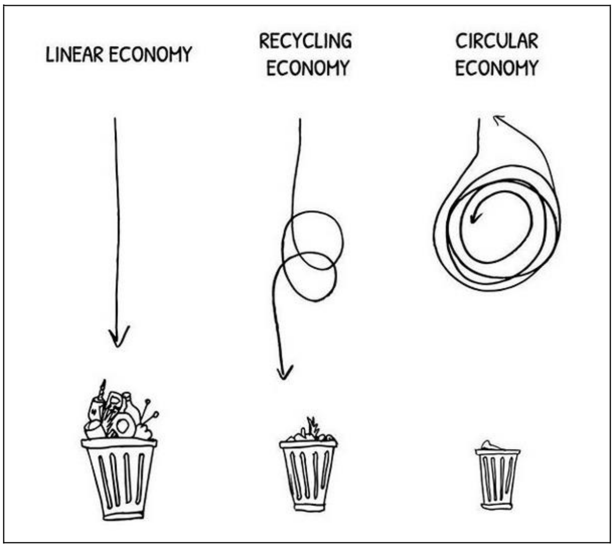
Figure 16: Linear economy and waste production

The Ellen MacArthur Foundation defines circular economy[40] as "The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. … In our current economy, we take materials from the Earth, make products from them, and eventually throw them away as waste – the process is linear. In a circular economy, by contrast, we stop waste being produced in the first place." UNEP's definition (2024, p.5) is similar "One of the current sustainable economic models, in which products and materials are designed in such a way that they can be reused, remanufactured, recycled or recovered and thus maintained in the economy for as long as possible, along with the resources of which they are made, and the generation of waste, especially hazardous waste, is avoided or minimized, and greenhouse gas emissions are prevented or reduced, can contribute significantly to sustainable consumption and production".
According to the WB (2018, p.120), "in a circular economy, products are designed and optimized for a cycle of disassembly and reuse. The intention is to extend the lifespan

[40] Ellen MacArthur Foundation website. https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview Accessed on 05 June 2024. Although the definition is not from a peer-reviewed journal, the Ellen MacArthur Foundation has done a lot of work and published a lot of reports on circular economy and therefore, this definition has been used here.

of consumables and to minimize the environmental impact of final disposal". Especially for materials which are not easily degradable, it is important to take disposal possibilities into account already at the designing phase of the product. According to Malinauskaite et al. (2017, p.2038), who define circular economy similar to the above definitions, in the EU, terms related to the circular economy are also "re-use, recycling and recovery". And more importantly, they conclude that WTE has an important role to play in the circular economy.

The following box presents three figures representing respectively the conventional linear economy, the recycling economy and the circular economy in a simplified way:



Source: Impact Hub website[41].

Figure 17: Linear economy, recycling economy, circular economy

The first figure presents the conventional linear economy whereby resources are used for production, products and used and then disposed off as waste. The line from the top to the bottom where the waste bin is, shows the linear path of resources and products from sourcing till landing in the waste bin. The second figure presents the recycling economy, whereby the resources and products remain longer in usage due to recycling and then land in the waste bin, thus reducing the amount of waste in the end. The third figure presents the concept of circular economy, which aims to reduce waste in the end to zero, in a closed-loop, by reusing, re-manufacturing and finally recycling the resources and products, thus keeping the materials in the cycle all the time, and not contributing to waste.

The following figure shows the waste disposal projections upto the year 2050 under consideration of the introduction of circular economy:

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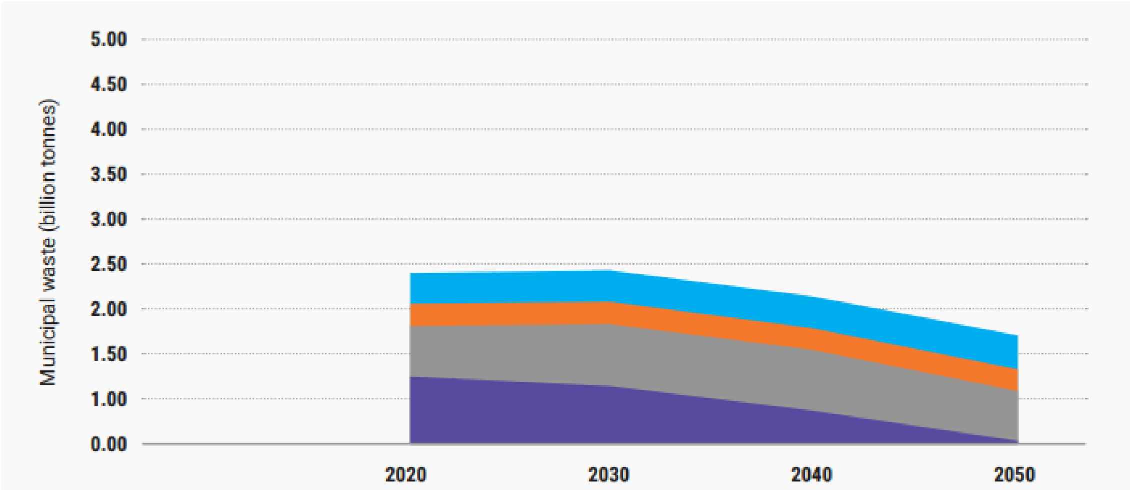
[41] https://berlin.impacthub.net/blog/how-circular-marketplaces-transform-material-usage/ [Accessed on 05 June 2024]. This picture has been included here because it illustrates a good idea of the principle of the circular economy concept in a simplified manner.

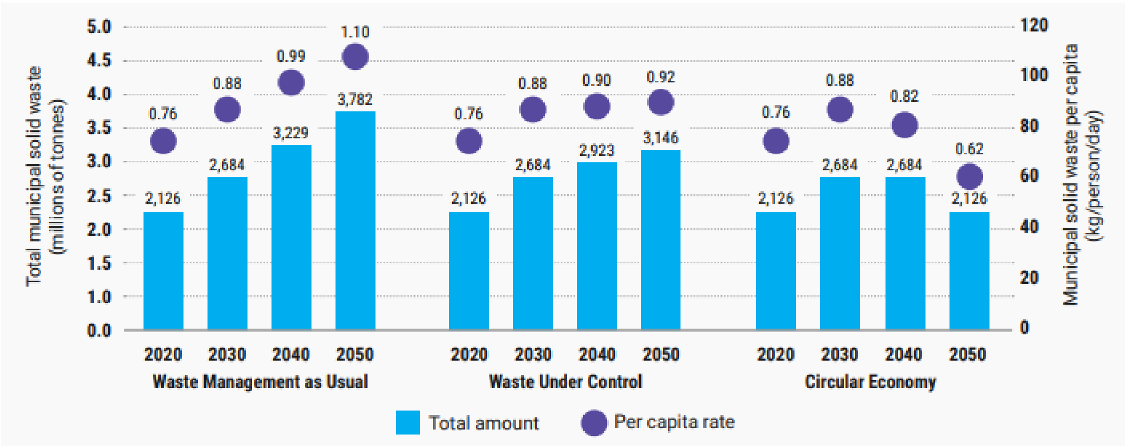


	2020	2030	2040	2050
Recycled	0.40	0.40	0.40	0.40
Waste-to-energy	0.27	0.27	0.27	0.27
Landfilled	0.64	0.78	0.76	0.63
Uncontrolled	0.81	0.70	0.37	0.00

Source: GWMO-II (2024, p.36).

Figure 18: Scenario 3 – Waste generation after implementing circular economy 2020-2050

The following figure shows a comparison of the three scenarios presented so far:

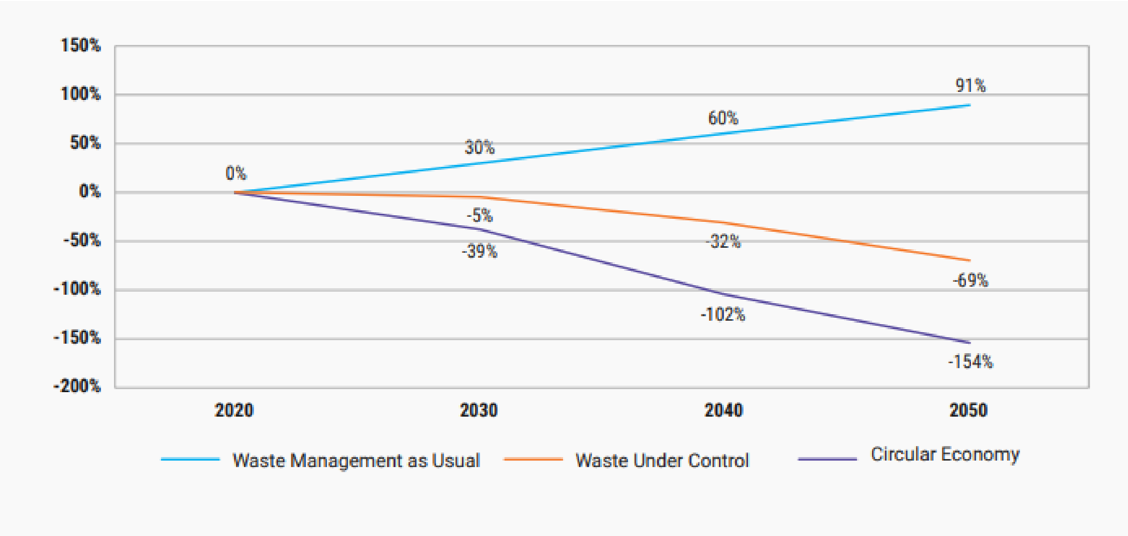


Source: UNEP (2024, p.37).

Figure 19: Comparison scenarios 1, 2, 3

The above chart (UNEP, 2024, p.37) shows graphs for projections of quantities of MSW in all three scenarios, namely, i. if waste management is carried out as usual, that is, inadequate or complete lack of a proper waste management system; ii. Introduction of a waste management system with 100% waste collection; and iii. quantity of MSW with introduction of the circular economy concept. It is clear from the above chart that the quantity of MSW in 2050 after introduction of the circular economy concept is expected to be the lowest. [Note of the MT author: although convinced at a personal level about the concept of circular economy, it is questionable, to what extent it can be implemented all over the world to have the impact on waste generation illustrated in scenario 3]. The second scenario is considered to be more realistic for execution, also in emerging economies. And if the waste generated in the second scenario could be directed away from landfills and towards WTE facilities, this might prove to be a better solution than hoping for the circular economy concept to be implemented properly all over the world.

The following figure shows the GHG emission projections from the three different scenarios:



Source: UNEP (2024, p.38).

Figure 20: Estimated impact on GHG emissions in 3 scenarios related to waste compared to 2020

The above graph shows the three scenarios and their respective impact on GHG from waste relative to 2020. The first – light blue – line shows the GHG emissions in scenario ‘business-as-usual’, with the GHG rising continuously and with a total increase of 91% in 2050 compared to 2020. In scenario 2, with full coverage of waste collection, the GHG emissions reduce by 160%, and in scenario 3 with the circular economy, the GHG emissions reduce by over 200%, thus speaking for the introduction and benefitsof the circular economy, at least in theory.

2.13 Use of technology in waste management

According to Lillesand et al. (2015, p.1), "Remote Sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation."

With increased sophistication of available technologies, they are also being used in waste management in different ways. According to Singh (2019, pp. 22-29), remote sensing and Geographic Information System (GIS) applications are used in waste management, for example, to find the locations of garbage bins, or identify efficient routes for MSW and identify appropriate sites for the different types of waste plants or even to establish landfills. Advantages are, inter alia, that larger spaces or distances can be covered in lesser time; they might prove to be effective in terms of cost; challenges to accessibility can be overcome; more data can be collected; and data can be analysed faster.

According to the Environmental Justice website[42], the Qalyubia Governorate in Egypt was planning[43] an application for smartphones via which the population would have the possibility to send pictures of waste and its locations, to enable authorities to pick it up.

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42 https://ejatlas.org/ [Accessed on 05 May 2024].

43 The result of this was not known at the time of writing the MT.

3 MSW management planning for selected economies in the WaPla software

3.1 WaPla software development and description

The following information is based on information provided in the 'Manual – Solid Waste Management Plan (WaPla) Tool 2.0 – MSW' (TU, 2019), and usage of the WaPla tool by the author of this MT:

The Institute for Water Quality and Resource Management at the Technical University of Vienna developed a software, the 'Solid Waste Management Plan (WaPla) Tool[44] 2.0 – MSW' within the framework and as part of three ongoing regional projects[45] of the United Nations Industrial Development Organization (UNIDO) in September 2022. It is designed in a manner which enables an assessment and illustration of waste management of MSW in a simplified way. The usage is not complex such that users of the WaPla software, especially in-country authorities responsible for MSW management, can use it easily and plan the management of MSW. It has been developed to be used in a Microsoft Windows environment.

The WaPla tool has made use of information from material flow analysis (MFA), as well as information on emissions from different established international sources, inter alia, the Stockholm Convention (SC), the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Human Settlement Programme (UN-Habitat).

Using some basic inputs of waste figures, the WaPla tool calculates and presents the following:

i. The pathways and final destination of waste;
ii. uPOPs;
iii. GHG; and
iv. Costs of waste management, whereby these are estimates, as the actual costs of waste management in each country depend on various factors.

When using the WaPla software, users have the possibility to gain an understanding of the waste management system existing in their own country, as they firstly, need to enter data, for which they need to have collected the required data; secondly, they also see the calculated emissions, and the change in emissions for different values of waste entered in the software. Thus, the software also provides an insight into waste disposal and corresponding GHG and uPOPs emissions.

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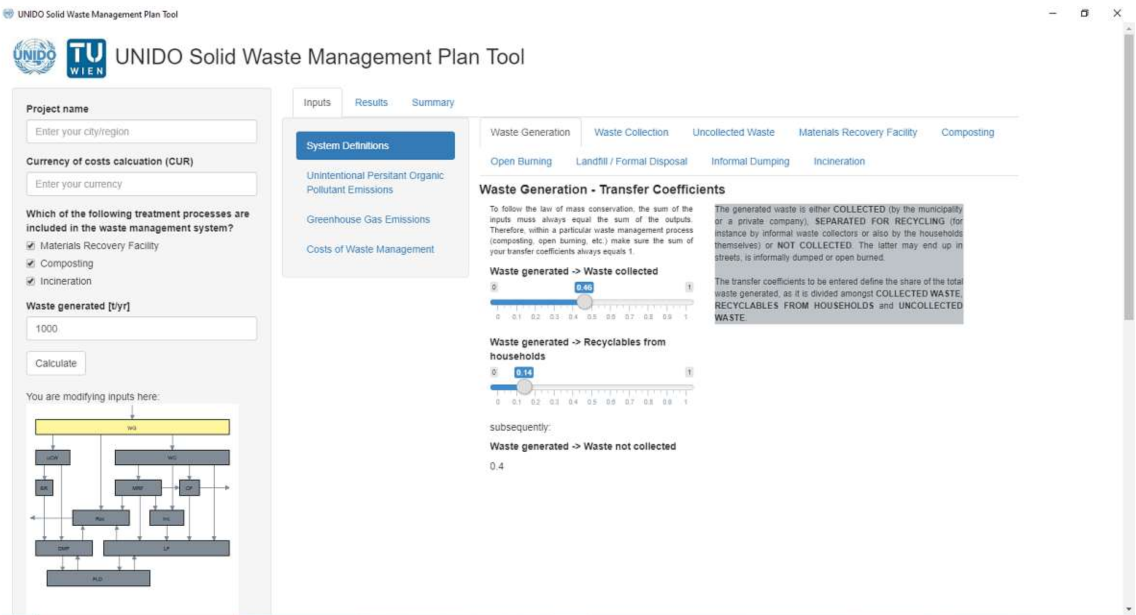
[44] Hereafter referred to as the WaPla software; the terms 'software' and 'application' are used interchangeably.

[45] "Promotion of BAT and BEP to reduce uPOPs releases from waste open burning in the participating African countries of SADC sub-region"; "Demonstration of BAT and BEP in open burning activities in response to the Stockholm Convention on POPs"; and "Development and Implementation of a Sustainable Management Mechanism for POPs in the Caribbean".

3.2 WaPla software usage

The following information is based on information provided in the 'Manual – Solid Waste Management Plan (WaPla) Tool 2.0 – MSW', and actual usage of the WaPla tool by the author of this Master Thesis:

As mentioned above, the WaPla tool has been developed to be used in a Microsoft Windows environment. It is freely available in zip format at the TUV's website https://owncloud.tuwien.ac.at/index.php/s/jrvgqxKeag0vnjz. It is necessary to download the tool for usage, and can then be initiated. Normally, it needs only a few seconds up to one minute to start the user interface. Sometimes, it takes time to open, but issues or problems were not faced in working with the WaPla software. It is very easy to use and the usage is elaborated with illustrations/screenshots in the following. The following figure shows the WaPla user interface:



Source: WaPla software.

Figure 21: WaPla user interface

In the above figure:

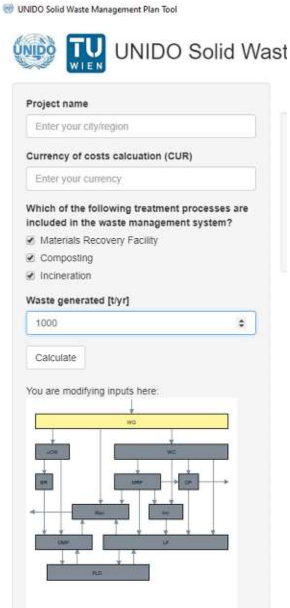
i. Project name: User can enter the name of the project, for example, of the city for which waste management analysis and planning are to be carried out;

ii. Currency of costs calculation: User can enter the currency for calculating costs, however, keeping in mind that these calculated costs are only estimates and

iii. Which of the following treatment processes are included in the waste management system?
   - Materials Recovery Facility
   - Composting

- Incineration

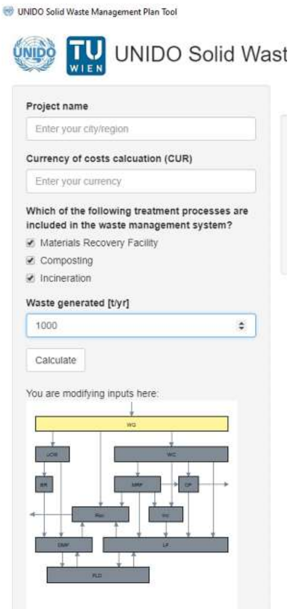
1. User can click in or click out those which are in or not in use, thus adapting the inputs into the software to the existing situation in the country or the city.
2. Waste generated [t/yr]: The following figure shows the empty box to enter the value of waste generated in the city, in tons per year.



Source: WaPla software.

Figure 22: Enter quantity of waste generation

3. Calculate: After entering the quantity of waste generated per year, the calculations/analysis by the software can be carried out by pressing the button ‘calculate’, illustrated in the following figure:

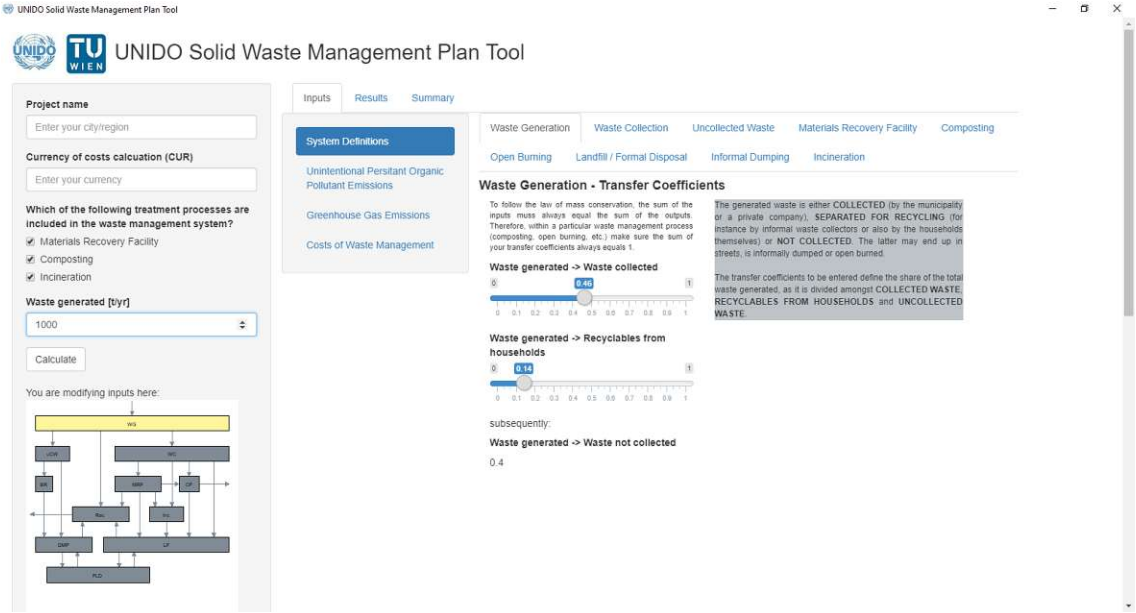


Source: WaPla software.

Figure 23: Calculate

Before moving on to the calculations, the other buttons are explained in the following.

4. The next figure shows the ‘System Definitions’. In case, all of the above 3 options, MRF, composting, incineration, have been clicked-in, they will also be shown in the tabs available for ‘System Definitions’.



Source: WaPla software.

Figure 24: System Definitions – Waste generation

In the following, the different tabs under ‘System Definitions’ are elaborated:

i. Waste Generation: After entering the quantity of total waste generated in tons per year, the user can adapt the following 3 options according to the existing system on the ground:

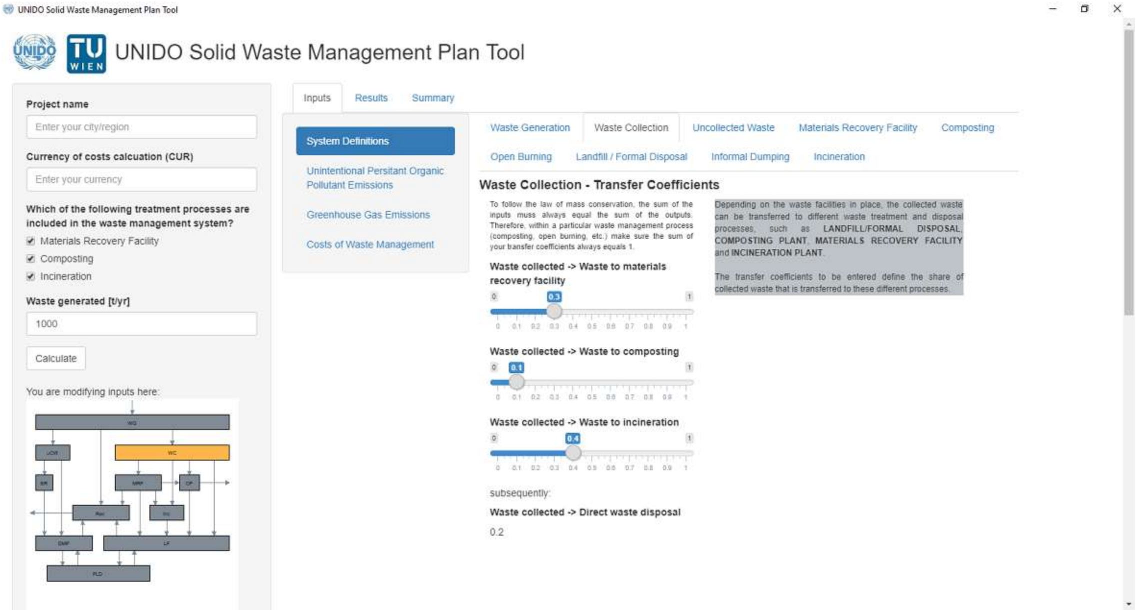
   a. Waste generated -> Waste collected: the quantity of waste that is collected from the total waste generated;

   b. Waste generated -> Recyclables from households: As the name suggests, here, the percentage of recyclables from households can be entered/adjusted;

   c. Waste generated -> Waste not collected: This would be rest after deducting the above 2 quantities from the total household waste.

   Note: The total is 100 per cent, that is, all the above 3 options together should add up to 100.

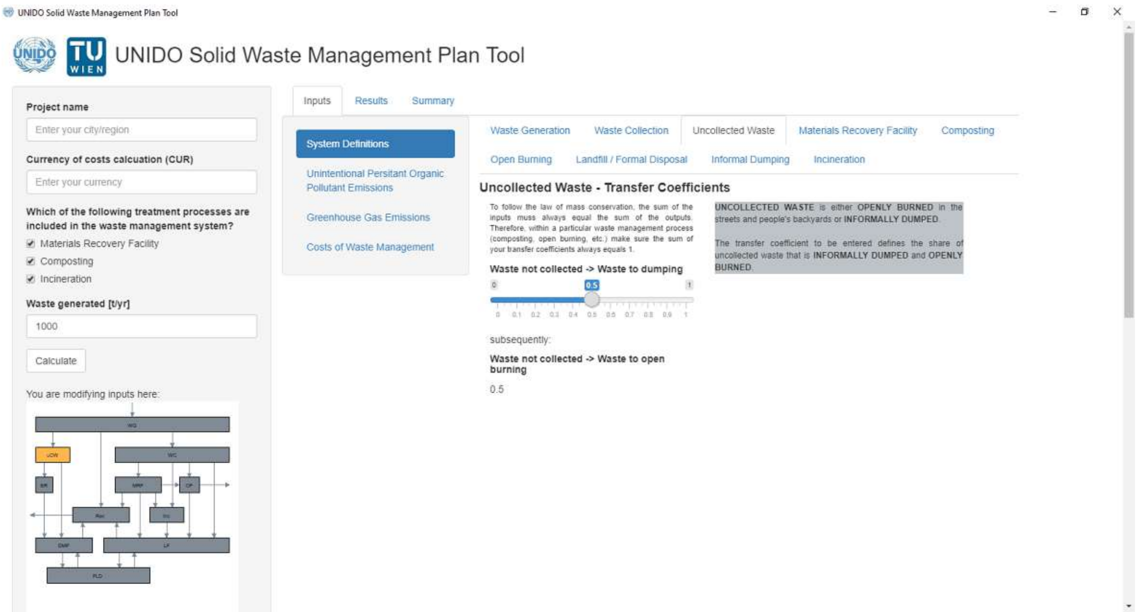
ii. Waste Collection: The following figure shows the waste collection transfer coefficients, taking into account whether or not MRF, composting and incineration have each been clicked-in, or not. The user has the possibility to adapt the percentage of each, that is, waste collected -> MRF, composting and incineration, depending on the actual situation on the ground. If actual figures are not available, this is normally done based on estimates. In case estimates are also not available, and all 3 options are 0, then the calculation is based on all collected waste going directly to waste disposal, that is, normally landfill.



Source: WaPla software.

Figure 25: System Definitions – Waste collection

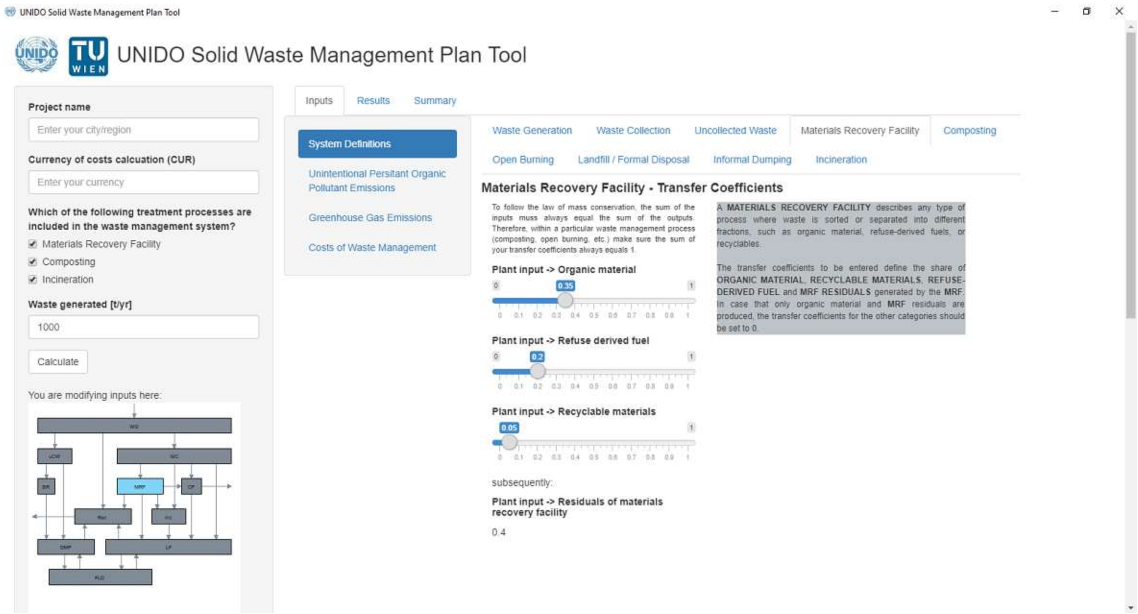
iii. Uncollected Waste: As shown in the following figure, uncollected waste is either disposed off on dumpsites and/or burned. Under this tab, the user can enter the corresponding percentages of both, which in total should sum up to 100.



Source: WaPla software.

Figure 26: System Definitions – Uncollected waste

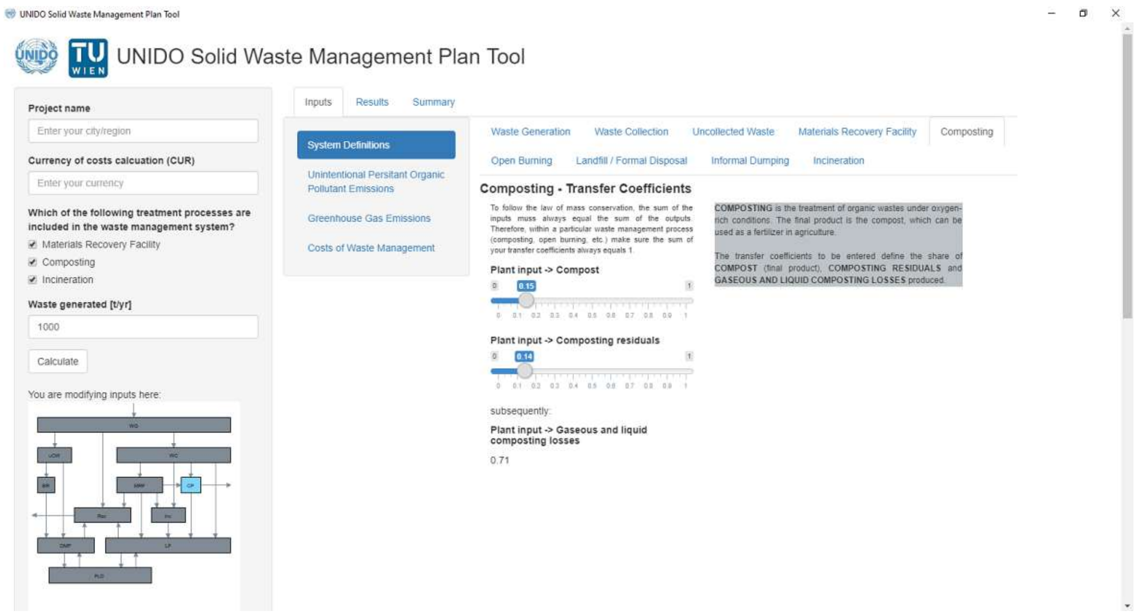
iv. Material Recovery Facility: The following figure illustrates the different types of waste which are recovered at an MRF, namely, organic material, RDF, recyclable materials, residuals of materials recovery facility. The user can adapt the different percentages of the different types of materials segregated at an MRF according to the actual situation on the ground.



Source: WaPla software.

Figure 27: System Definitions – Material Recovery Facility

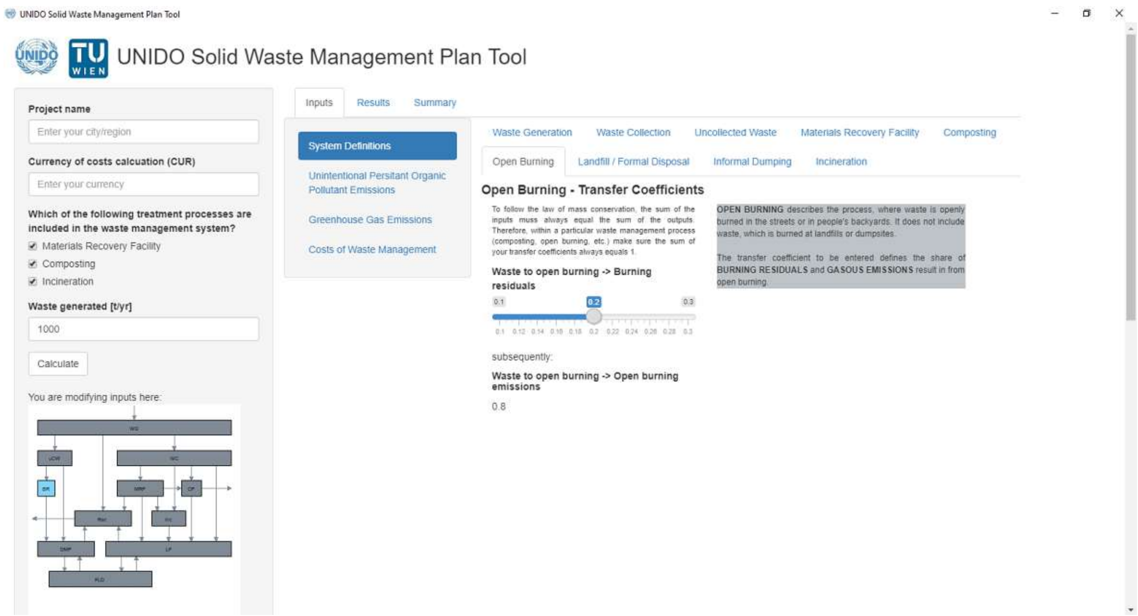
v. Composting: The percentage of compost produced, the percentage of composting residuals, and the remaining parts – gaseous and liquid composting losses, all summing up to 100 – is shown in the following figure:



Source: WaPla software.

Figure 28: System Definitions – Composting

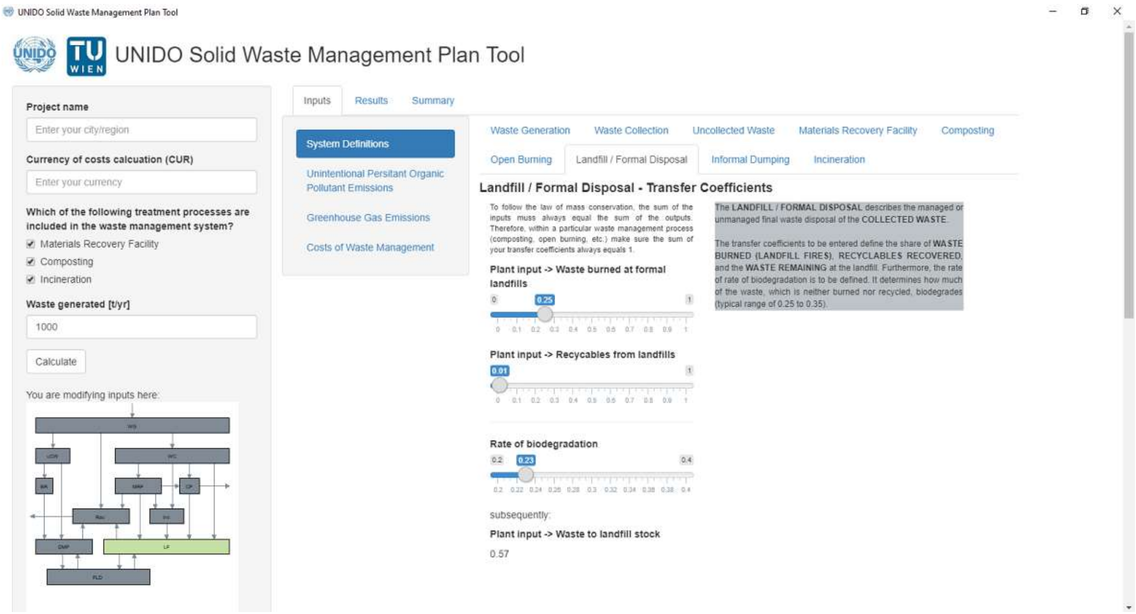
vi. Open Burning: As in the above cases, and as shown in the following figure, the percentage of residuals are calculated here, and the remaining parts, the emissions, and similar to the above, totalling 100.



Source: WaPla software.

Figure 29: System Definitions – Open burning

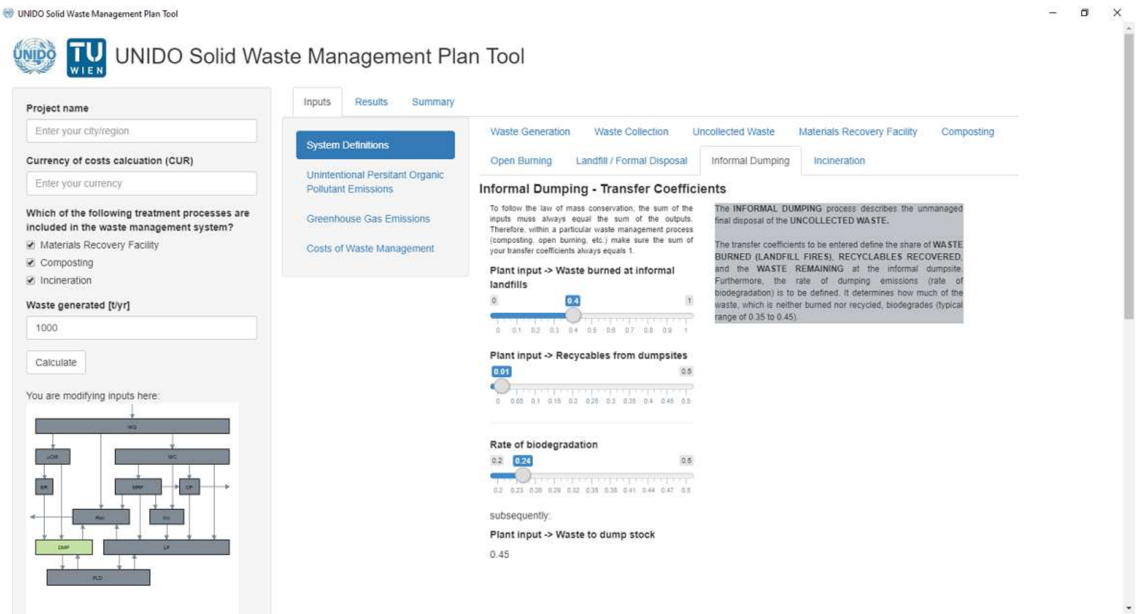
vii. Landfill/Formal Disposal: Shown in the following figure, the user can adapt the percentages of waste burned at formal landfills and recyclables from landfills, if they are known. Otherwise, the software uses pre-installed values for calculations.



Source: WaPla software.

Figure 30: System Definitions – Landfill/formal disposal

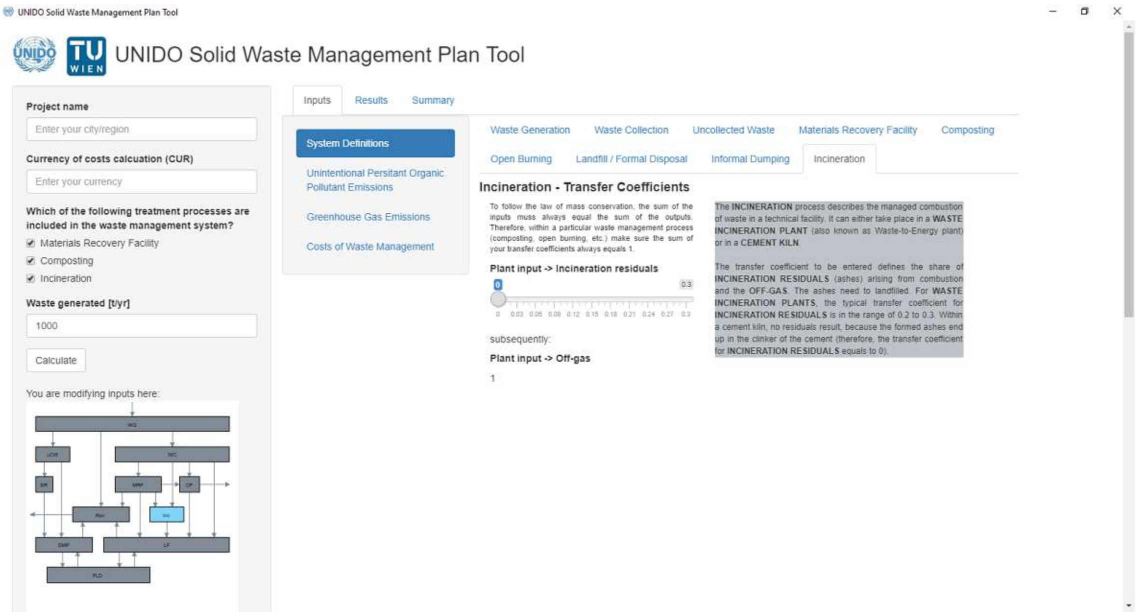
viii. Informal Dumping: If known, the user can adapt the percentages of waste burned at informal landfills and recyclables from dumpsites, as shown below:



Source: WaPla software.

Figure 31: System Definitions – Informal dumping

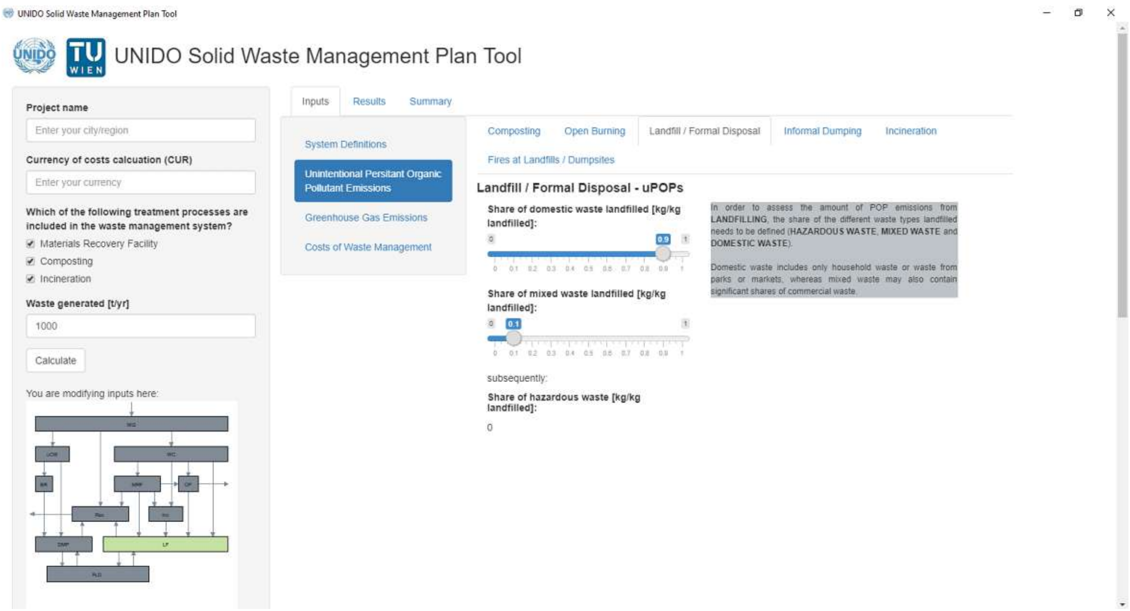
ix. Incineration: If 'Incineration' has been clicked-in, this tab will be shown, and will calculate the incinerator residuals and off-gas from incineration, as shown below:



Source: WaPla software.

Figure 32: System Definitions – Incineration

5. Unintentional POPs Emissions: If known, the user can adapt the quantities of domestic waste landfilled and mixed waste landfilled, as shown below:



Source: WaPla software.

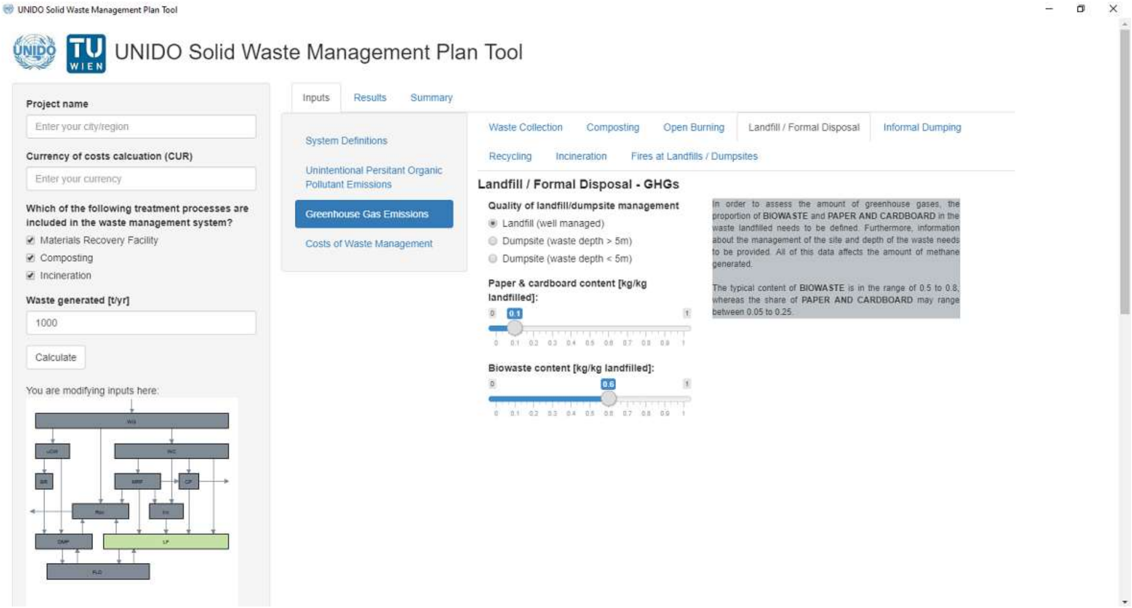
Figure 33: uPOPs – Landfills/formal disposal

6. Greenhouse Gas Emissions: As shown in the following figure, if known, the user can enter the following options:
   - Landfill well managed,

   The depth of waste at the dumpsite, with the options,
   - Less than 5m,

- More than 5m.

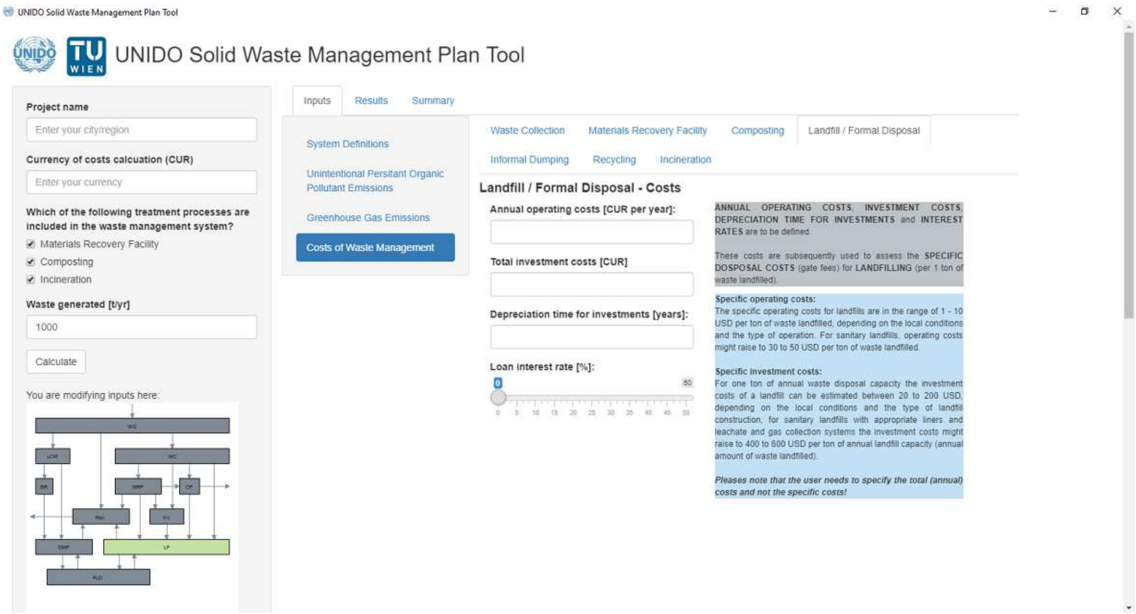
Further, the user can also add, if known, the quantity of paper and cardboard content and biowaste content, otherwise, the software uses pre-installed estimates for the calculations.



Source: WaPla software.

Figure 34: GHG emissions – Landfill/formal disposal

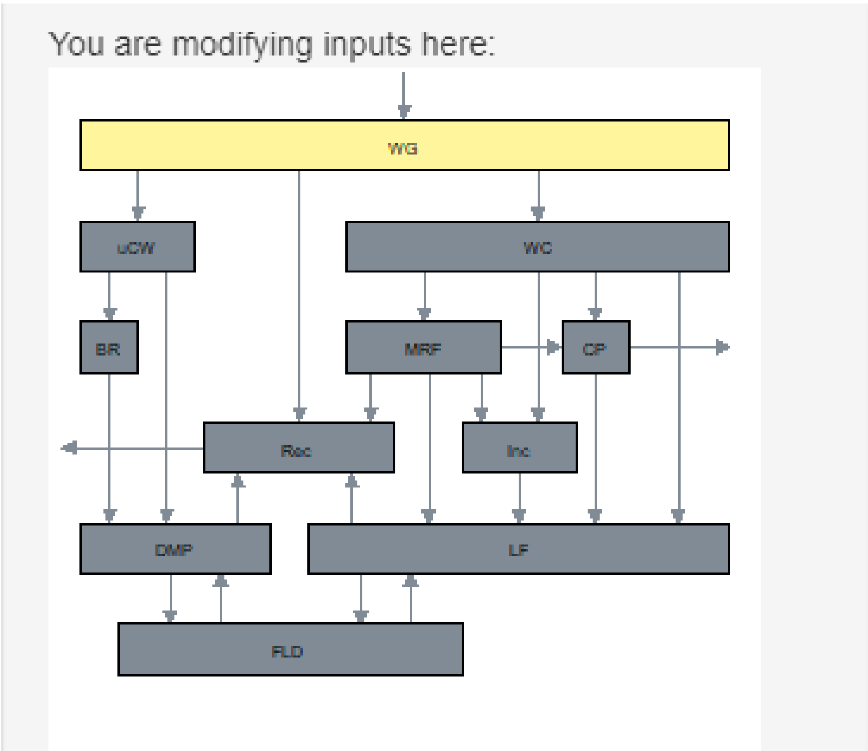
7. Costs of Waste Management: If known, the user can enter the amounts estimated for the landfill/formal disposal, as shown in the following figure:
   - Annual operating costs per year;
   - Total investment costs;
   - Depreciation time for investments in years; and
   - Loan interest rate in percentage.



Source: WaPla software.

Figure 35: Cost of Waste Management

8. The following figure shows the waste flow in the system, and which has been used in the WaPla software to calculate the flow of waste, some of the values based on estimates, which form an important part of the calculations, as the actual values are not known in a majority of cities and countries.



Source: WaPla software.

Figure 36: Waste Flow

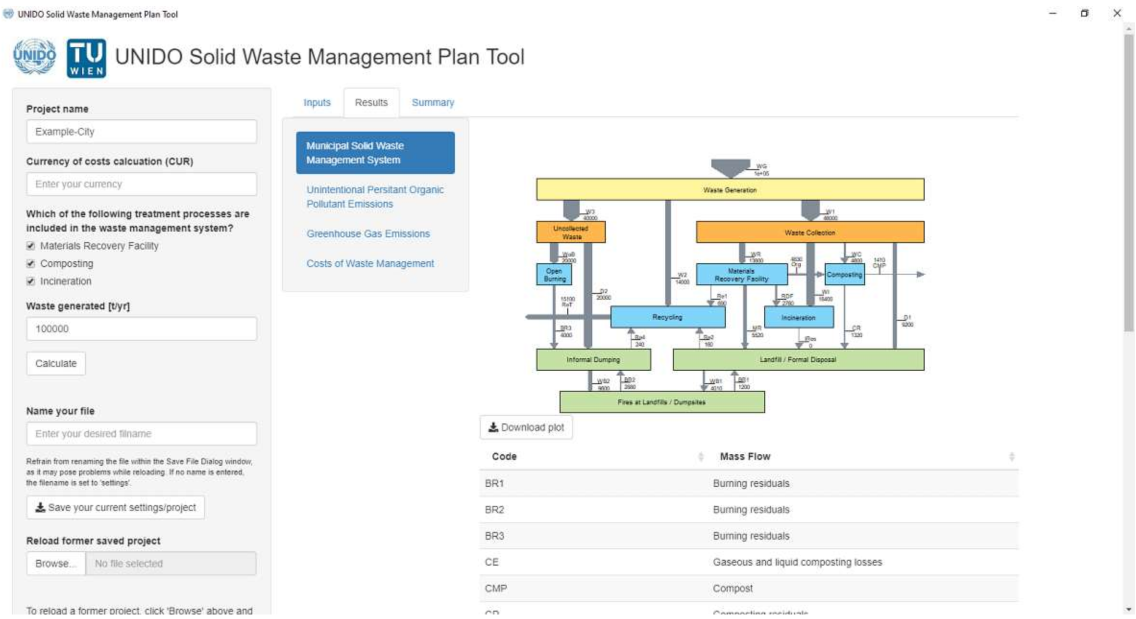
The abbreviations and full forms are shown in the table below:

Table 4: Abbreviations used in the waste flow diagram in WaPla

WG	Waste Generation	CP	Composting
ucW	Uncollected Waste	DMP	Informal Dumping
WC	Waste Collection	Inc	Incineration
BR	Open Burning	LF	Landfill
MRF	Materials Recovery Facility	Rec	Recycling
		FLD	Fire at landfills and dumpsites

Source: WaPla software.

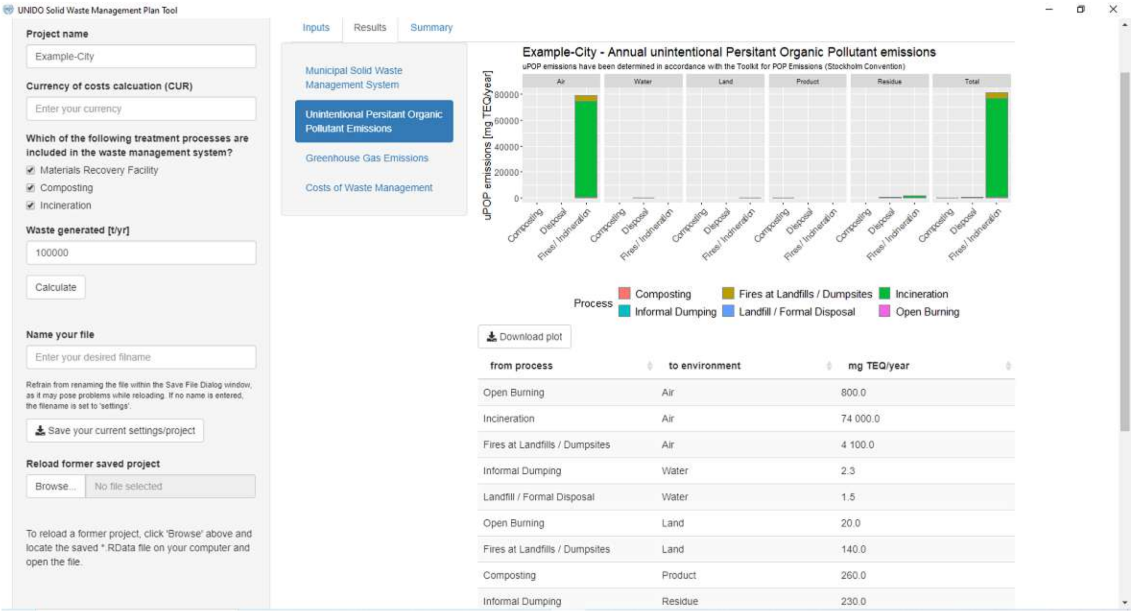
9. Results: For an example city, a waste quantity equal to 100,000 tons per year is entered and calculations carried out.
   i. The following figure shows the results of the material flow:



Source: WaPla software.

Figure 37: Results – Waste flow calculated

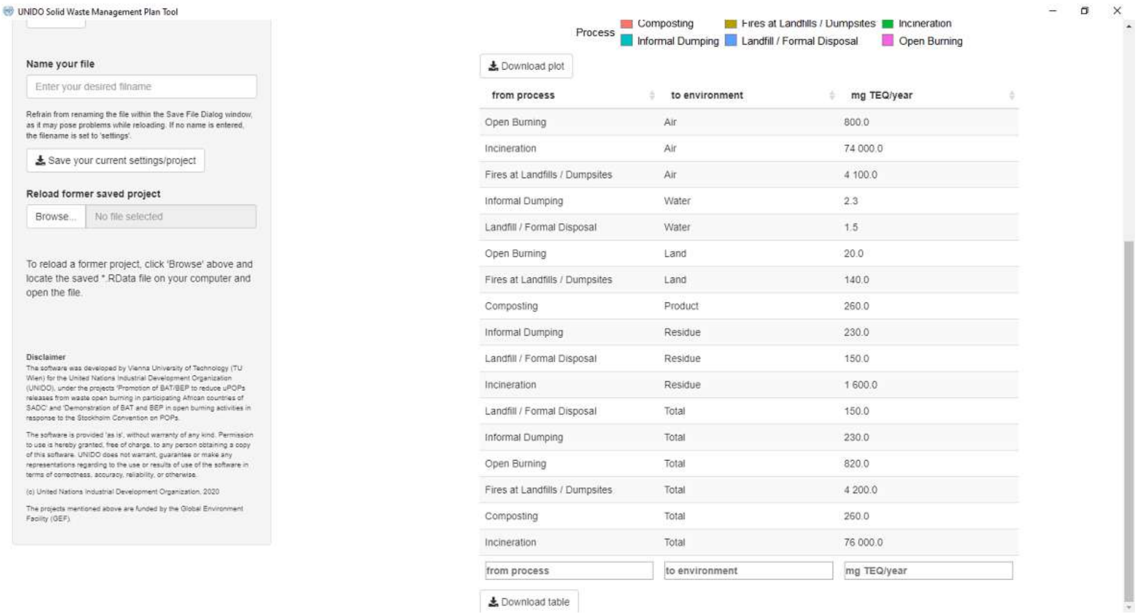
   ii. The following figure shows in a bar chart the quantities of uPOPs emitted, in the given example via incineration and fires at landfills/dumpsites:



Source: WaPla software.

Figure 38: Results – uPOPs emissions bar chart

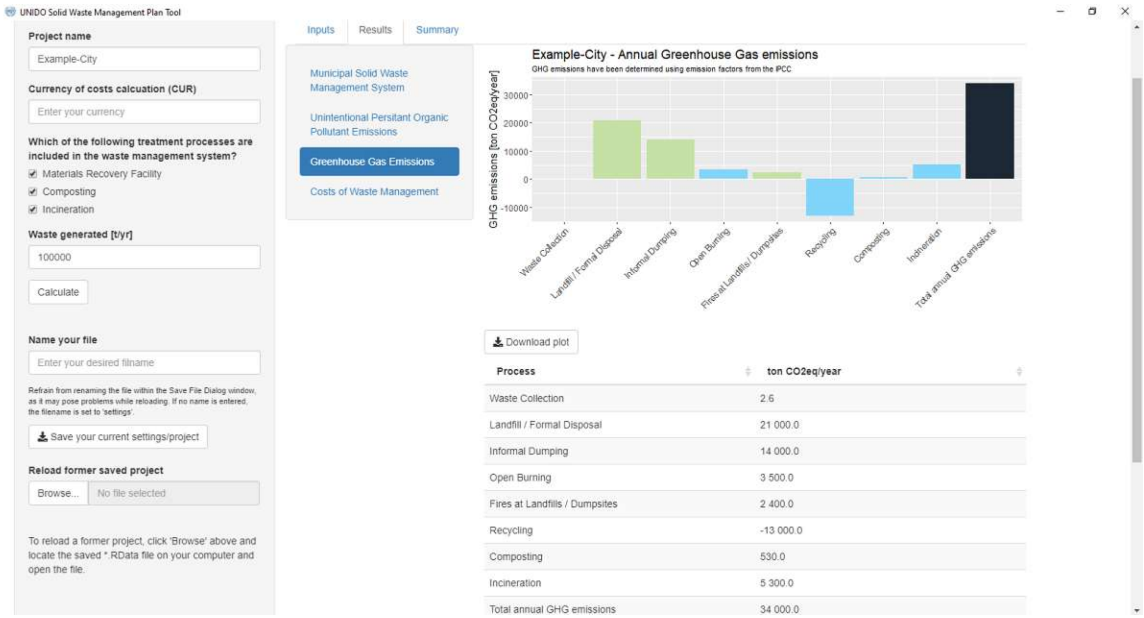
The next figure shows the actual quantities, from the process, to the specific environment.



Source: WaPla software.

Figure 39: Results – uPOPs emission quantities table

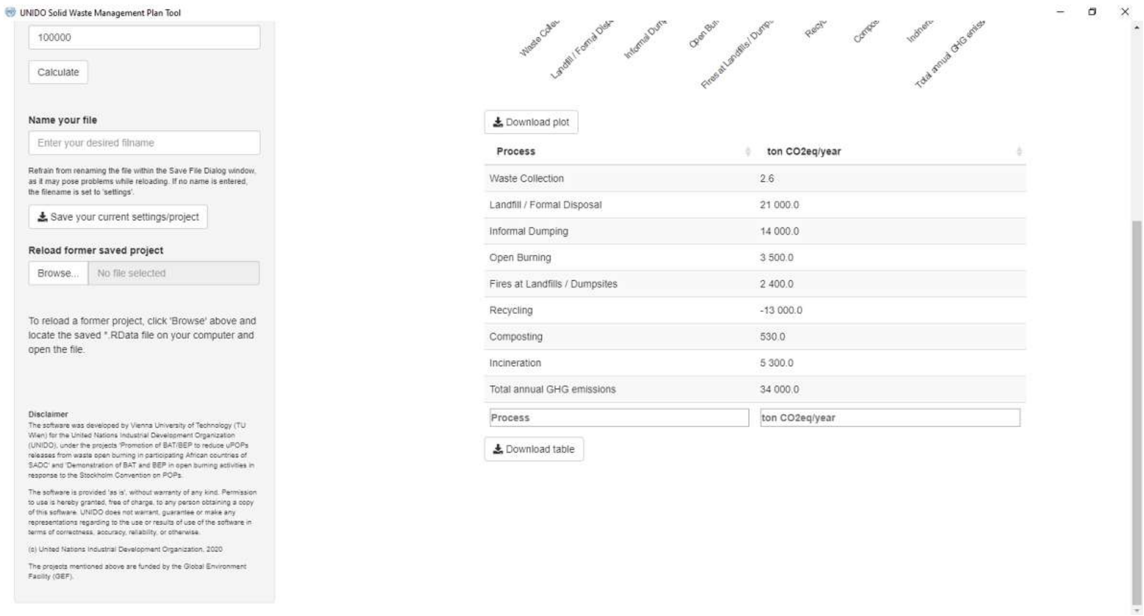
iii. The following figure shows in a bar chart the GHG emissions by the different waste disposal methods in the example, as well as the total quantity.



Source: WaPla software.

Figure 40: Results – GHG emissions bar chart

The next figure shows the process and corresponding quantities of GHG emissions. In this example, the costs have not been entered, otherwise the estimates of different costs[46] involved would also be calculated and shown.

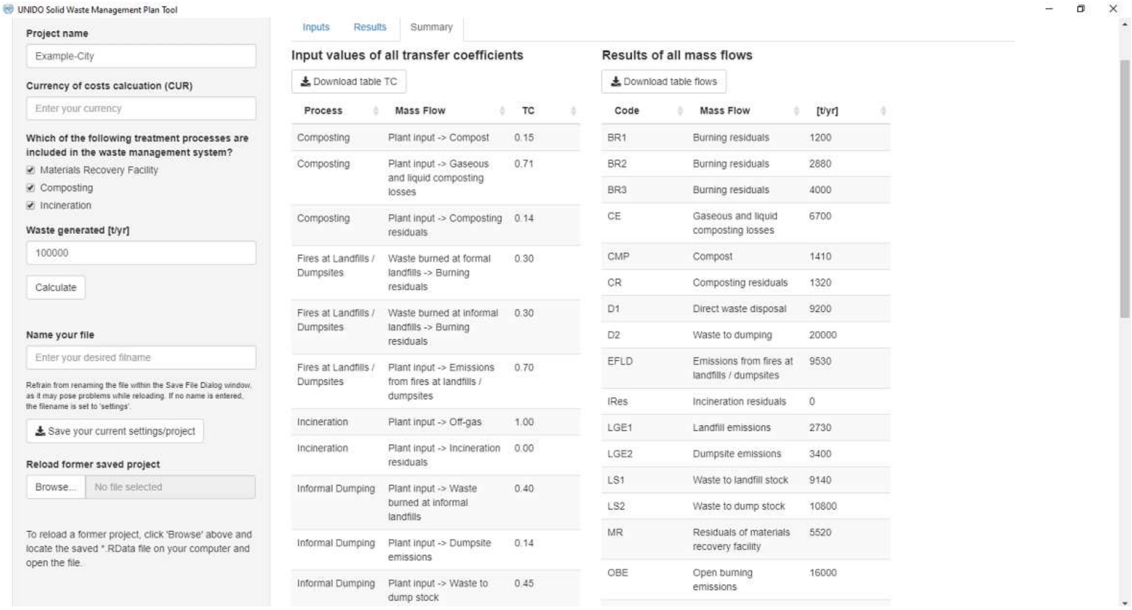


Source: WaPla software.

Figure 41: Results – GHG emissions table

[46] Ideally, the costs would be entered by knowledgeable persons from the country concerned and involved external waste-management experts; the former would know the in-country existing costs, and the latter would be knowledgeable about the costs of external technology, etc. and therefore, the cost estimate would be closer to actual costs to be expected.

10. Summary: The following figure shows the output under ‘Summary’, which shows, as the term says, a summary of all input values and all results of mass flows.



Source: WaPla software.

Figure 42: Results – Summary

3.3 MSW planning for emerging economies using the WaPla software

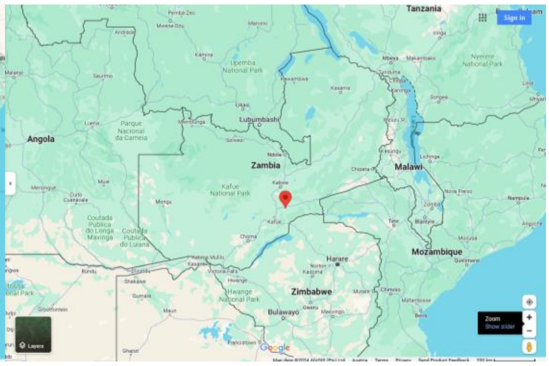
As elaborated under the section ‘Methodology’, the MT has worked with waste data from 2 cities/districts, namely, the Chongwe District in Zambia, explained and illustrated in sub-section 3.3.1 followed by the Giza Governorate – the 6th of October City and the Sheikh Zayed City – in Egypt detailed and shown in sub-section 3.3.2, entered them in the WaPla software, which then carried out its calculations and presented the results. The author of the MT has then analysed these results to present recommendations for waste-management planning for the Chongwe District and Giza Governorate respectively.

3.3.1 Chongwe District, Zambia

Republic of Zambia

The Republic of Zambia[47] is a landlocked country, located in Southern Africa and rich in terms of resources.

[47] www.worldbank.org/en/country/zambia/overview#1 [Accessed on 16 April 2024].

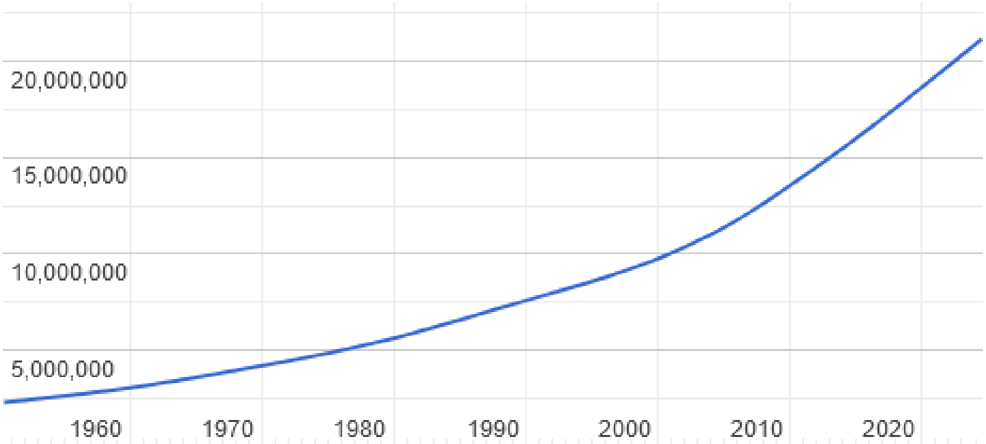


Source: Google Maps.

Figure 43: Location of Zambia in the African continent

Figure 44: Location of Zambia zoomed in

Its population is estimated to be around 19.6 million (2021) and the positive growth rate of the population is 2.7% per year. It has a GDP of (current) USD 29.16 billion (WB[48], 2022) and a GDP per capita of USD 1,456.90 (WB[49], 2022). It has been classified as a low-income country, with around 55% of the population (2015 estimate[50]) living below the poverty line. The following figure shows the population data of the country:



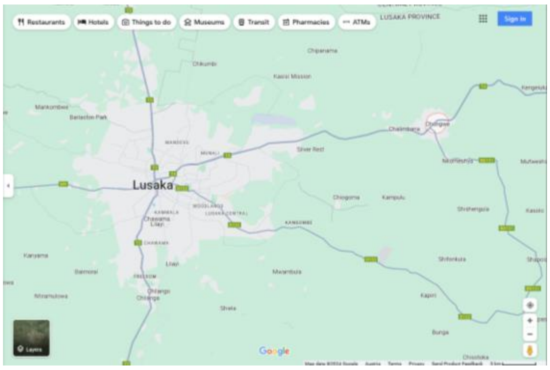
Source: Worldometers website[51].

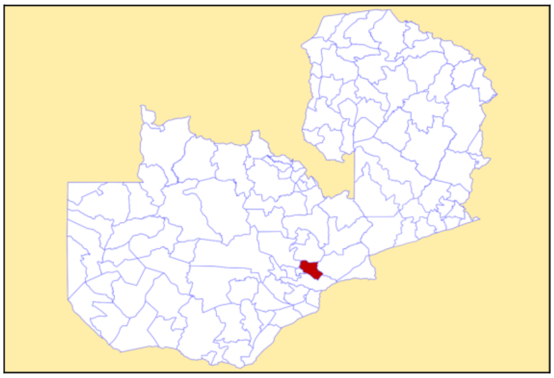
Figure 45: Zambia population 1960-2020

Its total carbon dioxide (CO2) emissions are estimated[52] (2019) to 6.798 million tons.

48 data.worldbank.org
49 Ibid.
50 CIA World Factbook.
51 https://www.worldometers.info/world-population/zambia-population/ [Accessed on 16 April 2024].
52 CIA World Factbook.

Chongwe District





Source: Google Maps and Wikipedia.

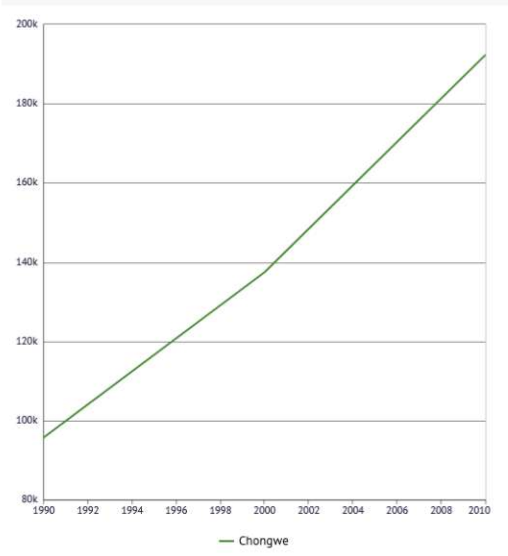
Figure 46: Location of the Chongwe District from Lusaka

Figure 47: Location of the Chongwe District in the country

Chongwe District is located in Lusaka Province in the Republic of Zambia[53]. The population of the Chongwe District is 313,389[54], and has been increasing steadily since 1990. According to information reviewed on different websites, there have been some changes in the composition of the District in the past, but they are not relevant for the current analysis of the waste produced in Chongwe, and therefore, not mentioned here. The closeness to the capital of the country is relevant, because similar to other cities in the world, as the capital city grows, economy-wise and population-wise, people will start moving to nearby areas, population will increase in nearby areas, as well as the need for related infrastructure and services. The population growth of the Chongwe District itself shows a positive trend since 1990, thus making it relevant in terms of future city and waste management planning, even without the geographical closeness to Lusaka city. The following figure shows the population (increase) in the Chongwe District since 1990.

[53] Hereafter, referred to as 'Zambia'.

[54] According to the website, a country-census was carried out in 2022, and this was the population figure reached during the census. https://tasks.hotosm.org/projects/14908#description Accessed on 16 April 2024. According to the UNIDO report (2019) 'Waste Management Study – Chongwe, Zambia', the population of the Chongwe District is 186,000 in 2019. However, in view of the aforementioned census in 2022, and the same being mentioned elsewhere, the population figure mentioned in the MT is 313,389.



Source: Open data for Africa website[55].

Figure 48: Chongwe District population 1990-2010

Taking the population into account, the size of the district is not large. This also presents a good opportunity for a pilot waste planning project to be carried out in the Chongwe District, results and lessons from which can then be taken into consideration for replication in other parts of the country[56].

Analysis of the current state of waste management using the WaPla software

For the analysis, with the help of the Institute for Water Quality and Resource Management at the Technical University (TU) of Vienna[57], waste data was requested from the University of Zambia. Literature provided entailed estimates of waste data. For the purpose of this MT, estimates of quantity of waste generated and waste collected, as reported in the 'Waste Management Study – Chongwe, Zambia, Assessment of Opportunities for the Reduction of Open Burning Practices' by UNIDO[58] (2019), hereafter referred to as 'the study', have been used, elaborated in the following. To enable ease of reading, the report has not been mentioned each time, but as applicable, the source of data, if any other than the study, has been mentioned.

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55 https://zambia.opendataforafrica.org/ZMPAD21016/population-and-demography-of-zambia?region=1000390-chongwe [Accessed on 16 April 2024].

56 At the same time, the MT author would also like to note that although it is a good idea to have a pilot project and then go for replication, a review and assessment of the waste situation in the whole country might also prove to be more beneficial, especially if high-cost options/solutions/technologies might be envisaged, for example, WTE plants. In this case, it might be better to review the situation of a larger geographic area which can be covered by the WTE facility, instead of reviewing the situation in only one city.

57 https://www.tuwien.at/en/cee/iwr [Accessed on 11 June 2024].

58 The study was prepared within the framework of a UNIDO project. It was provided to the author of this MT by the University of Zambia. It is freely available on the internet [checked on 16 April 2024].

According to the study, 61 tons of disposable waste is generated per day in the Chongwe District, that is, 22,265 tons per year, and 71 kg per capita per year, that is, 0.19 kg per capita per day. This corresponds to the WB (2018, p.22) estimate for sub-Saharan Africa with kg/capita/day quantity of waste generation between 0.11-1.57, and is more at the lower end of these estimated averages. Further, according to the study, around 34% of this waste, that is, around 7,570 tons/year, is collected and brought directly to the Council dumpsite[59]. Based on a waste sampling carried out, the following waste composition was identified, in % by weight:

Table 5: Chongwe District – Waste composition

Material	% by weight
Organics	53
Plastics	18
Glass	16
Wood and Paper	7
Rubber	3
Metals	1
Textiles	1
Other	<3

Source: UNIDO, 2019, p.6.

6% of the material is recyclable, this corresponds to 1,340 tons/year of recyclable materials from households[60]. The rest, around 13,400 tons/year, is not collected, and disposed off by informal/unregulated/uncontrolled burying and open burning.

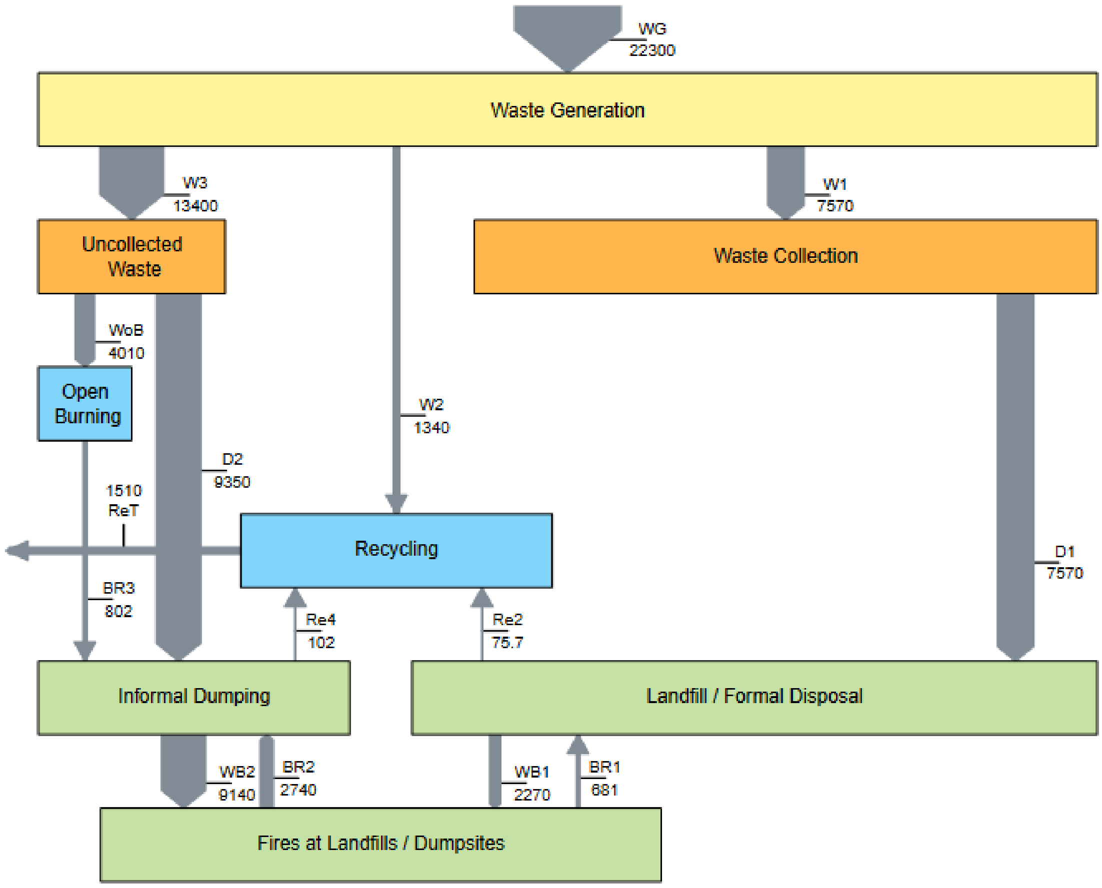
The above describes the data which was then entered in the WaPla software accordingly; a waste-flow diagram and graphs showing results of the analysis are included below for easy reference:

The following figures shows the waste flow in the Chongwe District, with the quantities mentioned above, and calculated in the WaPla software, that is, total waste generated is around 22,300 tons/year; waste collected is around 7,570 tons/year, which goes to the landfill; recyclable materials are around 1,340 tons/year, and uncollected waste amounts to around 13,400 tons/year, 9,350 tons/year being dumped at informal landfills/dumpsites, and 4,010 tons/year being informally burned. The quantities of

59 Understood here as a simple formal landfill site, as it belongs to the Council.

60 Share of plastics [kg/kg recyclables] 40%; share of scrap metals [kg/kg recyclables] 60%, as

recyclables collected from the Council dumping site, and fires at landfills/dumpsites[61], are calculated by the WaPla software and are estimate values. According to the study, there is no MRF or composting or formal incineration taking place. Therefore, these fields have been left unclicked in the application.



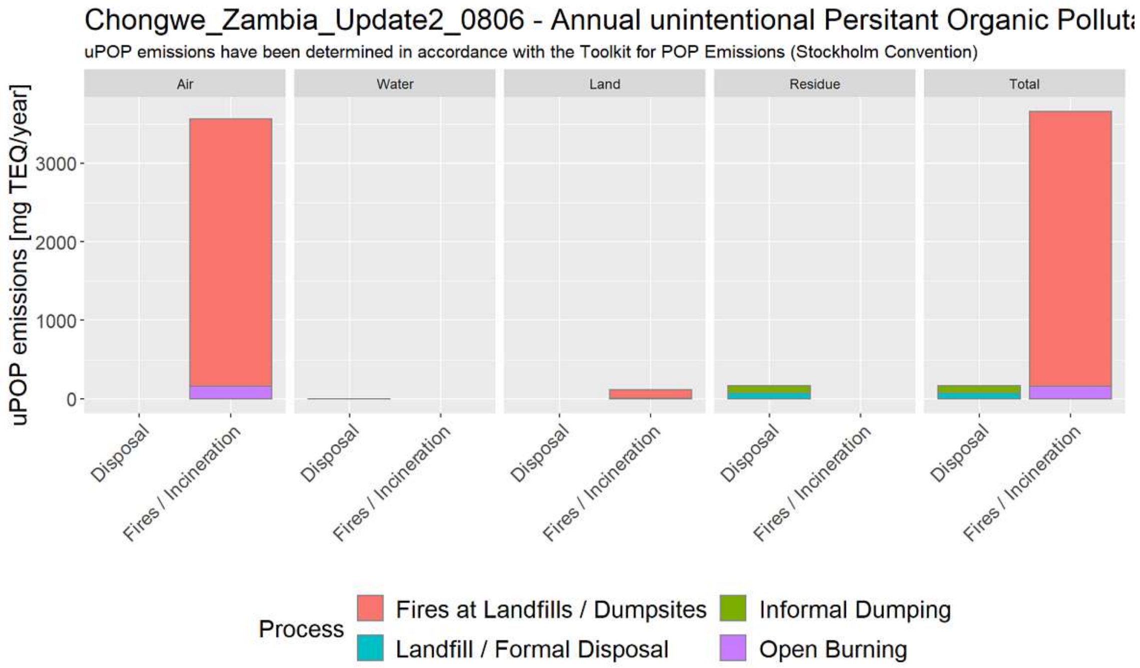
Source: WaPla software.

Figure 49: Chongwe District – Waste flow

The following figure shows the yearly uPOPs emissions as calculated by the WaPla software; the calculation is in compliance with the Stockholm Convention Toolkit for POP emissions[62].

[61] At informal dumpsites, 90% of the waste is assumed to be burned; the percentage of burning of waste at informal dumpsites has been assumed to be high, because it is an informal dumpsite.

[62] For open burning, default factors of 40 ug TEQ/t waste burned for air and 1 ug TEQ/t waste burned for land have been taken into account in the calculations in the WaPla software; these values are based on the *Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs (Stockholm Convention on Persistent Organic Pollutants)*. For fires at formal landfills/dumpsites, emission factors of 300 ug TEQ/t waste burned for air and 10 ug TEQ/t waste burned for land have been used in the calculations in the WaPla software; these values are based on the *Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs (Stockholm Convention on Persistent Organic Pollutants)*.



Source: WaPla software.

Figure 50: Chongwe District – uPOPs emissions bar chart

The above graph shows the uPOPs emissions, mainly PCDD and PCDF, hereafter dioxins and furans, due to open burning, and intended burning at the Council dumpsites in the Chongwe District, amounting to a total of around 3,800 mg TEQ/year. The detailed overview of emissions to the environment, calculated in WaPla, is presented in the following table:

Table 6: Chongwe District uPOPs emissions quantities

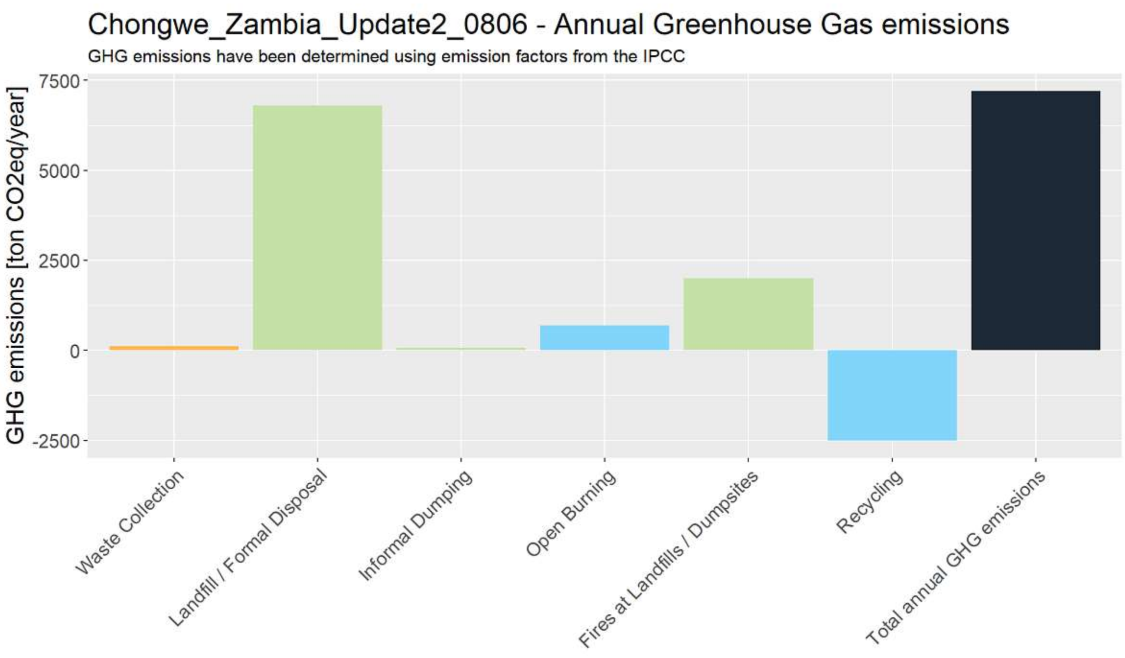
Process	To Environment	Mg TEQ/year
Open burning	Air	160.00
Fires at landfills/dumpsites	Air	3,400.00
Informal dumping	Water	0.96
Landfill/formal disposal	Water	0.72
Open burning	Land	4.00
Fires at landfills/dumpsites	Land	110.00
Informal dumping	Residue	96.00
Landfill/formal disposal	Residue	72.00
Informal dumping	Total	97.00
Landfill/formal disposal	Total	73.00
Open burning	Total	160.00

Fires at landfills/dumpsites	Total	3,500.00
	Total	**3,800.00**

Source: WaPla software.

From the table, it is clearly seen that the maximum uPOPs emissions are due to burning of waste, both at the Council dumpsites and in unregulated open burning. At the same time, this does not imply that other methods of waste disposal do not have any adverse effects to a large extent, as the emissions are not so high. It can also be clearly seen that there are emissions into the water, also possibly groundwater, and into land.

The following figure shows the estimation of GHG emissions produced during the whole waste flow per year; the calculation of GHG emissions is based on the emission factors of the IPCC.



Source: WaPla software.

Figure 51: Chongwe District – GHG emissions bar chart

The above bar chart shows that the maximum GHG emissions are at the landfills/dumpsites[63], followed by the unregulated open burning or waste and then the burning of waste at the regulated and unregulated landfills. Recycling is shown with a negative value of GHG emissions, as this quantity of GHG emissions is prevented due

[63] GHG-emissions as per IPCC 2006 Guidelines, Chapter 5 – Waste; related to landfills and incineration of waste.

to recycling, 40% plastics and 60% metal[64]. Altogether, the GHG emissions are estimated to achieve a value of over 7,000 tons CO2eq per year. The following table presents the calculated values of GHG emissions per process in the waste flow of the Chongwe District:

Table 7: Chongwe District GHG emissions quantities

Process	Tons CO2eq/year
Waste collection[65]	120
Landfill/formal disposal	6,800.0
Informal dumping	73.0
Open burning	700.0
Fires at landfills/dumpsites	2,000.0
Recycling	-2,500.0
Total GHG emissions	**7,200.0**

Source: WaPla software.

The table clearly shows that the maximum amount of GHG emissions is from the (formal) landfill due to the methane emissions from the landfill, followed by open burning and then intended and unintended fires at landfills/dumpsites. This also makes it clear where the Council actions should be directed at, namely, the (formal) landfill/dumpsite.

The above GHG emissions, 7,200 tons CO2eq/yr with a population of 313,389 amounts to 0.02297 tons CO2eq/capita/yr, or around 23 kg CO2eq/capita/yr for the Chongwe District.

Taking the CO2-emissions of Zambia, 6.798 million tons, and its population, 19.6 million, into account, the CO2-emissions are around 350 kg/capita/year.

Comparing the CO2-emissions/capita/year from the current waste-management practices in the Chongwe District to the total CO2-emissions per capita per year in Zambia, around 7% of the total CO2-emissions per capita per year are contributed by the current waste-management practices in the Chongwe District, which is above the global average of about 3 to 4%.

Based on the above-shown data and results, 4 different scenarios have been calculated in the WaPla software.

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[64] This was the composition of recyclable material entered in WaPla; this was based on information researched about the recycling taking place currently, and the materials being recycled.

[65] According to Larsen et al. (2009), diesel consumption in waste collection trucks is in the range of 1.4-10.1 Litre per ton of waste. Therefore, 6 Litre per ton of waste has been taken as reference value and the value then corresponding to the amount of waste collection has been entered in WaPla.

Scenario 1 - Composting introduced;

Scenario 2 – Composting and improved landfill, including reduced burning at LF;

Scenario 3 – Waste collection enhanced to double (68%), and only incineration;

Scenario 4 – Waste collection enhanced to 80%, and brought to WTE.

The screenshots of the results are included in Annex 6.1. A table including relevant data from all the 4 scenarios for the Chongwe District is as follows:

Table 8: Chongwe District – 4 scenarios for waste management

	Waste collected t/yr	Composting	Improvement of landfill	Incineration	WTE	UPOPs mg TEQ/yr	GHG t/yr	GHG emissions/ capita/ year
Current scenario	7,570	-	-	-	-	3,800	7,200	23.00 kg
Scenario 1 - Composting introduced	7,570	Managed	-	-	-	3,600	2,800	8.93 kg
Scenario 2 – Composting + enhanced LF (incl. lesser burning at LF)	7,570	Managed	X	-	-	2,415	6,500	20.74 kg
Scenario 3 – Waste collection enhanced to double (68%), and only incineration	15,100	-	-	good air pollution control	-	1,884	4,000	12.76 kg
Scenario 4 – Waste collection enhanced to 80%, and brought to WTE	17,800	-	-	-	good air pollution control	1,296	-5,400	

Key results from the above table are as follows:

Scenario 1: If only composting is introduced, and 90% of organic material from the collected waste is sent for composting, then the CO2eq emissions are reduced by over 60%; however, the UPOP-emissions do not considerably reduce.

Scenario 2: If 90% of the collected organic waste is sent for composting and the existing landfill facilities are improved, including reducing waste burning at formal landfills/dumpsites, the CO2-emissions are not reduced considerably.

Scenario 3: If waste collection is enhanced to double, that is to 68%, and waste is formally incinerated, the uPOP-emissions are reduced by over 50%, and CO2-emissions are reduced by almost 46%.

Scenario 4: If waste collection is enhanced to 80%, and collected waste is sent to a WTE facility, uPOP-emissions are reduced by over 60% and CO2-emissions are reduced by almost 200%.

Similar to the above, in the following sub-section, analysis has been carried out for 2 cities in the Giza Governorate. The current situation of waste-management followed by the different waste management scenarios are presented below.

3.3.2 Giza Governorate, Egypt

Arab Republic of Egypt

The Arab Republic of Egypt, hereafter referred to as 'Egypt[66]' is located in the northeast Africa.

Source: Google Maps.

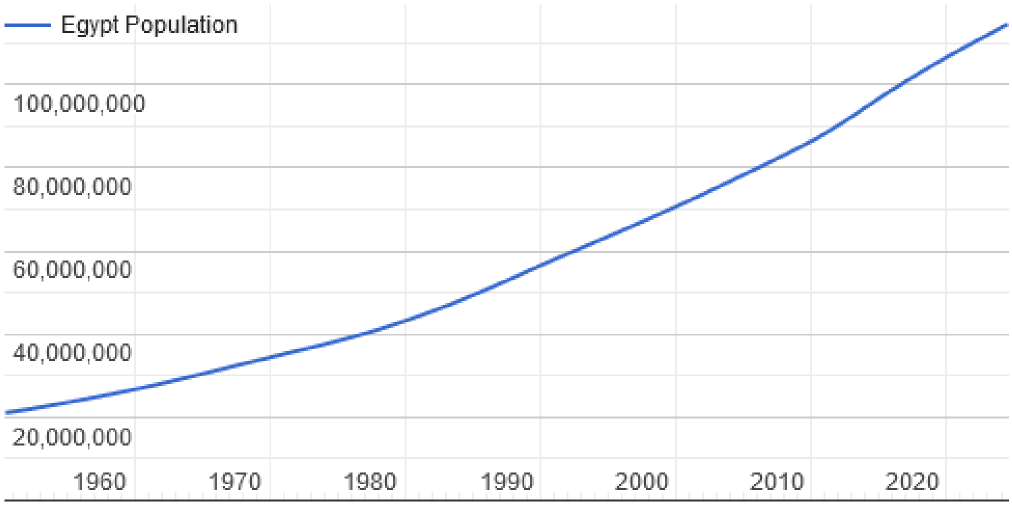
Figure 52: Location of Egypt in the African continent

Figure 53: Location of Egypt in North Africa

[66] The following country information has been retrieved from the CIA World Factbook, accessed on 19 April 2024.

With a population of almost 110 million, it ranks 14th in the world in terms of size of population, and 3rd in Africa, and has a population growth rate of 1.59%. Over 43% of the population lives in urban areas.

It has a GDP of around USD 477 billion (official exchange rate), the second largest in Africa. The GDP per capita is around USD 4,300 (current USD, WB[67], 2022) and the country is classified as a lower middle-income country (LMIC). The agricultural sector contributes with 11.8% (2017 estimate) to the GDP, industry with 34.3% (2017 estimate) and services with 54% (2017 estimate).



Source: Worldometers website[68].

Figure 54: Egypt population 1960-2020

A few pertinent indicators related to waste (management) have also been documented[69]. Annually, it generates 21 million tons (2012 estimate) of MSW, from which 2.625 million tons (2013 estimate) of material is recycled, that is 12.5% of MSW. CO_2 emissions have been estimated to be 238.56 megatons[70] (2016 estimate); and methane emissions to be 59.68 megatons (2020 estimate).

According to the Environmental Justice website, the country is planning actions for managing waste, namely, a three-stage waste recycling plant in the northeastern Qalyubia Governorate – for waste collection, recycling and incineration with energy generation, that is WTE. Moreover, the country has plans to decommission waste

[67] data.worldbank.org
[68] https://www.worldometers.info/world-population/egypt-population/ [Accessed on 19 April 2024].
[69] CIA World Factbook.
[70] Million metric tons.

dumpsites/landfills in a few Governorates, namely, Cairo, Qalyubia, Monufiya, Daqaliya and Gharbia, to establish landfills[71] in rural areas.

Egypt has functioning cement plants, which can knowingly also be used for waste disposal, including for several hazardous waste, due to the high temperatures existing inside the cement kilns. In 2016, the country announced plans to indeed start making use of the cement plants for waste disposal[72].

6th of October City and Sheikh Zayed City in Giza Governorate

The Al Jizah Governorate, also called Giza Governorate, and hereafter referred to as the 'Giza Governorate' is one of the 27 governorates of Egypt, as the country is divided into administrative regions or governorates. Both the cities the 6th of October and Sheikh Zayed are in the Greater Cairo area and belong administratively to the Giza Governorate, and population is reported to be around 1.85 million (2019) of the Governorate; population of the 6th of October City is estimated to be 700,000[73] and of the Sheikh Zayed City 375,000[74].

Source: Google Maps.

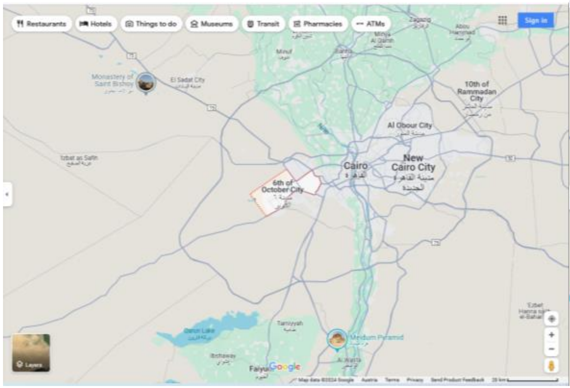
Figure 55: Location of Giza Governorate

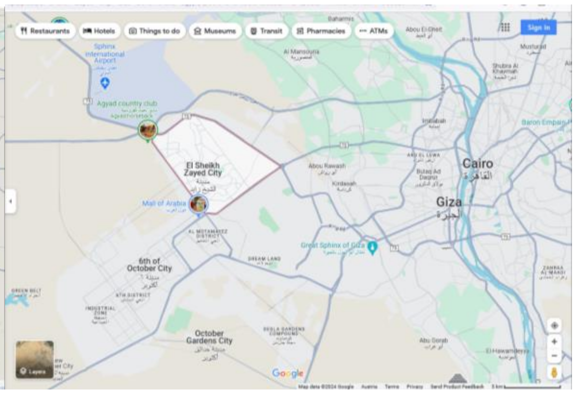
[71] Although this is not specifically mentioned on the website, it may be understood that the country intends moving towards 'sanitary landfills', as the text mentions "creating newer, more modern ones in remote areas".

[72] https://www.cemnet.com/News/story/160444/egypt-cement-plants-to-use-15-of-waste-by-2030.html [Accessed on 19 April 2024].

[73] According to the Weebly website http://6thoctobercity.weebly.com [Accessed on 19 April 2024].

[74] According to the Wikipedia website https://en.widipedia.org/wiki/Sheikh_Zayed_City [Accessed on 19 April 2024].





Source: Google Maps.

Figure 56: Location of the 6th of October City

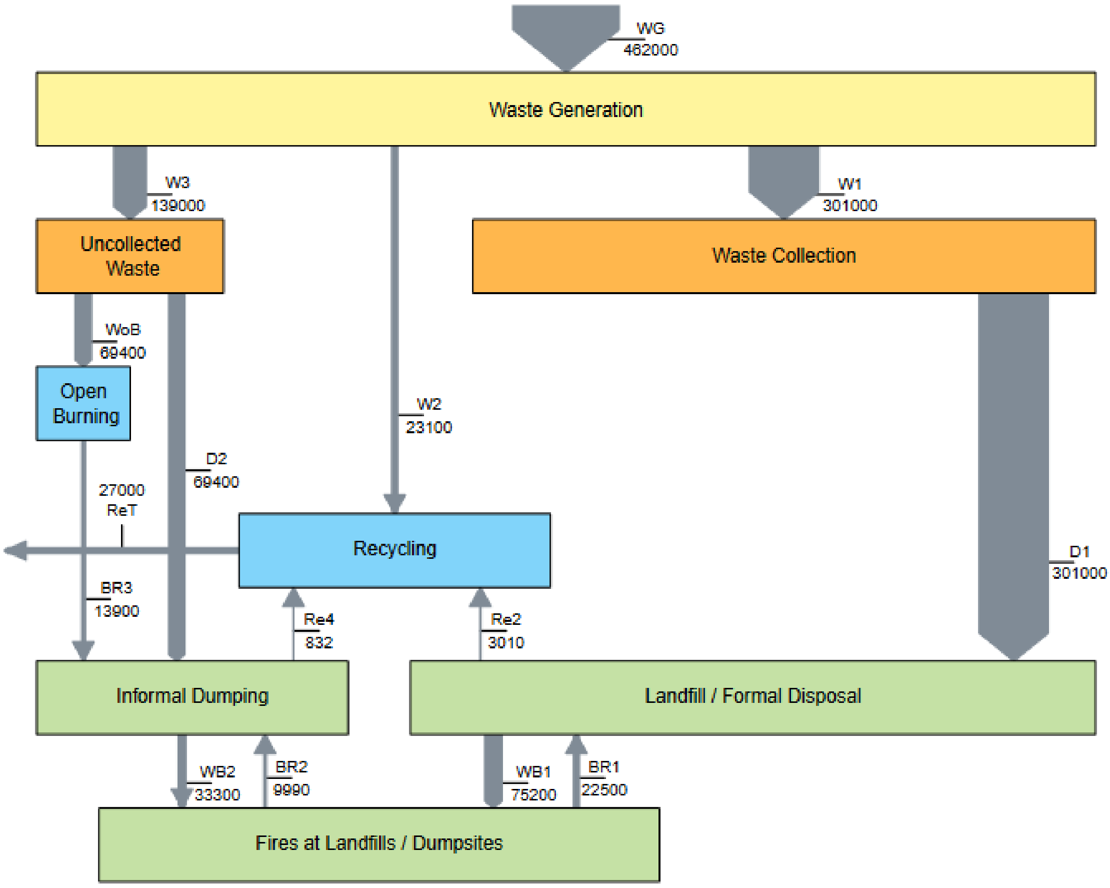
Figure 57: Location of Sheikh Zayed City

Analysis of the current state of waste management using the WaPla software

According to data received from the Chemonics Egypt Consultants in Giza, the total quantity of waste generated in the aforementioned 2 cities[75] in the Giza Governorate is unknown. Total waste collected from them is 301,016 tons/year. An MRF does not exist, and composting and (formal) incineration in an incinerator are not carried out. The collected quantity of 301,016 tons/year reportedly goes directly to a landfill. Moreover, the MSW does not undergo segregation, is normally dumped in the landfill/dumpsite and a sand-layer spread over it. Waste pickers [Note of the MT author: understood to be from the informal sector] take out some material such as paper and cardboard [Note of the MT author: since metal is in demand all over the world, and it is considered to be a normal practice in emerging economies that metal is removed from waste and sold to recyclers, the same has been assumed in this case].

As mentioned above, the amount of waste generated was not known. Based on data from two other Governorates in Egypt, namely, the Qalyubia and Assiut Governorates, for the purposes of calculating in the WaPla software, waste generated in Giza Governorate, in the 2 aforementioned cities, has been estimated; the estimated quantity is around 462,500 tons/year. Thus, data on waste generated and collected, based on the above, was entered into the WaPla software and calculations carried out, the results of which are presented in the following:

[75] Hereafter, for easy readability, referred to as only 'the Giza Governorate'.



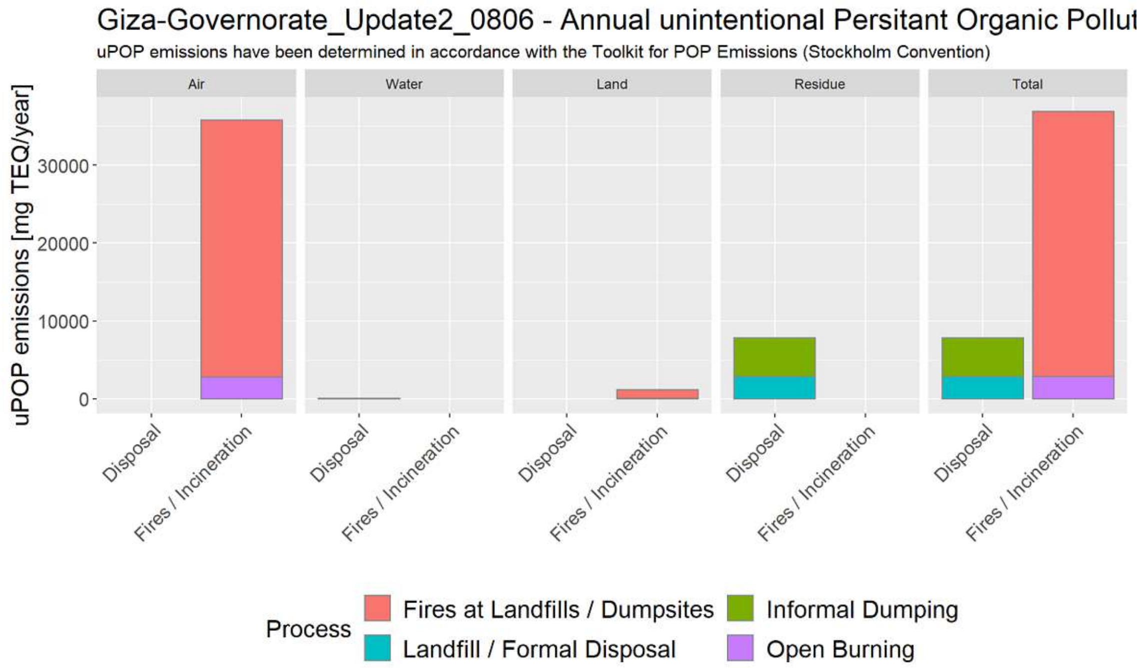
Source: WaPla Software.

Figure 58: Giza Governorate – Waste flow

In the above waste flow diagram, the waste generation is, as mentioned above, 462,000 tons/year, waste collected 301,000 tons/year, which goes directly to the (formal) landfill/dumpsite; therefore, uncollected waste is 139,000 tons/year, which goes directly into informal/unregulated open burning and dumping. Some material[76] for recycling is taken out from the total waste. Fires take place both at formal and informal landfill/dumpsites.

The following figure shows the uPOPs emitted per year:

[76] Estimated at 5% from households, that is, 23,100 tons/year. According to information received, some paper & cardboard are taken out; therefore, the share of paper & cardboard has been estimated to be 20% and share of metal to be 80% of the materials which are recycled.



Source: WaPla software.

Figure 59: Giza Governorate – uPOPs emissions bar chart

The following table presents the calculated quantities of emissions into the environment:

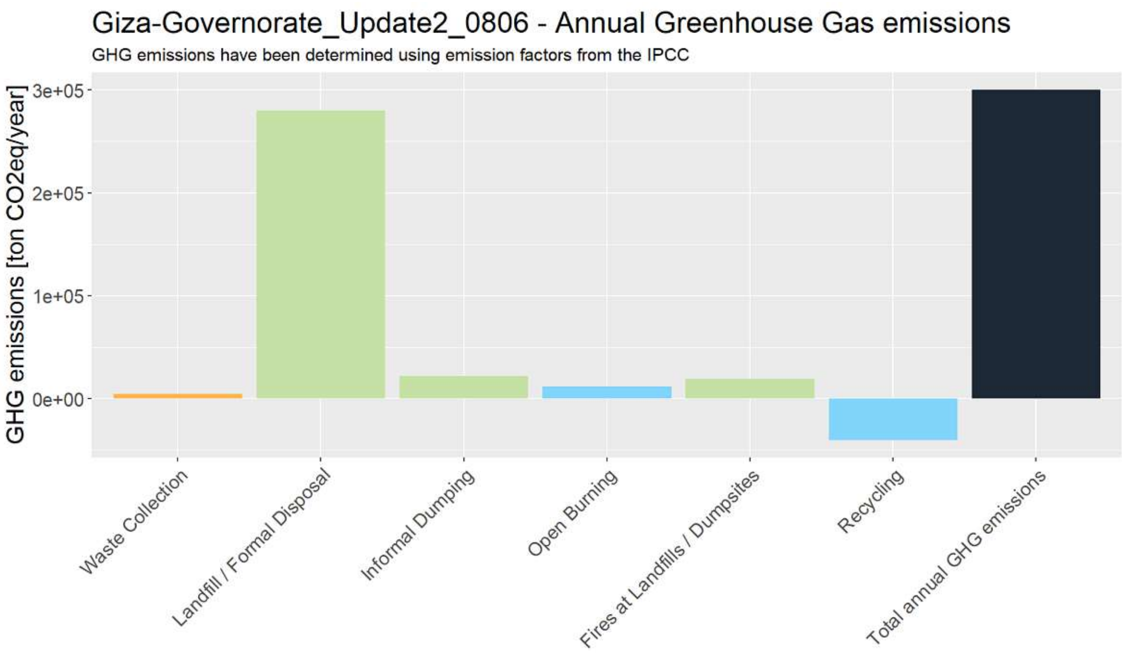
Table 9: Giza Governorate uPOPs emissions quantities

Process	To Environment	Mg TEQ/year
Open burning	Air	2,800
Fires at landfills/dumpsites	Air	33,000
Informal dumping	Water	49
Landfill/formal disposal	Water	29
Open burning	Land	69
Fires at landfills/dumpsites	Land	1,100
Informal dumping	Residue	4,900
Landfill/formal disposal	Residue	2,900
Informal dumping	Total	2,900
Landfill/formal disposal	Total	4,900
Open burning	Total	2,900
Fires at landfills/dumpsites	Total	34,000
	Total	**44,700**

Source: WaPla software.

As in the case of the Chongwe District in Zambia, the uPOPs emissions have been calculated according to the Stockholm Convention Toolkit for POPs emissions[77]. And similar to the Chongwe District, the highest uPOPs emissions are due to the (regulated and unregulated) fires at the landfills/dumpsites and open burning. The quantity of uPOPs is higher as the amount of waste is much higher in the case of the Giza Governorate as compared to the Chongwe District in Zambia.

The following graph illustrates the GHG emissions in the annual waste flow system:



Source: WaPla software.

Figure 60: Giza Governorate – GHG emissions bar chart

The following table presents the calculated quantities of GHG emissions:

Table 10: Giza Governorate – GHG emissions quantities

Process	**Tons CO2eq/year**
Waste collection[78]	4,700
Landfill/formal disposal[79]	280,000

[77] The given default factors of 40 ug TEQ/t waste burned for air and 1 ug TEQ/t waste burned for land are based on the *Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs (Stockholm Convention on Persistent Organic Pollutants). The given default factors of 300 ug TEQ/t waste burned for air and 10 ug TEQ/t waste burned for land are based on the Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs (Stockholm Convention on Persistent Organic Pollutants).*

[78] According to Larsen et al. (2009), diesel consumption in waste collection trucks is in the range of 1.4-10.1 Litre per ton of waste. Therefore, 6 Litre per ton of waste has been taken as reference value and the value then corresponding to the amount of waste collection has been entered in WaPla.

[79] Estimates entered in the WaPla software are as follows: Waste burned at formal landfills: 25%; recyclables from landfills: 1%; rate of biodegradation: 0.23; therefore, waste to landfill stock: 57%.

Informal dumping	22,000
Open burning	12,000
Fires at landfills/dumpsites	19,000
Recycling	-40,000
Total GHG emissions	**300,000**

Source: WaPla software.

Although the quantities are much larger, a pattern similar to that of the Chongwe District emerges. The GHG emissions are the highest at the regulated landfills/dumpsites, followed by at the unregulated dumpsites, and then at the unregulated landfills/dumpsite. GHG emissions in the recycling process are shown as negative to show the value of GHG emissions that would have taken place if these materials would not have been recycled, but also disposed off in another manner, for example, at the landfills/dumpsites.

The above table shows a calculated value of 300,000 tons CO2-emissions/year from the currently existing waste-management practices in the Giza Governorate. Taking the population of the 2 aforementioned concerned cities into consideration, together 1,075,000, this corresponds to 0.2790 tons/capita/year, or around 280 kg/capita/year.

In Egypt, the CO2-emissions are estimated to be 238.56 million tons/year, that is, 2.168 tons/capita/year.

The CO2-emissions per capita per year from the current waste-management practices in the Giza Governorate make up 12.92% of the total Egyptian CO2 per capita per year emissions.

Similar to the Chongwe District, 4 different scenarios have been calculated in the WaPla software:

Scenario 1 – only composting;

Scenario 2 – only incineration;

Scenario 3 – only WTE;

Scenario 4 – 80% collection + WTE.

The screenshots of the results are included in Annex 6.1. The table including relevant data from all the 4 scenarios for the Giza Governorate is included below:

Table 11: Giza Governorate – 4 scenarios for waste management

	Waste collected t/yr	Composting	Incineration	WTE	UPOPs mg TEQ/yr	GHG t/yr	GHG emissions per capita per year
Current scenario	301,016	-	-	-	44,700	300,000	280 kg
Scenario 1 – only composting	301,016	Managed	-	-	41,600	260,000	242 kg
Scenario 2 – only incineration	301,016	-	good air pollution control	-	37,610	100,000	93 kg
Scenario 3 – only WTE	301,016	-	-	X	37,610	-59,000	
Scenario 4 – 80% collection + WTE	370,000	-	-	X	30,050	-83,000	

Key results from the above table are as follows:

Scenario 1: If only composting is introduced and carried out, only a slight reduction in the uPOPs and CO2-emissions can be achieved.

Scenario 2: If 90% of all waste collected is incinerated, the CO2-emissions are reduced by 60%.

Scenario 3: If 90% of all waste collected is brought to a WTE facility, the CO2-emissions are reduced by over 100%

Scenario 4: If waste collection is enhanced to 80%, and collected waste is sent to a WTE facility, uPOP-emissions are reduced by 32% and CO2-emissions are reduced by 130%.

4 Summary and Conclusions

4.1 Summary and Conclusions

The following conclusions and suggestions are based on the analysis presented in the previous section.

WaPla software:

Based on the above examples, it is clear that the WaPla software is a very effective instrument for the following:

i. Provide an overview of MSW flows in a city or even country;
ii. Identify the most crucial/most affected waste disposal methods;
iii. Identify parts of the emissions into air, water and land;
iv. Calculate uPOPs and GHG emissions;
v. Identify the sources of highest uPOPs and GHG emissions;
vi. Enhance awareness about the waste data necessary to be collected;
vii. Adapt the data and assess different scenarios to be considered in waste management planning.

Similarities between the Chongwe District and the Giza Governorate:

Based on the above presented data, results and analysis of the WaPla software, a few similarities between both examples emerge[80]:

i. Population has a positive growth trend in both cases; this means that an increase in the quantities of waste can also be expected;
ii. Waste-related data collection has not or not consistently been carried out in both cases;
iii. In both cases, the coverage of waste collection has high scope for expansion;
iv. Waste in both cases consists of a high percentage, over 50%, of organic waste;
v. Landfills/dumpsites are a major critical issue in both cases and both countries should consider a shift away from the landfills/dumpsites.

Chongwe District:

i. Reference is made to scenario 1: Since the waste collected contains 53% organic material, and if 90% of the organic material from the collected waste is sent for composting, then according to the current set of calculations, an estimated 60% of the CO2eq emissions can be reduced. In the absence of

[80] Which are also in line with findings of the WB (2018), UNEP (2015, 2024), etc.

other waste-disposal options, other than landfilling, it might be worthwhile for the Chongwe District to consider introducing composting.

ii. Reference is made to scenario 3: If waste collection is enhanced to double, that is to 68%, and waste is formally incinerated, the uPOP-emissions are reduced by over 50%, and CO_2-emissions are reduced by almost 46%. The WaPla calculation has been done considering 'good air pollution control' at the incinerator. However, should this not be the case, then, the incineration process would add on to the emissions.

iii. Reference is made to scenario 4: If waste collection is enhanced to 80%, and collected waste is sent to a WTE facility, uPOP-emissions are reduced by over 60% and CO_2-emissions are reduced by almost 200%. This might present a good solution in the long-term, although the initial cost of establishing the facility and the running costs would be high, and relevant expertise would be required, as it would save valuable land in the long-term, which is being used for landfilling.

iv. Interestingly, a decision would depend upon whether only the CO_2-emissions are considered, both uPOPs and CO_2-emissions are considered, or both and the CO_2-emissions per capita are taken into account. The best values of both uPOPs and CO_2-emissions have been achieved by enhancing the rate of waste collection and by (the construction of a) WTE facility. However, a factor which has not been taken into consideration in the above calculations is cost.

v. The small size of population of the Chongwe District facilitates introducing pilot projects in the district with appropriate monitoring, the results of which can then be replicated in the country. At the same time, it might prove to be beneficial to consider a wider geographical coverage with a more expensive option, for example a WTE, which could cover more than just the Chongwe District.

vi. It is clear that waste collection needs to be enhanced urgently.

vii. The Chongwe District could start with introducing a composting facility and then make a decision on the type of disposal technology it wishes to establish, preferably away from landfilling.

Giza-Governorate/Egypt:

i. In view of the current high population of the country and especially the positive population growth rate, a continuation of the increase of the population can be expected, resulting in a corresponding increase in the quantity of MSW.

ii. Taking the high quantities of emissions, both uPOPs and GHG, at the landfills, it is clear that the country/the Governorates have to move away from the landfills/dumpsites. Also, in view of the existing large population and expected positive growth of population, the practice of landfills/dumpsites is not sustainable, and adverse impact on the environment and mainly on health can be expected in the future. As mentioned earlier, the country does seem to have plans to move away from current landfills/dumpsites.

iii. Reference is made to scenario 2: If 90% of all waste collected is incinerated, the CO2-emissions are reduced by 60%. This might present a good waste-disposal option for the Giza Governorate considering that a few cement kilns exist in Egypt; this might prove beneficial in that the initial investment in the construction of a completely new facility is not necessary.

iv. Reference is made to scenarios 3 and 4: If 90% of all waste collected is brought to a WTE facility, the CO2-emissions are reduced by over 100% and if waste collection is enhanced to 80%, and collected waste is sent to a WTE facility, uPOP-emissions are reduced by 32% and CO2-emissions are reduced by 130%. Since some articles have mentioned plans of the Government to establish WTE facilities, a WTE facility might indeed present a good solution, taking into consideration the growing population and the growing quantity of waste and ideally moving away from using further land for waste disposal.

   Similar to the Chongwe District, the costs have not been taken into consideration for the calculations in the WaPla software.

v. Till a final decision is made on an appropriate waste-disposal technology, similar to the Chongwe District, taking into consideration the high amount of organic waste, composting can be introduced in the meantime.

Suggestions for emerging economies regarding waste management:

Based on the information and analysis presented in chapters 2 and 3, it is crucial that emerging economies should:

i. Understand the critical situation of increasing waste quantities;

ii. Collect data on different types of waste;

iii. Increase the rate of waste collection from households;

iv. Make efforts to expand the coverage of waste collection;

v. If realistic, incinerate in incinerators or cement kilns non-hazardous non-recyclable waste, otherwise bring such waste to the (sanitary) landfills; however, in view of the increasing quantity of waste, a landfill may not be a good long-term solution;

vi. Carry out awareness-raising of the population with regard to sustainable consumption, waste, waste segregation and appropriate waste management;
vii. Monitor the situation of waste;
viii. Keep records of all data related to waste, including waste generation, types of waste, waste collection and waste disposal.
ix. Consider establishing WTE plants.

UNEP (2024, pp.69-75) has included the following recommendations for an improvement of waste management systems in emerging economies:

i. Ensuring inclusion and representation;
ii. Building national capacity;
iii. Including waste reduction in Nationally Determined Contributions (NDCs);
iv. Involving the private sector.

Moreover, it has prepared 'Guidelines for Framework Legislation for Integrated Waste Management' (2016, p.2) mainly for policymakers, but also for other persons and organizations involved in areas related to waste, with the objective "to build capacity in legislative development in the critical area of integrated waste management leading to a circular economy" (UNEP, 2016, p.2).

4.2 Critical discussion

Several aspects need to be taken into consideration while planning a proper waste-management system for a city, and possibly for a country. As shown above and in different chapters of this MT, this involves, inter alia, waste-related data, that is, waste generated, waste collected, type of waste, constituents of MSW, existing facilities, current practices, attitudes and behaviour of the population, costs of different waste collection practices, as well as cost of different technologies.

A waste-management planning software, such as the WaPla software, can prove to be very helpful for such a planning, as it is possible to enter different data and carry out different calculations for different scenarios. At the same time, it has its limitations. Firstly, it cannot select or present the best-case scenario based on the entered data. Secondly, although it is very easy to use, the expertise of a waste-management expert is still considered to be necessary, because each parameter can be changed in the software, thus making endless options possible to try out; and a waste-management expert may be able to pre-select a few options which can then be tried out in the software to see the calculated results. Thirdly, all figures are estimates, and the ground situation may be different. It is not possible to account for this in the software, and therefore, the results calculated by the software may not show the actual results. And lastly, many aspects of MSW management are not reflected because of the trade-off between the simplicity of usage and data availability and closeness to reality.

As mentioned earlier, costs have not been taken into consideration in the above calculations. Cement kilns exist in Egypt and it might be possible to use them for waste disposal purposes without too high investment. However, in countries where this is not the case, the country would need to take the costs into consideration.

Although a WTE facility seems to present a best-case scenario, its requirements in terms of resources – personnel, investment, running costs, knowledge – are high. In view of the involved high costs, a possible trade-off might also exist between environmental and cost aspects.

This also makes it clear that there is no one right solution to waste management. UNEP (2015, p. 29) has pointed out the same, “It is however essential to highlight from the beginning that every situation is different. Thus, there are no inherently ‘right’ or ‘wrong’ solutions, nor is it possible to provide a simple ‘user manual’ that will solve every problem. Rather, the GWMO intends to illustrate what can be achieved, and provide some interesting examples and case studies from which each country can draw lessons relevant to their own situation”. Tchobanoglous & Kreith (2002, p.1.25) have also concluded “There is no single prescription for an integrated waste management program that will work successfully in every instance”. The WB (2018, p.5) has mentioned the same, that focusing on only one solution, technology, may actually not present a solution for waste management in emerging economies, and that while planning, introducing or enhancing waste management systems, the emerging economies should consider the local conditions and solutions.

Altogether, it can be said that a proper waste management system would take all technical, financial and governance characteristics of a country into account, in order for it to be sustainable in the long-term. (UNEP, 2015, p.30).

4.3 Outlook

While starting with the MT, the author hoped that a solution can be found for a proper waste-management system in emerging economies. However, it is a complex task, and while carrying out work for the MT, the need for further research in several aspects has emerged, a few of which are mentioned in the following:

i. Collect relevant waste-related data in one example city and carry out a proper waste-management planning in the WaPla software.
ii. Carry out the calculations in the WaPla software for a waste-management planning, taking the costs into consideration.

iii. Carry out research on WTE facilities and how emerging economies can best make use of these.

iv. Carry out research on composting, for example, the costs involved in setting up and operating a composting facility, investments needed, initially and in the long run, etc., and which quantity onwards it would be feasible and beneficial for an emerging economy to introduce composting.

"***We're running out of planet***". (UNEP, 2015, p.43).

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Annex

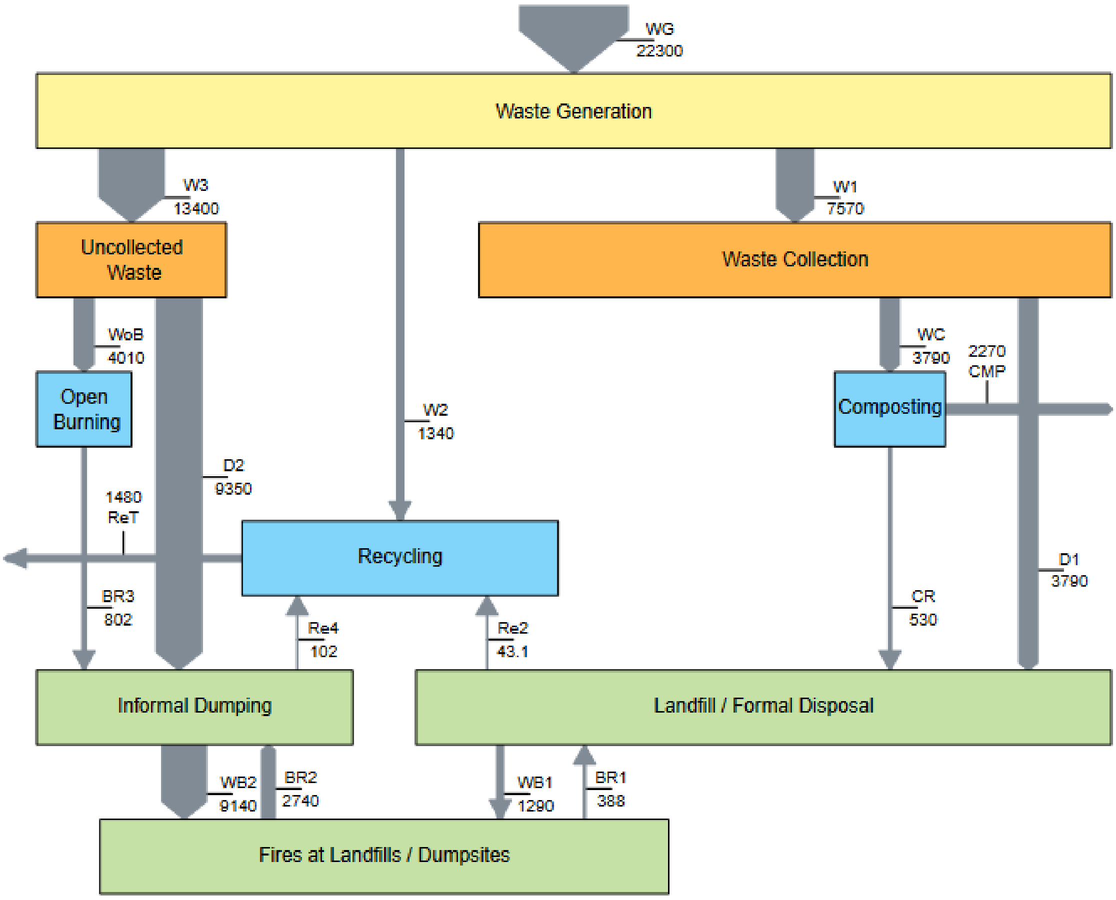
Screenshots of different waste-management scenarios

Following are the screenshots of different scenarios of waste-management planning carried out in the waste-management planning software WaPla, in the Chongwe District, followed by the Giza Governorate.

A. Chongwe District

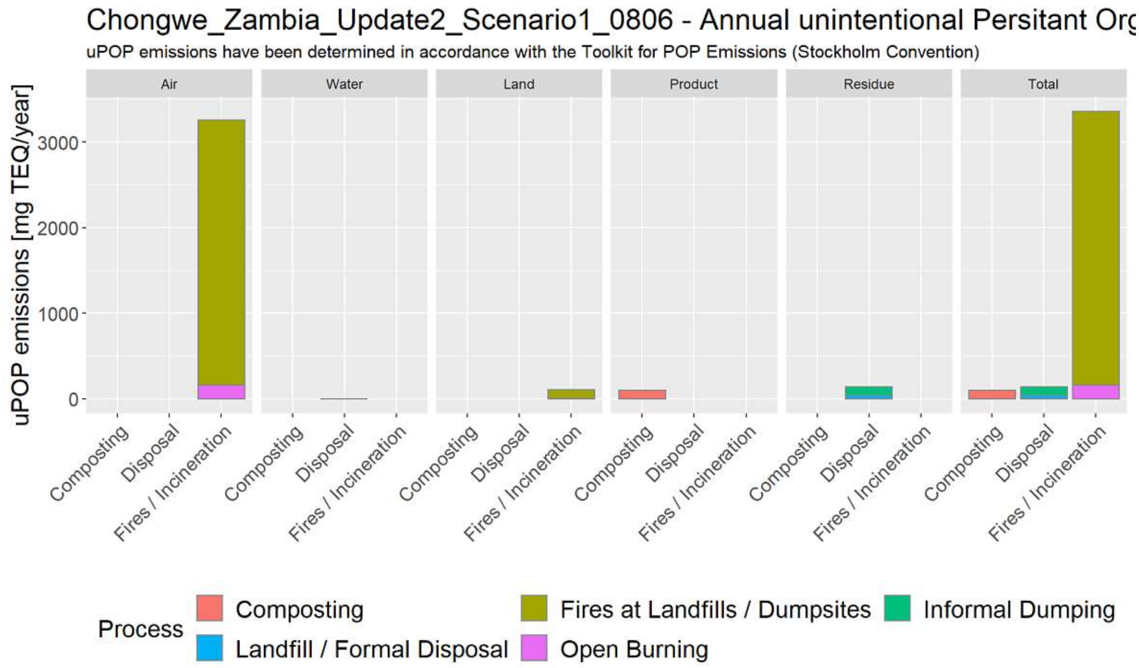
Scenario 1: Composting introduced

Since 53% of the waste is composed of organic waste, in scenario 1, composting has been introduced, and the results are as follows:



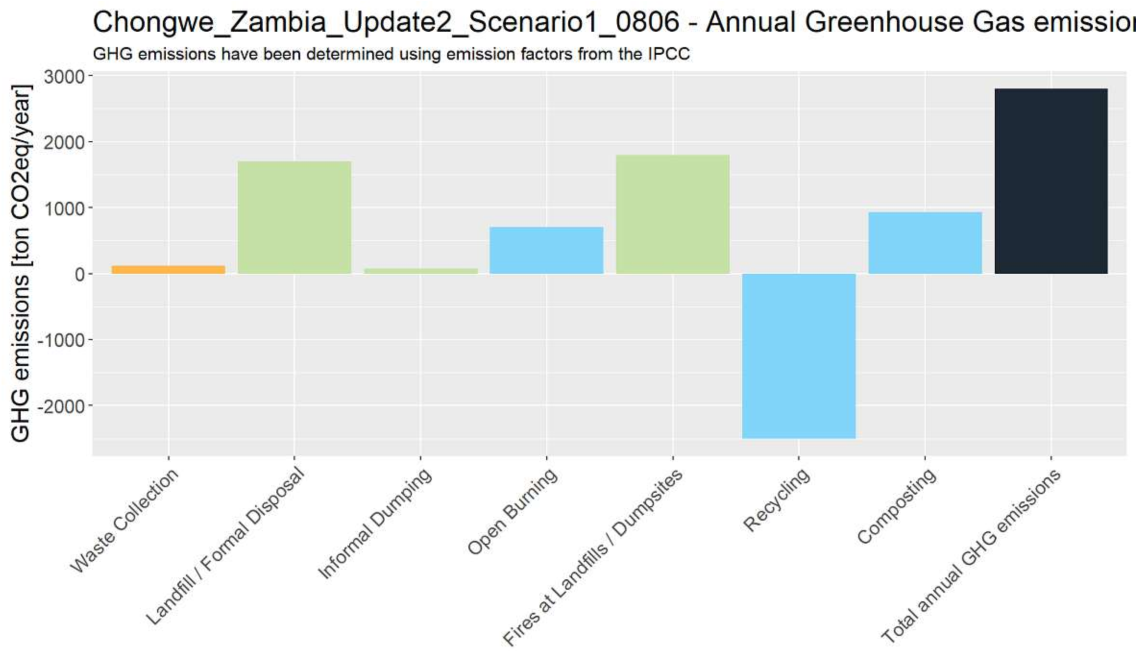
Source: WaPla Software.

Figure 61: Chongwe District: Scenario 1 – Waste flow



Source: WaPla software.

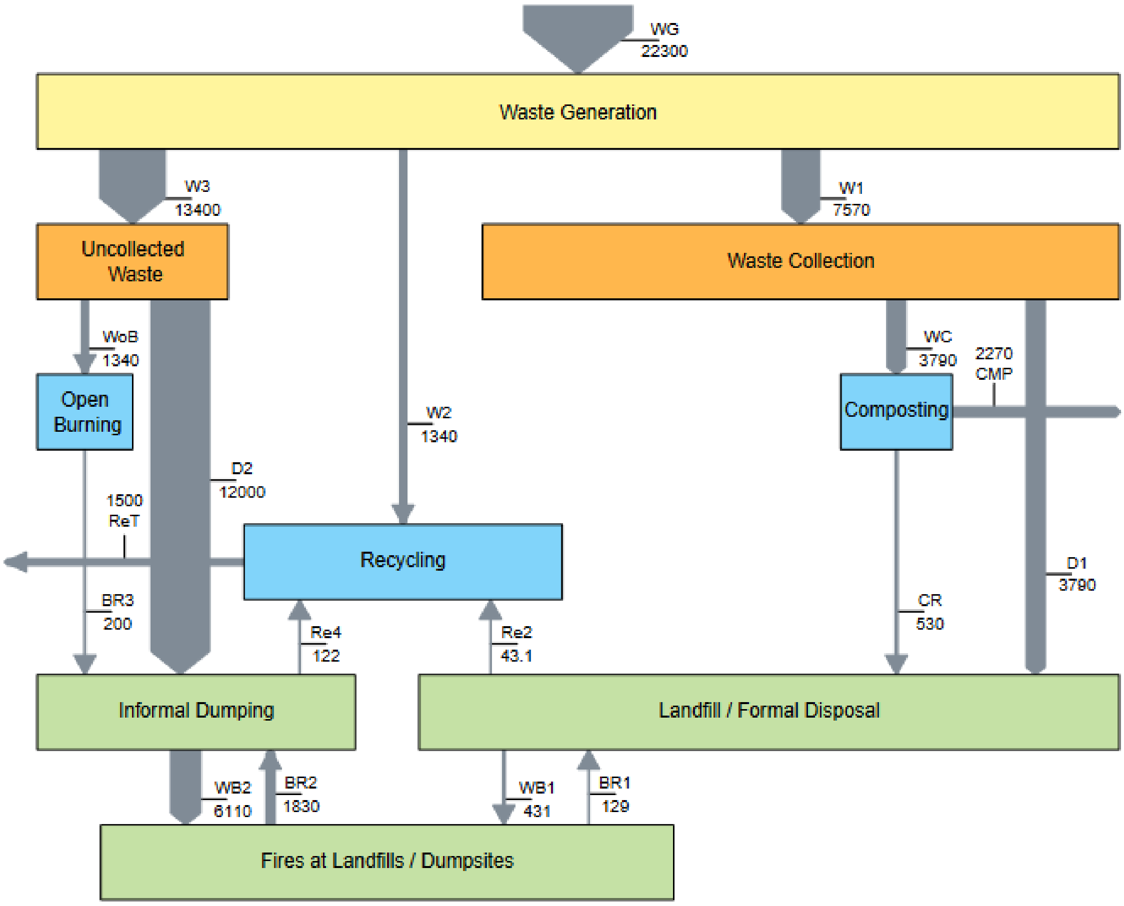
Figure 62: Chongwe District: Scenario 1 – uPOPs emissions



Source: WaPla software.

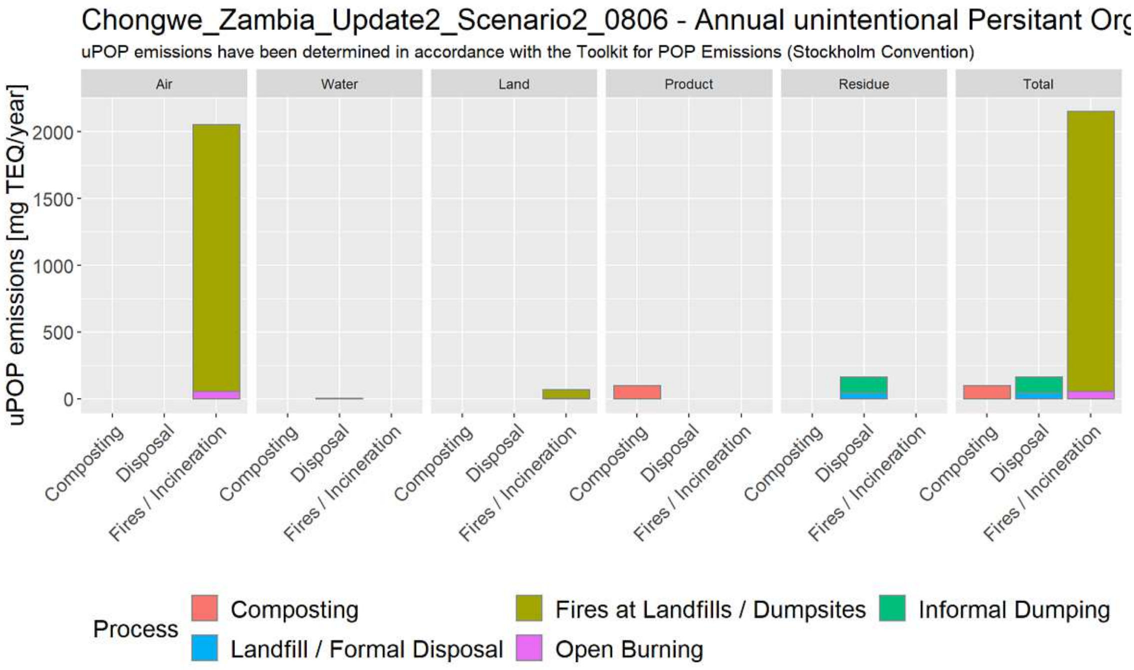
Figure 63: Chongwe District: Scenario 1 – GHG emissions

Scenario 2: Introduction of composting, improvement of landfill, reduction of burning at formal and informal landfills/dumpsites



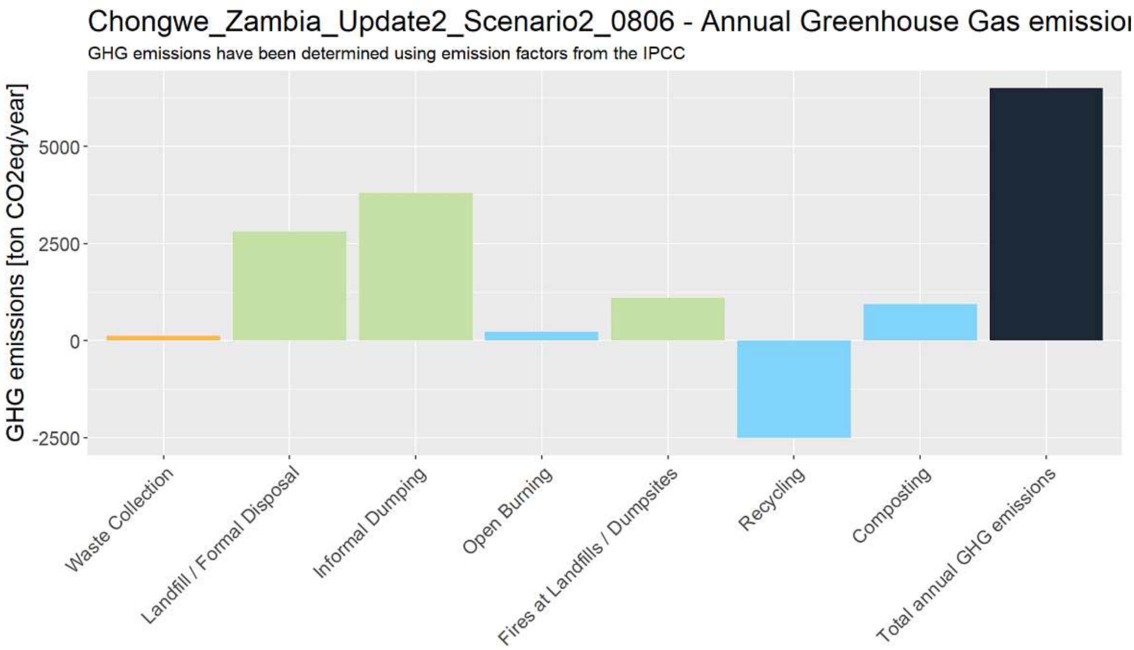
Source: WaPla Software.

Figure 64: Chongwe District: Scenario 2 – Waste flow



Source: WaPla Software.

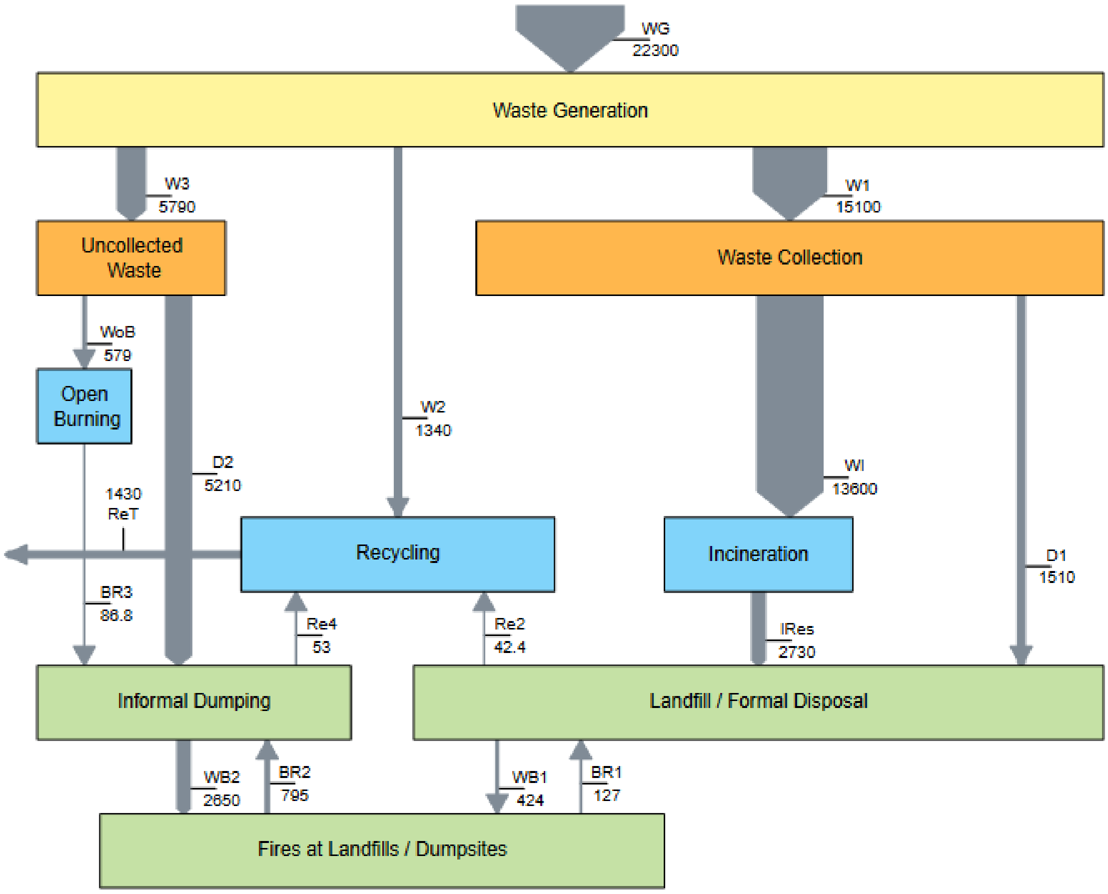
Figure 65: Chongwe District: Scenario 2 – uPOPs emissions



Source: WaPla Software.

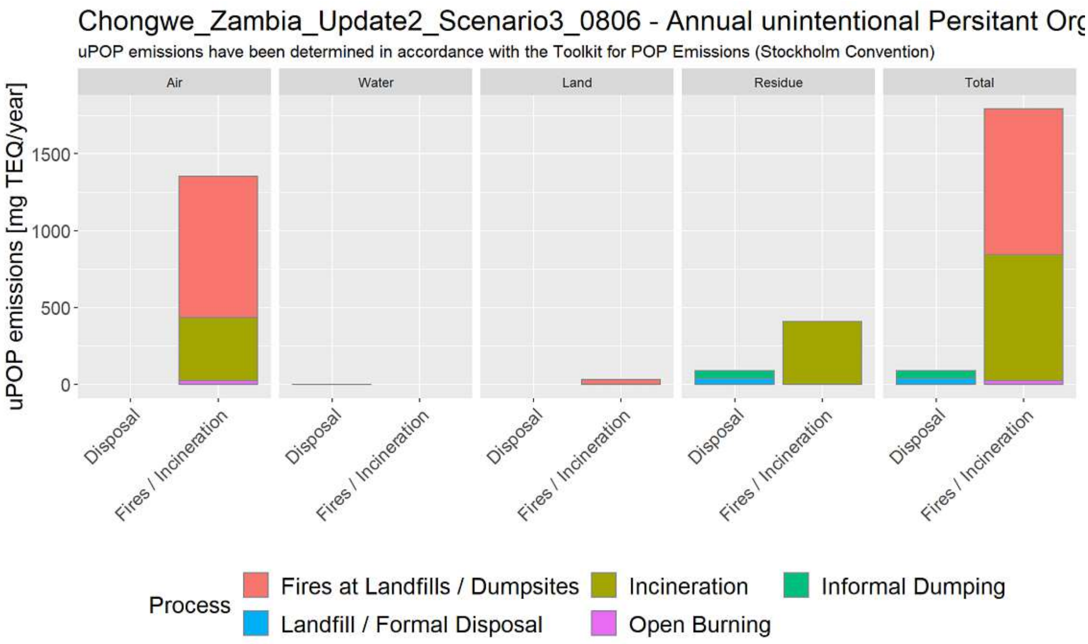
Figure 66: Chongwe District: Scenario 2 – GHG emissions

Scenario 3: Only Incineration (and no composting)



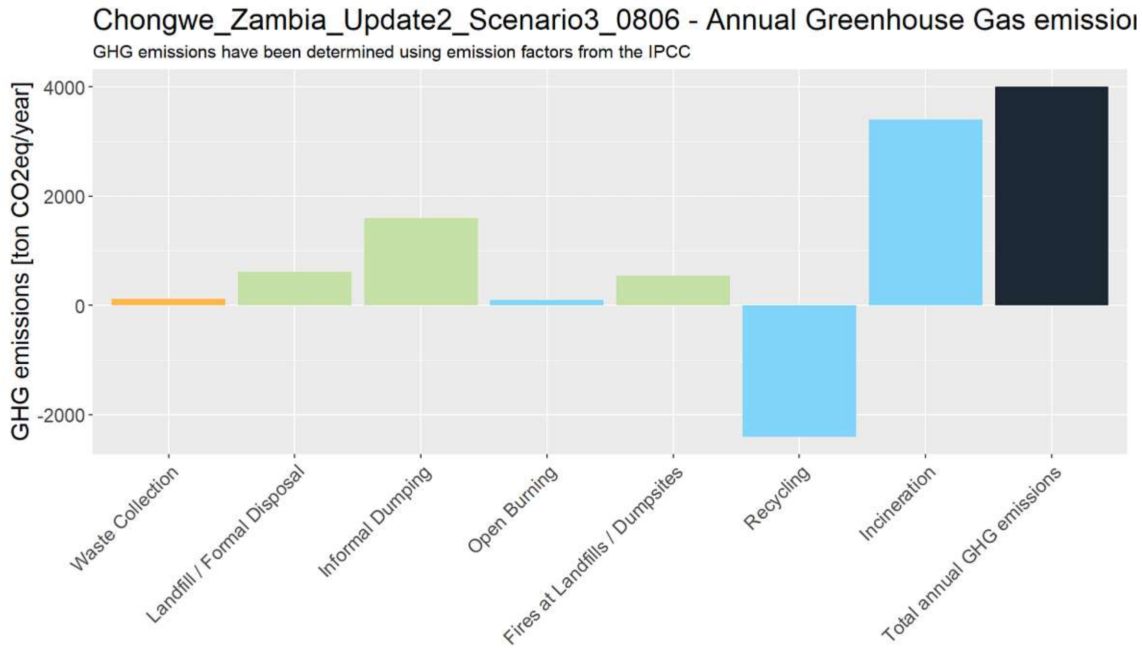
Source: WaPla Software.

Figure 67: Chongwe District: Scenario 3 – Waste flow



Source: WaPla Software.

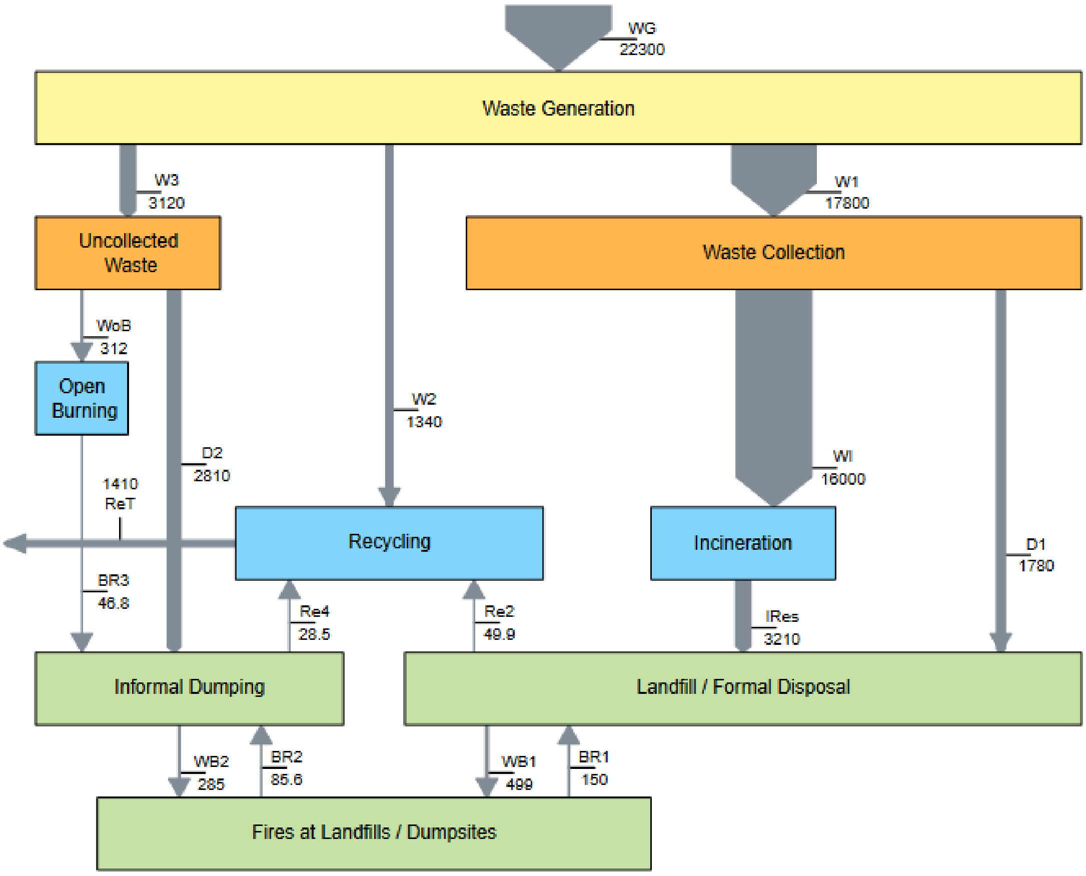
Figure 68: Chongwe District: Scenario 3 – uPOPs emissions



Source: WaPla Software.

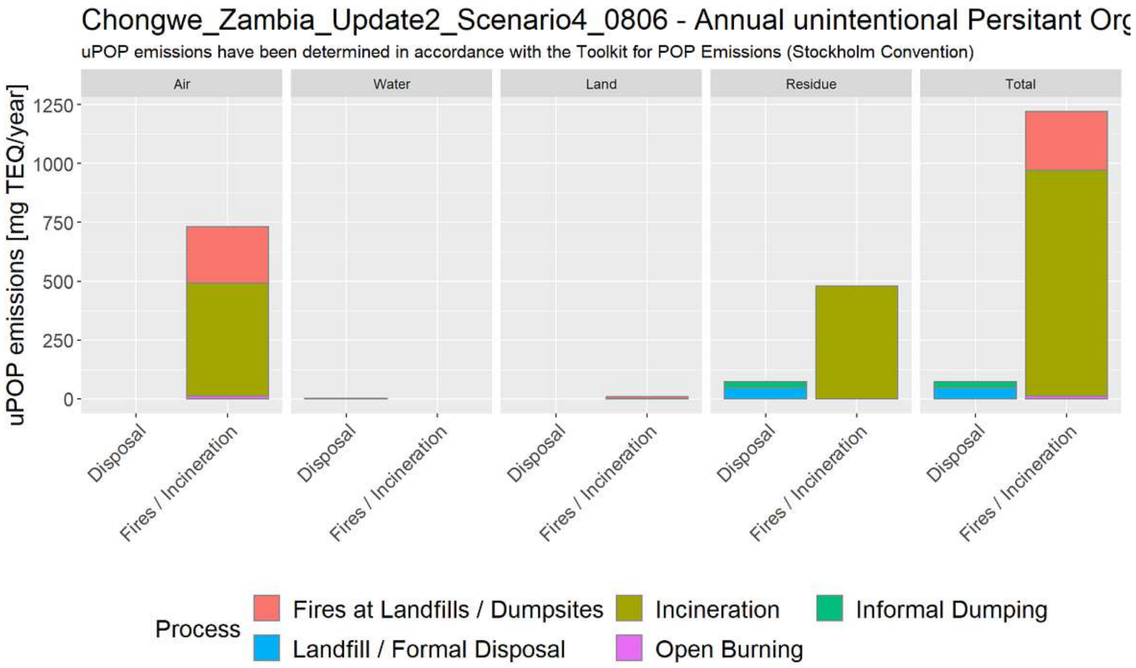
Figure 69: Chongwe District: Scenario 3 – GHG emissions

Scenario 4: Enhanced waste collection – 80% and WTE



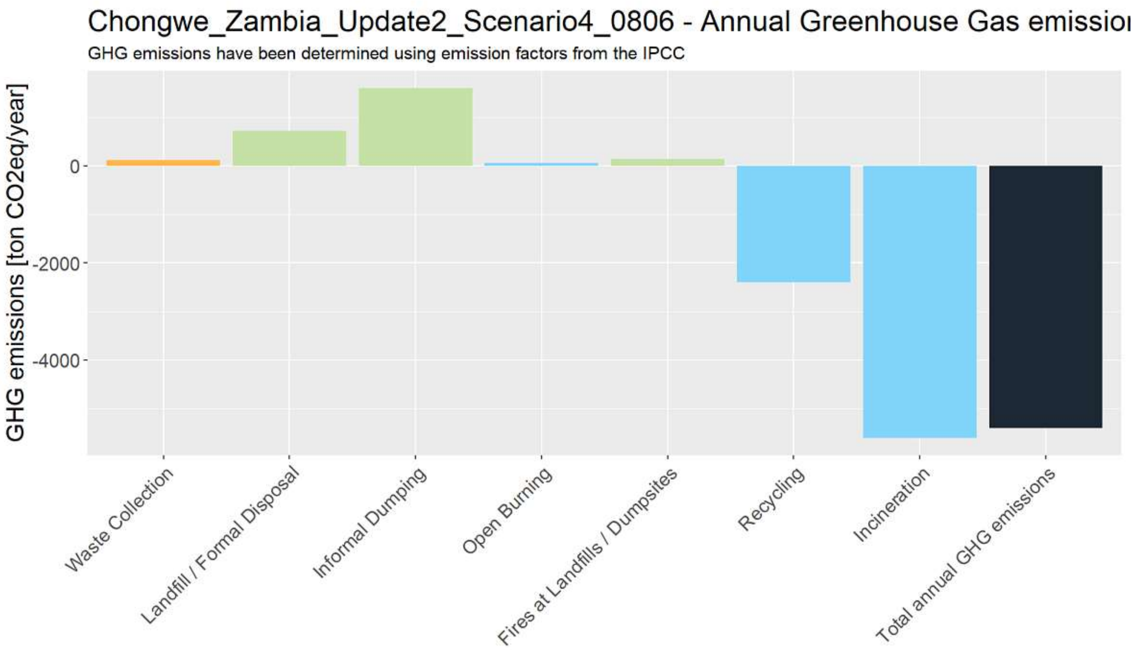
Source: WaPla Software.

Figure 70: Chongwe District: Scenario 4 – Waste flow



Source: WaPla Software.

Figure 71: Chongwe District: Scenario 4 – uPOPs emissions

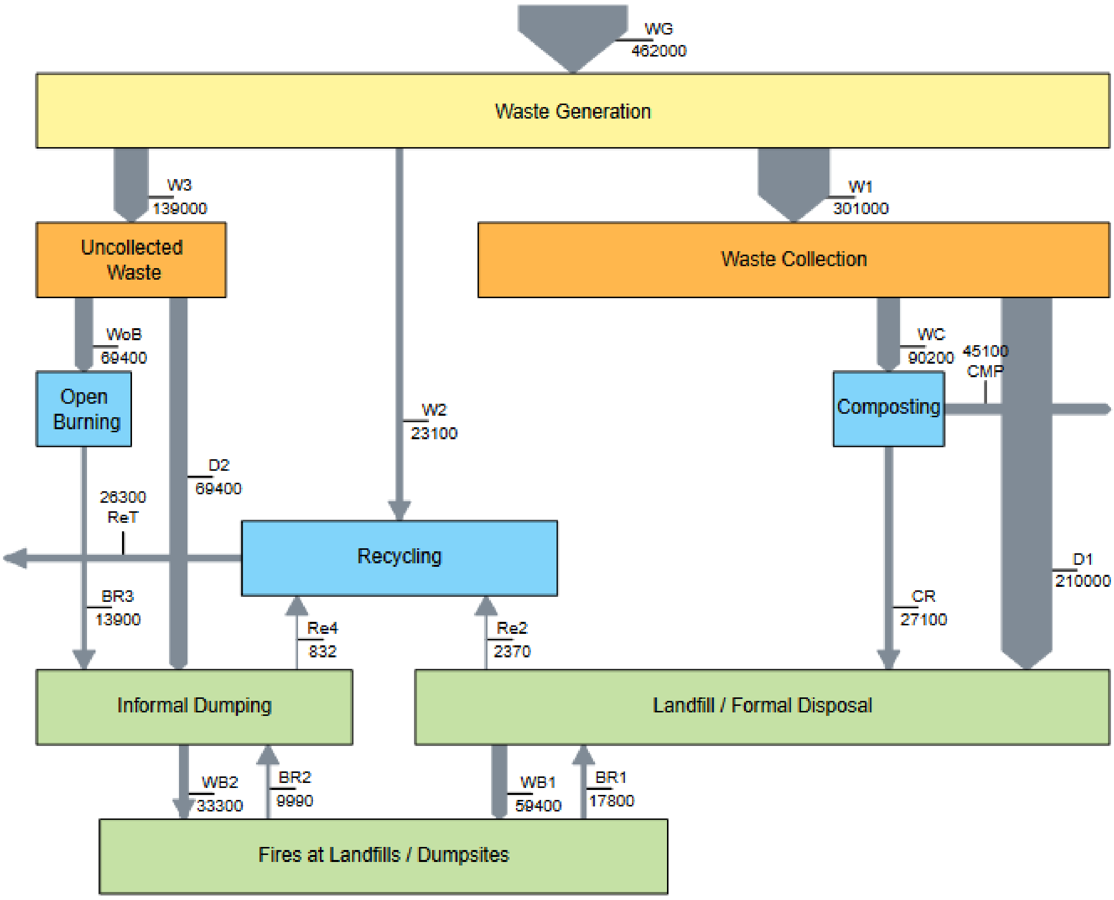


Source: WaPla Software.

Figure 72: Chongwe District: Scenario 4 – GHG emissions

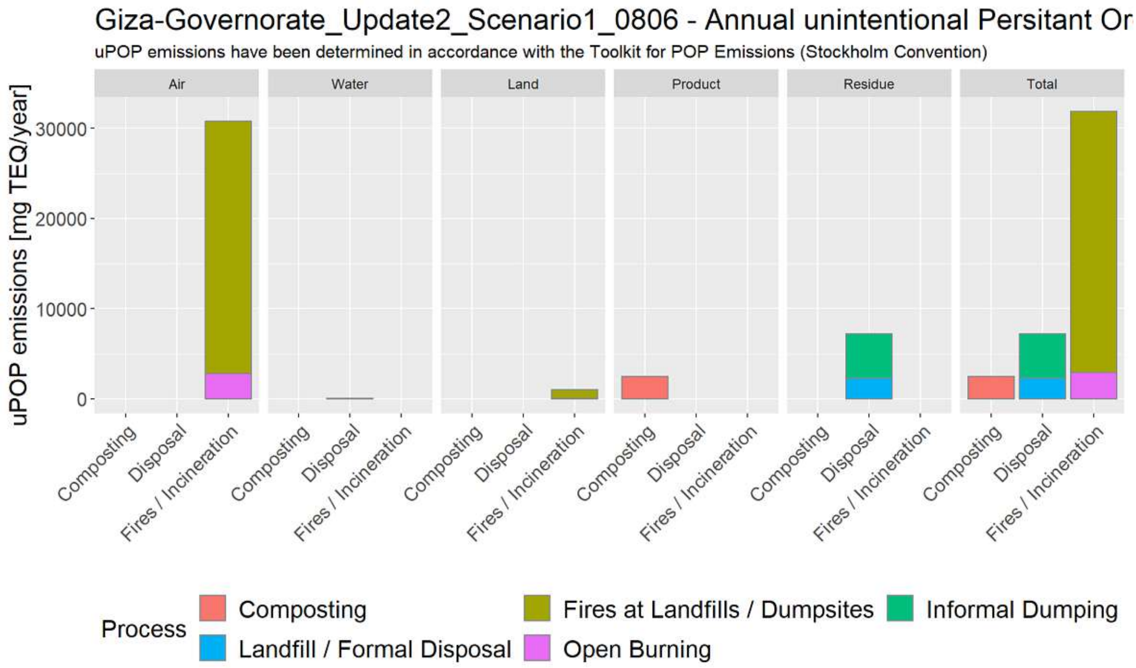
B. Giza Governorate

Scenario 1: Only composting introduced



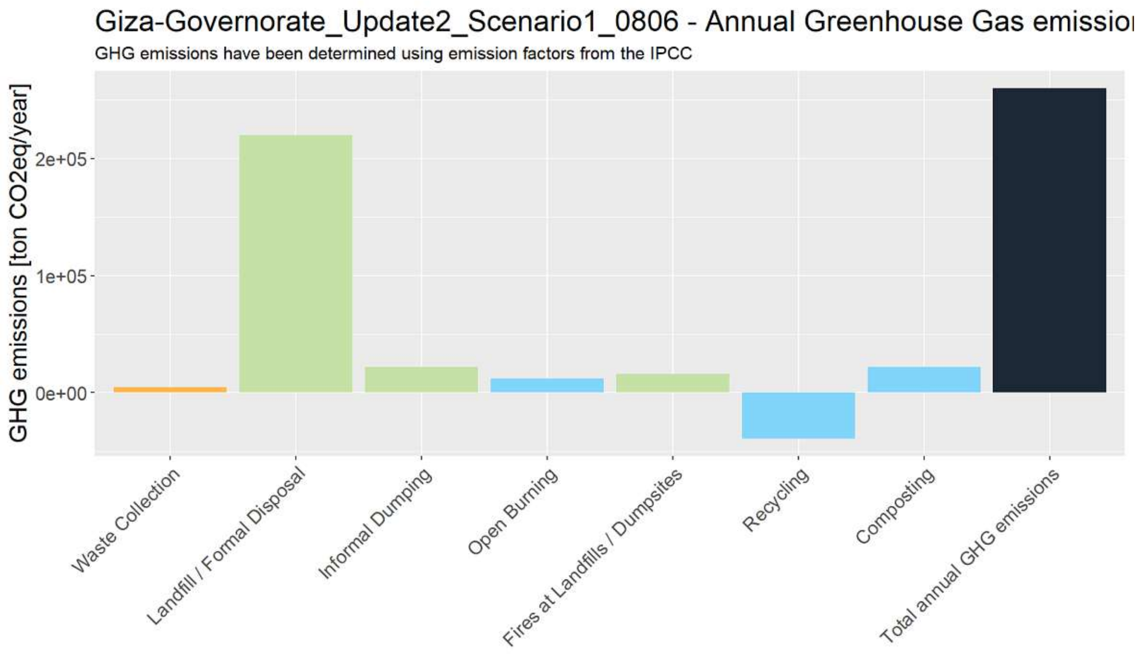
Source: WaPla Software.

Figure 73: Giza Governorate: Scenario 1 – Waste flow



Source: WaPla Software.

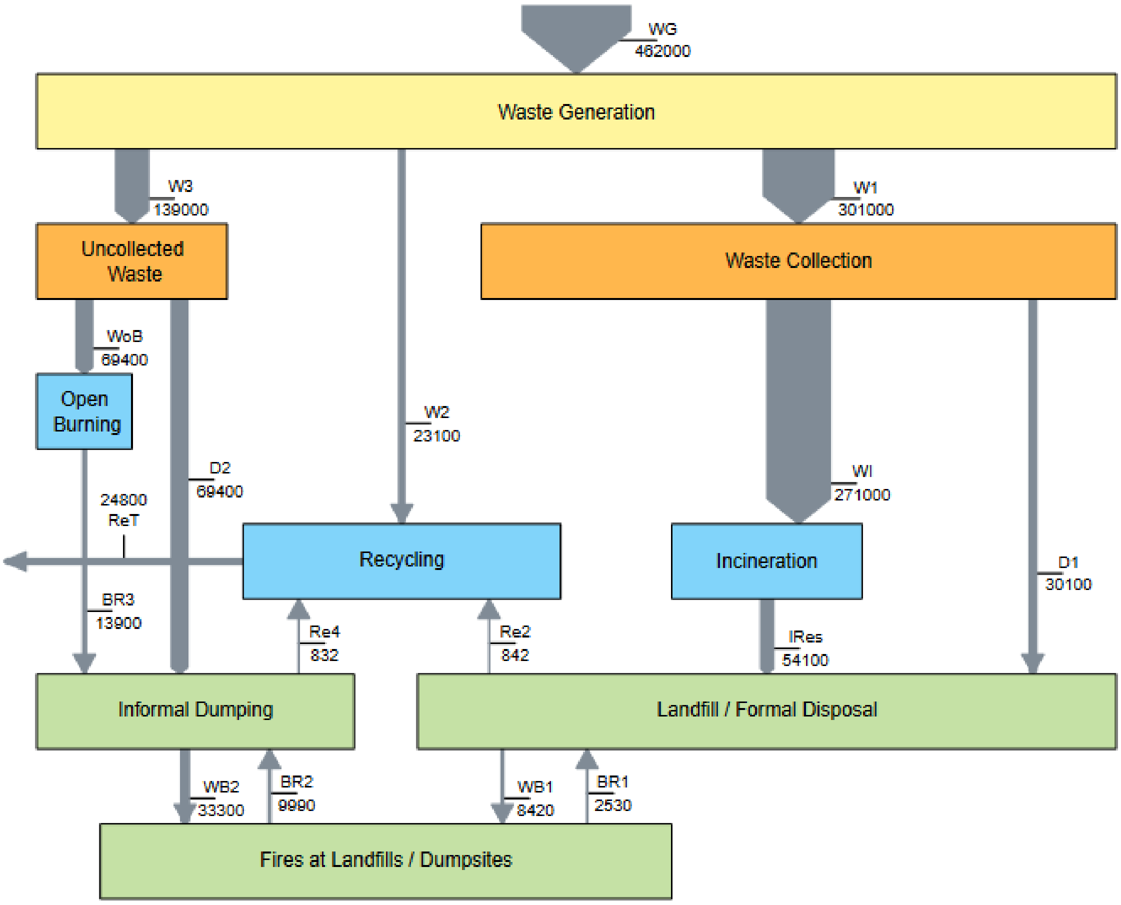
Figure 74: Giza Governorate: Scenario 1 – uPOPs emissions



Source: WaPla Software.

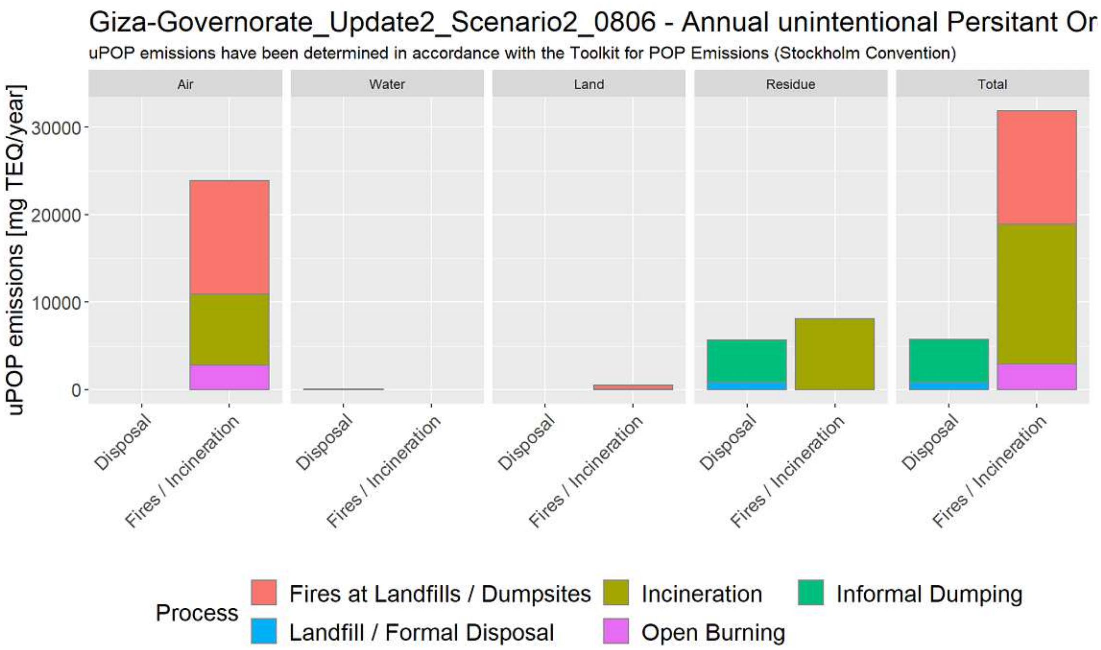
Figure 75: Giza Governorate: Scenario 1 – GHG emissions

Scenario 2: Only incineration (without composting)



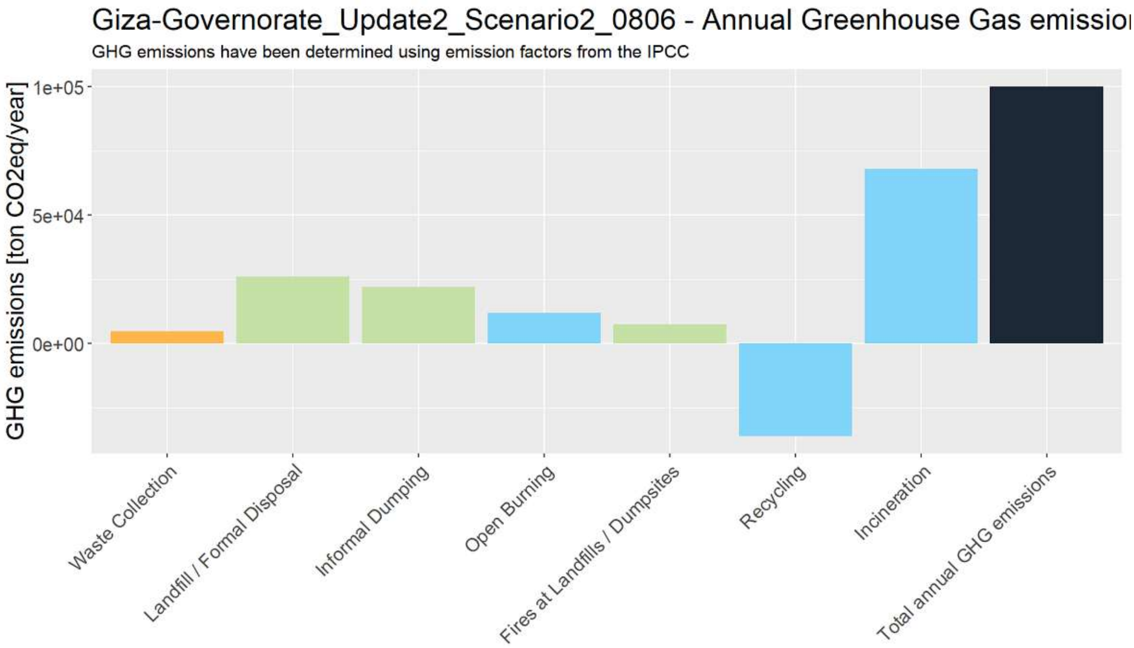
Source: WaPla Software.

Figure 76: Giza Governorate: Scenario 2 – Waste flow



Source: WaPla Software.

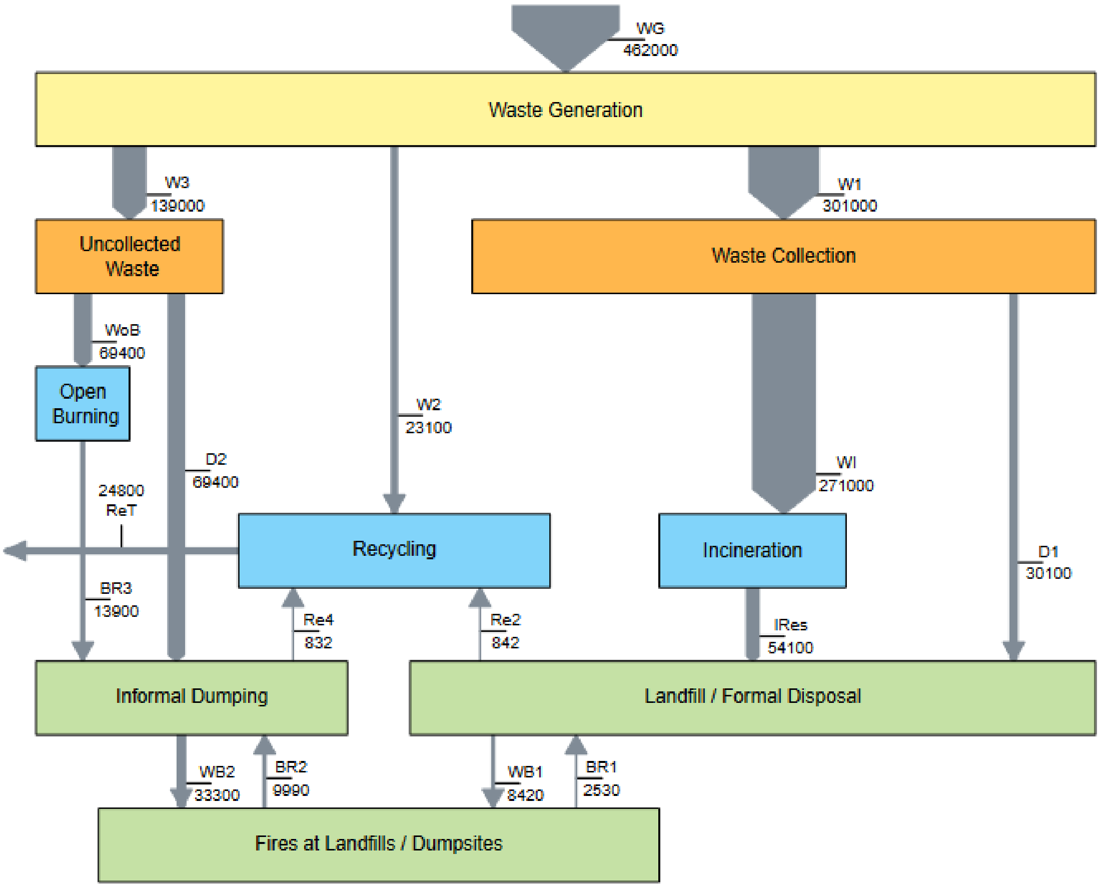
Figure 77: Giza Governorate: Scenario 2 – uPOPs emissions



Source: WaPla Software.

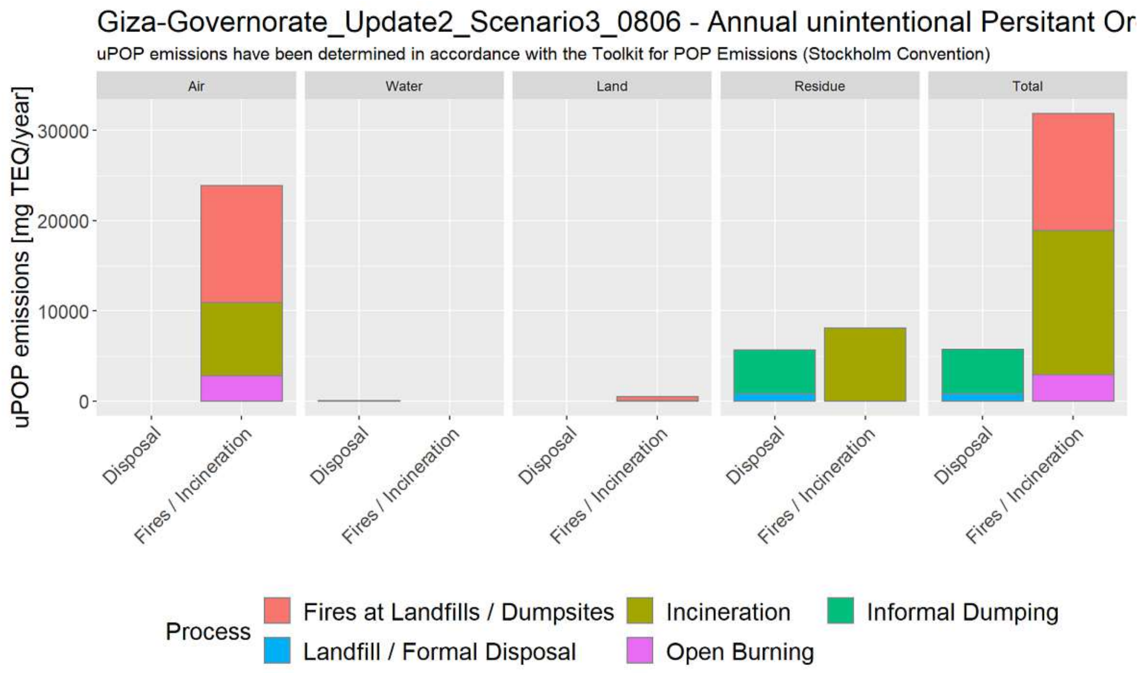
Figure 78: Giza Governorate: Scenario 2 – GHG emissions

Scenario 3: WTE



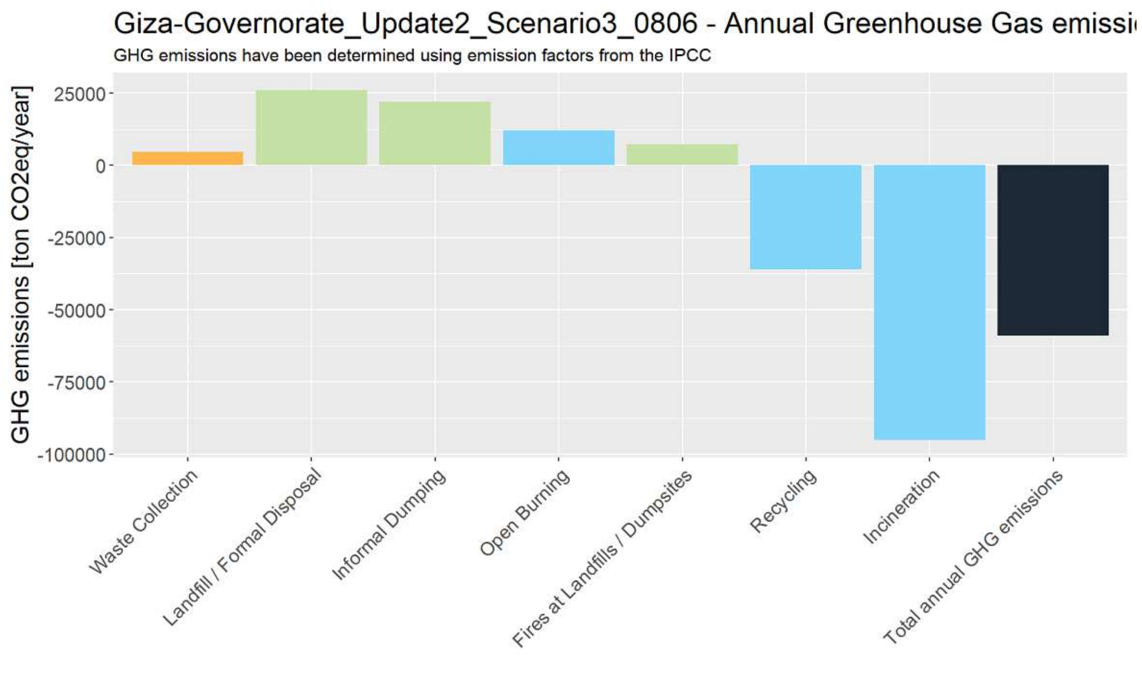
Source: WaPla Software.

Figure 79: Giza Governorate: Scenario 3 – Waste flow



Source: WaPla Software.

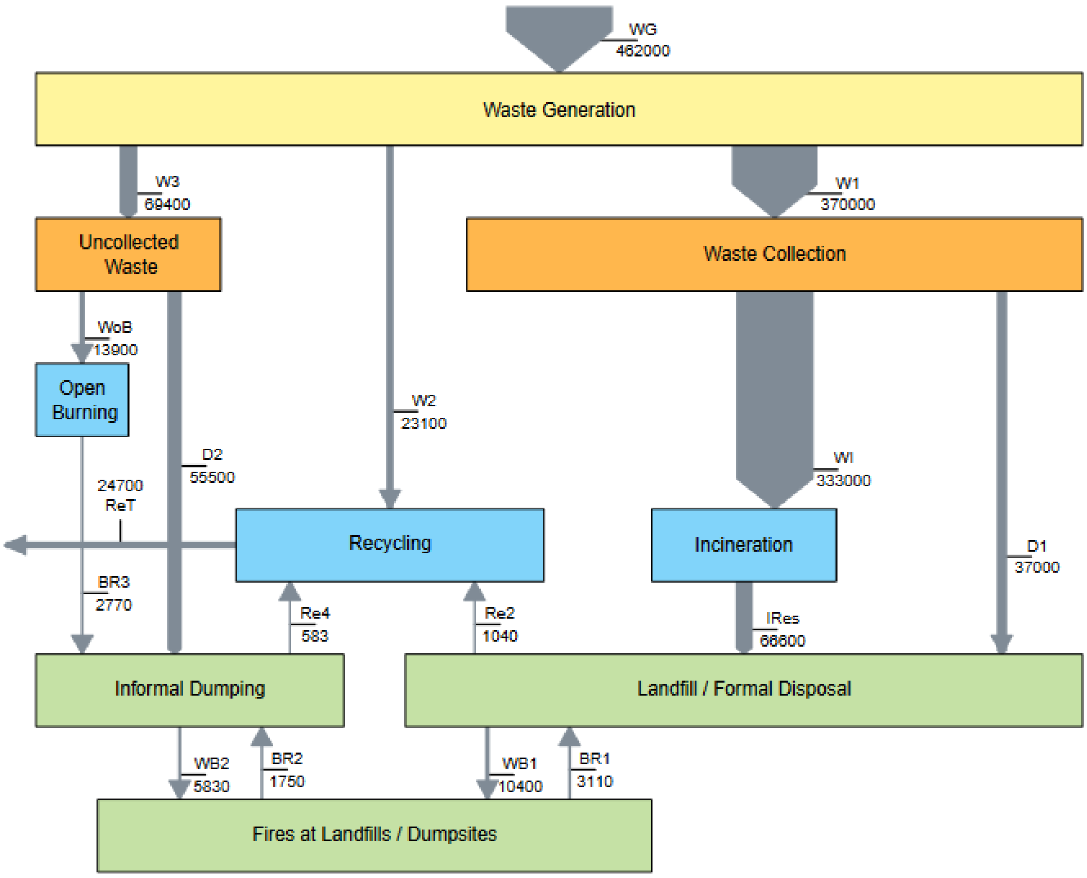
Figure 80: Giza Governorate: Scenario 3 – uPOPs emissions



Source: WaPla Software.

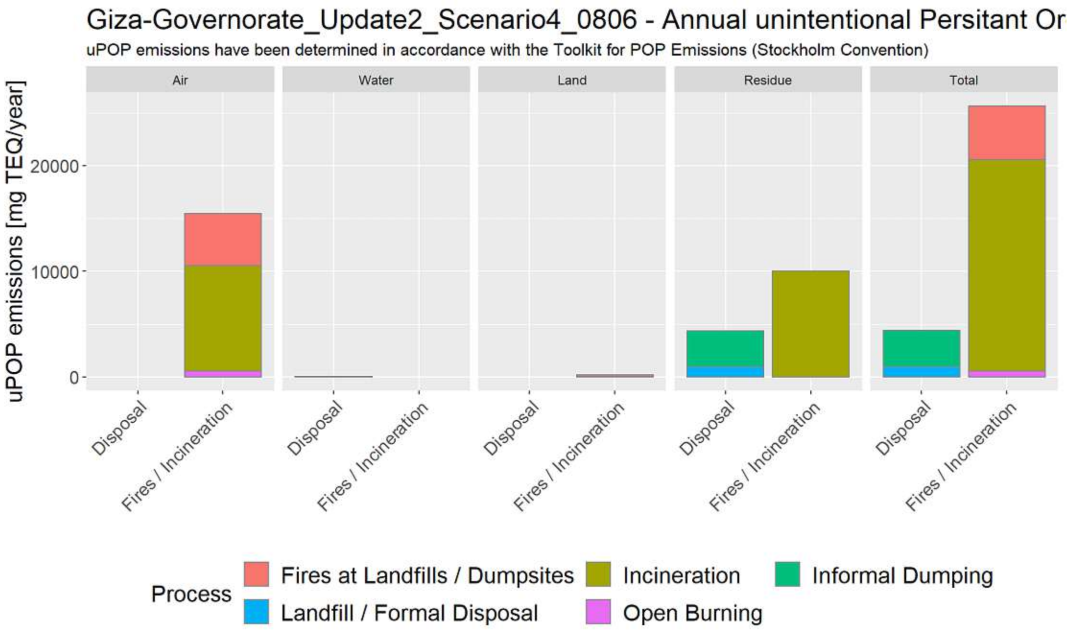
Figure 81: Giza Governorate: Scenario 3 – GHG emissions

Scenario 4: Enhanced waste collected of 80%, WTE



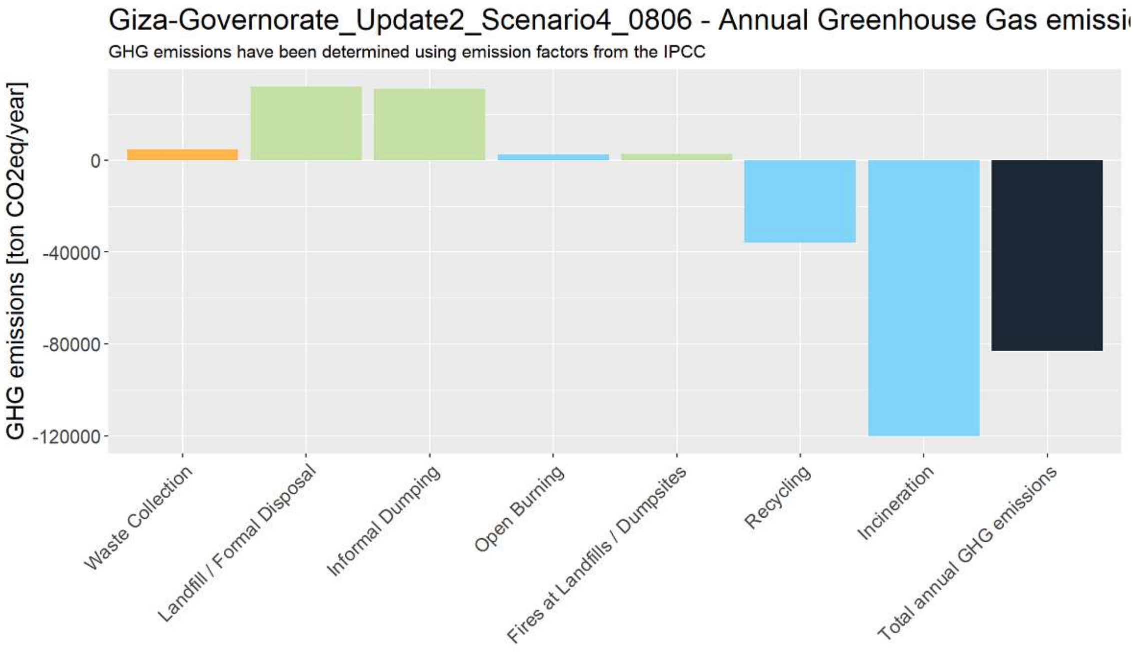
Source: WaPla Software.

Figure 82: Giza Governorate: Scenario 4 – Waste flow



Source: WaPla Software.

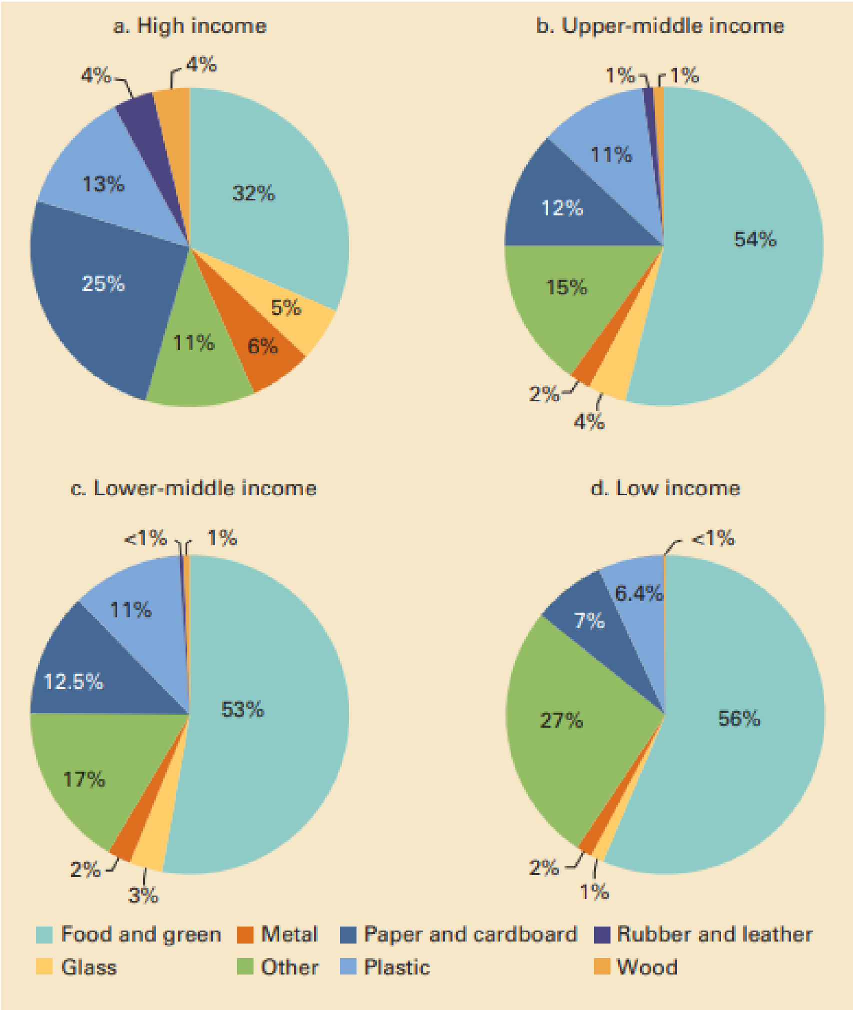
Figure 83: Giza Governorate: Scenario 4 – uPOPs emissions



Source: WaPla Software.

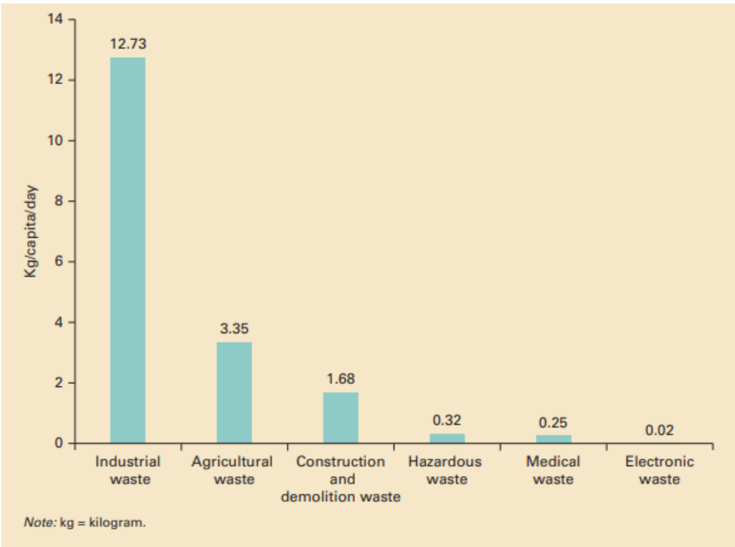
Figure 84: Giza Governorate: Scenario 4 – GHG emissions

Other figures used in the text



Source: WB, 2018, p.30.

Figure 85: Waste composition by income level



Source: WB, 2018, p.36.

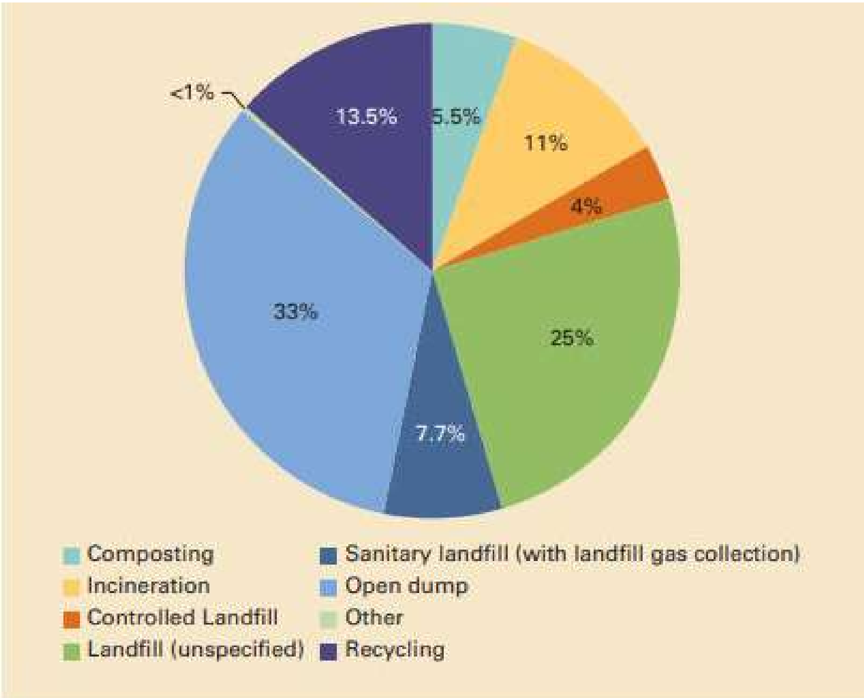
Figure 86: Special waste generation - world

kg/capita/day	Industrial waste generation	E-waste generation
High income	42.62	0.05
Upper-middle income	5.72	0.02
Lower-middle income	0.36	0.01
Low income	No data	<0.01

Note: kg = kilogram.

Source: WB, 2018, p.36.

Figure 87: E-waste and industrial waste generation according to income level



Source: WB, 2018, p.34.

Figure 88: Global waste treatment and disposal