SCHOOL OF CHEMICAL AND BIOENGINEERING

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ASSESSMENT OF THE CURRENT SOLID WASTE MANAGEMENT PRACTICE: A CASE STUDY OF DUKEM TOWN, CENTRAL OROMIA REGION, ETHIOPIA

A Thesis Submitted to the School of Chemical and Bio Engineering, Addis Ababa Institute of Technology as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Chemical Engineering (Environmental Engineering)

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Certification

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APPROVED BY BOARD OF EXAMINERS

This is to certify that we have read this MSc Thesis and that in our opinion; it is fully adequate, in scope and quality, as an MSc Thesis for the Degree of Master of Science in School of Chemical and Bio-Engineering Environmental Engineering stream.

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Declaration

I declare that this Thesis entitled "Assessment of the current Solid Waste Management Practice: A Case Study of Dukem Town, Central Oromia Region-Ethiopia" is my original work under the Supervision of Dr. Shimelis Kebede at School of Chemical and Bio Engineering in Addis Ababa Institute of Technology, Addis Ababa University and I have not previously submitted it entirely or in part for obtaining any qualification at any other University.

Name: Ikram Mohammed-Amin (GSR/7333/13)

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Date --

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Acronyms

DSWGR	Daily Solid Waste Generation rate
FDRE	Federal Democratic Republic of Ethiopia
GHG	Greenhouse gas
GWP	Global Warming Potential
HH	Household
ISWM	Integrated solid waste management
IWMS	Integrated waste management system
MFA	Material flow analysis
MoH	Ministry of Health
MSSE	Micro and small scale enterprises
MSW	Municipal solid waste
MSWM	Municipal Solid Waste Management
PCPDSWGR	Per capita per day solid waste generation rate
SDG	Sustainable development goals
SPSS	Statistical package for social science
STAN	Software for Substance flow analysis
SWM	Solid Waste Management
UN	United nation
UNEP	United Nation Environmental program
UNDP	United Nation Development program
WaCT	Waste wise cities tool
WMS	Waste Management System

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Abstract

Solid waste management is recognized as a global concern that impacts both individuals and governments. Insufficient waste management practices in cities, such as widespread waste dumping in water bodies and along roads and drainage canals, exacerbate sanitation issues in African nations, Ethiopia included. Ethiopia, categorized as a low-income country, grapples with the repercussions of ineffective management of solid waste, especially in its swiftly urbanizing areas. Dukem is one of the town located in a central Oromia region of Ethiopia facing the problem. The primary objective of this study is to evaluate the present state of solid waste management in Dukem Town. Descriptive survey and Multi-stage sampling technique was employed. The samples were collected from 90 household and from different commercial activities in the study area. The collected samples were sorted into 11 components and measured. Organic wastes represent a significant proportion of the total Solid Waste produced and accounts for about 67.34%. The remaining waste is made up of dense plastic (0.92%), film plastics (5.67%), paper and cardboard (4.08%), metals (1%), special wastes (0.36%), textiles and shoes (1.3%), glass (1.97%), composite products (0.15%) and other wastes (17.21%). According to the study's findings, Dukem Town generates 0.209 kg of solid waste per person every day with a density of 287 Kg/m^3. Material flow analysis can be applied in environmental research and it was used as a basis for analyzing and planning waste management and recycling systems and also to evaluate an existing solid waste management practice of Dukem. The analysis of the socio-economic effect evaluation of solid waste management strategies also looked at how it affected the content and amount of solid waste. Due to the wastes high organic content composting is good waste management option that has to be practiced, since there will be better chance of lowering the enormous volume of waste disposed away to disposal site as well as decreasing the Greenhouse gas emission. By composting 50% of the waste designated to the disposal site 39.5% of resource will be managed.

Key Words: *Dukem Town, Material flow analysis, Solid waste, Solid Waste Management*

1. Introduction

1.1.Background of the Study

The swift increase in population, coupled with a strong push for economic progress, placed a significant strain on resources[1]. Urbanization surged, aiming to enhance living standards globally. However, this transformation brought about adverse effects on urban environments [2], with human activities contributing to widespread waste generation [3]. It's widely acknowledged that as the population continues to proliferate and urban areas expand, the production of solid waste is also on the rise worldwide[4].

Solid waste encompasses materials disposed of due to human actions, which do not move naturally and comprise items like bottles, metals, plastics, refuse, paper, glass, food or animal byproducts, disposable bags, wood, and defective electronic gadgets.[5].

Municipal solid waste management involves a comprehensive approach that integrates various disciplines from both natural and social sciences[6], encompassing administrative activities and practices related to handling solid waste: regulation of waste generation, storage, collection, transfer, transportation, processing, and disposal[7]. As such, managing solid waste is among the most crucial and resource-demanding activities. Ineffectively managed solid waste can lead to significant detrimental impacts on human wellness as well as the surroundings[8]. The overarching objective of solid waste management is to mitigate and eradicate the negative impacts of waste on human health and the environment, while fostering economic development and enhancing quality of life[9].

Solid waste management is recognized as a global concern that impacts both individuals and governments. Across the globe, nations grapple with waste management challenges, with governments allocating significant financial resources to address these issues[10]. While countries with advanced economies generate greater quantities of waste compared to nations that are developing, the situation is more complex for the latter[11]. In developing countries, the challenge is exacerbated by limited understanding and awareness regarding contamination, waste reduction methods, and other aspects of solid waste management[12].

Insufficient waste management activities in cities, such as widespread waste dumping in water bodies and along roads and drainage canals, exacerbate sanitation issues in African nations, Ethiopia included[13]. Ethiopia, categorized as a low-income country, grapples with the repercussions of ineffective management of solid waste[14], especially in its swiftly urbanizing areas[15]. This issue ranks as a significant concern, influenced by factors such as limited awareness, inadequate funding, minimal community involvement, and outdated waste management methods The handling of waste lacks coordination, professionalism, and adherence to regulations[16], due to various factors, including weak institutional capacity, insufficient comprehensive waste data, limited collaboration among stakeholders, feeble commitment and prioritization, and ineffective planning and execution procedures[17].

The existing state of municipal solid waste management services in various Ethiopian towns is increasingly problematic. Studies have been undertaken in certain towns and cities nationwide to tailor suitable solid waste management strategies. To devise effective solid waste management plans for each locality, Data on the amount and composition of waste produced, plus the present practices used for management, must be gathered[18]. Therefore, the purpose of this study is to evaluate Dukem town's methods for managing solid waste. Dukem, situated in central Oromia, Ethiopia, lies within the Oromia special zone, approximately 37 kilometers from the capital, Addis Ababa. Positioned along the Addis Ababa-Adama expressway, it also serves as a stop on the Ethio-Djibouti railway.

Therefore, due to its rapid population expansion, Dukem faces a significant challenge with the escalating volume and variety of solid waste within the town. This issue demands considerable attention from residents, environmental groups, and governmental bodies.

Dukem Town seeks to establish institutional frameworks and foster community involvement in solid waste management efforts. The initial and essential step towards establishing efficient municipal solid waste management (MSWM) involves identifying primary sources and determining the rate and composition of waste generation. These factors serve as fundamental benchmarks for the entirety of MSWM activities. Therefore, obtaining reliable and precise data on these aspects is crucial. Consequently, the primary goal of this research is to assess the present state of managing solid waste in Dukem town, aiming to address data deficiencies. This initiative aims to fortify current and future waste management strategies and policies within the town.

1.2.Problem statement

The African continent is witnessing a rapid increase in population and urbanization rates, leading to a concerning rise in waste production. This surge is fueled by industrialization, urban development, and advancements in agriculture, particularly in Africa. Consequently, waste management capabilities are strained, exacerbating existing challenges[13]. In countries like Ethiopia, inadequate waste management poses a significant obstacle, especially in urban areas[19]. Many Ethiopian towns lack necessary financial means and institutional support to establish proper infrastructure for managing solid waste effectively[20]. Consequently, weak waste management systems contribute to degrade the surrounding and pose health risks in numerous countries[21]. Dukem town, as one of Ethiopia's swiftly expanding urban centers, is grappling with similar waste management issues.

Hence Dukem faces rapid population growth, leading to a significant increase in solid waste. This surge poses a critical issue demanding attention from residents, environmental groups, and authorities. Mismanagement exacerbates the problem. Notably, Dukem's municipal solid waste management lacks prior scrutiny on household and commercial waste generation, composition, and handling. Urgent action is imperative. A comprehensive assessment of the current municipal solid waste management is essential as it forms the foundation for effective planning. Accurate data on waste generation and composition are crucial for decision-making. Therefore, this study aims to evaluate Dukem's current solid waste management practices meticulously.

Few past studies have been conducted so far in line with this study giving more emphasis to issues like; “Wastewater and solid waste disposal patterns of Dukem town households in Ethiopia”[22], and “Solid waste characterization and its management system in Dukem town”[23]. Yet they do not definitively address the entirety of Dukem's municipal solid waste management. While some assessments have touched upon constraints in waste management, they fail to identify the fundamental factors impeding solid waste management in Dukem. This gap underscores the need for further investigation.

Therefore, this thesis aims to address the existing research gap concerning the reasons behind the inefficient and disorganized MSWM practices in the town, leading to improper waste disposal. Therefore, acquiring detailed data on solid waste composition and generation is crucial for establishing an effective management system. Furthermore, previous studies have predominantly focused on regional and sub-city levels within Addis Ababa, Ethiopia. Thus, this research endeavors to bridge the gap by examining solid waste management practices at the town level and shedding light on the current state of waste management.

This study is poised to determine the actual difficulties facing SWM practices in the town and endeavor to propose viable solutions. Consequently, it aims to explore the current state of solid waste management in the study area and serve as a launching pad for future researchers interested in conducting more in-depth investigations.

1.3.Research Objectives

1.3.1. General Objective

The overall objective of this study is to assess the current status of solid waste management practices in Dukem Town, Central Oromia Region Ethiopia.

1.3.2. Specific Objectives

The following goals are the focus of this study:

- To identify significant sectorial activities in terms of solid waste generation among commercial, industrial, or residential
- To quantify the waste generation rate and determine the solid waste composition generated by selected sectorial activities
- To identify the existing waste management processes and examine the town's solid waste management services' spatial coverage by selecting sectorial activities including Households
- To identify informal and formal waste recovery and disposal practices and systems
- To assess socioeconomic impacts of the solid waste management system
- To perform a preliminary solid waste material flow analysis

1.4.Significance of the study

Insufficient data regarding Rate of generated waste, composition, gathering, transporting and removal at the town level, alongside the status of managing solid waste practices at the present time, significantly contributes to inadequate management of waste. Consequently, this study aims to establish baseline data concerning generation rate of solid waste, physical composition, and overall management practices within Dukem town.

This research is projected to offer relevant data regarding several vital areas. Primarily, the study will provide essential guideline information to legislators, government officials, solid waste administrators, local authorities, scholars, and environmental conservation organizations aiming to improve the existing methodologies of waste management in Dukem town. Secondly, it will establish foundational data for subsequent research endeavors, enabling more detailed and comprehensive studies in Dukem or other similar areas. Additionally, it could serve as a precursor for further investigations, such as material flow analysis and Sustainable Development Goals (SDG)-based life cycle sustainability assessments of municipal solid waste management systems. Moreover, the study has the potential to contribute to a deeper conceptual awareness with regard to the overall features of solid waste and the difficulties in managing it throughout the population of Dukem town.

1.5.Scope of the study

Geographically, the research is confined to Dukem Town situated in Central Oromia Region of Ethiopia. Although various types and origins of waste exist, this study's specific objective is examining overall solid waste management procedures within Dukem. The research entails identifying solid waste, analyzing its generation patterns, determining its composition, and assessing the present waste management strategies implemented in Dukem. Various waste sources within the town, including household and commercial waste, are investigated as part of the research scope.

2. Literature review

2.1. Overview of solid waste management

The increasing volume and complexity of solid waste present an additional threat to the environment. Globally, it is estimated that between 1.7 to 1.9 billion metric tons of municipal solid waste are generated. However, the percentage of waste collected, disposed of in unregulated landfills, and processed through hazardous and informal recycling methods is below 70%, over 50%, and approximately 15%, respectively[12].

Solid waste management represents a significant environmental challenge worldwide, garnering attention as a prominent concern for nations across the globe. Waste management concerns are increasingly becoming a focal point on the global environmental agenda[24].

Managing solid waste presents a formidable difficulties for urban authorities in developing nations, primarily due to escalating volume of waste generated, which strains municipal budgets due to the high costs associated with its management. Additionally, there is a dearth of thorough knowledge about the numerous elements impacting the various waste management stages and the linkages needed to guarantee the efficient operation of the overall waste handling system. Managing solid waste encompasses wide array of responsibilities related to planning, engineering, finance, law, and administration aimed at addressing all aspects of solid waste issues[25].

Solid waste management encompasses efforts to mitigate the health, environmental, and aesthetic consequences of solid waste. Coping with the escalating volume of solid waste has emerged as a significant a problem in numerous towns across developing nations. When managed appropriately, solid waste can serve as a valuable resource, but inadequate management can lead to severe adverse effects. Consequently, solid waste management is one of the most essential and resource-intensive services offered by municipalities and is a critical component of urban sanitation[26].

2.2. Solid waste

The term "solid waste" describes items produced by human or animal activity that are typically discarded because they are deemed useless. It can also be described as material that has lost its original value to its owner and is subsequently discarded[27].

In Ethiopia, as per the Federal Democratic Republic of Ethiopia Proclamation (FDRE) No.513/2007 on Solid Waste Management, "Solid Waste" refers to any item that is neither in liquid nor in gas state and is discarded as unwanted. This encompasses various items such as yard sweepings, food remnants, ash, leftover chat (a local plant), dust, papers, glass, metals, batteries, plastics, grass, animal bones, and other materials contributing to environmental degradation[28].

Solid waste is experiencing not only an increase in volume but also a shift in composition, with a transition from predominantly organic matter to a higher presence of inorganic materials[29].

2.3. Municipal solid waste

Municipal solid waste is characterized as material that is abandoned within urban areas by its primary generator or user without the need for compensation upon abandonment[30]. Physically, it comprises the same materials found in useful products; the distinction lies in its lack of value, rendering it no longer necessary due to being broken, spoiled, or obsolete, including waste from households, commercial activities, institutions, and industries[1].

In a study conducted in Nairobi County, municipal waste is defined as solid waste[31], encompassing home waste, marketplace waste, yard rubbish, road sweepings and waste materials from businesses and institutions[32].

The term "municipal solid waste" encompasses solid wastes produced by various sources, including households, commercial and industrial establishments such as shops, hotels, garages, and agriculture, as well as institutions like schools, hospitals, care homes, and prisons, along with waste from public areas such as streets, bus stops, parks, and gardens[33].

Municipal solid waste also referred to as urban solid waste, comprises primarily household waste (domestic waste)[34]. As per the definitions provided by the United States Environmental Protection Agency, MSW excludes hazardous, construction and demolition waste[27].

The term "MSW" refers to a diverse group of wastes produced in metropolitan locations. The composition of MSW varies depending on various factors such as the standard living conditions and way of life of the people living in the area, the level of economic activity, and the diversity and availability of natural resources in the area, all of which differ among countries. Moreover, MSW encompasses materials discarded as a result of human activity, typically comprising everyday items[35].

Understanding the origins and categories of solid wastes, as well as information on their composition and generation rates, is fundamental for designing and operating the essential components involved in managing solid waste.

2.4.Sources and types of solid waste

Our daily activities contribute to a wide range of waste originating from different sources. Understanding the sources and types of solid waste is crucial for effectively managing solid waste.

To define municipal solid waste accurately, various classification criteria have been proposed, including waste generation source and the characteristics of the waste components. Based on the nature of the items comprising solid waste, it can be categorized as organic or inorganic, combustible or non-combustible, and putrescible or non-putrescible[36].

There are six different categories of municipal solid wastes based on the origin of the materials: street sweepings, building and demolition wastes, commercial, industrial, institutional, and home garbage. Domestic waste, originating from residential areas, constitutes the largest portion of solid waste[20].

Other waste classification also determined by its risk level and inherent characteristics. In terms of risk potential, it falls into two categories: hazardous and non-hazardous wastes. Regarding its characteristics, solid waste is further divided into biodegradable and non-biodegradable forms[12].

2.5.Characteristics of solid waste

To ensure the proficient and successful handling of waste within a given town, a comprehensive understanding and information regarding features of the waste are indispensable. Making decisions regarding the necessary facilities for waste management, optimal disposal methods, and forecasting future requirements all rely on accurate information concerning the amounts, humidity levels, densities, compositions, and energy content of the generated waste in the town[26].

While all the aforementioned characteristics hold significance, the researcher in this study specifically focuses on composition, density, and generation rate of the waste.

2.5.1. Solid waste generation rate

The rate at which solid waste is produced signifies the volume of waste discarded over a specific timeframe. Various approaches are employed to measure this, including direct measurement at the source, conducting surveys with vehicles, and analyzing records at disposal sites. Factors such as population growth, seasonal changes, location, economic progress, and public behavior toward waste disposal largely dictate the waste formation rate in a particular place[37].

By examining the correlation between GNP of developed and developing nations and their pace of waste production, it becomes apparent that countries with larger GNP tend to produce more waste. This implies that due to disparities in economic advancement, waste production rates are generally higher in developed countries compared to developing ones[38]. Despite having lower waste generation rates, developing countries still produce substantial quantities of waste due to their rapid population growth. This underscores the significant influence of number of residents on the pace of waste production[39].

The composition of the waste varies across countries and regions, leading to differences in their management systems. Various factors contribute to the production of solid waste, such as the availability and type of natural resources, the lifestyle of inhabitants, and their living standards[40].

Metropolitan areas like New York exhibit a waste generation rate of 0.018 per capita per day, whereas many urban centers in developing nations typically have rates below 0.001 per capita per day[38]. The production of MSW in the East Asian area has been steadily rising, with an annual increase ranging from 3 to 7%. This increase is ascribed to aspects like population growth, shifts in buyer behavior, and urbanization of trade and industry. Across Asian cities, the average MSW generation rate falls between 0.5 to 1.3 kilograms per capita per day, a figure that is closely linked to the per capita income levels of these cities[36]. Like in other nations that are developing, Ethiopia's swift development and growth in the number of peoples are the main causes of the rise in waste production. The typical rate of production of waste averages around 0.22 kilograms daily from each individual[3].

In developing nations, the amount of waste produced fluctuates daily and seasonally. Typically, waste generation is lower on weekends compared to weekdays. This is largely due to the influx of commuters from suburban and nearby residential areas into large or medium cities during the workweek, resulting in higher waste generation rates on weekdays and lower rates on weekends. Likewise, waste generation tends to spike during festive occasions[35].

Conversely, the rate of solid waste generation can be influenced by people's behaviors regarding waste, including their material usage patterns, methods of waste handling, commitment to waste reduction and minimization, and their tendency to avoid indiscriminate dumping and littering[40].

Hence, having precise information about the amount and pace of solid waste generation within a specific region is crucial for planning and executing effective MSWM strategies. This data informs decisions regarding the allocation of apparatus, money, and personnel needed for waste gathering and transporting. It also guides the formulation of pertinent waste reduction regulations and helps anticipate both present and afterward requirements of facilities for disposing of waste[39].

2.5.2. Density

Density-specific weight, which refers to the weight per unit volume, is controlled through the evaluation of the combined mass and volume of waste[41].

Density information is frequently required to evaluate the overall mass and volume of waste requiring management. However, there is a lack of consistency in how solid waste densities are documented in the literature, often failing to differentiate between un-compacted and compacted densities. This is because solid waste densities can significantly differ depending on geographic location, season, and duration of storage. Hence, it's important to exercise caution when selecting representative values. For instance, Municipal Solid Waste (MSW) delivered via compaction vehicles has been observed to range from 300 to 700 pounds per cubic yard[34].

2.5.3. Physical composition

Composition refers to the assortment of individual elements comprising a solid waste stream and their respective proportions, typically expressed as percentages by weight[40].

Details and statistics regarding the physical makeup of solid wastes are crucial for choosing and managing tools and services, evaluating viability of resource, and designing disposal sites. Solid waste composition differs among cities and nations due to factors such as living standards, lifestyle, social and religious customs, and dietary preferences[42].

The makeup of waste in a particular region is influenced by factors like the area's population size, climate, industrial output, societal norms, and the income level of its residents[31].

2.6.Municipal solid waste management

SWM encompasses comprehensive handling of solid wastes, spanning from their generation to disposal. It entails the proper management of unwanted waste in a form that safeguards both human wellness and the surrounding from direct harm[43]. The management of solid waste operations can be summed up as a field, encompassing their generation, storage, collection, transfer, transportation, processing, treatment, and disposal. The greatest requirements regarding engineering, economics, wellness, preservation, visual appeal, and other ecological concerns should be implemented by managing it. Moreover, it should be responsive to public sentiments[33].

Based on the provided definition, solid waste management presents a demanding and expensive endeavor. It necessitates the engagement of skilled personnel and various technologies across the entire process, a feat that demands substantial investment in institutional capacity building[44]. Establishing a successful solid waste management system hinges not solely on having sufficient funds but also on meticulous planning and design. This entails employing precise planning tools and relying on dependable data[45].

Effective management of municipal solid waste depends on having exact information regarding waste generation and composition. This information serves as a blueprint for planning and selecting an optimal waste management system[43]. To ensure efficient waste management, it's essential to have precise data on waste generation, along with insights into people's behaviors and attitudes toward waste. This is crucial since waste results from human behavior[46]. Effective management of waste necessitates dedication of municipal government and genuine involvement from community members[14]. Community involvement in managing waste is pivotal for developing a sustainable and cohesive initiative. The objective is to engage a wide array of local stakeholders to actively participate and contribute. Crucially, this includes fostering a sense of ownership among citizens whose waste is managed and whose local environment benefits from improvements[47]. Efficient management of solid waste relies on the collaboration of the community, and local authorities could implement measures to raise public understandings about the significance of waste management. This involves building support for environmental preservation and encouraging the active involvement of residents and community organizations in local waste management initiatives[10]. Solid waste management is evolving into a more intricate and vital task. It has emerged as a top priority for ensuring a clean and healthy nation[48].

The primary concerns within waste management can be categorized into three key areas: safeguarding public health by ensuring hygienic conditions, addressing environmental degradation encompassing local pollution of air, water, and soil along with issues linked to climate change and growing water scarcity, and managing resources effectively by aiming for a circular economy where materials and nutrients are recycled for beneficial purposes, crucial for maintaining productivity and food security. Waste management becomes a critical issue for both private and public interests in terms of health and environmental protection when the volume and nature of the generated waste surpasses the ecosystem's capacity to handle it[30].

Hence, the primary objective of MSWM is to protect the well-being of all people, enhance environmental standards, foster sustainability, and bolster economic productivity. Achieving these aims requires wholehearted adoption of strategies that local governments might use to manage solid waste sustainably, in partnership with both the public and private sectors[49].

The efficient and successful handling of solid waste is contingent upon equitable distribution of duties, power, and funds between the federal government and local authorities[50].

Furthermore, the main objective of Municipal Solid Waste Management is reducing substantial volume of waste and safeguard the wellness of urban residents, especially those in poor financial standing communities who are disproportionately impacted by inadequate waste management services[33].

As per the World Bank, the ultimate objective of solid waste management should encompass gathering, treatment, and removal of solid wastes produced by all segments of the population in a manner that is environmentally and socially acceptable, employing the most cost-effective methods available[51].

2.7. Worldwide practices for managing solid waste

Lately, there has been a swift and unprecedented global trend towards urbanization. Although urbanization offers the promise of driving development forward, it also brings along its own set of difficulties, one of which is the significant generation of solid waste[16]. In cities and metropolitan area worldwide, the amount of waste being produced is on a constant rise, driven by swift industrialization and population expansion. Yet, a large portion of the population remains uninformed about their contribution to this waste generation or the effects of their daily actions on its rate. Consequently, many people don't prioritize considering proper waste disposal methods for the waste they generate at home, neglecting the opportunity to contribute to a more appealing environment[48].

Solid waste management poses a universal challenge that impacts every individual across the globe. Annually, 2.01 billion tons of MSW are produced worldwide, a third of it is not managed in a way that is ecologically sound manner. Worldwide, every individual produces 0.74 kilogram of garbage daily on average, although this number ranges widely, from 0.11 to 4.54 kg per person per day[52].

The task of gathering and effectively handling solid waste presents a significant challenge for nations worldwide[53]. Serving just under half of the total population, many municipalities in developing nations allocate 20% to 50% of their funds for handling wastes. Despite this expenditure, it's typical for 30% to 60% of urban solid waste in these countries to remain uncollected. Additionally, in some instances, up to 80% of the collection and transportation equipment is non-functional, requiring repair or maintenance[9]. Inadequate handling of MSW can lead to noteworthy repercussions for human and animal well-being, local and global environmental stability, and the overall economy. While waste management may not be glamorous, it remains crucial for the resilience and survival of communities[5].

Waste management practices differ between developing and developed nations. In regions like Asia, which is predominantly developing, many countries grapple with significant challenges in handling urban solid waste. Similarly, research conducted in Ghana highlights a pronounced trend of urbanization across African nations, leading to a swift buildup of solid waste. Moreover, the social and economic advancements observed in many African countries since the 1960s have also contributed to a rise in garbage produced per capita[50]. While developed nations produce a larger volume of solid waste compared to developing countries, the issue of solid waste management is more pressing in developing nations than in developed ones[54]. It's highlighted that environmental harm stems not just from the volume of waste produced through consumption and production but also from how waste is discarded. In contrast to practices in the developed world, many cities in developing countries commonly resort to dumping waste in open spaces, along roadsides, and in valleys[46]. The practice of openly dumping solid waste poses numerous environmental and health risks. The decomposition of organic matter within these dumps releases methane, which can lead to fires and explosions while also exacerbating global warming. Additionally, the biological and chemical reactions within open dumps generate potent leachates, contaminating surface and groundwater. Periodic fires ignited by methane and heat from decomposition further worsen the situation, emitting smoke and adding to air pollution[55]. Dumping waste, both at authorized and unauthorized sites is a widespread practice that poses health risks to humans and disrupts ecosystems. In contrast, European countries, North America, and other developed nations employ methods to reduce domestic waste quantities and limit landfill disposal. Municipal managers in these developed regions are increasingly considering the establishment of sanitary landfills on the outskirts of cities as an initial solution. However, the effective operation of landfills demands significant land acquisition and diligent day-to-day management to mitigate potential adverse environmental effects[50].

SWM (Solid Waste Management) entities are under considerable pressure to transition towards sustainable practices. Waste management is increasingly recognized as an integral aspect of the worldwide sustainability agenda, extending beyond national borders both in terms of challenges and potential remedies. Consequently, there is a pressing necessity to incorporate waste management into strategies for sustainable development[48].

There are significant disparities between industrialized and developing nations concerning income levels, standards of living, consumption habits, institutional capabilities, and available capital for urban development. Conventional approaches frequently fail to consider these differences, leading to suboptimal results[55].

2.8.Solid waste management challenges in developing nations

The rise in affluence and migration to urban regions is correlated with an uptick in MSW generated per person. Additionally, swift urbanization and population expansion result in larger population concentrations, posing challenges in the comprehensive waste gathering and acquiring lands in order to treat and dispose of it[52]. In developing countries, the challenges surrounding Municipal Solid Waste Management (MSWM) typically revolve around insufficient service coverage, operational inefficiencies in service delivery, inadequate handling of hazardous and medical waste, and environmental concerns[56].

In many developing nations, waste is often scattered throughout urban areas or haphazardly disposed of in gorges. There is a lack of proper planning for managing waste, along with inadequate funding and technological knowledge. Personal attitudes towards proper waste collection and sorting are also lacking, aggravating sanitation and ecological issues in developing nations' cities[32].

Solid waste management in developing nations receives comparatively less focus from policymakers and academics compared to other urban environmental issues like air pollution and wastewater treatment. However, the inadequate handling and disposal of solid waste remain a significant concern[55].

Waste management issues in Africa are diverse and intricate, encompassing challenges related to infrastructure, politics, technology, society, economics, organization, regulations, and laws. The primary challenge faced by many African cities revolves around waste gathering and removal[20].

In recent times, MSWM persistently remained challenging concern, surpassing the capabilities of numerous municipal governments[1]. Broadly, the existing practices of MSWM are viewed to be ineffective in developing countries, especially in terms of gathering, analyzing, and disposing[57]. The challenges are exacerbated by the significant volume of waste generated, limited coverage of collection services, inconsistent collection practices (often due to the absence of municipal waste collection), unregulated incineration and littering that pollutes the air and water, and shortage designated waste disposal sites[58]. Due to ineffective MSWM systems, water becomes contaminated, GHG emissions rise, ecosystem services suffer, and tourism along with other business activities are deterred[54].

2.9.Municipal Solid Waste Management in Ethiopia

Like other developing nations, Ethiopia confronts a formidable obstacle in solid waste management. This issue is particularly critical because of its far-reaching social, economic, and environmental implications when not adequately addressed[28]. The predominant issues in Ethiopia regarding waste management include traditional transportation methods, irregular waste gathering schedules, lack of necessary equipment, and the absence of fencing for dumpsites[59].

Generally SWM in Ethiopia is inadequate, particularly in urban areas where it lacks sufficient, suitable, and appropriate implementation. Consequently, the environmental quality in cities has progressively deteriorated over time, leading to hardships for residents living in such conditions[57].

In Ethiopia, municipalities primarily bear the responsibility for solid waste management, leading to insufficient service provision. Towns in Ethiopia lacked appropriate and sufficient standards for waste collection and removal practice due to the shortcomings of the current systems for managing waste[54].

According to a 2004 UNDP study, the municipalities of Bahir Dar, Mekele, Adama, and Hawassa collected and disposed of 46, 48, 54, and 50% of the daily generated solid waste, respectively[1]. Consequently, a significant amount of waste remains ungathered[10].

The primary cause of these problems is the deficiency in the workforce and, notably, finances. Additionally, there is absence of transparent cost recovery framework associated with SWM in Ethiopia, resulting in minimal returns for the efforts invested in managing waste[57]. The operational status of SWM services in Ethiopia remains subpar, with limited efforts to improve the situation. Private sector involvement is also minimal, although there is a growing number of MSSE emerging to engage in primary waste gathering. These enterprises gather waste directly from residents and travel it to municipal waste containers and transfer points. In summary, addressing solid waste issue in Ethiopia requires more than just efforts from municipal governments; it necessitates significant involvement of the private sector overall, with particular emphasis on participation from micro-enterprises and the community[60].

The Federal Democratic Republic of Ethiopia government, as outlined in Proclamation number 513/2007, acknowledges that effectively addressing environmental issues, notably solid waste management, requires the active participation of local communities. Despite municipalities being responsible for solid waste management services, involving local communities in the planning, execution, and oversight of interventions aimed at enhancing SWM is essential[20].

Households, being the main generators of solid waste, and those affected by the consequences of un-gathered waste, could have the opportunity to engage in enhancing SWM. Consequently, the involvement of town residents in SWM services significantly influences the betterment of waste management within communities[59].

In Addis Ababa, certain aspects of solid waste management (SWM) have shown signs of improvement since 2003/4 due to enhanced planning and service implementation. However, in recent years, numerous MSSE have emerged to provide waste pre-gathering services. They receive compensation from either the beneficiaries or municipalities for collecting and transporting waste to municipal containers, thus addressing gaps in waste collection and transportation. These enterprises serve as a promising foundation for fostering private sector involvement and reaping its attendant advantages[28].

2.10. Functional Elements of Municipal Solid Waste Management

SWM is an ongoing, perpetual daily task. With each passing day, new responsibilities arise, including sweeping streets, gathering waste, hauling loads, and ensuring safe disposal[58].

When addressing municipal solid waste management, six operational components are recognized. Identifying these elements enables the description of the relationships inherent in each component. Consequently, managing a particular solid waste effectively necessitates considering the following six elements in concert. These include:

2.10.1. Solid Waste Generation

Waste production is the process of taking things that are judged useless and discarding them or grouping them for dumping. This operational aspect holds significant importance as it encompasses all activities related to recognizing and comprehending factors such as the rate, volume, composition, spatial distribution, specific variations, and anticipated changes over time in solid waste generation. Therefore, this functional component serves as a crucial stage for acquiring precise data essential for monitoring the current handling system and making judgments about institutions, finances, and regulations[26].

Globally, the cumulative volume of MSW produced attained 2.2 billion tons, reflecting a yearly growth of 7% since 2003. The observation by UNEP suggests that solid waste production is accelerating worldwide[37].

MSW production in East Asia has been on the rise, growing annually by 3 to 7%. This upward trend is ascribed to elements like population expansion and changing consumption habits, and industry. Across Asian cities, the daily average waste production pace per capita ranges from 0.5 to 1.3 kg, with a clear correlation observed with the city's per capita income. In developing nations, the typical generation rate tends to fall between 0.3 and 0.5 kilogram per capita daily[36].

2.10.2. On-site handling, storage, and processing

This operational aspect encompasses tasks related to the management, processing and storing of waste on the source.

On-site handling involves controlling solid waste up until storage container placement before gathering. Depending on the collection method, handling may also entail transporting filled containers to the collection point and returning empty containers to their storage location between collections[34].

Storage involves the accumulation of waste immediately upon its generation, encompassing the location where solid waste is kept before collection. This could be within skips or dustbins, emphasizing the importance of orderly storage rather than indiscriminate disposal. They emphasize that storage is crucial primarily due to aesthetic concerns[15]. At the point of production, actions related to storage fall into two kinds. First, as a hygienic precaution, interim storage is done at the level of the residence. The second category concerns systems for the shared storage of solid waste established by municipalities using public waste containers. Factors that must be considered while on-site storage comprise container type selection, container placement, considerations for public health and aesthetics, and chosen gathering approach[38]. To a significant degree, the selection and sizes of containers employed rely on attributes of waste slated for collection, the frequency of collection, and available place for container placement[60].

Grinding, sorting, compaction, shredding, and composting are among the on-site processing techniques employed to diminish volume, change physical composition, or salvage useful materials from solid waste[34].

2.10.3. Collection

Following on-site storage, the subsequent phase is a collection. A key component of waste administration is waste collection, which is moving solid garbage from its point of source to the site where it will be treated or disposed of. Furthermore, it includes collecting recyclables, which aren't quite rubbish, through curbside collection programs aimed at diverting them from municipal landfills[36].

The collection component entails more than just the retrieval or collection of solid waste and recyclable materials from diverse sources; it also involves transporting these wastes to the destination where the collection vehicle's contents are unloaded. This destination might be a transfer station, a landfill dumping site, or a facility for processing materials[44].

Solid waste can be gathered either through door-to-door collection or by utilizing communal containers. In numerous developing nations, collection often occurs via communal containers positioned at a designated area, where residents of the locality are expected to deposit their refuse[41].

The collection of municipal solid waste is the main element of waste handling in the city. In the majority of MSWM systems, the expenses of gathering constitute a substantial part of the overall costs[61].

Collection processes share a structural likeness across developing, transitional, and industrialized nations, yet there are notable technical and institutional variations in their execution. Generally, industrialized countries exhibit higher efficiency and effectiveness in collection methodologies, municipal government involvement, private sector engagement, and pertinent demographic and social factors compared to developing counterparts. In developing nations, collection commonly entails direct interactions between waste generators and collectors, with service levels typically lower. Waste generators often bear the burden of transporting their waste over long distances and depositing it into containers[15].

2.10.4. Transfer and Transport

Transfer involves transporting garbage from the initial collecting truck to bigger and more effective conveyance truck. When the last dumping location is situated at considerable distance from the collection places, transit points might be utilized[25]. Transferring places function as key locations where rubbish is loaded onto bigger trucks after being offloaded from numerous small collection trucks, which then transport the waste to the disposal facility[62]. Direct discharging and stored discharge are the two fundamental ways that transfer stations operate. The first step in the storage discharge method is to empty the waste from collection vehicles onto a big surface or into a storage trench. At a direct discharging place, on the other hand, every garbage truck discharges its contents straight into a bigger transporting truck[47].

Contrarily, transportation refers to any types of trucks that are utilized to convey solid waste from its source to a transfer station and subsequently to a place to be treated or disposed. This encompasses all currently in use trucks, ranging from simple manually operated buggies to complex mechanically propelled vehicles, along with vehicles specifically equipped to handle hazardous, heavy, and recyclable waste. A well-thought-out transfer and transportation system usually reduces gathering expenses considerably[39].

Transfer and transportation entail two stages: the transfer of waste from smaller collection vehicles to larger transport truck, followed by waste transportation, often covering extensive distances, to the final dumping sites. These operations involve waste transfer from public storage facilities to collection trucks and lastly waste is transported to disposal sites[9].

2.10.5. Processing and recovery

This operational aspect includes all methods, tools, and infrastructure employed to enhance the efficiency of other operational materials, and also to reclaim usable materials, produce energy, products conversion, and create compost from solid waste[35]. Moreover, it offers several benefits. Primarily, it aids in decreasing the total volume and weight of waste materials that need to be gathered, thereby minimizing the amount required for final disposal and conserving land resources, as land is often the fin destination for most waste products. In addition, it helps in lowering total transportation costs of waste to its ultimate dumping site[51].

Solid waste processing and recovery have traditionally commenced with sorting and processing of wastes at their point of origin. However, separation of a mixture of wastes typically takes place at materials recovery facilities, transfer stations, combustion facilities, and disposal sites[63]. This process frequently involves several steps such as segregation of large objects, manually separating of waste items, the sorting of waste materials by size using screens, and the segregation of ferrous and non-ferrous metals. Subsequently, these materials are directed to both large- and small-scale enterprises in order to be recovered. MSW that contains organic material, for example, might go through a number of biological and thermal processes. Burning is the most common thermal conversion technique, while aerobic composting is the most common biological conversion method.[39].

In Addis Ababa, specifically 10% of the entire produced solid waste undergoes composting and recycling. There is minimal effort at waste generation sources and within communities to diminish waste volumes through effective sorting, recycling, and composting initiatives[38].

2.10.6. Waste disposal

Disposal represents the ultimate stage in a SWM system. The last stage in the disposal process entails direct placement of solid garbage into a landfill[61].

Disposal stands as the final and least favored option within solid waste management. It entails locating a site to discard wastes that cannot be treated through any other alternatives[47]. The objective of waste dumping is to segregate waste from both people and the surrounding in a manner that ensures no harm is caused. This is particularly important because improper dumping of waste from various sources undergoes ecological pollution[21]. Waste disposal methods exhibit considerable variation based on revenue and geographical location. Public littering is widespread in nations with lower incomes, in which formal landfill facilities may be lacking. Approximately 93 percent of waste in low-income countries is either burned or disposed of in roads, open areas, or water bodies, whereas only 2 percent of waste is dumped in nations with higher incomes[36].

Currently, landfilling represents the ultimate location for all solid wastes, including household waste and residual items from material recovery services[64]. Nevertheless, in the majority of developed nations, this approach is formally prohibited. A sanitary landfill, as opposed to a dump, is an engineered site created to get rid of solid waste on land without creating annoyances or risks to the environment or public health[39].

While it remains widely utilized globally, traditional and environmentally harmful methods such as open burning, open dumping, and non-sanitary landfilling are employed up to now as a disposal methods[65].

Thus, waste disposal stands as one of the most crucial management activities requiring meticulous planning.

2.11. Sustainable Solid Waste Management

Sustainable solid waste management ensures that the needs of future generations are met without sacrificing environmental, social, or economic considerations. This approach, as outlined in Our Common Future, integrates three dimensions of sustainability: social, environmental, and economic[43]. The notion of sustainable solid waste management focuses on the continual enhancement of the environment, fostering economic prosperity and expansion, promoting health advantages, and offering respectful, secure, and stable employment opportunities to individuals[5].

In developed nations, sustainable solid waste management is significantly more sophisticated compared to developing nations. Many developing countries have encountered challenges in implementing sustainable SWM due to various barriers. Achieving sustainable solid waste management involves several strategies: assigning clear roles to pertinent agencies and improving their collaboration, cultivating a skilled and ample workforce, establishing self-sustaining financial mechanisms, facilitating strategic planning and diligent execution, and fostering awareness among the public and policymakers[31].

Prudent and sustainable handling of solid waste can avert environmental harm and preserve valuable resources. Efficient management of solid waste significantly enhances environmental quality, human health, and the socioeconomic dynamics of communities[19].

2.12. Strategies and options for sound waste management

Solid waste management encompasses governmental, economic, legal, planning, developmental, and engineering principles to address all waste-related issues. Resolving solid waste challenges often involves complex interdisciplinary factors such as political dynamics, regional planning, topography, finances, public health, community communication, demographics, conservation, sociology, as well as engineering and materials science[61].

Integrated solid waste management is an enhanced system that begins at the point of waste generation, encompasses disposal, and encompasses all stages in between, handling various waste types. Moreover, integrated SWM is methodical and strategic approach that integrates all sources, functional components, and aspects, aiming to achieve sustainable waste management by optimizing resource utilization efficiency[4].

An integrated waste management approach must consider the specific issues and requirements of each community and region, tailoring a unique and suitable set of solutions for each particular context[56].

Globally, Integrated Waste Management Systems (IWMS) have gained traction due to the increasing demand for environmentally friendly solid waste management, incorporating principles such as economics, aesthetics, energy recovery, and material conservation. Efficiency in a solid waste management system relies on integration, which ensures comprehensive analysis of all aspects and acknowledges that advancements in one area often impact activities in others. Consequently, properly implemented IWMS has the potential to offer practical answers to challenges with solid waste management faced by municipalities in developing regions[66].

A sound practice refers to a technology or policy that represents a sensible equilibrium among practical, cost-effective, sustainable, environmentally advantageous, and socially considerate solutions to solid waste management issues[56].

The Strategies for sound waste management are:-

2.12.1. 5 R’s of Waste Management

The concept of the five R’s involves a method aimed at enhancing the outcomes of recycling initiatives by minimizing the generation of waste. Employing a robust waste management program is crucial for maintaining environmental cleanliness and ensuring the safe disposal of hazardous waste. Integral to this process is the adoption of the five R’s steps[67].

The five principles of waste management, known as the 5 R's, consist of Refuse, Reduce, Reuse, Repurpose, and Recycle. Adhering meticulously to each of these steps is essential for the plan to achieve its maximum effectiveness.

Refuse

The initial aspect of the 5 R's hierarchy involves the first step of diminishing your waste production. To begin lowering the quantity of garbage produced, it's crucial to decline items incoming to your household initially. Select to decline products that are not recyclable, such as single-use plastics or items destined for immediate disposal[30].

However, the act of refusal also entails making thoughtful decisions with your purchases. For instance, while shopping, aim to prevent impulsive purchases of items that aren't necessary or won't be used promptly[68].

Reduce

Reducing entails minimizing the use of harmful, wasteful, and non-recyclable materials, which not only saves money but also benefits the environment. By decreasing reliance on such products, less waste is sent to landfills, thereby mitigating their adverse environmental effects. To prevent unnecessary waste, it's advisable to utilize the minimum amount of material necessary[69].

Source reduction concentrates on diminishing both the volume and harmfulness of waste produced at its origin. This phase significantly contributes to achieving the ultimate objective of the process. Simplistically, the most straightforward and efficient approach to SWM appears to be reducing volume of waste for disposal. Generally speaking, it is better to reduce amounts of waste through various methods for managing waste[70].

Efficient waste management is essential. The primary focus should be on segregating waste, ideally at the source, into reusable and non-reusable categories to minimize waste generation[71]. Reducing sources of pollutants, such as greenhouse gases that contribute to global warming, protects resources and also diminishes pollution[72].

Reuse

The next preferable choice after source reduction is waste reuse. Reuse involves utilizing materials again in their original state; meaning products or materials are employed for the same purpose they were initially intended. Reusing waste typically entails collection with minimal or no processing. It encompasses activities such as inspecting, cleaning, repairing, and/or refurbishing entire items or spare parts[25].

Reusing involves discovering alternative uses for discarded items. It entails using materials repeatedly, thereby aiding in the reduction of waste disposal and handling expenses[68].

lowering the amount of garbage that is intended to final disposal site is a crucial objective[71].

Repurpose

When items cannot be refused, reduced, or reused, turning to this step becomes essential. Repurposing involves repackaging items originally intended for one purpose for alternative uses. This practice is also referred to as up cycling within environmentally conscious communities[64].

Recycle

The ultimate stage in the process is recycling, which is exactly as it sounds the last but certainly not least step. After diligently following the preceding steps of the five R's, recycling stands as a commendable final choice. Continuing our commitment to environmental friendliness involves recycling anything that can be recycled[67].

Recycling encompasses separating recyclable items into raw materials and processing them, which are then reprocessed into new products through manufacturing[65]. Recycling involves transforming waste into new products that can be reintroduced into the market for sale[62].

Recycling addresses economic and environmental concerns. A lot of individuals are driven to recycle due to the considerations of the environment, such as reducing pollution, conserving energy, space, and resources, and safeguarding biodiversity. Economically, recycling can lead to cost savings, particularly for materials like paper, metals, and certain plastics, and it plays a significant role in the economy overall[69]. However, some critics primarily focus on the economic advantages of recycling. Economists argue that recycling may not be practical if the cost of recycling materials exceeds that of sending them to a landfill or incinerator. Additionally, they suggest that recycling may not always be necessary for conserving landfill space, as many regions are not facing shortages in this regard[30].

2.12.2. Composting

Composting solid waste represents a sustainable method of management, especially when there is an enormous quantity of organic garbage. Neglecting organic waste can lead to natural decomposition, resulting in odors and providing habitat and sustenance for various insects and pests. These pests, in turn, can serve as vectors for disease, posing significant health risks[73].

Composting involves the controlled biological decomposition of biodegradable waste by microorganisms, predominantly bacteria, and fungi, in conditions that are aerobic and thermophiles. The resultant compost is an organic material that has been stabilized, allowing it to be handled, stored, and applied to land as per specified guidelines. It's important to distinguish the process of composting from natural decomposition as it involves human intervention for control. This control aims to optimize microbiological activity, mitigate undesirable environmental and health effects such as odor, rodent infestation, and water or soil contamination, and ensure the desired quality of the end product[74].

Composting is regulated decomposition of organic material within a warm, moist setting, facilitated by bacteria, fungi, and other microorganisms. This method typically entails stacking organic waste in a pit then covering it with soil until decomposition occurs. It stands out among disposal techniques for its adherence to resource conservation principles and minimal environmental impact, while also offering some economic advantages. Upon completion of the process, the resulting product is a nutrient-rich, odor-free dark substance suitable for use as a soil conditioner or natural fertilizer[66].

Composting, an age-old tradition, is experiencing resurgence in many cities worldwide as they recognize the advantages of repurposing solid organic waste. It represents a natural method of readying waste for reuse[71].

2.12.3. Incineration

Incineration entails the controlled burning of solid waste within designated chambers at elevated temperatures. However, due to its high operational and maintenance expenses, it stands as the costliest and least utilized disposal approach[66].

Considering incineration solely as a disposal method isn't advisable because it still leaves behind residual ash, likely necessitating disposal in a landfill, and releases ash and chemicals into the atmosphere. Rather, its capacity to reduce waste that can reach 80–95% in regard to volume has to be taken into consideration[56].

2.12.4. Landfilling

It is thought that properly maintained landfilling is an appropriate and recommended method towards the last disposal of MSW. It constitutes a crucial aspect of MSW management since all alternative options generate some residue that necessitates landfill disposal. This method involves depositing waste into a specially engineered cavity, followed by daily covering with soil or authorized substitute materials. Day to day covering serves to deter the allure of insects and animals. The Federal regulations impose various certain specifications on landfills, comprising installation of multiple impermeable layers (comprising synthetic plastic and natural clay) at the bottom to prevent liquid leaching from contaminating groundwater[49].

A sanitary landfill is a specialized facility designated to final waste disposal, aiming to mitigate the health and environmental hazards associated with solid waste. Typically, sanitary landfills incorporate one, two, or three layers of liners at the bottom and sides of the disposal area to hinder leachate from contaminating nearby surface waters or aquifers, as well as to impede the underground migration of methane. Upon arrival, waste is packed down and given a layer of soil on top daily to prevent access by animals and facilitate decomposition. Additional pollution control measures at sanitary landfills may include collection and treatment of leachate, as well as the venting or burning (flaring) of methane gas. Moreover, electricity generation is feasible through the combustion of methane produced by landfills[41].

2.13. Material Flow Analysis

MFA is a methodical evaluation of the movement and quantities of material in a defined system, considering both spatial and temporal dimensions. It serves as a valuable tool in various waste management studies by quantifying the flow of waste materials[75].

Material flow analysis comprises several primary stages: identifying key material flow-related issues, analyzing the system (including selecting relevant materials, processes, indicator substances, and defining system boundaries), quantifying mass flows of materials and indicator substances, and finally, creating and assessing scenarios along with schematic representation, and interpreting the outcomes[76].

Material flow analysis tracks the mass balances within an economy, where inputs (comprising extractions and imports) are equivalent to outputs (including consumption, exports, accumulation, and waste). Rooted in the principles of thermodynamics, MFA assesses the sustainability of material flows by examining the environmental impact they generate[77].

The MFA/SFA (substance flow analysis) technique incorporates the concept of "metabolic" system within waste management. This involves monitoring waste flows and substances win the waste management model, scrutinizing all inputs and outputs in the system, and evaluating and comparing them[75].

MFA is increasingly advocated as a valuable approach to make decision in solid waste management systems. It is a useful instrument for monitoring and controlling the flow of residues, secondary products, and waste[78].

MFA is pivotal in assessing the effectiveness of a waste managing system and determining the extent of enhancement potential offered by proposed solutions[79]. Material flow analysis can aid in comparing various sanitation technology alternatives based on their environmental and financial consequences, facilitating decision-making among different sanitation options[77].

Material flow analysis has become widely used to delineate the phases in the supply chain and the makeup of material chains in environmental studies, notably in the handling of waste. Numerous publications from various nations using MFA have been found through previous research like employing MFA to quantify material flows and waste accumulation in Thailand, as well as utilizing analytics to inform decisions on waste management policy, similar to MFA assessments conducted for solid waste management in Germany[64].

As illustrated, MFA has been extensively utilized as an assessment tool to gather essential information for discussions on sustainable waste management. The insights gained have been applied to enhance product design efficiency and minimize waste generation. A comprehensive understanding of municipal solid waste (MSW) flows within Dukem town is necessary to identify process routes, factors, locations, inefficiencies, problems, and opportunities within the current waste management approach. While MFA primarily relies on data analysis, it holds significant potential for informing various detailed studies in the decision-making process. In this study, MFA is employed to assess material flows within Dukem town's existing waste management framework and to conduct an environmental evaluation of the waste handling system, concentrating on waste gathering performance, resource management, and GHG emissions/global warming potential (GWP).

In general, management of solid waste in most towns across Ethiopia is inadequate. Moreover, existing studies have primarily focused on regional and sub-city levels within Addis Ababa, Ethiopia. Therefore, this research aims to predict the research gap in SWM at the zonal level and recognize causes primarily impacting this small-scale. In order to properly handle solid waste in Dukem town, reliable and accurate data is crucial. However, both the town and the municipality have shown limited attention to this issue, with little filtration or verification of information related to SWM problems. For example, there is a lack of frequent and ongoing surveys concerning the content and pace of solid waste production in the town, despite its characteristic variability. Previous studies are scarce, and the available data are often fragmented and disorganized. According to the previous study conducted in the town, “Wastewater and solid waste disposal patterns of Dukem town households in Ethiopia”[22] , The study's sole concern was on residential garbage disposal methods, excluding considerations of waste generation and composition. The findings revealed insufficient domestic waste disposal facilities. Another past study was entitled “Solid Waste Characterization and its Management System in Dukem Town”[23], The research sought to evaluate the characterization of residential and commercial solid waste in Dukem Town. However, discrepancies were observed in the figures for waste generation rates, and the percentage composition by weight did not accurately reflect the true values. Consequently, such assessments don't offer a thorough understanding of MSW handling in the town due to data gaps.

This research gap prompted the investigation of solid waste handling activities. Therefore, the current research was conducted to address this data deficiency by examining the existing status of solid waste handling practices in Dukem Town. Thus, the thesis is timely in evaluating the town’s solid waste handling activities.

3. Materials and Methods

3.1. Explanation of the research area

3.1.1. Location

Dukem is a town situated in the Oromia special district, southeast of Addis Ababa, approximately 37 kilometers away from the capital along the route to Adama. It is positioned along the Addis Ababa-Adama expressway[80].

Figure 1. Map of Dukem

Source: Dukem City Administration

Dukem town extends predominantly along the paved highway connecting Addis Ababa to Bishoftu city. Areas lacking substantial infrastructure development exhibit less elongation within the town. To the southeast, Dukem is bordered by Bishoftu city, while Gelan town encompasses much of its northern perimeter. Four adjacent farmer organisations in the Akaki area surround the town's surviving eastern and western parts[80].

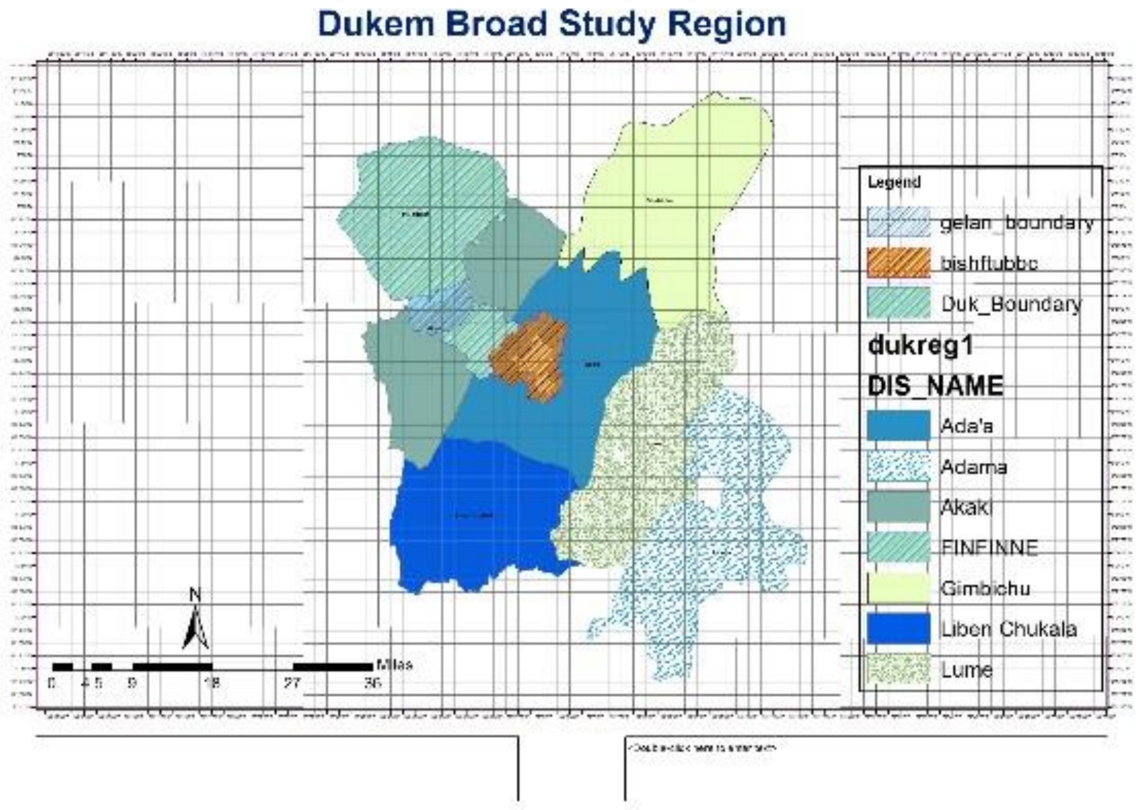


Figure 2. Dukem broad study region

Dukem town is situated between latitudes 8°47'25"N and 8°50'30"N, and longitudes 38°51'55"E and 38°56'5"E. Its elevation varies from 1890m to 2300m above Mean Sea Level, with a total altitudinal range of 410 meters. The town covers an area of 9630.6 hectares[80].

3.1.2. Climate

Dukem town experiences a semi-temperate agro-climate, with temperatures typically ranging from 15 to 20 degrees Celsius. The average annual rainfall in Dukem town and its surrounding area totals 963 millimeters[80].

3.1.3. Demographic Characteristics

Based on the 2014 census, it is estimated that Dukem town currently has a total of 159,209 people, of which 78,203 are women and 81,006 men. There are 35,380 households in the town when all was said and done, or an average of 4.5 persons per home. The population growth of the city is increasing by 4.5% annually. The reason for the increment in population is industrial expansion and Urbanization.

3.1.4. Socio-economic Profile and Investment of Dukem Town

Established in 1997 E.C., Dukem town is organized into four clusters or kebeles: Melka Dukem, Tedecha, Koticha, and Gogecha Kebeles. Designated as a First Grade Town by the Urban Development Bureau, it operates with both state and municipal functions, overseeing urban management responsibilities. The town boasts numerous investment opportunities across various sectors such as trade, industry, agro-industry, business, services, and more.

Dukem is emerging as one of the rapidly expanding urban hubs within the Oromia regional state[81]. The rapid urban expansion in Dukem town has led to significant land use conversion for various purposes, including residential settlements, industrial development, manufacturing, and service sectors. Its proximity to Addis Ababa has attracted increased investments, fostering rapid economic and social growth. However, this has also resulted in the reduction of farmland and the expansion of built-up areas over time. Being a town in a developing nation, Dukem has been unable to avoid the challenges associated with rapid urbanization[81].

Since the early 2000s, Dukem has risen to prominence as a key industrial hub in both the region and the country, earning the nickname "Eastern Industry Zone."[80]. As per information provided by the Investment Office of Dukem city administration, the Eastern Industry Zone stands out as the largest, spanning over 400 hectares of land. Within this zone, there are a total of 147 industries. The predominant types of factories include those for gypsum, steel, marble, plastic pipes, biscuits, pasta, iron sheets, magnesium, cosmetics, furniture, glass, garments, and more.

Currently, industrial activities are heavily concentrated in the western and northeastern regions of the town, particularly in areas locally known as Tedecha and Gogecha (Kebeles). According to data from the Dukem city administration's Investment Office, there are a total of 322 industries in the town.

As reported by the Dukem city administration's Trade Office, there are presently 2157 commercial sectors operating in the town, alongside only two health centers. Unfortunately, there are no hospital available, necessitating residents to travel to Bishoftu or Addis Ababa for medical care.

3.2.Research Design

Descriptive survey aims to examine the existing conditions and methods used in assessing solid waste management practices in the town. Employing a descriptive research design entails both quantitatively and qualitatively gathered data to provide an overview of the research.

3.3.Sample Size Determination

A sample comprises a chosen subset of people or objects that represent the entire population being studied. In any sample survey, determining the sample size is a crucial step. Therefore, the sample size, representing the entire population, was drawn from various groups, including households and commercial centers, to participate in the research. The sample size for the town was decided using proportional allocation according to the following formula.

According to Glenn (1992)[82], the simplified formula to calculate the sample size is as follows:-

$$\mathrm{n} = \frac{N}{1+(N*e^2)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where, N: - Total number of housing units

e:- Allowable error (the desired level of precision)

n:- Sample size of housing units

To attain the typically recommended confidence level of 95% with a margin of error of 5%, the sample size is computed based on the total number of housing units, which is N=35,380.

$$\mathrm{n} = \frac{35380}{1+(35380*(0.05)^2)} = 395.53 = 396$$

Therefore n= 396

The statistical confidence level and margin of error make clear how important the sample size is in determining the statistical significance of the results. The outcomes indicate that in order to reach the generally advised values of a 95% confidence level with a 5% margin of error, 396 households must be sampled. However, gathering garbage samples from 396 houses over a period of seven days in a town may often be both impracticable and costly. Consequently, a sample of 90 families for average cities is proposed in accordance with UN procedure, which chooses 10 households from each of three surveyed areas that correspond to high, middle, and low levels of income[83].

3.4.Sampling techniques and procedure

A multi-stage sampling method was utilized to select sample respondents from the population and achieve the objectives of this study. This involved employing a variety of sampling methods, including systematic random sampling and purposive sampling.

Systematic random sampling was utilized to identify and select the research sites, whereas purposive sampling was employed to choose units of inquiry (Key Informants) based on their easy accessibility.

In the research region, ninety households were chosen at random to take part in the questionnaire survey. The sample was selected proportionately according to each kebele's population and their income levels. Specifically, twenty-seven households were randomly chosen from Tedecha, fifty from Melka Dukem, nine from Koticha, and four from Gogecha.

Additionally, the determination of solid waste generation and characterization from different commercial units was conducted through representative sampling from each category, including Retail Trade shops, Cafés and bakeries, Restaurants, and Hotels. Based on this, a selected sample size of 20 commercial units was determined.

3.5.Data Sources

All necessary data for the study was gathered from both primary and secondary sources. Primary data collection methods included household surveys, surveys of commercial establishments, physical characterization, questionnaires, key informant interviews, and field observations. These methods were conducted by the standard procedures defined in the Waste Wise City Tool by the UN-Habitat project.

Secondary data, was attained from various sources such as published and unpublished materials from administrative offices, municipal solid waste management offices, journals, articles, policy briefs, and study reports.

3.6.Socio-economic analysis

Performing a Sustainable Development Goals (SDG) -based life cycle assessment of a MSWM system offers valuable insights into its environmental, social, and economic sustainability impacts across its entire life cycle. The findings from this assessment can serve as a foundation for decision-makers to enhance the sustainability of the system.

Key considerations include the economic viability and public acceptance of solid waste management schemes, alongside technological advancements and ecological impacts. This comprehensive approach integrates society, economy, and the environment, aligning with the principles of sustainable development. Recognizing the importance of economic factors in driving the adoption of innovative environmental technologies is widely acknowledged, and economic incentives are pivotal for policymakers to devise effective strategies. Additionally, studying social perceptions and attitudes can shed light on various factors influencing public awareness and actions regarding environmental initiatives[84].

Considerable attention has been directed toward the significance of pertinent social and economic research in formulating detailed strategies to bolster public acceptance of emerging technologies while maintaining cost-effectiveness. MSWM is recognized as a complex process involving numerous environmental and socio-economic considerations.

The influence of socio-economic factors on both the amount and composition of MSW has long been acknowledged in crafting effective SWM plans, emphasizing the necessity of reliable information. Various socio-economic variables impact recycling behavior and willingness to financially support recycling initiatives within SWM services. Effective decision-making in defining realistic policy objectives and operational measures, as well as exploring alternative solutions to SWM challenges, is crucial.

Transitioning from traditional SWM practices to a more integrated approach often necessitates the active involvement of a variety of social actors, including the government, local governments, companies, professions, and the general public. Ultimately, social acceptance and awareness must be integrated with economic considerations and environmental impact assessments to ensure the effective implementation of sustainable SWM initiatives.

To comprehensively evaluate the sustainability impacts of a system, it is imperative to gather not only data on material and energy flows but also socio-economic data across various life cycle phases. The selection of required data is determined by the indicator set applied, which must be tailored to the local context. These data are typically collected through appropriate questionnaires and interviews and also from the city administration offices.

3.7.Data collection instruments

The subsequent data-collecting tools are utilized to acquire ample and dependable information: - Questionnaires, Interviews, Field Observations, and Field measurements.

3.7.1. Questionnaire survey

Carefully crafted questions were used to perform a household survey. These questionnaires covered various aspects such as the characteristics of houses' demographics, details on waste production by type, waste removal methods, doorstep to doorstep methods of gathering, family's overall income and degree of education. The survey was conducted by travelling to carefully chosen houses doorstep to door step during June and July 2022G.C. Two visits were made to each home in order to compute the questionnaire. At the initial visit, socioeconomic data was gathered, and home owners were asked to segregate their waste into different plastic bags. After seven days, the waste was collected and weighed.

The household survey questionnaire is structured into three sections. The primary part focused on gathering demographic and socioeconomic information about the respondents, the second part examined on-site SWM practices of residents, and the final part addressed waste disposal practices of respondents. Data were collected through oral interviews and questionnaire administration from randomly selected individuals in Dukem town to assess SWM activities in the town.

3.7.2. Interviews

In terms of the questionnaires, interview questions were formulated to explore both the overall SWM activities and socio-economic impact. Key informant interviews were conducted with department heads, employees of the town municipality, and leaders of MSSE to gather comprehensive information about solid waste management practices

3.7.3. Field Observations and Measurement

The assessment of production of solid waste and the effectiveness of SWM program was conducted directly through visual inspection of the area and capturing photographs. Field observations were utilized to determine the geographic distribution of SWM strategies in families, including collection, separation, and disposal sites.

At the household level, measurements were taken to evaluate solid waste production rates and physical composition and separation practices. This involved distributing plastic bags to the selected 90 households to collect their waste. Each survey unit was treated individually for waste generation rate determination. All collected wastes were weighed and recorded on a sampling sheet. Subsequently, the specimens are evenly dispersed over a plastic sheet, and the waste components were manually sorted into 11 major categories. The sorted components were then weighed and recorded.

Collected waste Waste Sorting Measuring sorted waste

Figure 3. Collected waste, Waste sorting and measuring Sorted waste

DSWGR at the household level were computed following the guidelines outlined in the Waste Wise Cities Tool (WaCT)[83].

It was calculated as follows:-

$$DSWGR = \frac{Total\ solid\ waste\ generated\ \ for\ consecutively\ 7\ days}{Consecutively\ 7\ days * \text{sample size}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The PCPDSWGR is also calculated as follows:-

$$\text{PCP}DSWGR = \frac{Total\ solid\ waste\ generated\ for\ consecutively\ 7\ days}{Consecutively\ 7\ days * total\ family\ size\ household} \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Using the estimated population of Dukem town, DSWGR is determined by multiplying PCPDSWGR by the estimated total population of the town. Similarly, monthly rate of household solid waste production was calculated by aggregating daily generation rate over 30-day period.

- Bulk Density Analysis

The bulk density of waste is a crucial factor in planning, scheduling, and design of SWM infrastructure.

Field measurement of wastes was carried out in order to determine the bulk weight of wastes. This was achieved by figuring out the volume and weight of the waste using a calibrated bin. In order to accomplish this task Composite sample were created from each bag at each source. The process involved inserting the waste into bucket which is capable of attaining 20 liters to ascertain weight of the sample volume of solid waste. The mass of the waste was determined separately by placing it in a plastic bag. Then, the density was calculated by dividing the net weight of the solid waste sample in the plastic bucket by the bucket volume. Consequently, bulk density is calculated by using the formula:

$$BD = \frac{Weight\ of\ waste(Kg)}{Volume(cubic\ meter)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (4)$$

3.8.Data Analysis Methods

3.8.1. Qualitative and Quantitative Data Analysis

This section focuses on the presentation, analysis, and interpretation of the data collected in Dukem town. Both qualitative and quantitative methods are utilized to assess MSW production and removal circumstances.

Qualitative data obtained through questionnaires, interviews, personal observations, and secondary data review was discussed. The collected quantitative data underwent statistical analysis using the SPSS version 20.0 statistical software. The data was gathered, arranged, and condensed using basic descriptive statistical techniques.

3.8.2. Material Flow Analysis

MFA involves quantifying and evaluating the movement of substances within a system (such as a city or country) over a specific time frame. MFA operates on the principle of matter conservation, where flows are measured in kilograms per year or kilograms per capita per year. This method enables the identification of issues and the measurement of the effects of potential actions on resource utilization and environmental contamination[76].

MFA is an analytical approach used to evaluate the movement and quantities of materials within a system. It adheres to the principle "materials cannot be lost," that is derived from the 1st law of thermodynamics, emphasizing matter and energy conservation. The entire mass of intakes must equal the sum of products plus the stocks inside the system in order to define a boundary for the entity across both spatial and temporal scopes. The concept can be mathematically represented by Equation 5 as shown below[79].

$$\sum \mathrm{ki}\ \mathrm{m(input)} = \sum \mathrm{ko}\ \mathrm{m(output)} + \mathrm{m(stock)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5)$$

Where m denotes the flow/flush and ki and ko, respectively, indicate input and output flows.

Recognizing waste is a crucial component of Material Flow Analysis (MFA) because the goal of this analysis is to reduce material flows while optimizing the benefits they provide to society. MFA facilitates waste monitoring for economic assessment, making it a valuable technique for evaluating the effectiveness of material resource utilization. It plays a key role in industrial ecology and forms the foundation for material flow management[85].

To exemplify the proposed method, Material Flow Analysis (MFA) was conducted for Dukem town to support waste management decision-making. MFA software, STAN 2.7.101, was utilized to analyze municipal solid waste (MSW) data spanning the period of January 2021–July 2022, ensuring the construction and balancing of mass flows. Interviews with waste handling participants and direct observations in the field were employed to gather additional data. The utility of Material Flow Analysis was shown by forecasting how interventions in waste management could yield a more sustainable MSW flow, aiding decision-makers in selecting optimal solutions.

Overall, solid waste management (SWM) contributes to 5% of worldwide GHG emissions. The issue of global warming and climate change stemming from increased GHG levels is a significant worldwide concern. Thus, enhancing SWM systems to recover energy as well as materials would thereby improve the effectiveness of resources while mitigate greenhouse gas emissions[78].

To evaluate the potential enhancements in resource management as well as decrement of GHG emissions from SWM alternatives in Dukem, several waste management scenarios were considered. The study compared three scenarios, each involving a different proportion of solid waste allocated for composting (10%, 30%, and 50%).

In this research, the primary greenhouse gases emitted by the generation of solid waste are carbon dioxide and methane. The Intergovernmental Panel on Climate Change (IPCC) guidelines is adopted to estimate of GHG emissions from landfills, open burning, recycling and composting. These guidelines, also utilized by The United Nations for the Framework and Convention on Climate Change (UNFCCC), are adopted by all the member countries for reporting national GHG emissions. In this study, the IPCC (2006) guidelines are employed to determine GHG emissions from open burning, landfills, composting and recycling. It's important to acknowledge that due to uncertainties, the calculations are approximations, yet they remain valuable as a reference for estimating the potential impacts.

$$CH4 = \left[\left(MSW(land\ fill)\right) * MCF * DOC * DOCf * F * \left(\left(\frac{16}{12}\right) - R\right) * (1 - OX)\right] \ldots. (6)$$

Where: - CH4 = Methane Emission

MSW (Land Fill) = Total amount of MSW in the landfill

MCF = Methane correction factor

DOC = Degradable organic carbon in MSW

DOCf = the fraction of DOC that can decompose (fraction)

F = the fraction of methane in generated landfill gas

R = the recovered methane

16/12 is the molecular weight ratio of CH_4/C

OX = the oxidation factor

The estimation of CH_4 from the composting in this study is calculated adopting equation 7.

$$EM = [M * EF] * 10^{-3} - R \text{ .... (7)}$$

Where; EM = GHG emissions generated from composting

M = amount of composted MSW

EF = Emission factor

R = Methane recovery amount = (value used = 0)

Emission from open burning is calculated by using equation 8.

$$EMOB = EMi\,(CO2) + EMi\,(CH4) + EMi\,(BC) \text{ ... ...(8)}$$

Where; EM_{OB} = Emission for open burning

EM_i (CO_2) = Carbon dioxide emission

EM_i (CH_4) = Methane emission

EM_i (BC) = Black carbon emission

Emission from Recycling is calculated by using equation 9.

$$ER = MSW\,(Recycled) * EFi \text{ ... ... (9)}$$

Where; ER = Emission for Recycling

MSW (Recycled) = Total amount of MSW Recycled

EF_i = Emission factor

4. Result and Discussion

This section provides a concise overview and evaluation of the current SWM activities of Dukem Town.

4.1.Respondents' Characteristics

4.1.1. Demographic characteristics

Demographics refer to distinct characteristics of a population, which are categorized based on specific criteria to study the attributes of a particular group. Demographic information was gathered through surveys. Two significant demographic factors, namely age and gender of the participants, have been identified as crucial for evaluating service activities such as solid waste management practices due to several reasons:-

Behavioral Differences: Age and gender can significantly influence how individuals interact with waste management services. For instance, younger individuals might be more inclined towards adopting eco-friendly practices, while older generations might stick to traditional methods. Similarly, gender roles may influence responsibilities related to waste management within households and communities.

Preferences and Needs: Different age groups and genders may have distinct preferences and needs regarding waste management services. For example, families with young children may require more frequent waste collection due to the generation of diapers and other waste associated with childcare.

Community Engagement: Understanding the demographics of a community, including age and gender distributions, can aid in designing targeted and inclusive waste management programs. It allows service providers to tailor their outreach efforts and educational campaigns to effectively engage various segments of the population.

Policy and Planning: Data on age and gender demographics can inform policy-making and strategic planning for waste management at local, regional, and national levels. It enables policymakers to allocate resources effectively, prioritize interventions, and develop long-term, sustainable solutions that address the unique needs of various demographic groups.

Overall, incorporating age and gender considerations into the evaluation of SWM practices enhances comprehensiveness, efficiency, and inclusivity of waste handling initiatives. Hence, these variables have been highlighted in the Table below.

- **Gender and Age**

Table 4.1 Respondent distribution by gender and age group

Characteristics of Variables	Description	Frequency	Percent
Age of respondents	21-30	16	17.8
	31-40	29	32.2
	41-50	23	25.5
	51-60	14	15.6
	Above 60	8	8.9
Sex	Female	48	53.3
	Male	42	46.7

Source: Field survey, 2022

The table above illustrates that approximately 53.3% of the participants were female, with the remaining being male household heads, indicating a predominance of female heads within the survey population. This suggests that women are closely involved in the daytime to daytime practices concerned with household SWM practices compared to men.

Additionally, Table 4.1 indicates that the highest concentration, comprising one-third of their answers, falls in between 31 and 40 years, followed by 23 respondents within 41-50 age group. This implies that more than half of the respondents were aged between 31 and 50. Consequently, it can be concluded that the respondents are at an age where they are likely to understand the importance of environmental quality and consequently make informed decisions regarding solid waste management.

4.1.2. Socio-economic status

- **Educational status**

The educational attainment of household heads is often considered a crucial factor influencing household solid waste management practices. Hence, an effort was made to evaluate their backgrounds of education. Consequently, the participant's educational status is outlined in Table 4.2.

Table 4.2 Respondents Educational status

Characteristics of Variables	Description	Frequency	Percent
Educational status	Illiterate	2	2.2
	Read and Write	14	15.6
	Primary school	14	15.6
	Secondary school	31	34.4
	Higher education level	29	32.2

Source: field survey, 2022

Table 4.2 illustrates that a significant portion of the respondents (34.4%) have completed secondary school education. Following this, 32.2% have attained higher education, while approximately 15.6% have finished primary school. This suggests that the majority of respondents have achieved secondary school education or higher, indicating a positive correlation regarding the household head level of education with their SWM activities. The prevalence of higher education among the sampled households is expected to contribute to diverse and informed perspectives. As household educational levels increase, there is likely an improvement in household solid waste management practices, indicating that educated individuals possess a better understanding and knowledge regarding waste management and related issues.

- **Household Size**

Household size is considered a factor influencing SWM activities at home. It is hypothesized that greater labor force within a household correlates positively with more efficient solid waste management practices. However, it's important to acknowledge that larger household sizes typically result in greater solid waste generation. To assess whether these hypotheses align through the practices of surveyed houses, the household size of individual respondent was evaluated, as indicated below in Table 4.3.

Table 4.3 Respondents by their Household size

Characteristics of Variables	Description	Frequency	Percent
Family size	1-3	12	13.3
	4-6	55	61.1
	7-10	20	22.2
	Above 10	3	3.3

Source: field survey, 2022

As illustrated in Table 4.3, approximately 61.1% of respondents have a household family size of 4-6, while roughly 13.3% have a household size of 1-3. This distribution suggests both the advantageous and disadvantageous aspects of larger household sizes, as discussed earlier. It's worth noting that larger household sizes tend to result in increased solid waste generation.

- **Income**

It's generally believed that households with higher incomes are better positioned to afford efficient solid waste management practices compared to those with lower incomes. Additionally, affluent households tend to produce more solid waste than less affluent ones, all else being equal. Moreover, the composition of produced waste can also varies based on the economic background. To explore this further, the respondents' average monthly salary was examined and categorized into five groups, as shown in Table 4.4. Around half of the respondents reported an income of 5000-8000 birr/month, while 17.8% reported incomes of 8000-15,000 birr. Additionally, about 6.7% earned 2000-5000 birr per month. It's presumed that households with higher incomes produce additional solid waste than those with lower incomes. However, the type of solid waste generated may differ based on economic background. For instance, lower-income households might rely more on wood and charcoal for fuel, resulting in the production of ash, thereby contributing to higher solid waste generation. Unfortunately, eighteen respondents declined to disclose their monthly household income, accounting for 19.9% of the total.

Table 4.4 Respondents by their monthly income

Characteristics of Variables	Description	Frequency	Percent
Family income/Month	No Income	1	1.1
	2000-5000	6	6.7
	5000-8000	43	47.8
	8000-15000	16	17.8
	>15000	6	6.7
	Unknown	18	19.9

Source: field survey, 2022

- **House tenure structure**

The ownership status of the households' residences can influence the effectiveness of their solid waste management practices. Table 4.5 affords a summary of tenure condition of the houses in which households reside.

Table 4.5 Respondents by tenure status of the houses

Characteristics of Variables	Description	Frequency	Percent
Housing Condition	Private	62	68.9
	Rented	18	20.0
	Kebele	10	11.1

Source: field survey, 2022

The tenure status of the respondents, as depicted in the table above, can be summarized as follows: 68.9% of the respondents resided in their private homes, 20% lived in rented houses, and 11.1% occupied kebele houses at the time of the survey. A higher number of homeowners in the study suggest that many households are likely to invest in improving environmental quality. Individuals who own their private houses typically have greater opportunities to effectively manage their household solid waste compared to those living in rental or kebele (public housing) houses for several reasons:

Homeowners have greater autonomy in decision-making regarding waste management practices on their property. They can implement personalized waste reduction, recycling, and composting strategies without relying on external approvals.

Private homeowners typically have more space available on their properties compared to rental or kebele houses. This additional space enables them to allocate areas for waste sorting, composting, or storage, facilitating more organized waste management practices. Homeowners have space to store primary materials for waste management and can engage in activities such as composting organic waste from their households, including ash, grass, food scraps, and fruit waste. However, despite these opportunities, many homeowners may lack awareness and technical skills for compost preparation

Homeowners tend to have a long-term commitment to their property, leading to a vested interest in maintaining cleanliness and environmental sustainability. This motivation may drive them to adopt and sustain effective waste management practices over time.

Homeowners may have more financial resources available to invest in waste management infrastructure, services, or technologies compared to renters. This financial stability enables them to afford solutions that optimize waste management efficiency.

Homeowners often have more flexibility in adhering to waste management regulations and guidelines, as they are not subject to the same restrictions imposed by landlords or housing authorities. This flexibility allows them to tailor waste management practices according to their preferences and needs.

Overall, homeownership provides individuals with the autonomy, resources, and space necessary to implement effective household waste management practices, which may not be as readily available to renters or residents of kebele houses.

To generalize the demographic characteristics and socio-economic status of the respondents, the table below summarizes correlation of respondent’s characteristics with different solid waste handling practices like waste sorting, composting and reusing.

Correlations					
		How often do you prefer to collect waste directly from the house?	Do you separate kitchen waste from other household waste?	Do you compost wastes?	Do you reuse Household Wastes?
Gender of Respondent	Pearson Correlation	-0.129	-0.136	-0.089	-0.104
	Sig. (2-tailed)	0.253	0.209	0.415	0.335
Age of Respondent	Pearson Correlation	0.145	0.071	-0.053	-0.028
	Sig. (2-tailed)	0.210	0.523	0.637	0.803
Educational status of Household Head	Pearson Correlation	-0.080	0.017	0.039	-0.130
	Sig. (2-tailed)	0.479	0.878	0.720	0.229
Profession of the Household Head	Pearson Correlation	0.164	0.070	0.029	0.057
	Sig. (2-tailed)	0.145	0.520	0.793	0.597
Family Income/Month	Pearson Correlation	-0.115	-0.159	-0.170	-0.145
	Sig. (2-tailed)	0.365	0.193	0.160	0.228
Housing Conditions	Pearson Correlation	-0.163	0.018	0.101	0.060
	Sig. (2-tailed)	0.145	0.871	0.351	0.573
Household Family Size	Pearson Correlation	-0.025	0.052	-0.013	-0.112
	Sig. (2-tailed)	0.824	0.632	0.906	0.296
****. Correlation is significant at the 0.01 level (2-tailed).**					
***. Correlation is significant at the 0.05 level (2-tailed).**					

Table 4.6. Correlation of Respondents characteristics with solid waste management practices

4.1.3. Energy Availability

Table 4.7 Respondents by Energy Availability

Characteristics of variables	Description	Frequency	Percent
Energy Availability	Firewood, Cow dung and charcoal	20	22.2
	Firewood, Charcoal, Kerosene and Electricity	70	77.8

Source: field survey, 2022

Approximately 77.8% utilize firewood, charcoal, kerosene, and electricity as their primary energy sources, while the remaining 22.2% rely on firewood, cow dung, and charcoal. The preference for firewood, charcoal, and cow dung among some respondents contributes to a higher production of solid waste, particularly ash.

4.2.Characteristics of Municipal Solid Waste

One fundamental service currently garnering significant attention in many Ethiopian towns is the handling of MSW. This heightened focus arises as of the prevalent issue of inadequately handling and managing solid waste generated in most Ethiopian towns. However, these challenges can be mitigated and resolved through meticulous planning and the implementation of various components of MSWM. The initial and essential step in establishing an effective MSWM system is identifying the primary sources, as well as determining solid waste's amount and production pace. These factors serve as the foundation intended for the subsequent components of MSWM. Thus, to appropriately manage the waste in Dukem town, obtaining reliable and accurate data regarding these aspects is crucial.

4.2.1. Determination of Generation Rate

The following data was gathered to calculate DSWGR and PCPDSWGR: Over 7 days, a total sample weight of 744.51kg was collected from 90 households, with a family size averaging 509 individuals. Utilizing the formula for DSWGR, it was determined that the town produces approximately 1.18kg of waste per day. The PCPDSWGR was calculated by dividing total waste produced over the 7-days by the total family size multiplied by 7 days, yielding a pace of 0.209kg. Hence, the daily waste production for Dukem town is valued at 0.209kg/person. Comparable trends were noted when these findings were compared with studies conducted in other main Ethiopian cities, for instance 0.21 kg of Gondar[45]; 0.22 Kg of Bahirdar[29]; 0.229 kg of Gambella town[53]; 0.231kg of Dessie[15]; 0.231 Kg of Hawassa[26]; and 0.233 Kg for East African cities developed by WHO [30].

The total daily solid waste produced for the entire population of Dukem town was computed by multiplying the population size (159,209 individuals) by the daily waste generation per person (0.209kg/person/day). Consequently, the daily amount of waste produced by houses is 33,274.7kg.

For commercial units, data was collected from a sample size of 20, with a total sample weight over 7 days amounting to 695.513kg. From this, it was deduced that each commercial unit produces 4.97kg of waste daily, resulting in a total solid waste generation from commerce of 13,687.3kg per day.

4.2.2. Municipal solid waste sources and amount of generation

Municipal solid waste encompasses a diverse mixture of discarded materials originating from urban households, commercial enterprises, institutions, and industrial operations. Likewise, as reported by the solid waste management office of Dukem town, there are four primary sources of solid waste. The combined daily total of solid waste generated from these sources amounts to approximately 73,750.3 kg, with an annual accumulation reaching 26,918,852.6 kg (26,918.9 tons).

Table 4.8 Major solid waste source, daily and annual amount of generation

Waste Source	Daily amount of Generation (Kg)	Annual Generation (Kg)	waste quantity [T/a]	weight-% of total generated waste
Households	33,274.7	12,145,265.5	12,145.3	45.00%
Commerce	13,687.3	4,995,864.9	4,995.9	19.00%
Institutions	2,973.42	1,085,298.3	1,085.3	4.00%
Industry	23,814.86	8,692,423.9	8,692.4	32.00%
Total	73,750.3	26,918,852.6	26,918.9	100%

4.2.3. Solid Waste Composition Analysis

In the planning of solid waste management systems, the composition of waste holds equal importance to its quantity. The waste was categorized as follows during sorting:

1. Organic wastes- includes kitchen and garden wastes

Kitchen waste   Garden/park waste

Figure 4. Organic wastes

2. Paper and Cardboard   3. Film plastics

Figure 5. Paper & cardboard, and Film plastic wastes

4. Dense Plastics   5. Glass

Figure 6. Dense plastic and Glass wastes

6. Metal 7. Textiles and Shoes

Figure 7. Metal and Textile wastes

8. Special wastes 9. Composite products

Figure 8. Special wastes and Composite products

9. Wood- there was no wood waste

11. Others

Figure 9. Other wastes

As shown in the pie chart below, the predominant component of waste is organic waste. The World Bank notes that typically, in urban waste streams of low- and middle-income countries, there is a significant percentage of compostable organic materials, ranging from 40 to 85% of the total waste composition[45]. In developing nations, the typical urban waste stream consists of more than 50% organic material on average [8]. Metropolitan cities in developing nations exhibit a notably larger proportion of food waste within their total waste composition[53]. The combination of everyday activities, consumption patterns, seasonal variations, and natural decomposition processes contributes to the higher production of organic waste compared to other waste categories. The significant presence of organic content in the waste suggests a potential for recycling these organic materials into valuable resources, such as compost.

PIE CHART OF COMPOSITION ANALYSIS

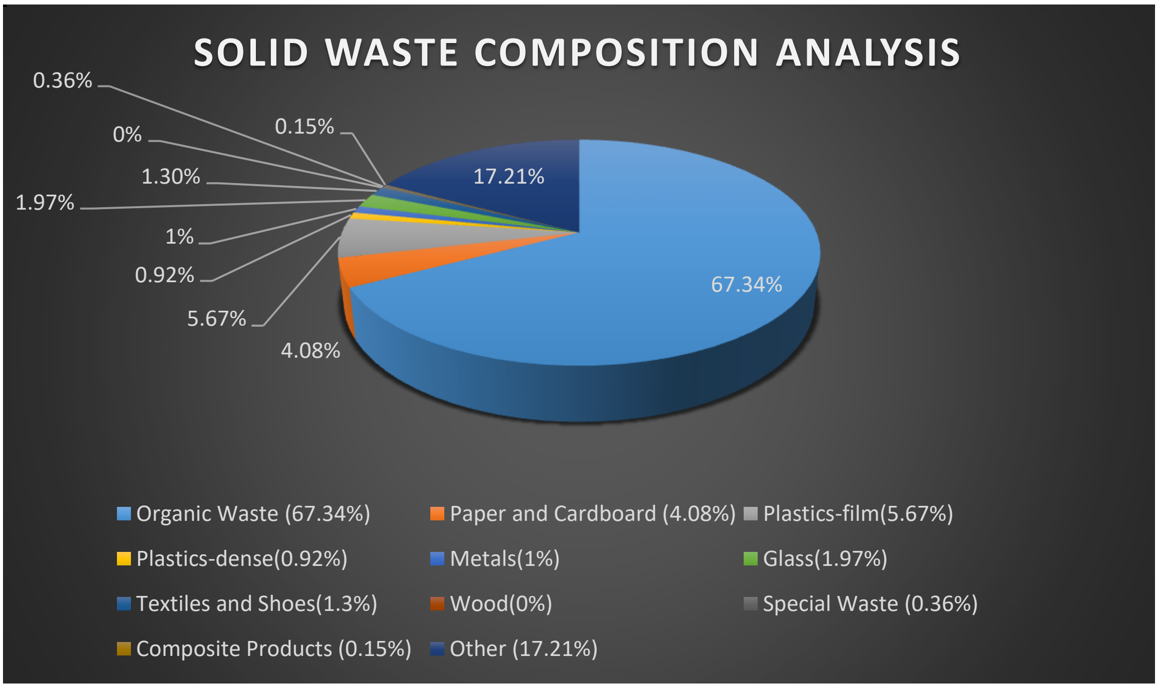


Figure 10. Solid waste composition analysis

4.2.4. Bulk density Analysis

The bulk density of the solid waste was calculated as follows:-

BD = Weight of waste (kg)/ Volume (m^3) = 5.74 kg / 0.02 m^3 = 287 kg/m^3

Hence, the bulk density measures at 287 Kg/m3, falling within the range of 205 to 370 kg/m3 documented for Addis Ababa[21], Additionally, it falls within the range of 250-500 kg/m3 documented for low-income countries[5].

4.3.Solid Waste Storage Facility, Its Handling and Disposal Practices

This aspect of Municipal Solid Waste Management (MSWM) involves an activity performed by both waste generators and managers in the town. It entails promptly storing solid waste in specific materials or containers upon generation and safely managing it until final disposal. This encompasses identifying suitable storage materials and quantities, selecting appropriate locations, determining collection methods, and mitigating potential health, environmental, and aesthetic concerns associated with storage materials. Consequently, information regarding the temporary storage and handling practices in Dukem town has been collected and briefly elucidated. Residents of Dukem utilize various materials for storage within their compounds, as detailed in Table 4.9. The findings reveal diversity in storage material types among households, influenced by factors such as waste characteristics, collection frequency, available space, types of collection equipment, and household economic status. Concrete evidence of these variations is presented in the subsequent table```.

Table 4.9 Primary solid waste storage materials at household level

Characteristics of variables	Description	Frequency	Percent
Is there a temporary storage container at home?	Yes	87	96.7
	No	3	3.3
Type of Temporary storage Container	Plastic bag	10	11.1
	Sack	77	85.6

Source: field survey, 2022

As evident from Table 4.9, 96.7% of respondents possess temporary storage containers for their household waste. Among these, 85.6% utilize synthetic sacks ("Madaberiya") for temporary storage, primarily due to their affordability, widespread availability, and capacity to hold substantial amounts of waste. Approximately 11.1% of households employ plastic bags for temporary storage. Despite variations in storage material choice and usage, many Residents don't have set protocols for handling and often neglect proper care to this aspect. Consequently, storage materials of the houses often exhibit unfriendly features resulting from inappropriate managing, leading to scattered solid waste around storage areas. Moreover, due to space constraints, a majority of households position storage containers near their homes. The survey highlights that many residents in the town inadequately store and handle household solid waste, particularly in outlying residential areas, contributing to an unsightly environment and adversely impacting sanitation and the town's aesthetic appeal. Without effective management, such practices can pose significant adverse effects on the environment and public health. The table below details the solid waste removal practices of households:

Table 4.10 Household's Solid waste disposal practices

Characteristics of variables	Description	Frequency	Percent
Who disposes of Household Waste?	Servant	3	3.3
	Family member	12	13.3
	The city corporation picks up waste from homes	75	83.4
Do you use open dump as a disposal Method?	Yes	9	10.0
	No	81	90.0

Source: Field survey, 2022

Based on the data presented in the table, the following key points can be summarized: Approximately 83.4% of household waste is disposed of through this method, involving collection by the city corporation and locally hired individuals. About 13.3% of household waste is managed by family members, while servants handle the remaining 3.3%. The majority of households refrain from utilizing open dumps for waste disposal, with only 10% of respondents reporting its use.

4.4.Solid Waste Segregation, Processing, and Recovery Activities

In this research, the terms "solid waste separation, processing, and recovery activities at source and by municipality" encompass all exertions aimed at segregating recyclable, reusable, and compostable waste either for sale or self-recovery of resources. Implementing these practices holds significant importance for both waste generators and municipalities, as it reduce removal charges, generate income, and extend the lifetime of dumping sites. Consequently, solid waste managers worldwide are increasingly seeking ways to divert biodegradable and recyclable materials away from landfills. However, in Dukem town, such activities are currently at a rudimentary stage, lacking notable outcomes or progress. The subsequent section provides an overview of these activities at the houses.

- **Solid waste segregation**

An effort was undertaken to evaluate separation activities of the residents in the town, focusing on segregating waste that are exchangeable or sellable, and to a certain level, organic waste. Corresponding with the observations, the responses from respondents are presented in Table 4.11, revealing that approximately 52.2% of respondents separate their kitchen waste from other household waste. However, 47.8% of respondents do not engage in separating their household solid waste. In Jigjiga, it was found that only 35.5% of households segregate matters that are marketable or exchangeable locally[6]. This suggests that the majority hold a certain extent of understanding and awareness regarding waste separation.

Table 4.11 Solid waste separation

Characteristics of variables	Description	Frequency	Percent
Do you separate your kitchen waste from other household waste?	Yes	47	52.2
	No	43	47.8

Source: Field Survey, 2022

- **Resource recovery activities**

To evaluate resource recovery endeavors, recycling, reusing, and composting activities were examined as fundamental criteria. It was discovered that societal involvement in these activities is notably minimal, even in comparison to solid waste separation. Initially, the number of households with awareness about recycling, reusing, and compost preparation is low, indicating a general lack of understanding regarding sustainable SWM activities inside the community. Subsequently the concepts of recovering resource are foundational aspects of sustainable SWM; this deficiency underscores the need for increased awareness and education on these principles.

Table 4.12 Resource recovery activities

Characteristics of variables	Description	Frequency	Percent
Do you reuse Household waste?	Yes	20	22.2
	No	70	77.8
Do you compost Waste?	Yes	23	25.6
	No	67	74.4

Source: Field Survey, 2022

The table above illustrates that only 22.2% of households engage in reusing practices. This finding aligns with the results of the study conducted in Bahirdar city[29]. The primary materials commonly reused include glass, bottles, metallic items, and plastics. The primary reason for the limited engagement in practicing reuse and recycle among the community is lack of attention and the minimal financial viability. Although some individuals express interest in such practices, barriers such as insufficient technical skills, financial resources, materials, space, and lack of support from family and society hinder their implementation. Regarding composting, approximately 25.6% of households are involved in this activity, representing an improvement compared to the results observed in Bahirdar city, where only 13.81% of sampled households were found to be separating solid waste for composting[11] and Merely 3.5% of households in Woliata Sodo town are engaged in home composting[8]. Throughout the research, it was noted that there are individuals who are aware, at the very least, of the utilization of organic waste for enhancing soil fertility. However, based on information gathered from respondents, the majority of household composting efforts fail due to a lack of technical expertise in compost preparation.

The table below outlines household waste selling practices. Thirty-five point five percent (35.5%) of households engage in selling waste. Among these, twenty-four point four percent (24.4%) commonly sell metals, seven point eight percent (7.8%) plastics, and three point three percent (3.3%) paper waste. Additionally, thirty-four point four percent (34.4%) of solid waste is sold for Korales.

Table 4.13 Solid waste selling practice of households

Characteristics of Variables	Description	Frequency	Percent
Do you commonly sell waste?	Yes	32	35.5
	No	58	64.5
What type of waste do u sell?	Plastics	7	7.8
	Metals	22	24.4
	Papers	3	3.3
For whom do you sell waste?	Korales	31	34.4
	Formal recycling centers	1	1.1

Source: Field Survey, 2022

Another concern is the burning of household waste, a practice observed in the town and summarized in the table below. Sixty-six point six percent (66.6%) of respondents engage in incinerating household waste, with twenty-three point three percent (23.3%) conducting burning inside their compound and forty-three point three percent (43.3%) outside the compound. Uncontrolled waste burning is likely to contribute to urban air pollution[8].

Table 4.14 Burning of household wastes

Characteristics of variables	Description	Frequency	Percent
Do you burn Household waste?	Yes	60	66.6
	No	30	33.4
Where do you Incinerate?	Inside the compound	21	23.3
	Outside compound	39	43.3

Source: Field Survey, 2022

4.5.Solid Waste Collection and Transportation Systems

Here, the system entail gathering waste from its point of origin, transporting it to transfer stations, and ultimately depositing the waste at a disposal site. This operational aspect is essential in managing solid waste for the reason that the effectiveness of this facility depend greatly on it.

Table 4.15 Solid waste collection

Characteristics of Variables	Description	Frequency	Percent
If waste is picked up straight from your home, how often would you prefer it to happen?	Daily	8	8.9
	Every two days, once.	4	4.4
	Every three days, once.	56	62.2
	Once per week	22	24.5
When do you dispose of your waste?	The Morning after 6 am	70	77.8
	No definite time	20	22.2
When would you like the collection of your waste?	Morning	84	93.4
	In the afternoon	2	2.2
	Evening	4	4.4

Source: field survey, 2022

According to data from the solid waste management office, gathering of the waste is conducted by MSSEs once per week from households. However, responses from some respondents suggest that waste collection is irregular. Despite this, the majority of respondents indicated that waste collection occurs once per week. Table 4.15 illustrates that a significant majority (62.2%) of respondents prefer their waste to be collected once every three days directly from their house, while only 24.5% of households prefer waste to be collected once per week. Additionally, approximately 77.8% of respondents currently dispose of waste in the morning after 6 am, with 93.4% of households preferring waste collection to take place in the morning.

4.6.Solid Waste Disposal Practices

The door-to-door solid waste collection in the town is minimal in both its geographical reach and effectiveness. Consequently, households are limited to only two main options for SWM. In the first choice, solid garbage is burned, buried, or dumped inside their enclosures, while in the second alternative; solid waste is discarded of on the road, in open spaces, or next to rivers.

To evaluate the typical method of solid waste disposal among households and assess their satisfaction with the current waste removal system, respondents were queried about their usual disposal practices. The survey findings are outlined in the subsequent table.

Table 4.16 Household Solid Waste Disposal Practice

Characteristics of Variables	Description	Frequency	Percent
Which system do you use for the removal of your household waste?	A collector will collect the waste from house	47	52.2
	At a specific location and time, the collector will arrive; you will hand him the garbage	33	36.7
	At a designated time, you will place your garbage by the side of the road, and the collector will come get it	10	11.1
How much are you currently spending for waste disposal per month? (Birr/month)	15.00	1	1.1
	30.00	4	4.4
	40.00	5	5.5
	50.00	75	83.5
	100.00	5	5.5
Degree of satisfaction with the current solid waste removal system	Very Good	32	35.6
	Good	36	40.0
	Ok/Medium	13	14.4
	Not Satisfactory	9	10.0

Source: field survey, 2022

As depicted in the table above, 83.5% of respondents are presently paying 50 birrs per month for waste disposal. A small number of respondents pay 15, 30, and 40 birr per month due to their lower income, while 5.5% of households pay 100 birr per month, reflecting their disposal of larger volumes of solid waste. Regarding satisfaction with the current municipal waste removal system, 35.6% of respondents rated it as "very good," while 40% rated it as "good." The satisfaction level regarding solid waste disposal closely mirrors that of the study conducted in Jigjiga[6] and In contrast to the findings of the study conducted in Robe town, where 70.7% of households expressed dissatisfaction[7] and also In Bahirdar city, approximately 78% of respondents believe that the current services fall significantly below the necessary standard, while 22% express satisfaction with the existing waste management services[54].

4.7.Formal Solid Waste Management Practices of the Town

The town hosts a SWM Office, operated within the city municipality. However, the town lacks a separate annual budget dedicated solely to solid waste management. Instead, it operates as a department within the municipal service. The SWM Office oversees all waste managing practices in the town and currently employs 12 staff members, comprising 10 males and 2 females.

Table 4.17 Education status of the staff of the solid waste management office

Education status	Number
Diploma	2
Bachelor degree	7
Masters (Postgraduate)	3

At present, there are four MSSEs involved in providing waste gathering services. Each enterprise operates under an agreement with the municipal solid waste management office. Each kebele (neighborhood) has its own micro and small-scale enterprise, which hires waste collectors. The total workforce across the four enterprises consists of 102 employees, with 67 males and 35 females. Only two of these enterprises own trucks for waste collection and transportation, while the other two rent trucks for this purpose. Additionally, the city municipality's solid waste management office operates one tractor with a collection capacity of 9m3, primarily used for collecting waste from the open market and major streets of the town. All truck utilized in the system of transportation and collections of solid garbage are informal.

4.8. Solid Waste Management Service coverage in the Town

Information provided by the municipality indicates that municipal solid waste originates from various sources, including households (residential units), commercial establishments, institutions, and industries. The majority of solid waste comes from residential/household sources, followed by industrial waste. In Dukem town, residents typically store their solid waste in synthetic sacks ("Madaberiya"). However, solid wastes from different sources are not stored in standardized or authorized municipal containers. Additionally, there is a lack of public waste containers in various places of the town, exacerbating sanitation issues in a rapidly growing population and expanding geographical areas. Improper waste disposal practices, such as dumping in open spaces, further compound the problem.

Solid waste collection and transportation services are provided by four MSSEs. A doorstep to doorstep gathering system is employed to gather waste generated from commercial activities, with the collected waste then transported to the disposal site. For some commercial units, waste is collected once every two or three days, while for most, it occurs once per week. The monthly fee for these services varies depending on the type of commercial activity, with a minimum charge of 50 birr per month for small commercial services, while others vary based on the volume of waste generated.

Dukem Town currently employs two methods for household waste collection:

1. Direct door-to-door collection: Employed workers collect waste directly from households and load it onto vehicles.

2. Door-to-door collection followed by transportation to a transfer station: Waste is collected from households using hand-pushed carts and transported to a transfer station, which is an open space. The waste remains at the transfer station until it is picked up by the truck.

Figure 11. Collected solid waste by using hand pushed carts

The workers gather these wastes from areas convenient for loading into the vehicle, which then transports the waste to the disposal site. Solid waste collectors collect household waste once a week and typically charge a fee to each homeowner.

Table 4.18 Collection fee of households per month

For Household	Birr/month
One synthetic sack per week	50
Two synthetic sacks per week	100
Three synthetic sacks per week	150

As illustrated in the table above, the typical monthly payment for these services is 50 birr/month, although some individuals pay lower amounts of 15, 30, or 40 birr/month due to their lower income levels. The cost of waste collection is 2.22 birr per person per week. Waste collected is transported to the disposal site by trucks, with 1-2 trips made per day.

Many rural areas are not covered by waste collectors, as residents in these areas dispose of their waste in rivers and water bodies. Additionally, there are urban areas where residents refuse to pay for or utilize the services provided by the enterprises, instead opting to dispose of their waste in ditches and along roadsides.

Residents' illicit dumping of waste material is caused by several circumstances. These include the dearth of door-to-door garbage pickup offerings, social constraints that place other considerations ahead of sustainable waste management, a lack of public waste containers, and a loss of explicit and adequate knowledge on appropriate SWM System.

Face-to-face interviews with personnel from the Solid Waste Management Office have revealed that many residents lack vibrant and sufficient information about the various mechanisms of SWM and their proper implementation. For example, households are responsible for storing waste properly and disposing of it correctly and legally using micro and small-scale enterprise services, municipality vehicles, or burning. However, many households do not actively engage in these activities and instead handle and dispose of waste improperly.

4.9.Formal and Informal Collection of Recyclable and Reusable Waste

4.9.1. Formal Collection of Recyclable and Reusable Waste

At the disposal site, the separation of recyclable and reusable wastes is undertaken by 36 workers, all of whom are male, operating under six micro and small-scale enterprises. Approximately 77.8 kg/day of recyclable waste is gathered by these enterprises. Since there is no recycling facility in the town, the collected recyclable wastes are sold to recycling facilities located outside the town.

Table 4.19 Types of recyclable waste and their price

Type of recyclable waste	Unit	Price(Birr)
Dense plastic	Kg	10
Synthetic sack	pcs	2
Metal	Kg	30-35
Cardboard/Cartoon	Kg	10
Textile	Kg	15

4.9.2. Informal Collection of Recyclable Waste

In the town, there exist informal recyclable waste collectors, commonly known as scavengers, who engage in collecting and recovering reusable and recyclable wastes directly from sources such as households, commercial sectors, industries, and streets. Based on field observations, it is noted that a significant portion of the town's commercial and industrial recyclable waste is gathered by private collectors, who operate informally. Additionally, there are informal waste collectors who retrieve recyclable materials from the disposal site. These collectors typically sell the recyclable waste through intermediaries to recycling industries. However, there is no comprehensive estimate available for the number of informal waste pickers in the town.

4.10. Current Status and Administration of Solid Waste Disposal Facility

Transportation and collection of waste are merely part of SWM. Appropriate dumping of garbage in suitable locations is another requirement of effective supervision. My field observations indicate that Dukem Town's solid waste disposal facility is insufficient and fails to conform to the requirements of the sector. The current disposal site, located near Dukem River, is an unmanaged landfill without cover or compaction. Additionally, the site's location is characterized by poor road infrastructure, making it unsuitable for vehicles, particularly during rainy seasons when the issue is exacerbated.

Figure 12. Dukem River near the disposal site and the road to the disposal site

The solid wastes collected from various sectors and sources within the town are disposed of together at the final disposal site located in Mendelo, situated in Gogecha Kebele. This site is approximately 5km away from the town and spans a total area of 3 hectares. It is characterized as an open and unsanitary landfill site and has been operational since 1997 under the jurisdiction of the municipality's solid waste management office. However, the landfill site selection process did not adhere to standard conditions including elevation, the gradient, the flow of water, flexibility, availability, separation from unsuitable land uses, and acceptability by the community. Consequently, the disposal site in Dukem fails to meet any of these criteria.

There are several serious issues connected to this unsanitary exposed landfill:

1. Careless trash disposal can have detrimental effects on the environment and human health.

2. The presence of high levels of methane gas leads to frequent fires, posing threats to human safety and causing air pollution.

3. Odors emanating from the disposal site diminish the quality of the surrounding air.

4. Leachate, generated from the site, has the ability to contaminate soil, groundwater, and surface water. For instance, the site is adjacent to Dukem River, and leachate directly flows into it, contaminating the river. Additionally, solid waste dumped at the site is carried into the river through water and wind erosion, affecting the health of residents downstream who rely on the river for farming and washing purposes.

5. Due to the site's accessibility to both humans and animals, solid waste is dispersed across the neighborhood, endangering the health of the locals.

Figure 13. Disposal site

4.11. Solid waste management system's socioeconomic impact assessment

The worldwide issue of waste management is closely intertwined with the socioeconomic progress of cities. Cities aiming to excel in MSW management beyond the expectations dictated by their country's average socioeconomic development must address systemic failures inherent to their socioeconomic status. Doing so can unlock development opportunities across various urban management sectors[87].

The socio-economic impact of solid waste management practices was evaluated based on health, financial, and employment aspects. The analysis revealed that SWM practices in the community have both positive and negative effects. On one hand, they have led to job creation, with individuals employed in various waste management activities such as street sweeping, collection, transportation, and sorting. However, these practices have also been associated with health risks, environmental pollution, soil degradation, and contamination of groundwater[73].

Various socioeconomic factors influence the daily generated waste amount. Additionally, the composition of solid waste varies based on different socioeconomic statuses. This implies that people's socioeconomic status, typically assessed through a combination of education, income, and occupation, significantly impacts both solid waste production pace and its composition[88].

Studying how waste removal practices of homes correlate with environmental awareness, person’s perceptions, and consummation with local capacities can aid in making decisions regarding the sustainability of MSWM. Educating households about SWM is crucial for encouraging them to opt for proper waste collection methods instead of resorting to open dumping or burning. Additionally, factors such as the type of housing and the position of households play a character in determining waste disposal systems. The tendency to dispose of waste in unauthorized locations is primarily influenced by socioeconomic factors rather than household income or welfare[89].

Active engagement in the community emerges as a pivotal factor in better understanding people's behaviors and instilling a high level of confidence in SWM practices. Promoting the dissemination of expert knowledge and fostering public participation can bolster positive attitudes toward SWM systems. Efforts should prioritize enhancing public acceptance and participation while urging policymakers to devise more effective strategies for implementing innovative and cost-efficient SWM systems. Economically speaking, an improved waste planning and management strategy is essential for achieving cost reduction.

In summary, social acceptance and awareness, coupled with the assessment of economic concerns and environmental impacts, should be comprehensively considered. This holistic approach connects society, economy, environment, and policymaking to ensure the effective implementation of sustainable SWM initiatives.

4.12. Prediction of Future Waste Generation

Table 4.20 Prediction of future Waste Generation for Dukem Town

Year	Population number	Households Generation(Kg/day)	Households Generation (T/Yr.)
2023	166,374	34,772	12,692
2024	173,860	36,337	13,263
2025	181,684	37,972	13,860
2026	189,859	39,681	14,484
2027	198,403	41,466	15,135
2028	207,331	43,332	15,816
2029	216,661	45,282	16,528
2030	226,410	47,320	17,272
2031	236,599	49,449	18,049
2032	247,246	51,674	18,861

As depicted in the table above, the projected household waste generation for the next ten years was forecasted. Previously, it was determined that Dukem town generates 0.209 kg of waste per person per day. The future waste prediction for households was based on this generation rate, taking into account a population growth rate of 4.5%. After 10 years, the total waste generated from households is estimated to reach 18,861 tons per year, indicating a 35.6% increase from the current solid waste generation level.

4.13. Solid waste material flow analysis

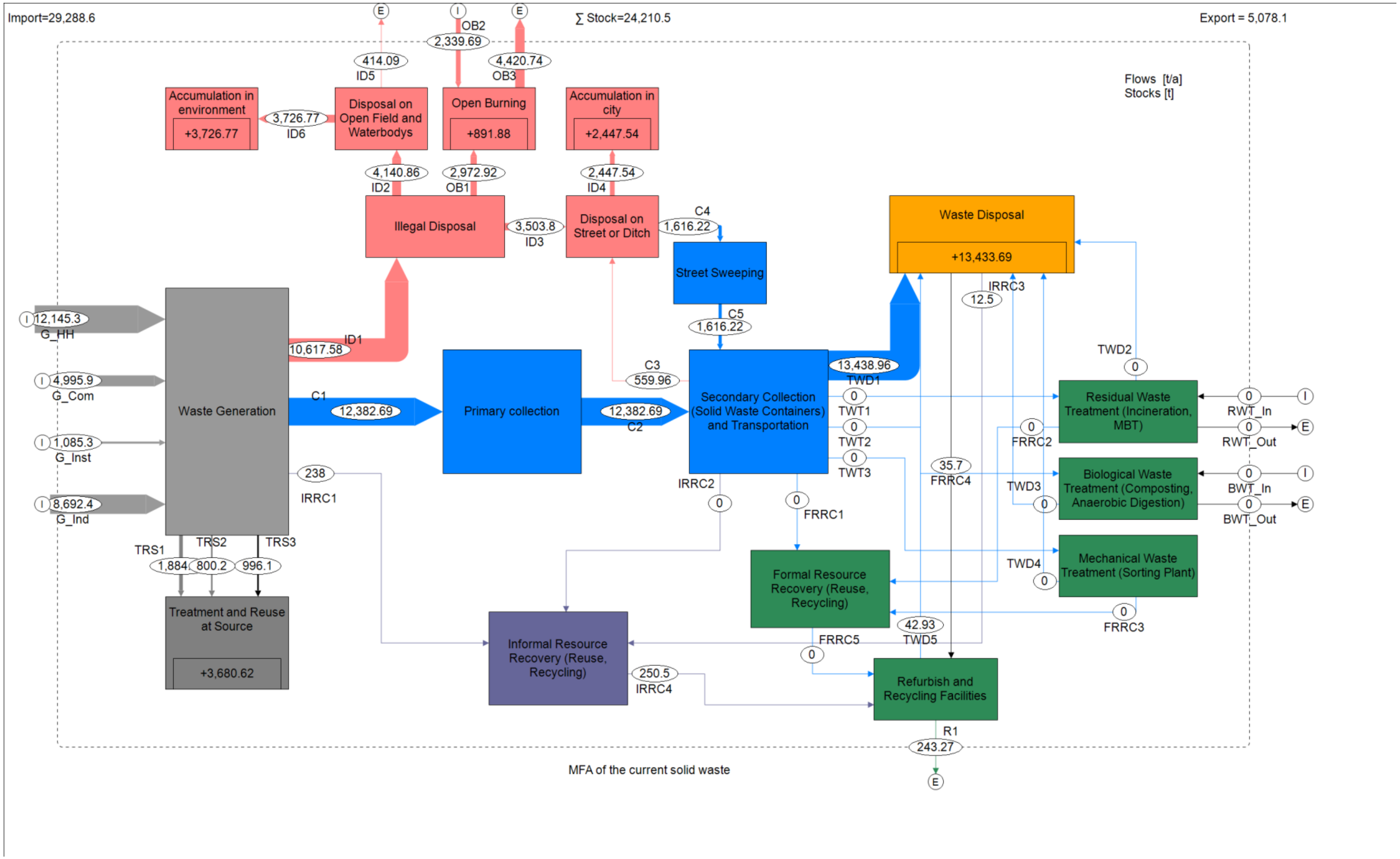
MFA involves examining the flow of materials through various process chains, encompassing chemical transformations, consumption, recycling, and disposal activities. MFA can also be applied to analyze the flow of materials within waste treatment processes[90].

Material flow analysis is commonly employed in waste handling research to offer a thorough examination movement of materials. It aids in analyzing material characteristics to assess the extent of a problem, pinpoint the underlying causes, and recommend appropriate management strategies[64].

MFA has seen growing utilization as a foundation for analyzing and designing waste management and recycling systems, as well as evaluating current SWM practices. Through MFA, it becomes feasible to evaluate the potential for efficiency enhancement, select the most preferable approach, and make decisions regarding an integrated and sustainable waste management system. When data reliability is high, MFA offers a precise method for assessing the effectiveness of waste management systems[79].

The findings from MFA indicate minimal advancement in the implementation of the country's integrated SWM program. This underscores the urgent need for interventions to mitigate risks to public health and prevent further environmental pollution. The STAN Software was utilized to illustrate the material flow, as depicted in the figure below:-

Figure 14. Current solid waste material flow analysis



The diagram above illustrates the Material Flow Analysis of current solid waste in Dukem town. The primary sources are households, industries, commercial activities, and institutions, generating 12,145.3T/yr, 8,692.4T/yr, 4,995.9T/yr, and 1,085.3T/yr of waste, respectively. This totals 26,918.9 tons of waste generated annually from major sources.

However, only 46% of the total generated waste is collected through primary collection. The remaining 54% of the waste is distributed as follows: 39.4% is illegally disposed of, 13.7% is treated and reused at the source, and 0.9% is collected by informal recyclable waste collectors at the source.

Out of the illegally disposed waste, 39% is dumped in open fields and water bodies, 33% is discarded on streets and ditches, and 28% is burned in open spaces without proper control. Out of the total generated waste, 13.7% undergoes treatment at the source. This includes:

- 1,884.32 tons per year of waste treated directly at the source through home composting, where organic matter is composted at the household level. This practice is highly recommended for proper solid waste management.

- 996.1 tons per year of waste treated and reused at industries.

- 800.2 tons per year of waste reused at the source, primarily at the household level.

Additionally, 0.9% of the total generated waste is collected by informal recyclable waste collectors at the source. These collectors gather recyclable materials from major waste generators.

Wastes collected through primary and secondary collection systems are directly disposed of at the disposal site. There are both formal and informal recyclable waste collectors operating at the disposal site. Annually, 243.3 tons of recyclable wastes are collected for refurbishment and recycling facilities. However, there are no biological or mechanical waste treatment practices implemented in the town. Ultimately, 13,433.7 tons of wastes are dumped at the disposal site each year.

4.14. Evaluation of the existing waste collection performance, Resource management and Greenhouse gas emission

4.14.1. Waste collection performance

Table 4.21 Waste collection performance

Waste collection performance	
mass of waste formally collected [T/yr]	13,438.96
mass of waste generated [T/yr]	26,918.9
waste formal collection rate [%]	49.9%

4.14.2. Resource Management

Table 4.22 Resource management

Resource Management	
mass of waste material recovered [T/yr]	3,923.9
mass of waste generated [T/yr]	26,918.9
(mass of waste material recovered [T/yr] /mass of waste generated [T/yr]) [%]	14.6%

The total amount of waste material recovered annually is 3,923.9 tons, while the total annual waste generation amounts to 26,918.9 tons. By dividing the mass of recovered waste material by the mass of waste generated, we can determine the proportion of resources managed. Therefore, the percentage of resources managed is calculated to be 14.6%.

4.14.3. Greenhouse Gas Emissions

Climate change is an urgent global environmental concern that is gaining greater importance. It has been identified as a prominent example of the environmental impact associated with solid waste management[78]. The waste sector is identified as a major contributor to anthropogenic CH4 emissions, which have played a significant role in global warming in recent decades[91]. Reducing emissions is essential for addressing climate change challenges and attaining environmental sustainability[86].

The table below provides a summary of the greenhouse gas emissions resulting from the current solid waste management practices in the town;

Table 4.23 Greenhouse gas emission

Greenhouse Gas Emission	
Illegal waste Disposal GHG Emissions	6,384.64 T co_2-eq / yr
Recycling GHG Emissions	-499.42 T co_2-eq / yr
Waste Treatment GHG Emissions	0.00 T co_2-eq / yr
Waste Disposal GHG Emissions	22,837.29 T co_2-eq / yr
Total Greenhouse Gas Emissions	28722.5 T co_2-eq / yr
	1.07 T co_2-eq / T waste

The positive values of greenhouse gas emissions from illegal waste disposal and waste disposal indicate a detrimental impact on the environment. Due to the absence of a waste treatment plant, there is neither a positive nor negative effect. Recycling, on the other hand, results in negative values, indicating that recycling offers the advantage of reducing greenhouse gas emissions.

4.15. Scenarios

To guide the development of scenarios, a target has been established for municipal solid waste (MSW), which includes minimizing the adverse effects of waste on the environment and human health, conserving resources, and decreasing the quantity of waste sent to landfills[75].

The primary greenhouse gas emissions originating from the waste sector predominantly consist of methane produced in landfills[92]. Organic waste, paper, wood, and textiles are the primary contributors to methane emissions in landfills. Among these, organic waste accounts for the largest proportion, approximately 70%, followed by paper at around 17%[91].

Composting involves the transformation of organic matter from waste streams through a process that eliminates pathogens. This process yields compost, which comprises stable organic material beneficial for agricultural use as a soil conditioner. Composting enhances soil fertility, structure, water retention capacity, and buffering capacity.

Managing municipal solid waste (MSW) in this scenario would involve segregating organic waste from landfill disposal. The scenario entails employing biological waste treatment, specifically bio-composting. Three scenarios were devised, treating 10%, 30%, and 50% of the total collected waste to produce compost.

Table 4.24 Scenarios

Formally collected waste designated to disposal site (T/yr)	Scenarios	Percentage of waste to be composted (%)	Amount of waste to be composted (T/yr)
13,438.96	Scenario 1	10	1,343.9
	Scenario 2	30	4,031.7
	Scenario 3	50	6,719.5

From the data presented in the table, it can be concluded that increasing the proportion of waste designated for composting can reduce the amount of waste sent to the disposal site.

The three scenarios outlined below include their respective material flow analyses. Each analysis was conducted using current data, with varying percentages of waste allocated for composting. Consequently, there will be fluctuations in the quantity of waste disposed of, as organic waste undergoes biological treatment.

Given that Dukem is an industrial zone, certain industries have authorization to dispose of their waste at the designated site. This results in the accumulation of non-organic industrial waste, which cannot be treated biologically. Consequently, there may be a surplus of waste that cannot be converted into compost as initially anticipated.

Scenario 1 Material Flow Analysis: 10% Compost

In this scenario, the material flow analysis involved composting 10% of the waste from the disposal site. The quantity of waste selected from the disposal site for composting was 1,343.9 tons per year. Through the treatment of organic waste, this process yielded 399.6 tons per year of compost.

Scenario 2 Material Flow Analysis: 30% Compost

This scenario's material flow analysis included composting 30% of the waste from the disposal site. The amount of waste designated from the disposal site for composting was 4,031.7 tons per year. By treating the organic waste, this process resulted in the generation of 1,200.5 tons per year of compost.

Scenario 3 Material Flow Analysis: 50% Compost

In this scenario's material flow analysis, 50% of the waste from the disposal site was selected for composting. The quantity of waste chosen from the disposal site for composting amounted to 6,719.5 tons per year. Through the treatment of organic waste, this process produced 1,998.2 tons per year of compost.

4.15.1. Scenarios Resource Management and Greenhouse Gas Emission

Composting organic waste can significantly enhance resource management and reduce greenhouse gas emissions. The graphical representation below illustrates the number of resources managed for each scenario:-

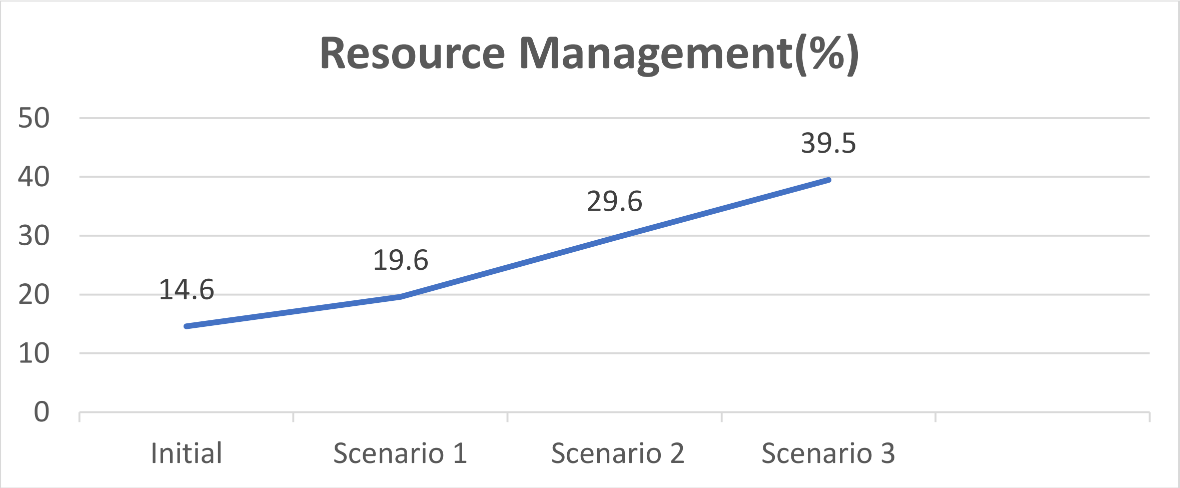


Figure 14. Resource management

In the initial scenario, 19.6% of the resource is managed, while in the second scenario, this figure rises to 29.6%. In the third scenario, the resource management reaches 39.5%.

The reduction of greenhouse emissions for the scenarios is described below graphically:-

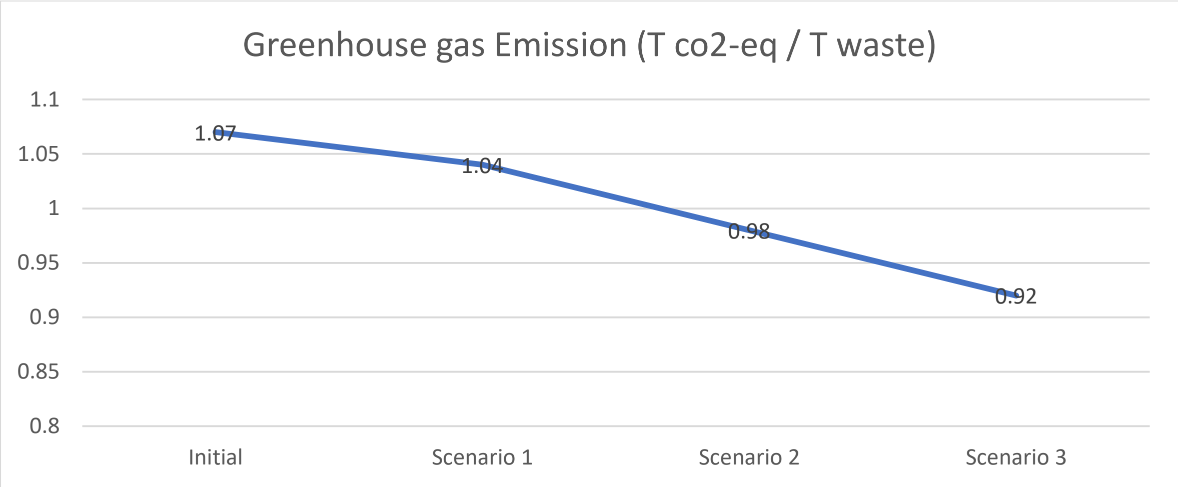


Figure 15. Greenhouse gas emission

5. Conclusion and Recommendation

5.1.Conclusions

This paper undertook an analysis of the current municipal solid waste management (MSWM) practices in Dukem town. The study encompassed an examination of waste generation rates, waste composition analysis, waste management practices, and the spatial coverage of waste management services in the town. Key elements of effective MSWM, including waste handling, storage, collection, transportation, and disposal, were addressed through household surveys, field observations, measurements, interviews, and document reviews.

The analysis revealed a per capita waste generation rate of 0.209 kg/person/day in Dukem town, with eleven identified waste components. Organic waste, particularly from kitchen and garden sources, constituted a significant portion, accounting for approximately 67.34% of the waste stream. This high organic content highlights the need for frequent collection and presents an opportunity for prioritizing organic waste recycling through composting, although further investigation is required to ensure the sustainability of this practice.

Annual waste generation from major sources was estimated at 26,918.9 tons, with only 49.9% of this waste being collected. The remaining 50.1% was either illegally disposed of (35.5%), treated and reused at the source (13.7%), or collected by informal recyclers (0.9%).

The study identified several factors contributing to the inefficiency of the MSWM system in Dukem town, including poor waste separation and handling practices, limited collection and transportation capacity, inadequate resources for waste collection, a scarcity of waste management facilities, the absence of recycling companies, and limited use of organic waste for composting.

Addressing these challenges requires strengthening enforcement mechanisms, increasing budget allocations, improving waste management infrastructure, organizing the informal waste sector, promoting microenterprises, raising public awareness, and enhancing stakeholder involvement.

Ultimately, the study underscores the need for comprehensive improvements to the SWM system in Dukem town, including institutional reforms, capacity building, and the development and implementation of effective waste management plans. These efforts are crucial for ensuring the proper management of waste and enhancing the overall cleanliness and environmental sustainability of the town.

5.2.Recommendations

According to the findings of this study, the following measures are crucial for addressing the municipal solid waste management (MSWM) challenges in Dukem Town:

- Encouraging waste sorting at the source to reduce the volume of waste requiring collection and disposal. Households should be incentivized by MSWM enterprises to separate their waste into different categories at the point of generation.
- Proper waste segregation would facilitate recycling and reuse, leading to benefits such as the conservation of valuable raw materials, reduced landfill space requirements, less energy-intensive product manufacturing, and job creation in recycling industries.
- Low public awareness and knowledge about solid waste management issues among Dukem town residents highlight the need for comprehensive awareness-raising

efforts. The municipal solid waste management office and health department should conduct training and awareness campaigns on sustainable waste management practices.

- Adoption of Integrated Solid Waste Management (ISWM) principles to ensure effective waste management in the area.
- Further development of composting facilities for organic waste treatment and soil amendment production.
- Promotion of MSW recycling in Dukem town and nationwide by encouraging markets for recycled materials.
- Formulation of regulations against littering and improper waste disposal, with penalties for violators.
- Ensuring regular waste collection by MSWM enterprises to prevent waste accumulation on roadsides, along with ongoing monitoring of waste collection activities by the solid waste management office.
- Proper covering of waste during transportation by waste collection workers to minimize environmental and health risks.
- Restricting landfilling to non-biodegradable, inert waste and other materials unsuitable for recycling or biological processing.
- Effective management and routine monitoring of the dump site to prevent waste accumulation and negative environmental impacts on nearby communities, including consideration of relocating the dump site.
- Allocation of adequate budgets by the Dukem town municipality and regional government for MSWM to enable the effective functioning of the municipal solid waste management office.

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APPENDIX

Appendix 1: Survey Questionnaires

1. QUESTIONNAIRE ON SOCIO-ECONOMIC DATA

A. Demographic and social status

Kebele ______________________________ House No.___________

1. Age of respondent's ______

2. Sex of respondent's _________

Family size in number___________

3. Educational Status of the household head

(a) Read and write (b) Primary (c) Secondary (d) Higher (e) Illiterate

4. Occupation of the head of the HH…………………..

(a) Government employee (b) Private employee

(c) Business (d) Student

(e) Housewife (f) Retired

5. Family income /Month

(a) No income (b) 2000-5000 (c) 5000-8000 (d) 8000-15,000 (e) >15,000 Birr

6. Housing Situation Ownership of a home

(a) Private (b) Rented (c) Kebele (d) Other, specify____________

7. Energy accessibility

(a) Firewood and cow dung (b) Firewood, cow dung and charcoal

(c) Firewood, charcoal, kerosene, electricity (d) if others make specific

B. On-site Solid Waste Management practice

1. Does your home have a temporary trash can where created waste can be kept? (a) Yes (b) No

2. If yes, the type of temporary storage container:

a) Plastic Dust Bin b) Plastic Bag

c) Paper dust bin d) if others, make specific

____

3. Who gets rid of the trash in your home?

(a) Servant

(b) Family member

(c) The city corporation picks up waste from each home

(d) A worker hired locally gathers waste from the residence.

C. Solid Waste Disposal practices

1. Household waste disposal material:

(a) Polythene /plastic packet (b) Small basket (c) Any other container

2. How often does the city municipality collect the waste?

(a) Daily (b) Once in two days (c) Once in three days

(d) Irregularly (e) Once per week

3. How frequently would you like your rubbish to be picked up right from your home?

(a) Every day (b) Once every two days (c) Once every three days

4 . When do you usually get rid of your trash?

(a) Morning after 6 am (b) Between 12am to 6pm

(c) After 6pm/ evening (d) No definite time

5. When do you prefer for your waste to be collected?

(a) Morning (b) Noon

(c) Afternoon (d) Evening

6. Which strategy do you employ to get rid of the waste in your home?

(a) The garbage will be removed from the home by a collector.

(b) You will provide the rubbish to the collector when he arrives at a designated location at a specific time.

(c) The trash will be disposed of by you in the dustbin.

(d) At a designated time, you will place your garbage container by the side of the road, and the collector will pick it up.

7. How do you get waste materials to the containers?

(a) By hands (b) Hand pushed carts (c) Horse drawn carts (d) Others specify

8. Do you keep kitchen garbage and other home waste separate?

(a) Yes (b) No

9. Do you reuse rubbish from your home? (a)Yes (b) No

If Yes,

Type of reused wastes ____

Purpose of Reused wastes ____________________________________

10. Do you compost wastes? (a) Yes (b) No

If yes,

Types of composted wastes __________________________________

11. Do you burn household wastes? (a) Yes (b) No

Type of incinerated wastes? __________________________________

12. Where do you incinerate?

a) Inside the compound
b) Outside the compound

13. Do you dispose of waste using an open dump? (a) Yes (b) No

14. Do you sell wastes? (a)Yes (b) No

15. If so, what kinds of wastes are you typically selling?

(a) Plastics (b) Metals (c) Papers (d) Leaves and grasses

16. For whom do you sell wastes?

(a) Korales (b) Formal recycling centers (c) Others

17. How much a month do you now spend on rubbish disposal? (Birr/month)

18. Degree of satisfaction with the current municipal waste removal system:

(a) Very good (b) Good

(c) Ok/medium (d) Not satisfactory

19. Do you agree that community involvement is essential for the local rubbish collection system and environmental improvement? Yes / No

20. Current priority need (1, 2, 3, and 4):

Facilities	Priority No
Water supply	
Sanitation	
Solid waste management	
Drainage	

2. Examination of existing waste management and recycling systems

A. Formal collection system

1. What is the annual budget of the town for solid waste management?

2. How much waste is collected by the formal waste collection sector (per day)?

3. How many staff is employed for waste collection? (Male ----- Female --------)

4. Payment system for the waste collector

4. How many people work in trash management overall?

5. What kind of apparatus is being used?

6. How is the waste transported?

7. What is the number of trucks that the city uses to collect trash? Additionally, include the number of daily trips made and the capacity of each truck.

8. Are there any transfer stations?

9. Do both businesses and households have to pay collection fees? If so, could you kindly elaborate?

10. Does the formal sector collect recyclable waste?

11. How much money is made by selling recyclable garbage in the formal sector

12. How are the recyclables disposed? Is there any recycling plant?

B. An examination of how a present landfill is run

1. Does the town have a sanitary landfill?

2. If so, what is the duration of its operation?

3. How far away from the town is the landfill?

4. What is the crude dump's or landfill's total area?

5. How many tonnes of garbage are transported into the plant each day?

6. Please describe the landfill site:

   a. Unmanaged landfill site with no cover and compaction

   b. Managed landfill site with cover and compaction

   c. Landfill site with cover, compaction, liner, gas collection system and leachate Collection system

Appendix 2: MFA system legend

Abbreviation Flow	Name / Description of Flow	Source	Target
BWT-In	Auxiliary and operating materials Biological Waste Treatment	input	WT-2
BWT-Out	Output materials Biological Waste Treatment	WT-2	output
C1	mixed collected waste from primary collection	WG	PC
C2	mixed collected waste from primary collection transported to secondary collection points	PC	SC
C3	waste losses from primary and secondary collection	SC	ID_SD
C4	waste collected through street sweeping	ID-SD	SS
C5	waste collected through street sweeping	SS	SC
FRRC1	recyclable materials collected through formal primary collection	SC	FRR
FRRC2	recyclable materials from residual waste treatment	WT-1	FRR
FRRC3	recyclable materials from mechanical waste treatment	WT-3	FRR
FRRC4	total formally collected recyclable materials	FRR	RRF
G-Com	total waste generated by commerce	input	WG
G_HH	total waste generated by households	input	WG
G-Ind	total waste generated by industries	input	WG
G-Inst	total waste generated by institutions	input	WG
ID1	total waste illegally disposed	WG	ID
ID2	waste illegal disposed on open field and in water bodies	ID	OFD
ID3	waste illegal disposed in city area	ID	ID-SD
ID4	illegal disposed waste accumulated in city	ID-SD	ID-AC
ID5	waste discharged out of investigation area	OFD	output
ID6	illegal disposed waste accumulated in close environment	OFD	OFD-A

Abbreviation Flow	Name / Description of Flow	Source	Target
IRRC1	recyclable material informally collected from waste generators	WG	IRR
IRRC2	recyclable material informally collected from municipal waste containers	SC	IRR
IRRC3	recyclable material informally collected from waste disposal sites	WD	IRR
IRRC4	total recyclable material informally collected	IRR	RRF
OB1	waste illegal disposed through open burning	ID	OB
OB2	ambient air for open burning	input	OB
OB3	combustion air for open burning	OB	output
R1	recycled material	RRF	output
RWT-In	Auxiliary and operating materials Residual Waste Treatment	input	WT-1
RWT-Out	Output materials Residual Waste Treatment	WT-1	output
TRS1	generated waste directly treated (home composting) at source	WG	TRS
TRS2	generated waste reused at source	WG	TRS
TWD1	collected waste transported to disposal site	SC	WD
TWD2	residues from residual waste treatment to disposal site	WT-1	WD
TWD3	residues from biological waste treatment to disposal site	WT-2	WD
TWD4	residues from mechanical waste treatment to disposal site	WT-3	WD
TWD5	residues from recycling facilities to disposal site	RRF	WD
TWT1	collected waste transported to residual waste treatment facilities	SC	WT-1
TWT2	collected waste transported to biological waste treatment facilities	SC	WT-2
TWT3	collected waste transported to mechanical waste treatment facilities	SC	WT-3

Abbreviation Process	Name of Process
FRR	Formal Resource Recovery (Reuse, Recycling)
ID	Illegal Disposal
ID-AC	Accumulation in city
ID-SD	Disposal on Street or Ditch
IRR	Informal Resource Recovery (Reuse, Recycling)
OB	Open Burning
OFD	Disposal on Open Field and Waterbodies
OFD-A	Accumulation in environment
PC	Primary collection
RRF	Refurbish and Recycling Facilities
SC	Secondary Collection (Solid Waste Containers) and Transportation
SS	Street Sweeping
TRS	Treatment and Reuse at Source
WD	Waste Disposal
WG	Waste Generation
WT-1	Residual Waste Treatment (Incineration, MBT)
WT-2	Biological Waste Treatment (Composting, Anaerobic Digestion)
WT-3	Mechanical Waste Treatment (Sorting Plant)

Appendix 3: Default values Greenhouse Gas Emission

Conversion factors of co_2-eq		
	GWP-100	**source**
Carbon Dioxide	1	[93]
Methane	25	
Nitrous oxide	298	
Black Carbon	910	[94]

Emission factors for Composting			
GHG emission type	**Emission factor**	**unit**	**source**
Methane	4	g/kg	[91]
N_2O	0.3	g/kg	

Emission factors for Open Burning			
GHG emission type	**Emission factor**	**unit**	**source**
Methane	3.7	g/kg	[95]
Black Carbon	0.65	g/kg	

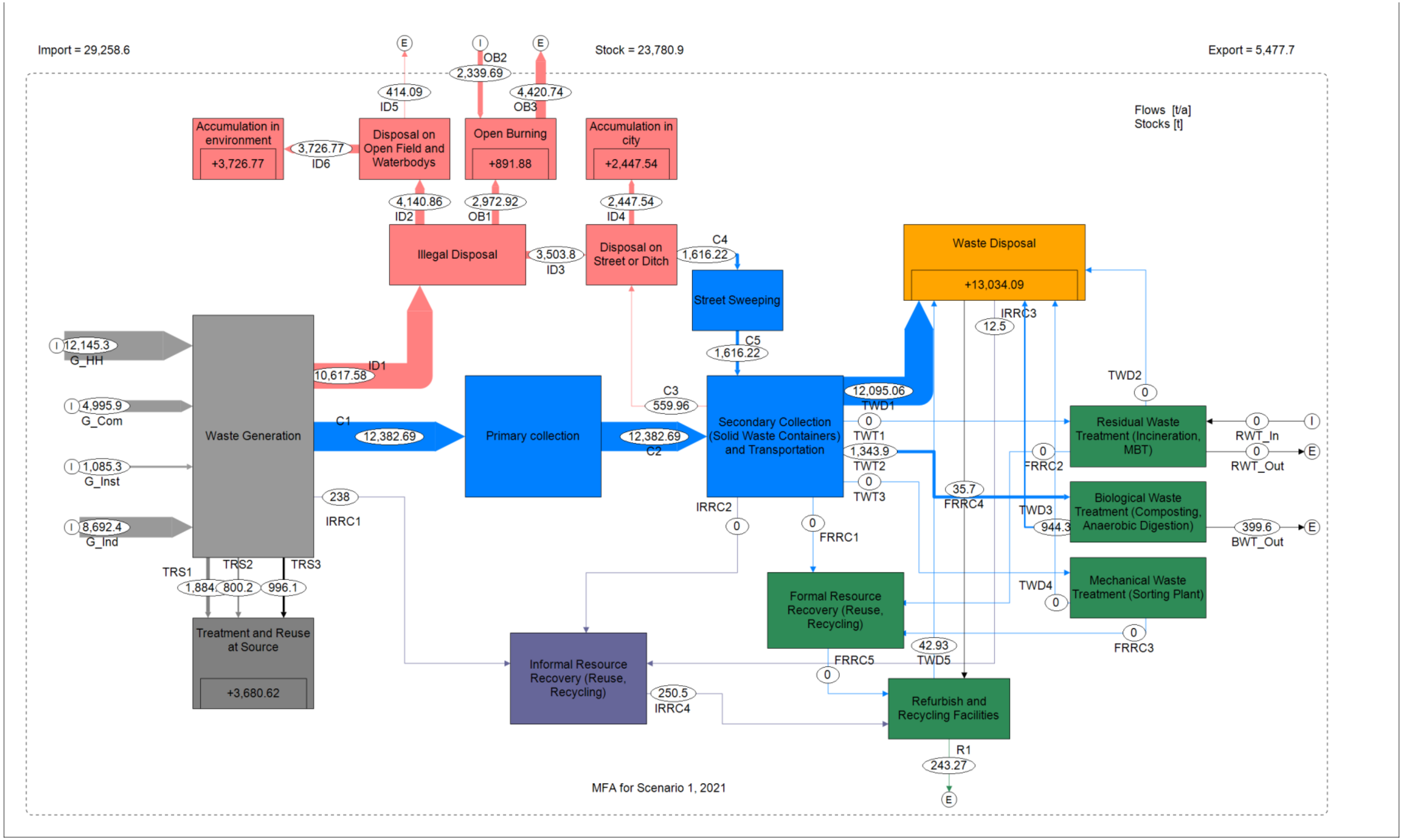
Emission Factor For Incineration / Open Burning Fraction			
Incinerated Fraction	**Emission factor**	**unit**	**source**
OW, Organic Waste	0.044	T (co_2-eq) / T (material input)	[96]
Wo, Wood	0.044	T (co_2-eq) / T (material input)	
PC, Paper and Cardboard	0.044	T (co_2-eq) / T (material input)	
T, Textiles	0.470	T (co_2-eq) / T (material input)	
Pl, Plastics	2.569	T (co_2-eq) / T (material input)	
M, Metal	0.000	T (co_2-eq) / T (material input)	
G, Glass	0.000	T (co_2-eq) / T (material input)	
SW, Special waste	0.470	T (co_2-eq) / T (material input)	
Others	0.470	T (co_2-eq) / T (material input)	

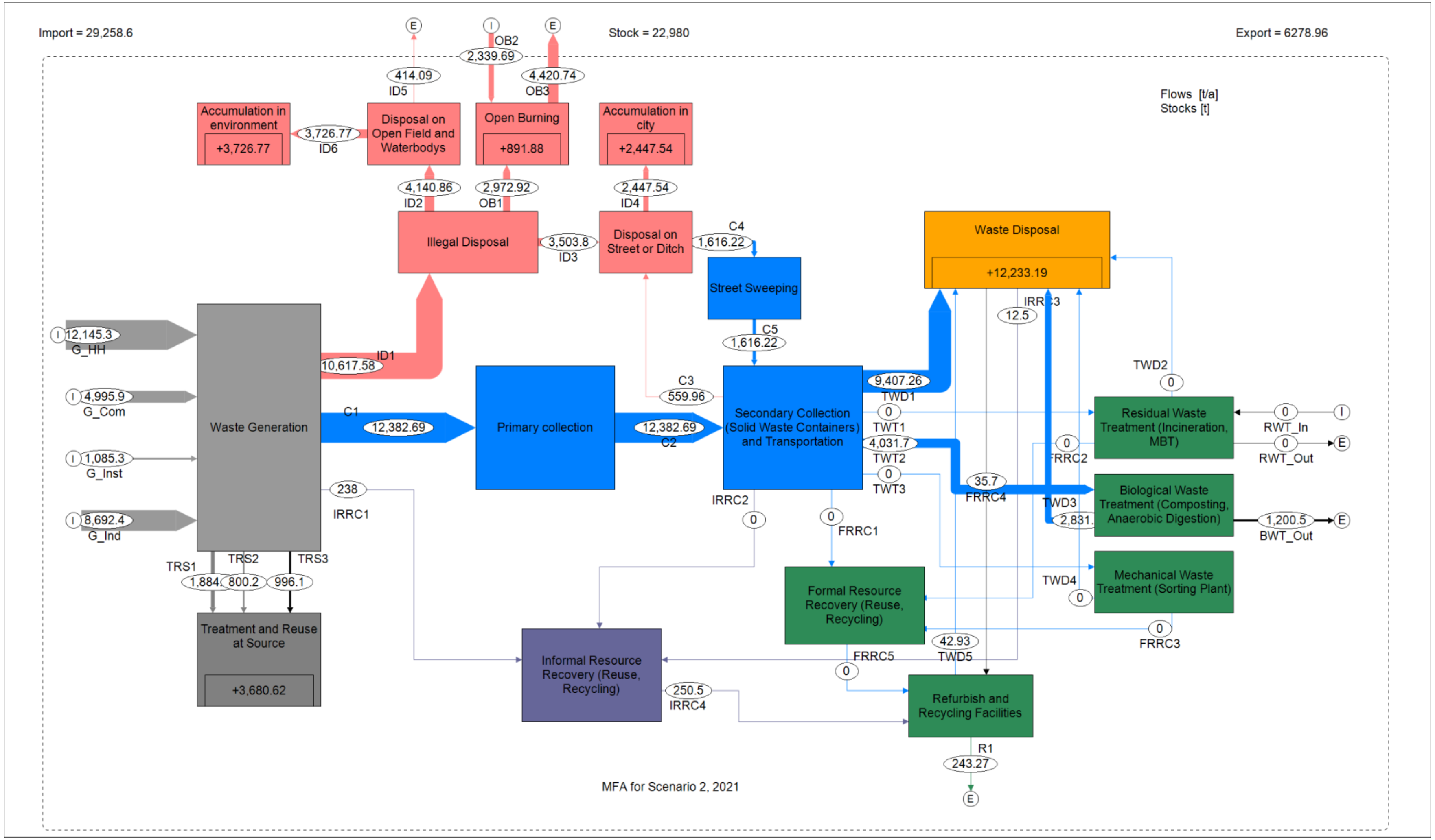
Net Emission Factor for Recycling			
Recycled Fraction	**Emission factor**	**Unit**	**Source**
Mixed Papers	-3.91	T (co_2-eq) / T (material recovered)	[96]
Mixed Plastics	-1.03	T (co_2-eq) / T (material recovered)	
Mixed Metals	-4.84	T (co_2-eq) / T (material recovered)	
Glass	-0.31	T (co_2-eq) / T (material recovered)	

Default Values Waste Disposal Emission Calculation		
MCF (methane correction factor to take account of the type of waste disposal site)		
1	managed landfill site – anaerobic	[97]
0.8	unmanaged open dump – deep (> 5 m waste) and/or high water level	
0.4	unmanaged open dump – shallow (< 5 m waste)	
Oxidation Factor		
0	default value	[97]
0.1	covered (e.g. soil, compost), well-managed landfilled site	

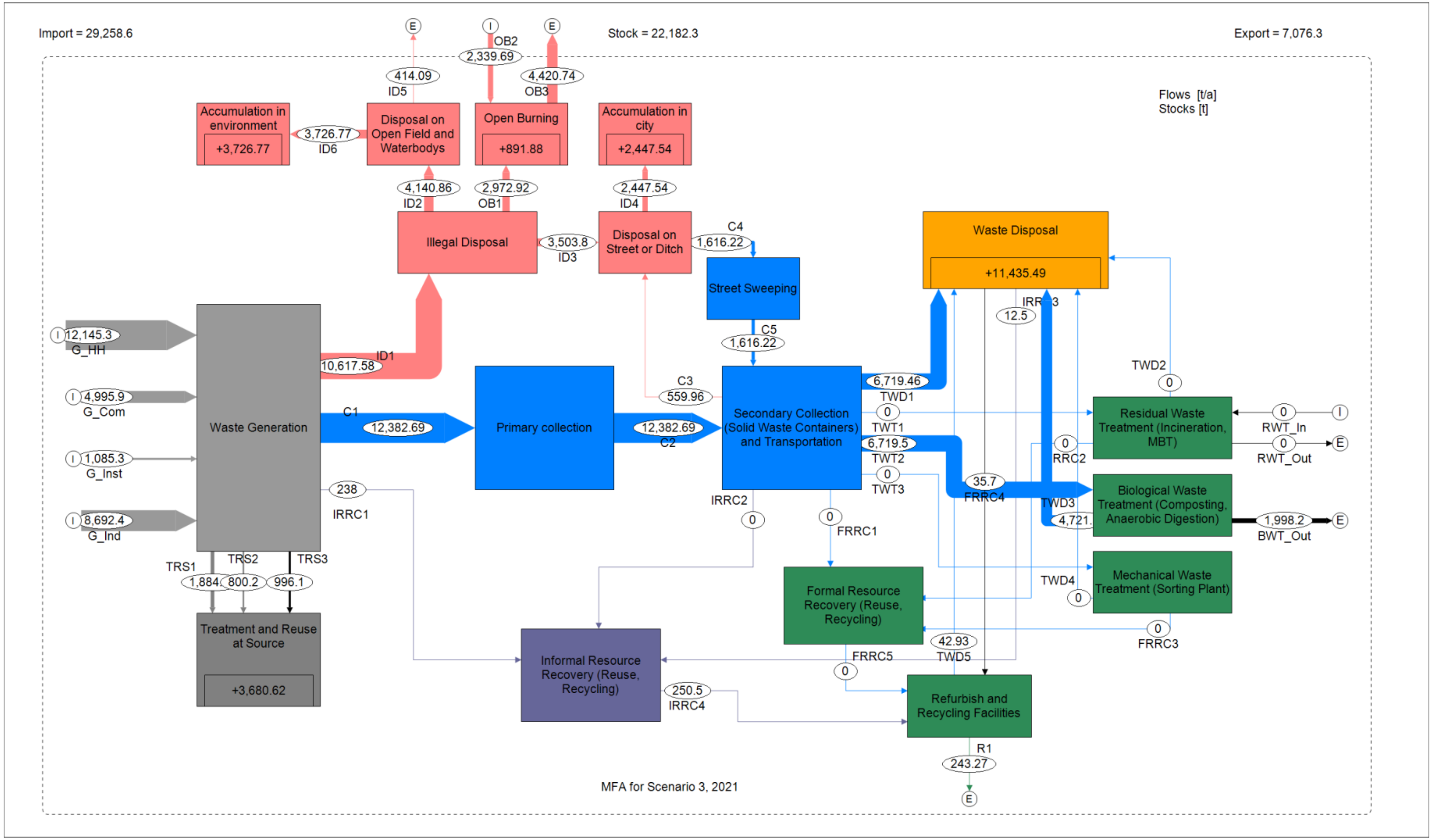
GHG Emission Calculation for Waste Disposal Facilities				
	managed landfill	unmanaged open dump – deep (> 5 m) and/or high water level	unmanaged open dump – shallow (< 5 m)	source
DOC in T C / T waste	0.3	0.3	0.3	[97]
DOCf	0.5	0.5	0.5	
Methane content of landfill gas in vol%	0.5	0.5	0.5	
MCF	1	0.8	0.4	
OX	0	0	0	

Appendix 4: MFA Diagram for the Three Scenarios





Import = 29,258.6
Stock = 22,980
Export = 6278.96
Flows [t/a]
Stocks [t]
Accumulation in environment
+3,726.77
Disposal on Open Field and Waterbodys
Open Burning
+891.88
Accumulation in city
+2,447.54
Illegal Disposal
Disposal on Street or Ditch
Street Sweeping
Waste Disposal
+12,233.19
Waste Generation
Primary collection
Secondary Collection (Solid Waste Containers) and Transportation
Residual Waste Treatment (Incineration, MBT)
Biological Waste Treatment (Composting, Anaerobic Digestion)
Mechanical Waste Treatment (Sorting Plant)
Formal Resource Recovery (Reuse, Recycling)
Informal Resource Recovery (Reuse, Recycling)
Refurbish and Recycling Facilities
Treatment and Reuse at Source
+3,680.62
12,145.3 G_HH
4,995.9 G_Com
1,085.3 G_Inst
8,692.4 G_Ind
10,617.58 ID1
4,140.86 ID2
3,503.8 ID3
2,447.54 ID4
414.09 ID5
3,726.77 ID6
2,972.92 OB1
2,339.69 OB2
4,420.74 OB3
12,382.69 C1
12,382.69 C2
559.96 C3
1,616.22 C4
1,616.22 C5
9,407.26 TWD1
0 TWD2
2,831. TWD3
0 TWD4
42.93 TWD5
0 TWT1
4,031.7 TWT2
0 TWT3
238 IRRC1
0 IRRC2
12.5 IRRC3
250.5 IRRC4
0 FRRC1
0 FRRC2
0 FRRC3
35.7 FRRC4
0 FRRC5
0 RWT_In
0 RWT_Out
1,200.5 BWT_Out
243.27 R1
TRS1 1,884
TRS2 800.2
TRS3 996.1
MFA for Scenario 2, 2021


Import = 29,258.6
Stock = 22,182.3
Export = 7,076.3
Flows [t/a]
Stocks [t]
Accumulation in environment
+3,726.77
3,726.77
ID6
Disposal on Open Field and Waterbodys
414.09
ID5
Open Burning
+891.88
2,339.69
OB2
4,420.74
OB3
Accumulation in city
+2,447.54
4,140.86
ID2
2,972.92
OB1
2,447.54
ID4
Illegal Disposal
3,503.8
ID3
Disposal on Street or Ditch
C4
1,616.22
Street Sweeping
C5
1,616.22
Waste Disposal
+11,435.49
12.5
IRRC3
12,145.3
G_HH
4,995.9
G_Com
1,085.3
G_Inst
8,692.4
G_Ind
Waste Generation
ID1
10,617.58
C1
12,382.69
Primary collection
12,382.69
C2
C3
559.96
Secondary Collection (Solid Waste Containers) and Transportation
6,719.46
TWD1
0
TWT1
6,719.5
TWT2
0
TWT3
TWD2
0
Residual Waste Treatment (Incineration, MBT)
0
RWT_In
0
RWT_Out
0
RRC2
35.7
FRRC4
TWD3
4,721.
Biological Waste Treatment (Composting, Anaerobic Digestion)
1,998.2
BWT_Out
Mechanical Waste Treatment (Sorting Plant)
TWD4
0
0
FRRC3
238
IRRC1
IRRC2
0
0
FRRC1
Formal Resource Recovery (Reuse, Recycling)
42.93
TWD5
FRRC5
0
TRS1
TRS2
TRS3
1,884
800.2
996.1
Treatment and Reuse at Source
+3,680.62
Informal Resource Recovery (Reuse, Recycling)
250.5
IRRC4
Refurbish and Recycling Facilities
R1
243.27
MFA for Scenario 3, 2021

Appendix 5: Calculation for the Evaluation of different factors in the existing waste collection system

Greenhouse gas Emissions			
Illegal waste Disposal			
waste open burned		2972.90	T / a
		3297.48	T co_2-eq / a
waste uncontrolled disposal	waste quantity uncontrolled disposed	3087.16	T / a
	DOC (degradable organic carbon in the deposited waste)	0.30	T C / T waste
	DOCf (fraction of DOC that is dissimilated over time)	0.50	Default value according to [97]
	F (methane content of the landfill gas)	0.50	
	MCF (methane correction factor to take account of the type of waste disposal site)	0.40	
	OX (oxidation factor)	0.00	
	gas collection efficiency (RT)	0.00	
	GHG emissions waste uncontrolled disposal	3087.16	T co_2-eq / a
Illegal waste Disposal GHG Emissions		6384.64	T co_2-eq / a
Recycling			
Mixed Papers		72.99	T / a
		-285.39	T co_2-eq / a

Mixed Plastics	116.78	T / a
	-120.29	T co_2-eq / a
Mixed Metals	17.03	T / a
	-82.43	T co_2-eq / a
Glass	36.50	T / a
	-11.31	T co_2-eq / a
Recycling GHG Emissions	-499.42	T co_2-eq / a
Waste Treatment		
Waste Treatment GHG Emissions	0.00	
Waste Disposal		
mass of waste designated to disposal facility /site	13433.70	T / a
share of managed landfill site – anaerobic	0.000	% of waste designated to disposal site
share of unmanaged open dump – deep (> 5 m waste) and/or high water level	0.700	% of waste designated to disposal site
share of unmanaged open dump – shallow (< 5 m waste)	0.300	% of waste designated to disposal site
managed landfill site – anaerobic	0.00	T / a
unmanaged open dump – deep (> 5 m waste) and/or high water level	9403.59	T / a
unmanaged open dump – shallow (< 5 m waste)	4030.11	T / a
managed landfill site – anaerobic	0.00	T co_2-eq / a
unmanaged open dump – deep (> 5 m waste) and/or high water level	18807.18	T co_2-eq / a
unmanaged open dump – shallow (< 5 m waste)	4030.11	T co_2-eq / a
Waste Disposal GHG Emissions	22837.29	T co_2-eq / a
Total Greenhouse Gas Emissions	28722.50	T co_2-eq / a
	1.07	T co_2-eq / T waste

Appendix 6: Resource management for the Scenarios

Resource Management for 10% Compost	
mass of waste material recovered [T/a]	5267.8
mass of waste generated [T/a]	26918.9
[%]	19.6%
Resource Management for 30% Compost	
mass of waste material recovered [T/a]	7955.6
mass of waste generated [T/a]	26918.9
[%]	29.6%
Resource Management for 50% compost	
mass of waste material recovered [T/a]	10643.4
mass of waste generated [T/a]	26918.9
[%]	39.5%

Appendix 7: Calculation for the Evaluation of different factors for the three scenarios

Scenario 1:-

<table>
<tr><th colspan="4">Greenhouse gas Emissions</th></tr>
<tr><td colspan="4">Illegal waste Disposal</td></tr>
<tr><td colspan="2" rowspan="2">waste open burned</td><td>2972.90</td><td>T / a</td></tr>
<tr><td>3297.48</td><td>T co_2-eq / a</td></tr>
<tr><td rowspan="8">waste uncontrolled disposal</td><td>waste quantity uncontrolled disposed</td><td>3087.16</td><td>T / a</td></tr>
<tr><td>DOC (degradable organic carbon in the deposited waste)</td><td>0.30</td><td>T C / T waste</td></tr>
<tr><td>DOCf (fraction of DOC that is dissimilated over time)</td><td>0.50</td><td rowspan="5">Default values according to [97]</td></tr>
<tr><td>F (methane content of the landfill gas)</td><td>0.50</td></tr>
<tr><td>MCF (methane correction factor to take account of the type of waste disposal site)</td><td>0.40</td></tr>
<tr><td>OX (oxidation factor)</td><td>0.00</td></tr>
<tr><td>gas collection efficiency (RT)</td><td>0.00</td></tr>
<tr><td>GHG emissions waste uncontrolled disposal</td><td>3087.16</td><td>T co_2-eq / a</td></tr>
<tr><td colspan="2">Illegal waste Disposal GHG Emissions</td><td>6384.64</td><td>T co_2-eq / a</td></tr>
<tr><td colspan="4">Recycling</td></tr>
<tr><td colspan="2" rowspan="2">Mixed Papers</td><td>72.99</td><td>T / a</td></tr>
<tr><td>-285.39</td><td>T co_2-eq / a</td></tr>
<tr><td colspan="2" rowspan="2">Mixed Plastics</td><td>116.78</td><td>T / a</td></tr>
<tr><td>-120.29</td><td>T co_2-eq / a</td></tr>
<tr><td colspan="2" rowspan="2">Mixed Metals</td><td>17.03</td><td>T / a</td></tr>
<tr><td>-82.43</td><td>T co_2-eq / a</td></tr>
</table>

Glass		36.50	T / a
		-11.31	T co_2-eq / a
Recycling GHG Emissions		-499.42	T co_2-eq / a
Waste Treatment			
Bio waste Composting	input waste	1343.90	T / a
	Net GHG emission factor	-0.10	T (co_2-eq) / T (material input)
	Net GHG emissions	-134.39	T co_2-eq / a
Waste Treatment GHG Emissions		-134.39	
Waste Disposal			
mass of waste designated to disposal facility /site		13034.09	T / a
share of managed landfill site – anaerobic		0.000	% of waste designated to disposal site
share of unmanaged open dump – deep (> 5 m waste) and/or high water level		0.700	% of waste designated to disposal site
share of unmanaged open dump – shallow (< 5 m waste)		0.300	% of waste designated to disposal site
managed landfill site – anaerobic		0.00	T / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		9123.86	T / a
unmanaged open dump – shallow (< 5 m waste)		3910.23	T / a
managed landfill site – anaerobic		0.00	T co_2-eq / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		18247.73	T co_2-eq / a
unmanaged open dump – shallow (< 5 m waste)		3910.23	T co_2-eq / a
Waste Disposal GHG Emissions		22157.95	T co_2-eq / a
Greenhouse Gas Emissions total		27908.78	T co_2-eq / a
		1.04	T co_2-eq / T waste

Scenario 2:-

Greenhouse gas Emissions			
Illegal waste Disposal			
waste open burned		2972.90	T / a
		3297.48	T co_2-eq / a
waste uncontrolled disposal	waste quantity uncontrolled disposed	3087.16	T / a
	DOC (degradable organic carbon in the deposited waste)	0.30	T C / T waste
	DOCf (fraction of DOC that is dissimilated over time)	0.50	Default values according to [97]
	F (methane content of the landfill gas)	0.50	
	MCF (methane correction factor to take account of the type of waste disposal site)	0.40	
	OX (oxidation factor)	0.00	
	gas collection efficiency (RT)	0.00	
	GHG emissions waste uncontrolled disposal	3087.16	T co_2-eq / a
Illegal waste Disposal GHG Emissions		6384.64	T co_2-eq / a
Recycling			
Mixed Papers		72.99	T / a
		-285.39	T co_2-eq / a
Mixed Plastics		116.78	T / a
		-120.29	T co_2-eq / a
Mixed Metals		17.03	T / a
		-82.43	T co_2-eq / a
Glass		36.50	T / a
		-11.31	T co_2-eq / a
Recycling GHG Emissions		-499.42	T co_2-eq / a

Waste Treatment			
Bio waste Composting	input waste	4031.70	T / a
	Net GHG emission factor	-0.10	T (co_2-eq) / T (material input)
	Net GHG emissions	-403.17	T co_2-eq / a
Waste Treatment GHG Emissions		-403.17	
Waste Disposal			
mass of waste designated to disposal facility /site		12233.19	T / a
share of managed landfill site – anaerobic		0.000	% of waste designated to disposal site
share of unmanaged open dump – deep (> 5 m waste) and/or high water level		0.700	% of waste designated to disposal site
share of unmanaged open dump – shallow (< 5 m waste)		0.300	% of waste designated to disposal site
managed landfill site – anaerobic		0.00	T / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		8563.23	T / a
unmanaged open dump – shallow (< 5 m waste)		3669.96	T / a
managed landfill site – anaerobic		0.00	T co_2-eq / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		17126.47	T co_2-eq / a
unmanaged open dump – shallow (< 5 m waste)		3669.96	T co_2-eq / a
Waste Disposal GHG Emissions		20796.42	T co_2-eq / a
Greenhouse Gas Emissions total		26278.47	T co_2-eq / a
		0.98	T co_2-eq / T waste

Scenario 3:-

Greenhouse gas Emissions			
Illegal waste Disposal			
waste open burned		2972.90	T / a
		3297.48	T co_2-eq / a
waste uncontrolled disposal	waste quantity uncontrolled disposed	3087.16	T / a
	DOC (degradable organic carbon in the deposited waste)	0.30	T C / T waste
	DOCf (fraction of DOC that is dissimilated over time)	0.50	Default values according to [97]
	F (methane content of the landfill gas)	0.50	
	MCF (methane correction factor to take account of the type of waste disposal site)	0.40	
	OX (oxidation factor)	0.00	
	gas collection efficiency (RT)	0.00	
	GHG emissions waste uncontrolled disposal	3087.16	T co_2-eq / a
Illegal waste Disposal GHG Emissions		6384.64	T co_2-eq / a
Recycling			
Mixed Papers		72.99	T / a
		-285.39	T co_2-eq / a
Mixed Plastics		116.78	T / a
		-120.29	T co_2-eq / a
Mixed Metals		17.03	T / a
		-82.43	T co_2-eq / a
Glass		36.50	T / a
		-11.31	T co_2-eq / a
Recycling GHG Emissions		-499.42	T co_2-eq / a

Waste Treatment			
Bio waste Composting	input waste	6719.50	T / a
	Net GHG emission factor	-0.10	T (co_2-eq) / T (material input)
	Net GHG emissions	-671.95	T co_2-eq / a
Waste Treatment GHG Emissions		-671.95	
Waste Disposal			
mass of waste designated to disposal facility /site		11435.49	T / a
share of managed landfill site – anaerobic		0.000	% of waste designated to disposal site
share of unmanaged open dump – deep (> 5 m waste) and/or high water level		0.700	% of waste designated to disposal site
share of unmanaged open dump – shallow (< 5 m waste)		0.300	% of waste designated to disposal site
managed landfill site – anaerobic		0.00	T / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		8004.84	T / a
unmanaged open dump – shallow (< 5 m waste)		3430.65	T / a
managed landfill site – anaerobic		0.00	T co_2-eq / a
unmanaged open dump – deep (> 5 m waste) and/or high water level		16009.69	T co_2-eq / a
unmanaged open dump – shallow (< 5 m waste)		3430.65	T co_2-eq / a
Waste Disposal GHG Emissions		19440.33	T co_2-eq / a
Greenhouse Gas Emissions total		24653.60	T co_2-eq / a
		0.92	T co_2-eq / T waste