Department of Waste and Resource Management

Universität Rostock

FEASIBILITY ASSESSMENT OF WASTE MANAGEMENT AND TREATMENT IN JORDAN

DISSERTATION

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SAFWAT HEMIDAT

Born in Sammu 1977, Kingdom of Jordan

Rostock, Germany

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Gutachter:

1. Gutachter:

   PD. Dr.-Ing. habil. Abdallah Nassour

   Universität Rostock

   Justus-Von-Liebig-Weg 6, 18059 Rostock, Germany.

2. Gutachter:

   Prof. Dr.-Ing. Kerstin Kuchta

   Technische Universität Hamburg

   Harburger Schloßstraße 36, 21079 Hamburg, Germany.

3. Gutachter:

   Dr. Motasem Saidan

   University of Jordan

   Queen Rania Al-Abdallah Str.- Amman, 11942 Amman, Jordan.

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Declaration of Independency

I hereby declare that the present work is prepared and submitted by me independently without any assistance other than from those cited and acknowledged in the thesis.

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Safwat Hemidat

Summary

Recently, Jordan has introduced the integrated solid waste management (SWM) concept. Collection and sorting, composting, incineration of medical waste and sanitary landfills are starting to be implemented, while recycling, reuse and resource recovery are still in the initial stages. In Jordan, up to 50% of the generated waste goes uncollected, and the waste that is collected is mainly mixed with industrial and medical waste during handling and disposal. The typical method of municipal waste disposal in Jordan is landfill, which is poorly managed and lacks most of the basic engineering and sanitary measures for the collection and treatment of gas and leachate. The inability of the existing waste management systems to cope with the growing waste generation rates has led to significant health and environmental problems in Jordan.

The problem represents a measurable threat to public health and environmental quality and requires national attention of the highest priority and urgency. The large influx of refugees, the increase of per capita solid waste (SW) generation rates, the impact of dumping SW in non-engineered landfills, the gaps in current related legislation, as well as the absence of proper practices for SW collection and management are the key challenges making this problem highly complicated for the government bodies responsible for handling and managing SW. Therefore, a fresh view is required. There is a need for action. A new integrated SW management system focusing on the overall SW management cycle (street-cleaning, collection, transfer and transport, treatment and disposal) and supplemented by legal, organisational and institutional recommendations is required to ensure optimum results throughout the Kingdom.

The purpose of this thesis is to examine the MSW treatment practices in Jordan in order to submit possible treatment approaches, which could be adopted and implemented locally, for sustainable solid waste management in the future.

This PhD was conducted in four phases. The first phase was the evaluation of the current situation of SWM practices in Jordan. In this phase, a comprehensive overview of the current situation of the waste management system in Jordan was undertaken. The second phase was an examination of the possibility of optimising the collection route by implementing a route-solving solution using advanced software, the ArcGIS Network Analyst tool, that can lead to benefits related to substantial cost savings, CO_2 emissions and so forth. To this end, a Geographic Information System (GIS) has been created based on data collection involving GPS tracking (collection route/bin position). Both key performance and key operational costs indicators of the actual state (Scenario S0) were evaluated, and by modifying particular parameters, other scenarios were generated and analysed to identify optimal routes.

The third phase was the assessment of the compost produced from source-separated organic materials. The study was conducted to explore the physical and chemical properties of compost made from different segregated bio-waste raw materials. The compost produced was monitored in terms of moisture content, bulk density, pH, EC, total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium

and C/N ratio, heavy metal concentrations and compost respiration. Final product quality was examined and assessed against the quality specifications of the German End of Waste Criteria for bio-waste (BioAbfV) which has been subjected to composting.

The fourth phase was the investigation of the potential for refuse-derived fuel (RDF) production and utilisation as an alternative fuel for the Jordanian cement industry by using the biodrying process as a solution for the conditions in Jordan to overcome some of its MSW management problems. During this study, laboratory analysis of RDF samples was carried out, to evaluate the RDF quality and compare it with criteria and limits set by some European countries. The biological drying process of solid waste by aerated windrow composting was used as a method of pre-treatment of mixed MSW prior to landfill, in order to produce high calorific material RDF and recover valuable material from the waste stream. Furthermore, the performance of the biological drying process of solid waste by aerated windrow composting was investigated as a pilot scale experiment carried out in Jordan.

In conclusion, the findings indicate that GIS-based optimised scenarios could serve as an efficient management tool for the daily operations of solid waste collection and transportation. From an economic point of view, compared to the current situation, the results show that the proposed scenarios allow significant savings of about 23% in overall operational costs. Moreover, vehicle operating time was seen to decrease by 30%, in addition to other extra benefits related to CO_2 emissions. A good alternative for Jordan is the composting of source-separated organic materials. A high quality compost with acceptable chemical properties (OM, TOC, TKN, total P, total K, heavy metals) and physical properties (bulk density, moisture content, etc.) was produced. The absence of local standards, monitoring systems and the legal barriers prevent the control of the sale and application of the compost produced to end users on agricultural/horticultural land.

Overall, the results conclude that an efficient waste treatment system could be achieved with a fairly basic and low-cost MBT concept. This is by utilising the biological drying process to produce a substitute fuel for industrial processes. This would reduce the landfill areas required, as well as reduce the air emissions from the landfill, in particular greenhouse gases. High capital investment is needed to set up an RDF plant. However, return on investment is not guaranteed to treat the designated waste quantity for all cases. Therefore, the success of SWM is based on the partnership and cooperation between different parties involved (politicians, local private sector, public sector and international consultant companies). The selection of the appropriate solution for MSW must be based on many factors, such as the availability of land for disposal, the market for recyclable material and the need for energy production, and taking into account the economic and social aspects, with particular attention to environmental issues.

Aufgrund von Veränderungen bei Jordaniens politischen, demographischen und wirtschaftlichen Bedingungen, hat die Nachfrage nach einer sicheren und effektiven Abfallwirtschaft stetig zugenommen. Diese Nachfrage ist besonders in Bezug auf feste Abfälle groß, vornehmlich bedingt durch ihre direkten Auswirkungen auf die Gemeinden. Dem Königreich fehlt jedoch die Auswahl integrierter Verfahren in den Bereichen Straßenreinigung, Abfallsammlung, -transport, -transfer, -behandlung und -beseitigung. Das Ziel dieser Dissertation ist es, die vorhandenen Abfallbehandlungsmethoden in Jordanien zu untersuchen, um mögliche Behandlungsansätze für eine nachhaltige Entsorgung fester Abfälle darzulegen, die lokal angenommen und umgesetzt werden könnten.

In dieser Studie wurden, basierend auf den Ergebnissen, die zum Status des Abfallmanagementsystems in Jordanien überprüft wurden, verschiedene Ansätze der Abfallwirtschaft durch experimentelle Projekte untersucht. Diese Ansätze wurden als Fokus meiner Forschung ausgewählt und als kritische Hindernisse für die Abfallwirtschaft in Jordanien betrachtet.

Die Forschungsarbeiten wurden an der Universität Rostock, in Zusammenarbeit mit verschiedenen internationalen Organisationen wie GIZ, UNDP und INFA, lokalen Regierungsinstitutionen wie MoMA und GAM sowie lokalen privaten Unternehmen wie Jaar Establishment for Consultation und Tadweer, durchgeführt. Dabei wurden verschiedene Sektoren der Abfallwirtschaft angesprochen, darunter:

GIS – technisch unterstützte Verbesserung der Sammlung und des Transports fester Abfälle: In dieser Studie wurden mit dem ArcGIS Network Analyst-Tool optimierte Szenarien entwickelt, um die Effizienz der Sammlung und des Transports von Abfällen in Jordanien zu verbessern. Sowohl die Leistungs- als auch die Betriebskostenindikatoren für den Ist-Zustand wurden bewertet. Durch Veränderungen bestimmter Parameter wurden weitere Szenarien erstellt und analysiert, um optimale Routen zu ermitteln.

Bewertung der Kompostproduktion (unter Berücksichtigung der Kompostqualität): Die Studie zielte darauf ab, die physikalisch-chemischen Eigenschaften von Kompost, hergestellt aus verschiedenen sortenreinen Bioabfallmaterialien, zu untersuchen. Die Endproduktqualität wurde geprüft und anhand der Qualitätsvorgaben der deutschen Bioabfallverordnung (BioAbfV) für die Kompostierung bewertet.

Herstellung von EBS aus gemischten Siedlungsabfällen als alternativer Brennstoff für die Zementindustrie: Ziel dieser Studie war es, die Realisierbarkeit der Erzeugung von RDF aus festen Siedlungsabfällen mithilfe eines Biodrying-Verfahrens für die Co-Verarbeitung in Zementöfen in der Region zu untersuchen. Diese Studie untersuchte die Auswirkungen und den Nutzen für die Umwelt sowie die wirtschaftlichen Kosten und Gewinne der RDF-Erzeugung.

Mögliche Abfallbehandlungs- und Entsorgungsansätze für gemischte Siedlungsabfälle in Jordanien: Es wurden verschiedene nachhaltige Lösungen mit unterschiedlichen Strategien vorgeschlagen. Drei Ansätze, die Einführung einer getrennten Sammlung von Nass- und Trockenfraktionen, sowie zwei Behandlungskonzepte für getrennte und für gemischte Siedlungsabfälle wurden vorgeschlagen. Ferner wurden zwei technische Modelle für die Errichtung von Recyclingzentren (Umladestation, Sortier- und Kompostierungsanlage) auf kommunaler Ebene und einer Verbrennungsanlage, insbesondere für die Stadt Amman, ausgearbeitet.

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LIST OF ABBREVIATIONS

€: Euro

AFD: French Development Agency

AT4: Respiration activity test

BMZ: German Federal Ministry for Economic Cooperation and Development

Cd: Cadmium

CLO: Compost-Like Output

Cr: Chrome

Cu: Copper

DFAT: The Australian Department of Foreign Affairs and Trade

DIFD: UK Department for International Development

DM: Dry Matter

EBRD: European Bank for Reconstruction and Development

EC: Electric Conductivity

EU: European Union

GAC: Global Affairs Canada

GAM: Greater Amman Municipality

GEF: Global Environment Facility

GHG: Greenhouse Gas

Hg: Mercury

HHW: Household Hazardous Wastes

ISWM: Integrated Solid Waste Management

JD: Jordanian Dinar

JICA: Japan International Cooperation Agency

JNS: Jordan National Strategy

JSC: Joint Service Council

LHV: Lower Heating Value

MBT: Mechanical Biological Treatment

MoEnv: Ministry of Environment

MoMA: Ministry of Municipal Affairs

MRF: Materials Recovery Facilities

MSW: Municipal Solid Waste

MSWFF: Bio-dried MSW Fine Fraction

NARC: National Agricultural Research Center

Ni: Nickel

Pb: Lead

PET: Polyethylene terephthalate

PMB: Pre Mechanical Biological

PP: Polypropylene

RDF: Refuse Derived Fuel

SRF: Solid Recovered Fuel

SWM: Solid Waste Management

UHV: Upper Heating Value

UNEP: United Nations Environment Program

UNICEF: United Nations International Children's Emergency Fund

USAID: United States Agency for International Development

USEPA: United States Environment Protection Agency

W/C: Water Content

WtE: Waste to Energy

Zn: Zinc

1. Introduction and Problem Statement

Recently, solid waste management (SWM) has become a major concern and is presently one of the main subjects under discussion. This is probably due to the rapid growth of the population, booming economy, rapid urbanisation and the rise in community living standards that have greatly accelerated the solid waste (SW) generation rate. This has become one of the most critical current environmental problems (Onwosi et al., 2017). As SW quantum increases, more effort and capacity are needed for efficient solutions to manage it in an environmentally safe manner (Santibanez-Aguilar et al., 2013). Solid waste is an environmental problem in both developed and developing countries. Solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden imposed on the municipal budget as a result of the high costs associated with its management, the lack of understanding of a diversity of factors that affect the different stages of waste management and the linkages necessary to enable the entire handling system to function (Guerrero et al., 2013).

Jordan is considered to be a developing entity and has much in common with other developing countries. Solid waste management has been complicated by the sharp increases in the volume of solid waste generated as well as the qualitative changes in the composition of this waste due to significant changes in living standards and conditions. Solid waste management systems in Jordan must deal with many difficulties, including low technical experience and low financial resources, which often cover only collection and transfer costs, leaving no resources for safe final disposal (Ikhlayel et al., 2016). Provision of adequate SWM services is critical because of the potential impact on public health and on the environment. The challenges facing SWM in Jordan are numerous. Financial constraints, shortage of adequate and proper equipment, and limited availability of trained and skilled manpower together with massive and sudden population increases due to several waves of forced migration have contributed much to the poor solid waste management programmes in Jordan (Aljaradin, 2014).

Due to political instability in the Middle East, Jordan has received several influxes of refugees since decades. Recent waves of refugees from Syria have led to a noticeable increase in the country's population: from 6.99 million inhabitants in 2011 to 9.5 million in 2015. The number of Jordanians is around 6.6 million, while the number of non-Jordanians who reside in the country is around 2.9 million, representing 30.6 % of overall population. The number of Registered Syrian Refugees according to the UNHCR is 655,344 individuals. However; the actual number of registered and non-registered Syrian refugees is about 1.265 millions. This has put an enormous pressure on services and infrastructure: in particular, the solid waste management has been considerably affected (Abu Qdais, 2017).

According to the latest report of the Ministry of Municipal Affairs (MoMA) in 2018, solid waste management costs the Jordan Government around 90 million annually, of which 80% (70 million) are incurred by municipalities. The fees collected are very low, covering only 60% of the costs in the Greater Amman municipality and no more than 30% in the other municipalities. Furthermore, in some cases the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms. The fees for managing waste are generally charged on the electricity bill. The cost recovery is very low, covering no more than 30% of the costs. Furthermore, in some cases the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms.

Landfills are the primary disposal method in the country's waste management plan. Twenty landfill sites are available throughout the country, but only one sanitary landfill, the only and the biggest sanitary landfill, is available which receives waste from the capital city and nearby cities. Only 5 to 10% of Jordan's solid waste is being recycled at the moment, as there is no large scale and effective government-run solid waste sorting practice or recycling system as yet in place. The solid waste recycling industry in Jordan remains untapped and most of the existing and operating solid waste recycling activities are limited to the private sector and NGOs (Saidan et al., 2016). There are still several improvements that must be targeted in the field of waste management in terms of policy, strategy, institutional set-up, legal framework, waste treatment and disposal and capacity building.

The problem represents a measurable threat to public health and environmental quality in Jordan and requires national attention of the highest priority and urgency. The large influx of refugees from neighbouring countries, the increase of per capita SW generation rates, the impact of dumping SW in non-engineered landfills, the gaps in current related legislation, as well as the absence of proper practices for SW collection and management are the key challenges making this problem highly complicated for the government bodies responsible for handling and managing the SW. These factors point to the urgent need to remodel the way waste is managed.

To tackle such issues with the current SWM system, the country has to improve its waste management. Therefore, a fresh look is required and there is a need for action. Logically, a new integrated SWM system focusing on the overall SWM cycle (street-cleaning, collection, transfer and transport, treatment and disposal) and supplemented by legal, organisational and institutional recommendations is needed to ensure optimum results throughout the Kingdom (Ikhlayel et al., 2016).

The potential impacts caused by waste on the environment, the use of valuable space by landfills and poor waste management that causes risks to public health are the obstacles to overcome. The problem has to do with the quantity of solid waste generated and effective ways of management; while, the solution lies in the policy laid down or conceptual framework, configured as '3Rs' or 'RRR', that is, 'reduce, reuse and recycle' (Peprah et al., 2015).

An effective system of solid waste management involves the adoption of various treatment methods, technologies and practices. All technologies and systems adopted must ensure the protection of public health and the environment. There are a wide variety of alternative waste management approaches and strategies available to deal with mixed solid waste to limit the residual amount left for disposal in landfill sites. With proper solid waste management and the right control of its polluting effects on the environment, solid waste has the opportunity to become a precious resource and fuel for future sustainable energy. Waste-to-Energy (WtE) technologies are able to convert the energy content of different types of waste into various forms of valuable energy (Rechberger, 2011; Rotter, 2011). Moreover, combustion and biological processes that yield thermal power, refuse-derived fuel, compost and stabilised production of SW before landfill disposal have drawn increasing attention worldwide (Scaglia et al., 2013).

This study is not only relevant, but is also timely in the wake of the large influx of refugees from neighbouring countries and rapid urbanisation, in order to achieve efficient and cost effective waste management. It is aimed at finding new possible treatment approaches, which could be adopted and implemented locally, for sustainable solid waste management in the future. Within this context the objectives of this thesis were to:

- Describe and review the current waste management practices in Jordan and identify the factors that influence waste management in the country.
- Assess the current practices for solid waste collection and evaluate the key indicators that affect the performance and cost efficiency of the waste collection and transportation system.
- Identify the resource potential of waste streams and the extent new approaches could be applied to utilise solid waste as a resource.
- Assess the possible SWM systems and some of the technologies that could be suitable for the local situation and conditions.
- Assess the quality of compost made from different source-separated organic waste raw materials.
- Examine a possible technology that can produce good quality RDF and be a part of the Jordan's SWM solution.
- Investigate the potential for RDF production and the quantity of RDF that would be produced by using the biological drying/stabilisation process.
- Identify the possible RDF composition that would be produced from mixed MSW in Jordan.
- Recommend practices that will improve and yield benefits in the SWM process in Jordan.

2. REVIEW OF SOLID WASTE MANAGEMENT IN JORDAN

Millions of metric tons of municipal solid waste (MSW) are generated in Jordan from agricultural, municipal and industrial sources every year. The growing industrialisation and high population growth rate due to the recent forced migration has led to a rapid increase in solid waste generation in the country which has, in turn, put increasing pressure on the existing waste management infrastructure. The current solid waste management (SWM) services within the local municipalities are no longer of the same standard as that prior to the massive influx of refugees and the daily generation rate of MSW has dramatically increased (Saidan et al., 2016).

Solid waste management has become one of the major environmental problems facing Jordan's municipal authorities. It has been aggravated over the past few years by the sharp increase in the volume of waste generated as well as qualitative changes in its composition. The provision of adequate waste management services is critical because of the potential impact on public health and on the environment (Ikhlayel et al., 2016). Lack of planning, lack of proper disposal, limited collection services, use of inappropriate technology, inadequate financing, limited availability of trained and skilled manpower together with massive and sudden population increases due to several waves of forced migration are considered to be the main problems facing SWM (Aljaradin, 2014).

2.1. OVERVIEW OF JORDAN AND THE ENVIRONMENT SECTOR

Jordan is home to about 10 million inhabitants in a surface area covering around 89,328 km^2, of which over 80 percent is characterised by semi-desert conditions. However, some wetlands do exist, including the Azraq Basin. Over two-thirds of the growing population are living in urban centres such as Amman, Zarqa and Irbid. It is a small, middle-income, open economy country, with a limited natural resources base and an active trade flow. Currently, the population stands at around 9.5 million, including 2.9 million guests. Due to the crisis in Syria, Syrian refugees constitute 46 percent of non-Jordanians living in the Kingdom and 13.2 percent of the overall population (DoS, 2015).

Jordan is a country with a tremendously fragile environment. It faces substantial environmental challenges due to its delicate environmental resources and its limited financial assets. Enhancing Jordan's environmental management can not only improve the well-being of Jordanians, but also enable the country to better compete in increasingly environmentally conscious markets. Over the last decade, the government of Jordan has made considerable progress in its ability to reduce environmental degradation through an improved legislative framework, stronger institutions and a number of publicly funded projects. Solid waste management has been improved over the last 15 years, since the mid-1990s, with improvement of the legal framework and institutional capacity the main drivers of the sector's development. The current collection rates are estimated at 90% and 70% in urban and rural areas, respectively. With the notable exception of Amman (which accounts for about 50% of total solid waste generation), safe disposal remains a concern, since most of the other municipalities discharge solid waste in open dump sites with no lining, leachate management, or biogas collection. Management of hazardous and medical waste is also inadequate. Hazardous waste totalled 23,000 tons in 2001 and this amount was expected to increase to 68,000 t/year by 2017; it is disposed of without any treatment (Ikhlayel et al., 2016).

Nevertheless, Jordan's environmental performance compared to other countries in the Middle East and North Africa (MENA) region, was good and it ranked second in the region, after Morocco and 84th worldwide. The good environmental performance of Jordan can be attributed to the fact that the country has less energy depletion and low values of natural resources (World Bank, 2009; EEA, 2010). This also could be an indication of favourable conditions for focusing the country's effort on the main present and future environmental challenges, provided that there is adequate information on relative priorities across environmental themes and on key trade-offs to be addressed to make progress on those priorities (Ikhlayel et al., 2016).

2.2. CURRENT SITUATION OF WASTE MANAGEMENT

Recently, several countries, of which Jordan is one, have realised that the way they manage their solid waste does not satisfy the objectives of sustainable development. Therefore, these countries have decided to move away from traditional SWM options to more integrated SWM approaches. Collection and sorting, composting, incineration of medical waste and sanitary landfills are starting to be implemented, while recycling, reuse and resource recovery are still in the initial stages (Elnaas et al., 2014). Despite the many attempts put in place by the various stakeholders in Jordan, SWM is still facing many challenges (Figure 2-1) and does not benefit from a well-defined national policy and a specific and implementable legislative framework. It can be observed that several improvements still need to be targeted in terms of policy, strategy, institutional set-up, legal framework, involvement of the private sector and capacity building. Indeed, there is a need for immediate action to establish an integrated system for SWM in Jordan. This must begin with issuing coherent policy, legal and institutional frameworks and enhancing cost recovery (Nassour et al., 2011).

In Jordan, rapid urbanisation and the uncontrolled growth rate of the population are the main reasons why MSW has become an acute problem. The rapid urban population increase has resulted in large unplanned settlements and an excessive amount of solid waste. Lack of legislation, lack of financing, lack of training/human resources, inappropriate technologies/processes, lack of availability of primary data on per capita waste generation, inadequate data on waste characteristics, the influence of informal sectors, different reports giving different values and projections and lack of good governance, as well as civil society inactivity are the main common problems with regard to waste management facing the decision makers. Therefore, it is difficult to assess the land requirements and select appropriate treatment/disposal techniques. System failures include a lack of a comprehensive policy framework for waste management and a shortage of tools to analyse and improve efficiency, effectiveness and sustainability (World Bank, 2009; Aljaradin, 2014).

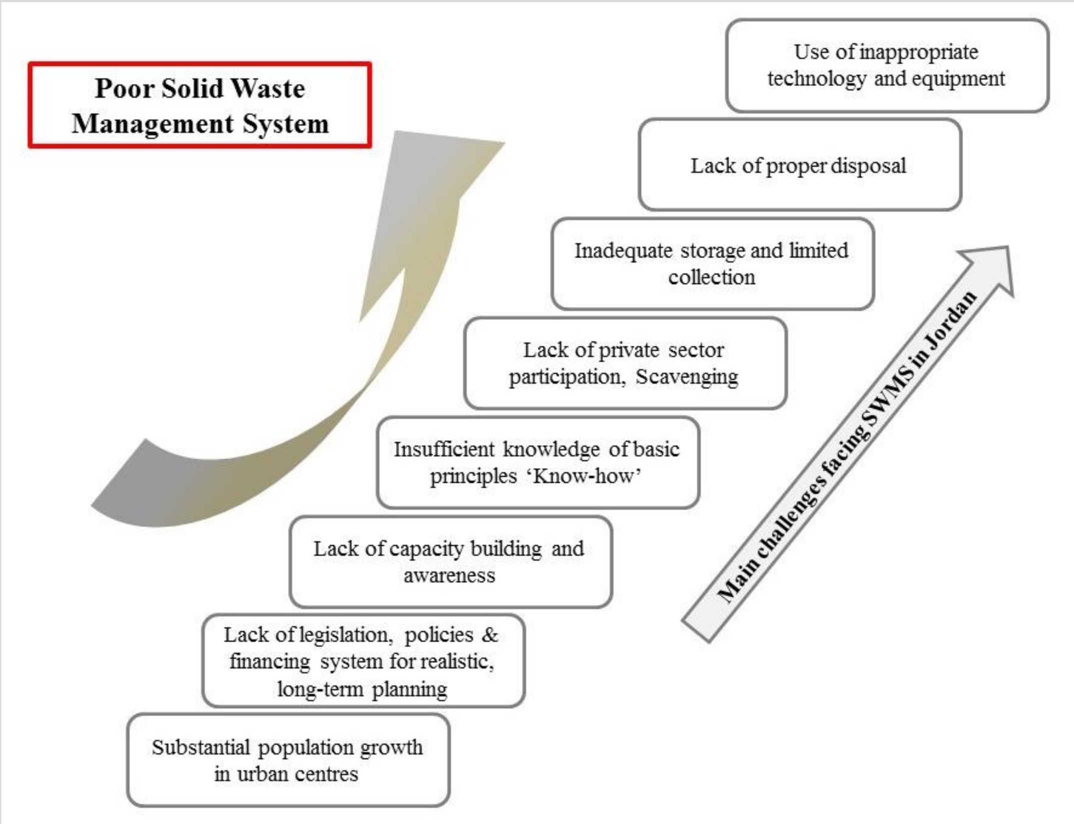


Figure 2-1. *Major challenges facing the solid waste management system in Jordan*

Although Jordan has improved its waste management during the last few years, landfill is still the major SW treatment technology utilised in the country; up to 95% of SW goes to landfill, leading to large environmental problems. Presently, up to 50% of the waste generated goes uncollected, and the waste that is collected is mainly mixed with industrial and medical waste during handling and disposal. The typical method of solid waste disposal in Jordan is dumping, where it is poorly managed and lacks most of the basic engineering and sanitary measures for the collection and treatment of gas and leachate. The current landfills are still causing environmental problems such as contamination of groundwater and surface water resources. However, the landfill sites and the issue of their adverse impacts was thoroughly investigated in recent literature (Abu Qdais, 2007a; Abu Qdais, 2007b; Al-Jarrah and Abu Qdais, 2006; Aljaradin and Persson, 2010; Aljaradin and Persson, 2012; Aljaradin and Persson, 2013).

Frequently quoted practical problems include limited solid waste collection services; inadequate, poorly maintained, out of date, or too little equipment or spare parts; or equipment that is inappropriate for local conditions. All of these are exacerbated by the increases in population and of volume of waste per household (Hemidat, 2017). Other obstacles for waste management are connected to limited availability of trained and skilled manpower or under-functioning staff who are not motivated or difficult to find because of low status, low salaries and difficult working circumstances (Aljaradin, 2014).

Financial problems regularly include imbalances between income and expenditure because of rising costs and inadequate revenues. Adding to the financial difficulties are inefficient (and sometimes overpriced) waste processing facilities and increasing costs of waste collection and transfer and disposal (Abu Qdais, 2007a; Ikhlayel et al., 2016). The costs of managing waste are generally connected with the electricity bill. However, the fees collected are very low, covering only 60% of the costs in Greater Amman municipality and no more than 30% in the other municipalities. Furthermore, in some cases the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms (Nassour et al., 2008). Nowadays, there is an attempt towards increasing charges for waste management services by introducing an Extended Producer Responsibility (EPR) system in Jordan.

The public awareness and willingness of the local community in Jordan for waste recycling and separation practices are also not reaching the required level. Furthermore, the relevant public awareness campaigns were short term and carried out at pilot scales. In the absence of effective inventive programmes, these weakly designed pilot-scale public awareness campaigns did not have a proper positive impact, in fact, they resulted in a negative impact. Indeed, the public awareness campaigns should be considered as fundamental tools for increasing the social marketing of any waste recycling and sorting practices, and should include different levels of social marketing and behaviour change campaigns in both the upstream (advocacy) and downstream (behaviour change) levels. Most municipalities do not find it easy to cooperate or communicate with their own citizens, who appear to be uncooperative with the municipality. Behaviour such as illegal dumping of waste, misuse or non-use of containers, damaging and stealing communal storage containers and resistance to service charges has led authorities to believe that the citizens are part of the problem, rather than an ingredient of the solution.

The participation of the local Jordanian private sector in the different work fields of SWM is still limited and very modestly explored. Development in the Private-Public Partnership (PPP) concepts and models in waste recycling and segregation in Jordan has recently been explored. However, almost all MSW recycling activities in Jordan, present and past, are considered to be pilot projects and small-scale interventions. The vast majority of the recycling pilot projects operating in Jordan are mostly initiated and supported by the NGOs and other international organisations, for short and/or mid-term funding schedules. The Corporate Social Responsibility (CSR) initiatives should be highlighted at the local community level to ensure long-lasting and sustainable waste recycling and sorting practices in terms of investments, performance and outcomes.

In the absence of national formal recycling systems or structures, and due to the ever-present socio-economic needs especially in the poorer regions, an informal waste recycling sector consisting of local waste-pickers and scavengers has developed during the last twenty years. Several thousand individual scavengers usually collect waste with a small fraction of market value directly from the MSW collection containers distributed around the urban cities, or the MSW delivered to the official landfill/dumpsites is sorted by them through a kind of contractual framework.

Many issues and areas in the waste management system in Jordan should be tackled in order to move towards improving the waste system and shifting from a waste disposal to a waste management system. The inability of the existing waste management systems to cope with the growing waste generation rates has led to significant health and environmental problems in Jordan. Therefore, there is a necessity for new regulations that deal specifically with solid waste to promote waste minimisation, recycling and resource recovery in order to reduce the solid waste directed to landfills (Abu Qdais, 2007a, b; World Bank, 2009; Aljaradin & Persson, 2010; Ikhlayel et al., 2016; Nassour et al., 2011).

The problem represents a measurable threat to public health and environmental quality and requires national attention of the highest priority and urgency. The large influx of refugees, the increase of per capita SW generation rates, the impact of dumping SW in non-engineered landfills, the gaps in current related legislation, as well as the absence of proper practices for SW collection and management are the key challenges making this problem highly complicated for the government bodies responsible for handling and managing the SW. Therefore, a fresh look is required. There is a need for action. A new integrated SW management system focusing on the overall SW management cycle (street-cleaning, collection, transfer and transport, treatment and disposal) and supplemented by legal, organisational and institutional recommendations is required to ensure optimum results throughout the Kingdom.

2.3. LEGAL FRAMEWORK AND POLICIES

In early 2015, the Government of Jordan (GoJ) adopted a specific National Strategy for SWM including timely planning frameworks in order to develop an effective SWM sector. This National SWM Strategy is considered to be the umbrella under which the relevant regulations and projects operate. It is the outcome of a regional and local development project and includes short- and long-term targets with the aim of improving the existing MSWM system towards a "modern and integrated one" (MoMA, 2014). The new National SW Strategy encourages environmentally-sound SWM approaches such as source separation of waste, reduce, reuse, recycle and recovery of waste at both municipal and dumpsite level, in addition to the treatment of the SW stream through biological and mechanical methods. Due to the massive influx of refugees, a focus of emergency measures has been set to cater for the most urgent needs of the Jordanian municipalities and Joint Service Councils (JSCs).

Solid waste management in Jordan is a complex field. Legislation and policies of solid waste management in Jordan are regulated by a number of authorities under different pieces of legislation that are implemented through different governmental sectors. The most important entities are the Ministry of Municipal Affairs (MoMA), the Ministry of Health (MoH) and the Ministry of the Environment (MoEnv), with a very weak level of coordination.

The Ministry of the Environment is responsible for setting up waste management policies and regulating the waste management sector as well as monitoring and enforcing the established policies. While MoMA has two key tasks: supervision of municipal functions and service delivery and the regulation of the MSWM. To achieve these goals, MoMA has two executive arms, on the one hand, the municipalities and, on the other hand, the Joint Service Councils (JSC). The municipalities are responsible for implementing and monitoring of any task set up by the MoMA regarding fields like waste collection, transport, treatment, fee system, etc. The JSCs are in charge of the final treatment and disposal, i.e. the construction and operation of landfills and dumpsites. There are other ministries involved in SWM in Jordan such as the Ministry of Energy and Mineral Resources, which is in charge of regulating the renewable energy market. It cooperates with the municipalities developing waste-to-energy projects.

There are no regulations dealing specifically with solid waste issues in a comprehensive, efficient and detailed manner, with clear responsibilities and enforcement mechanisms. Moreover, there are no defined objectives, priorities or standards for generation, collection and transport of SW, the treatment of unsorted SW, including sanitary landfills, incineration, recycling and composting as well as the co-processing in cement kilns in Jordan. However, many steps should be taken to achieve these recommendations. There is also a lack of effective operational planning and monitoring and an evaluation framework, with no effective regulatory role for monitoring and enforcement. No specific legal framework for waste-to-energy facilities is in place. Concerned ministries and municipalities lack an effective framework, tools, and the capacity to monitor and evaluate technical and financial aspects of the performance of their SWM system. These are the reasons which stand against the development of a proper management of solid waste in Jordan. Therefore, a legal framework that promotes resource recovery and minimisation options and enforces the polluter-pays principle is needed (Aljaradin, 2014).

2.4. INSTITUTIONAL FRAMEWORK AND RESPONSIBILITIES

Solid waste management in Jordan is undertaken through the public sector and the private sector is not a significant player in this field. Numerous government institutions are involved in solid waste planning and management in Jordan, with overlapping mandates and responsibilities and unclear lines of authority (Figure 2-2). This uncertainty concerning the institutional framework and responsibilities is a major obstacle for the implementation of an integrated SWM system (Aljaradin and Persson, 2010).

At national level, Jordan’s regulations give MoEnv the responsibility for developing environmental policies, programmes, issuing permits to construct industrial and development projects and regulating activities with potential impacts on the environment and natural resources including SWM. On the financial side, MOMA plays a central role by virtue of its administration of municipal affairs. A key responsibility of this ministry consists of providing the municipalities with funds to invest in the SWM infrastructure in addition to responsibility for the implementation of the legal framework.

Joint Service Councils are responsible for operating and managing disposal in a safe manner. There are 22 JSCs running 24 landfills disposing of MSW, sewage sludge, olive oil and industrial waste (METAP 2008; Aljaradin and Persson, 2010; Aljaradin, 2014).

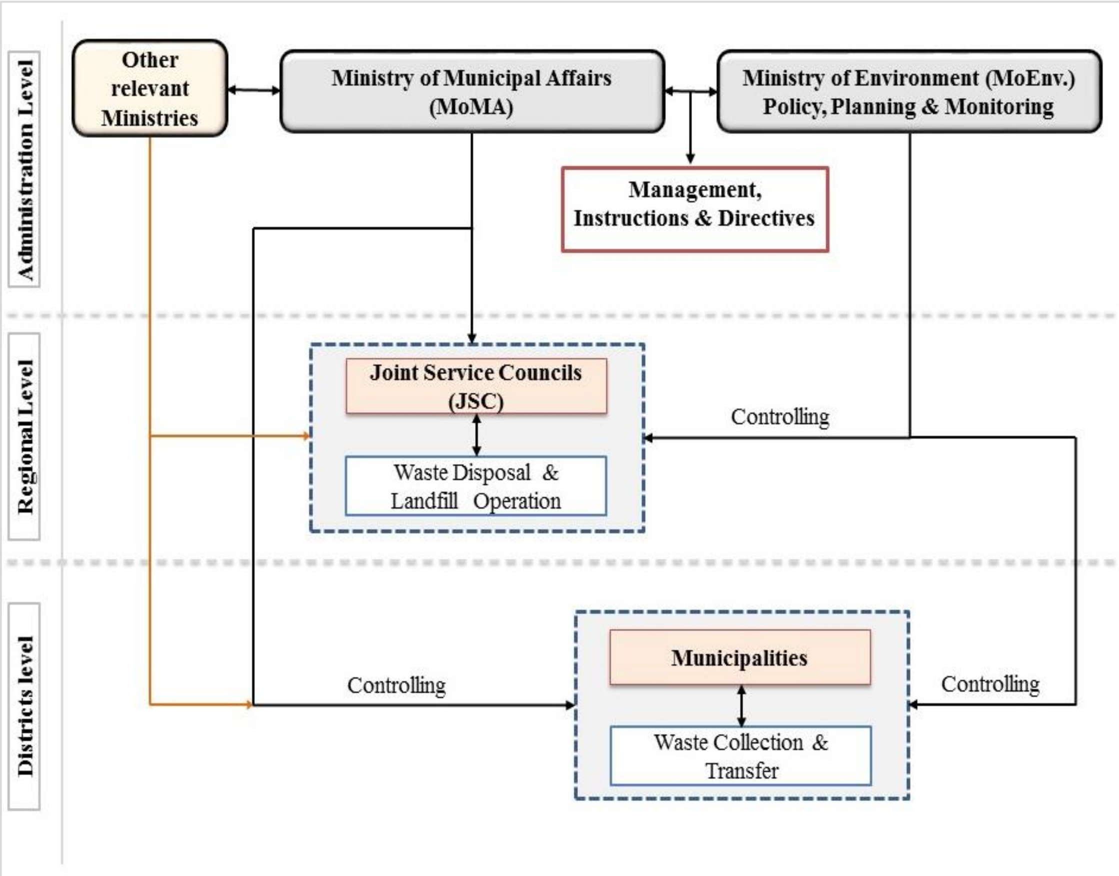


Figure 2-2. *Institutional framework and responsibilities of solid waste management in Jordan (Adapted from GIZ, 2015, Final Report Project: Waste to (positive) Energy)*

Municipalities are fully responsible on a day-to-day basis for SWM operations. Regionalised delivery of municipal services is well-established in Jordan under the authority of the legal framework governing municipal structure and operations. As a consequence, municipalities share waste disposal facilities. In some cases, they also share waste collection systems, although more commonly individual municipal units operate their own waste collection systems. Governorates are in charge of monitoring waste disposal sites from a health and safety perspective (METAP 2008; Hemidat, 2017).

The concepts of integrated solid waste management (ISWM) and utilising waste as a resource has been spreading in Jordan. However, as Figure 2-2 shows, the solid waste sector can be characterised as a disorganised sector with sporadic service coverage. Waste management in Jordan is one of the major responsibilities of local government, with no significant participation by the private sector. Subcontractors are rarely brought in to handle specific activities such as collection and transportation.

2.5. FINANCIAL FRAMEWORK

Municipalities are responsible for financing waste management infrastructure and systems. The MoMA offers low interest loans to finance municipal activities, including waste management. International grants also play a significant role in financing waste management activities. In 2014, the Ministries of Industry and Municipal Affairs issued the instructions for fees for the collection, transportation, disposal and treatment of SW. These were published in the official newspaper number 2917 on 16 December 2014. The cost recovery mechanism involves the waste collection fee being included as an item on the monthly electricity bill. The following describes the solid waste fees system in Jordan (Abu Qdais, 2007a).

- A fixed annual lump-sum fee (JOD 20 per household) that is paid in monthly instalments plus JOD 0.005 per KWh (for every KWh above 200 KWh consumption per month), levied with the monthly electricity bill and applicable for households in the Amman municipality;
- A fixed annual lump-sum fee (JOD 24, 15, or 8 per household depending on municipality class) that is paid in monthly instalments, levied with the monthly electricity bill and is applicable for households in municipalities except Amman municipality;
- For any professional licensee of commercial, institutional and industrial activities in municipalities including Amman municipality, 20% of any professional licence fee is levied annually;
- For any professional licensee for commercial, institutional and industrial activities in Amman municipality, a fee is levied annually based on special professional licence fee instructions (4 classes); and
- Other municipalities and private companies pay a gate fee to dispose of their waste at the Ghabawi disposal site.

However, the fees collected are very low, covering only 60% of the costs in the Greater Amman municipality and no more than 30% in the other municipalities. Furthermore, in some cases the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms. The fees for managing waste are generally charged on the electricity bill. The cost recovery is very low, covering no more than 30% of the costs. Furthermore, in some cases the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms. There has been an attempt towards increasing charges for waste management services (Abu Qdais, 2007a; Nassour et al., 2008; Nassour et al., 2011). Introducing the polluter-pays principle through the development of an EPR system as well as the implementation of a functioning waste separation system, focused on recycling and composting, will also generate an income from the sale of such products. Nowadays, there is an attempt towards increasing the charges for waste management services by introducing an EPR system in Jordan.

2.6. SOLID WASTE GENERATION

Recently, the crisis in Syria, the rapid increase in the population, accelerated rates of urbanisation, rapid industrialisation, the rise in community living standards, changing consumption patterns and the lack of public awareness has accelerated solid waste generation per capita. According to the Jordan National Strategy (2014), the amount of MSW produced per capita is estimated to be 0.87 and 0.99 kg per day, in rural and urban areas, respectively. About 2.7 million tons of solid waste was generated and collected by the relevant authorities in Jordan in 2014, produced by a population of 6.7 million inhabitants which included around 1 million Syrian refugees living in refugee camps and urban areas (Saidan et al., 2016; Al-Hamamre et al., 2017).

In comparison, in 2009, the annual amount of SW generated was 1.9 million tons for a population of 5.8 million inhabitants (MoMA, 2010). These figures indicate a very rapid rise of the SW generation rate in Jordan, which has been estimated to continue increasing by 3% annually (Al-Hamamre et al., 2017). In addition, the influx of refugees is estimated to have added an additional 10% to the population (UNDP, 2015), which has increased the annual projected amounts of generated MSW by 0.5 million tons. Moreover, it is expected that the waste generation per capita will increase within the years to come. The National Strategy determines the growth rate at 1.40 % for urban and 1.02 % for rural areas in Jordan, due to the improvement of living standards and the change in consumer behaviour.

The material flows of the SW generated were illustrated by Ikhlayel et al. (2016) in their study, where they reported that the collection coverage is 70%, 90% and 100% in rural areas, urban areas and Amman City, respectively (Figure 2-3). In all of Jordan's cities, landfills are the primary disposal method in the country's waste management plan. Twenty landfill sites are available throughout the country, but only one sanitary landfill, the only and the biggest sanitary landfill, is available which receives waste from the capital city and nearby cities. Nowadays, 50% of the SW is treated at the sanitary landfill site in the capital city. Over 35% of the waste generated in the entire country is placed in any of the 19 controlled landfill sites, 11% is open dumped and the remainder is unofficially recycled (Ikhlayel et al., 2016). Only 5 to 10% of Jordan's solid waste is being recycled at the moment, as there is no large scale and effective government-run solid waste sorting practice or recycling system as yet in place. The solid waste recycling industry in Jordan remains untapped and most of the existing and operating solid waste recycling activities are limited to the private sector and NGOs (Saidan et al., 2016).

To tackle such issues with the current SWM, Jordan has had to improve its waste management over the last ten years (Ikhlayel et al., 2016). Despite the lack of a well-defined policy and strategy, there have been considerable achievements in the sector in terms of city cleanliness, engineered landfilling and service cost recovery, achieving one of the best rates in the MENA region. Jordan, and in particular the Greater Amman Municipality (GAM), has successfully moved from unsanitary landfills to more sanitary methane collection (Aljaradin, 2014).

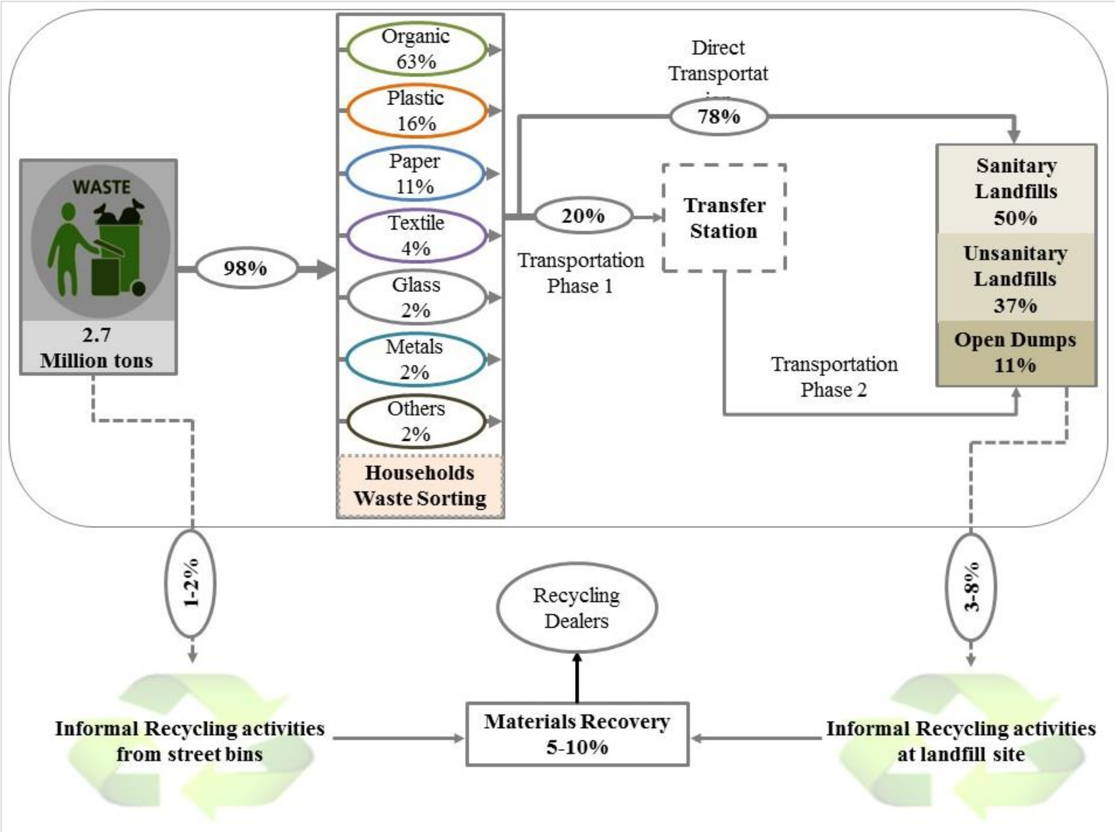


Figure 2-3. *Materials flow of the entire SWM system in Jordan*

However, there are still several improvements that must be targeted in the field of waste management in terms of policy, strategy, institutional set-up, legal framework, waste treatment and disposal and capacity building (Al-Hamamre et al., 2017).

2.7. CHARACTERISTICS OF SOLID WASTE

One of the most significant differences between the waste generated in developed and developing nations is in terms of its composition. The waste generated in developed countries is mainly inorganic in nature, whereas organic content forms a large portion of waste in developing countries (Hoornweg, 1999; Medina, 2002; Zerboc, 2003; Zurbrugg 2003). In a developing country, the proportion of organic content in waste is almost three times higher than that in developed countries, followed by recyclable materials, particularly plastics and paper (Al-Jarallah and Aleisa, 2014). Even though the volume of waste generated in developing countries is much lower, as compared to that in developed countries, the nature of waste is denser and has a very high humidity content (Zurbrugg, 2003; Al-Jarallah and Aleisa, 2014).

The nature and composition of waste is influenced by several factors, such as the lifestyle, the activities existing in a region, geographical and climatic conditions and population (Abu-Salah et al., 2013). Being highly organic and humid in nature, SW in developing countries presents both opportunities and constraints that are entirely different to those faced by developed countries (Hoornweg, 1999; Zurbrugg, 2003). A study by Pohlmann in 2017 showed that of the total solid waste generated in Jordan, more than 50% was organic, 16% plastic, 11% paper and cardboard, 10% hygienic products and the remainder included glass, metal and other miscellaneous types of waste (Figure 2-4). Pohlmann's results are largely consistent with the results of a comprehensive MSW composition analysis conducted by Hemidat in Amman (GAM) in 2018 based on the weight percentage of its waste composition.

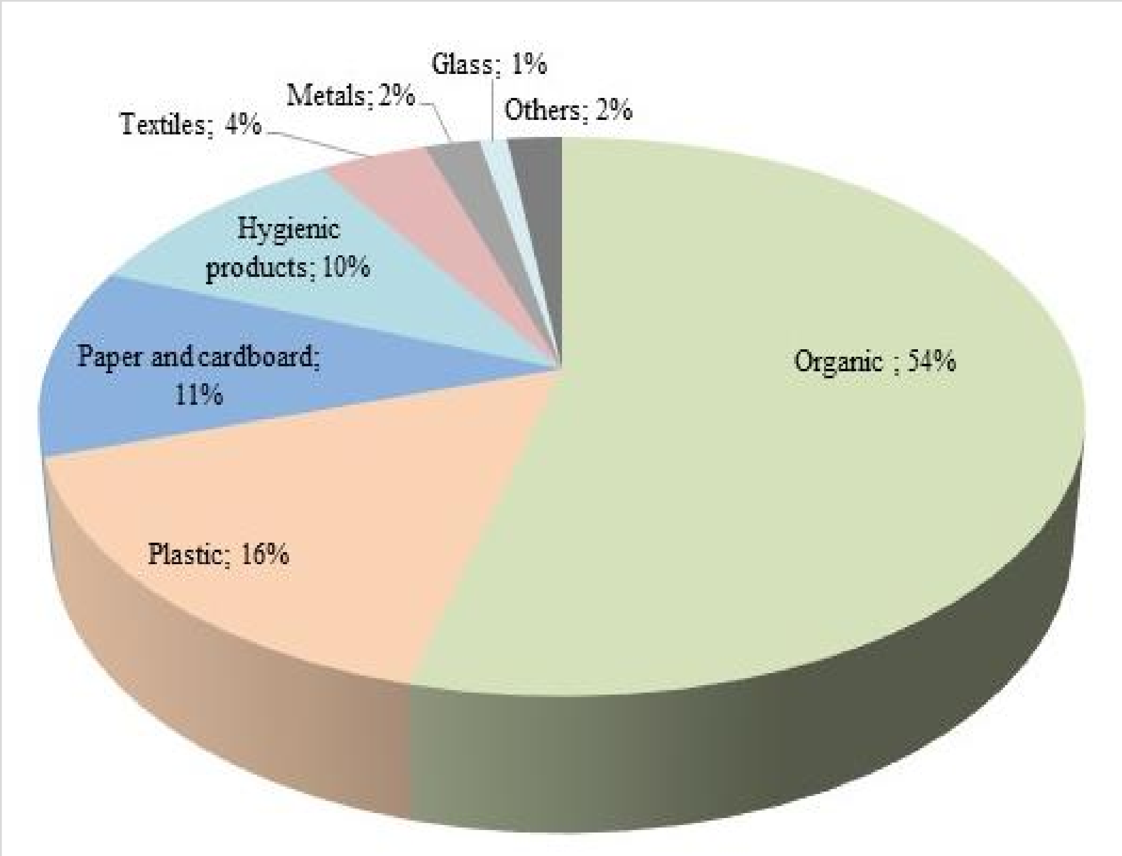


Figure 2-4. *The physical composition of municipal solid waste in Irbid city, Jordan (*Pohlmann, 2017)

Hemidat's results show that organic, plastic, cardboard, paper, hygienic textiles and combustible waste constituted up to 90% of total MSW (55% organic, 11% paper and cardboard, 9% plastic, 9% hygienic and 5% combustible). In general terms, solid waste in Jordan is characterised by a high organic content, with combustible matter (consisting of plastic, paper and kitchen waste) comprising more than 90% of the total waste, while the remainder is inert matter (Pohlmann, 2017).

It is also noticeable that the major proportion of composition is food waste (organics, which implies a high value of moisture content) followed by recyclable materials. The moisture content in the waste ranged between 55% and 60% with an estimated heating value of the waste of about 7-8 MJ/kg (Pohlmann, 2017).

2.8. SOLID WASTE MANAGEMENT AND TREATMENT

2.8.1. SOLID WASTE COLLECTION AND TRANSPORTATION

The waste collection in Jordan is disorganised. The community bin collection system is adopted in most of the cities. The bins are common for both decomposable and non-decomposable waste (no segregation of waste is performed). The responsibility on a day-to-day basis for collection and transport of SW to the final destination sites lies with local municipalities. An exception is Aqaba City, where the solid waste generated is collected by a private company contracted by the Aqaba Special Economic Zone Authority (ASEZA) (Al-Hamamre et al., 2017).

Collection rates of solid waste in Jordan are estimated at 90% and 70% in urban and rural areas, respectively (Ikhlayel et al., 2016). Due to the geographical area and population, the cities concerned are divided into zones or districts for effective solid waste collection (Hemidat et al., 2017). The existing SW collection system is considered to be adequate in urban centres, but services tend to be poor or non-existent in small towns and rural areas. Jordan lacks the facilities for proper handling, collection and transportation of the generated waste. Inadequate planning and layout, due to rapid urbanisation, causes urban areas in Jordan to be more congested and populated. Often the waste collection trucks cannot reach every part of the town, compelling the residents to throw their waste into open dumping spaces near human settlements. Traffic congestion makes transportation of waste more time consuming and, as a result, more expensive and less efficient. A lack of proper transportation vehicles is also one of the problems facing SWM in developing countries. Most of the vehicles used for transporting waste are often outdated, improper and non-functional.

Different types of collection vehicles are used. Open bed, covered and compactor vehicles are generally used in urban areas. Transfer stations are not used in many regions of Jordan. The collection bins are neither properly designed nor properly located and maintained. Storage bins can be classified as movable bins and fixed bins. Depending on the finances available, either plastic or steel 120 litre to 1100 litre bins are used, with a current trend to supply plastic bins of between 240 litres and 1100 litres in collaboration with Germany and other European countries (Hemidat et al., 2017).

2.8.2. RECYCLING AND RECOVERY

A recycling, reuse and recovery industry does not exist in Jordan. These are still in the initial stages, although they are gaining increased consideration. Until now, there have been no formal recycling or separation activities, or infrastructures included in the entire public municipal SWM chain and systems in Jordan. Most of the current waste recycling and picking activities running in Jordan are informal and being implemented by the private sector and/or individuals from the local community. The SW recycling industry in Jordan remains untapped and most of the different existing and operational SW recycling and waste-picking activities are informal and limited to private corporations, CBOs and NGOs as well as individuals. Some 5–10% of Jordan's SW is being recycled at the moment, as there is no large-scale and effective government-run MSW sorting practices or recycling system yet in place, so much of the recycling is done inside landfills (UNDP, 2015; Saidan et al., 2016). The national MSWM Strategy has defined the structure of the waste-picking system in Jordan (Figure 2-5). In general, MSW recyclables are collected through the following three categories:

- Informal waste-pickers at the dumpsite level, usually selling to middlemen.
- Informal waste-pickers at the city level, usually selling to middlemen.
- Formal waste-pickers at the dumpsite level, hired by contractors "small enterprises".

The participation of the local Jordanian private sector in the different working fields of SWM is still limited and very modestly explored. Development of the Private-Public Partnership (PPP) concepts and models in waste recycling and segregation in Jordan has recently been explored, however, almost all MSW recycling activities in Jordan, present and past, are considered to be pilot projects and small-scale interventions. The vast majority of the operational recycling pilot projects in Jordan have mostly been initiated and supported by the NGOs and other international organisations, for short and/or mid-term funding schedules. Once the NGOs' projects were terminated, so was the recycling (JGBC, 2016).

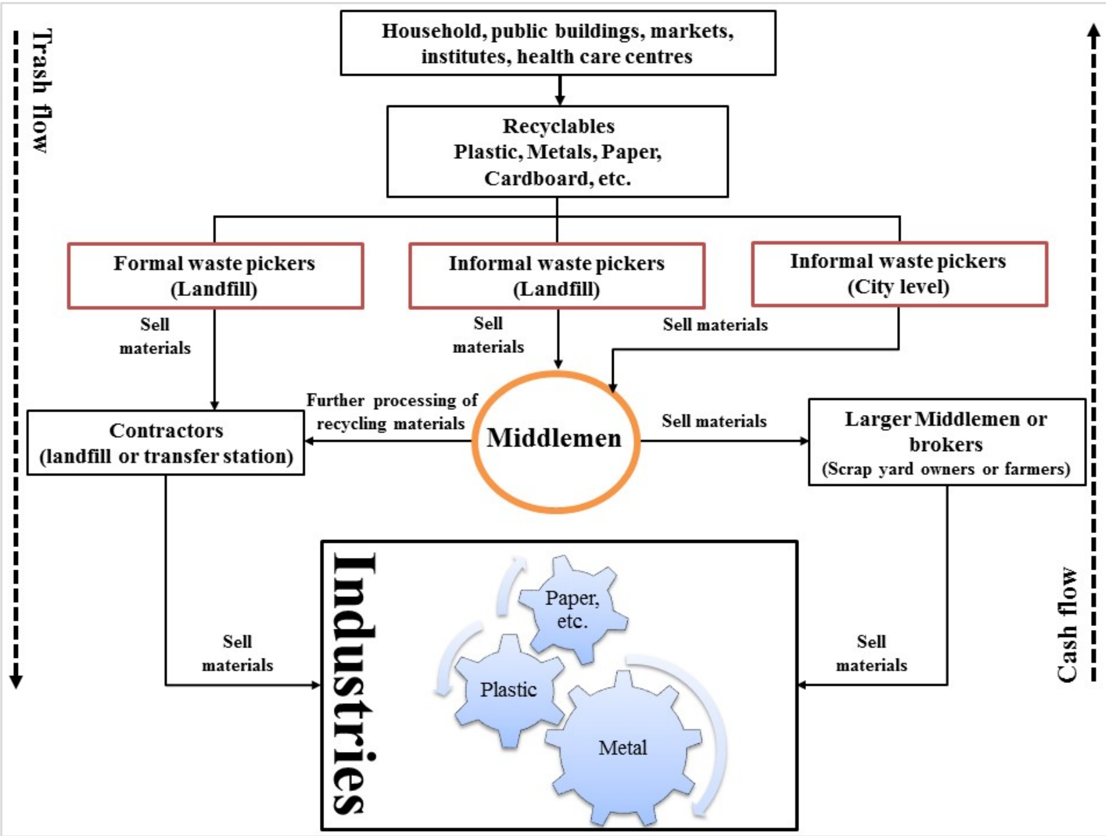


Figure 2-5. *Waste-picking system in Jordan*

Currently, an organised system does not exist in Jordan, and there is a lack of clear policies and legislation. This does not prevent private companies from overseeing the sorting and recycling by street vendors. They collect the remnants of certain materials, such as soft drinks glass bottles (98% of these are returned to bottle companies for reuse), plastic, cardboard and aluminium cans from many places in society and sell them to waste traders. The private sector companies in Jordan have recognised the importance of recycling and the economic benefit that may accrue from this process (METAP, 2008; Aljaradin, 2014).

Street waste-pickers are considered the first resource recovery step once the recyclables enter the waste cycle. Plastic, cardboard and metals are all recovered, with aluminium, copper and bread given the preference for being lightweight and more profitable. Moreover, a number of companies are active in the sorting of waste within landfills. Most of the work done inside landfills is done by scavengers employed by the private sector. Most of the Jordanian landfills are rented by private sector companies and the waste recycling process depends mainly on the prices of the sorted materials (Figure 2-6).

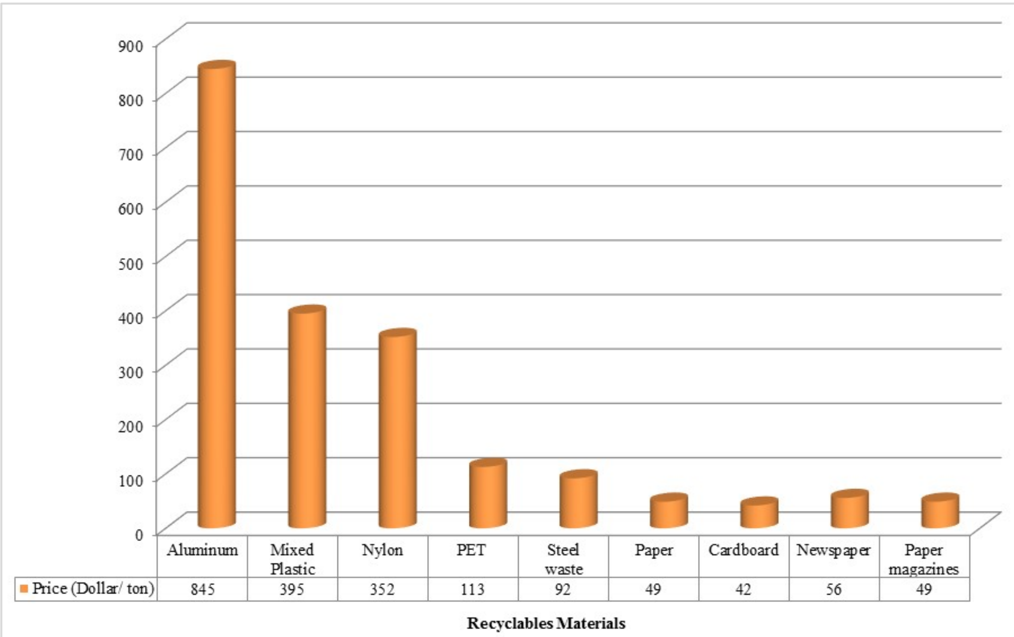


Figure 2-6. *The prices of some recyclable materials in Jordan*

The current prices of recyclable materials in the local market, based on the recent supply and demand status (JGBC, 2016) is demonstrated in Figure 2.6. The recycling market and industry in Jordan is responsive and highly reactive to both endogenous and exogenous variables and shocks. For instance, the local market prices are influenced by global commodity prices, internal demand and transport costs. The most impacting administrative measure is, however, the export duty taxation albeit limited to export oriented brokers (GJBC, 2016). The high electricity prices are the main challenge to Jordanian plastics recycling companies. Moreover, the cost of energy multiplies its effect across the value chain of plastics, mainly when it is combined with the reduced international price.

The process of material recovery from waste is an intricate process that involves various formal and informal players exercising key roles at different levels. Waste pickers, itinerant buyers and various small and large waste dealers are key stakeholders of the informal sector in waste management. In Jordan, the informal sector is effectively subsidising the formal sector by decreasing a considerable amount of generated waste.

The recycling flow in a conventional Jordanian city shows that recovery from waste streams is initiated directly from the households. Households sell the material to itinerant buyers while waste pickers, itinerant buyers and the commercial sector sell recyclables directly to brokers or dealers and the entire fraction finally reaches recycling industries (Figure 2-7). The itinerant buyers can be seen in alleys calling for the sale of recyclables. Some of them are self-employed while most are hired by junk shop owners who provide them with vehicles and money to purchase recyclable materials from households. Typically, they purchase all kinds of plastics at the same price, paper and cardboard at equal rates and all metals from household at the same price as iron.

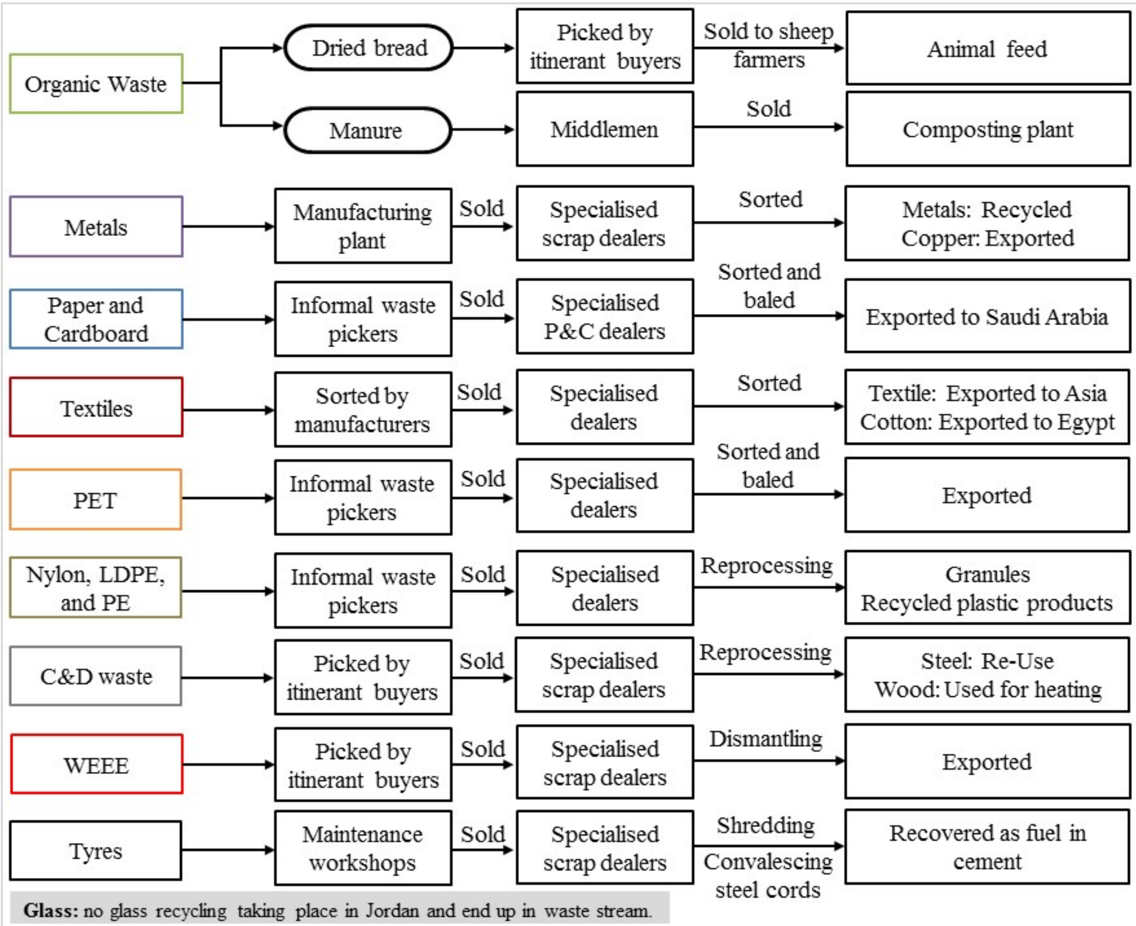


Figure 2-7. *Flow of the main recyclables in Jordan*

Organic waste is the dominant fraction. Without any retrieval activity, recyclables represent 5–10 % of the total waste stream. Major recyclables include paper, cardboard, plastics, glass and metals. Although produced in limited amounts, the waste materials are recovered and recycled to a large extent due to the high source separation at different levels. However, the MSW composition in Jordan, and particularly in Amman, includes the following recycling options (GAM, 2017):

2.8.2.1. Organic waste

Organic waste is the predominant waste fraction within MSW, ranging generally between 50 and 65% of collected MSW deliveries in Jordan. For urban centres with higher urbanisation indexes like Amman, organic fractions account for 50% of the total MSW stream. Organic waste includes food waste, wet market waste including fruit and vegetable residues and garden and park waste. Organic waste is also the least valorised waste stream. Due to the current MSW infrastructures, namely controlled landfilling at the Al-Ghabawi landfill site, organic waste is a major source of landfill gas. Until now, apart from a small composting pilot project at Al-Ghabawi, there are no projects or infrastructure in place for treating the mixed organic waste fractions derived from the MSW streams in Amman through composting or aerobic biological stabilisation. The only food waste being recovered is dried bread, which is then sold to sheep farmers for feedstock. The introduction of a separate collection system for the MSW organic fractions and the application of composting or anaerobic digestion will result in a high quality compost that will be suitable for agricultural use.

Composting

Composting of organic waste derived from the MSW stream to produce organic MSW-based fertilisers is not yet operational in Jordan. This is for reasons such as the absence of source separation for MSW at the city-level, low acceptance of organic MSW-based compost by farmers, limited usefulness of compost derived from MSW in comparison with chemical fertilisers and strict regulations, and monitoring and quality standards of the product in terms of chemical and physical properties and toxic heavy metals content. Therefore, there are currently no composting plants in Jordan that deal directly with organic waste derived from MSW (neither pure nor mixed). According to the USGS 2013 Yearbook for Jordan, the quantity of locally produced chemical fertilisers locally was 678,000 tonnes for the year 2013, which was constituted of nitrogen, phosphorus, and potassium nitrate and potassium sulphate. The amount of imported chemical fertilisers in 2015 was around 84,000 tonnes with an estimated cost of 32 million JOD (DoS, 2015; GAM, 2017).

Recently, in 2017, UNDP Jordan established a manure treatment facility at the Al-Hussainiyat landfill site in the northern town of Khaldiya, Mafraq Governorate. The project aims to reduce the local waste problem and improve the community's sanitation. The composting facility receives 40 to 45 tonnes per day of manure, 60 percent of which comes from the local dairy farms while the remaining 40 percent comes from the local poultry farms. It takes about 60 to 90 days to treat 40 tonnes of manure through composting methods before it is safely repackaged and resold to the community. The facility is operated by an NGO body (Future Pioneers). It should be noted that Mafraq

Governorate, which is located near the Syrian border, hosts the second largest number of refugees in Jordan, with over 162,888 Syrian refugees recorded by the UNHCR as of the end of July, 2015 (UNDP 2015). The establishment of the Khaldiya recycling facility has helped many of these refugees and low income Jordanians to earn low wages and improve their livelihoods.

Anaerobic digestion (biogas)

There is an old anaerobic digestion plant located at the closed landfill, Russeifeh, but this has not been in operation for several years due to structural damage resulting from subsidence and it is unlikely to be refurbished. There are also plans to build a small facility at the transfer station to provide the required power to the station. It has been concluded from the interviews with the Government that there is potential at the national level to use livestock manure waste in Jordan for biogas collection and electricity production. It is expected that multiple sizeable projects might be established in the next few years in Jordan and particularly in Mafraq, where 60% of the key manure generators are placed. It would be scoped mainly to use fresh manure waste as a basic input for waste-to-energy concepts. An anaerobic digestion plant will produce gas that can be used in gas engines or turbines or for industrial heating purposes, so there is certainly a market for the gas. The other product produced by an anaerobic digestion plant is a compost similar to the compost produced by a composting facility, so the market considerations presented above will also apply to this case.

2.8.2.2. METALS

Metals usually represent between 2 and 4% of the MSW generated in Jordan and reach 1% in Amman due to the intensive waste-picking activities. Metals include ferrous: iron and steel and non-ferrous: aluminium and copper. Metals are the oldest and most established recycling practices. This is due to a longstanding tradition of metal recovery across the world and throughout history, the relative ease of recycling metals, and the high value of the materials compared to others. In particular, the presence of several aluminium smelters and steel mills in Jordan, along with a developed metallurgy manufacturing sector and the wide variety of use for metal products in both consumer products and construction, creates the ideal conditions for the development and maintenance of such a recycling sector.

Metals are segregated at source by the manufacturing plants, although such practices are more widespread in metallurgy manufacturers than in others, due to the higher amount of scrap produced. Similarly, machine and repair workshops, scrap car dealers and construction firms operate source segregation of the metal scrap produced. Depending on the quantities produced, this is then sold either to itinerant waste brokers or directly brought to small and specialised scrap dealers. Ferrous and aluminium scrap is mainly recycled in country, although there are a number of specialised waste brokers who also sell on the international, regional and global markets. Additionally, the low specialised industrial and manufacturing capacity and the high commodity price drive copper to be exported rather than recycled in country.

2.8.2.3. Paper and cardboard

The paper and cardboard market faces competition both internally and on the international markets, with raw virgin materials and imported recycled products being a viable substitute to the products recycled within national borders. Moreover, in spite of the existing production of recycled paper in the country, some Jordanian cardboard manufacturers prefer to use imported substitutes as they present better quality with a minimal price difference.

Recycled papers, along with many other paper products like paper towels, are imported from Saudi Arabia and even Europe. Saudi products mainly benefit from reduced transportation costs, lower energy prices and larger economic scale. Electricity prices seem to be the biggest burden on Jordanian companies, to the point that paper waste is shipped to Saudi Arabia to be then reimported after recycling. Some Jordanian businesses have actually moved their production sites to Saudi Arabia for that reason. The introduction of an export duty tax and the closure of the Syrian border due to the crisis have had a serious and varied impact on the sector. The export duty tax has now been abolished, but the levels of cardboard and paper being exported and recycled abroad are still significantly lower than before the tax was introduced, due to the political situation of neighbouring countries.

2.8.2.4. Synthetic and other textiles

Textile waste originates mostly from garment industries operating in the Free Trade Areas (FTAs, formerly Qualified Industrial Zones - QIZs), and its final destination depends on the scraps' size and composition. The biggest cloth cuttings (10x10 cm minimum) are sorted by manufacturers and then directly re-exported to Asia for reuse and recycling. The smaller scraps are discarded by factories and end up in the waste streams. They are gathered by waste collection contractors and then sorted, based on their composition and final destination.

Cotton is sold to specialised brokers and exported to Egypt for reprocessing; white cotton scraps being especially sought after for the ease of dying. The market for recycled textiles experiences seasonal variations and availability can sometimes exceed current demand, thus making final disposal an alternative option to recycling. In contrast, synthetic scrap is sometimes sold to local companies for furniture fill. However, the lack of a buyer is often the case and it ends up in the landfill site for disposal. Only a limited potential for developing this recycling market has been identified.

2.8.2.5. PET – Polyethylene terephthalate

Among thermoplastics, PET (mostly in the form of plastic bottles), does not seem to have a market in Amman and Zarqa at the moment. This is an unusual state of affairs relative to other middle-income countries, where PET is one of the most widely traded plastic resins. This is due to a number of factors. First, there is no internal market for recycled PET flakes as there is a gap in the production system. Currently, there is no PET manufacturer employing recycled PET. It is not currently recycled in Jordan and, due to the drop in prices for recycled PET on the international markets, profit margins are so low that only a handful of selected specialised brokers still trade it, in addition to the middlemen or specialised brokers who can afford the space to store sorted PET bottles whilst waiting for the prices to rise again. At the same time, the recent drop in oil prices has led to a major slowdown in the export of recycled PET.

All PET still traded in Jordan is sorted, collected, baled and exported, with none remaining in the country because there is no recycling plant for the material. Most importantly, there is no manufacturer employing PET in their production process. Currently, manufacturers in Jordan using PET are contracted to use virgin PET only. The implementation of modern PET recycling processes and the progressive adoption of quality standards in recycled products, however, may lead to a change in such provisions and promote the demand for recycled PET in Jordan.

2.8.2.6. Nylon, LDPE and PE

Nylon, LDPE, PE bags and other plastic sheeting are commonly used in Jordan and are currently collected and recovered to be recycled in the country, but only to a minor extent compared to other plastics. The recent introduction of a ban on plastic bags for food packaging items will likely reduce the market for recycled PE.

The recovered material is traded up through the value chain through small and medium scrap dealers and specialised waste brokers, eventually making its way to local plastic recycling plants or to Amman and Zarqa, where most of the recycling takes place. After reprocessing into granules, the recycled plastic enters the production process again, with manufacturers preferring the raw recycled material for its lower price compared to the virgin product. Lack of source segregation and, consequently, contamination is the main limiting factor to recovery, as it introduces new costs to the recycling process in terms of cleaning and, consequently, with stricter production standards in place, reduced marketability.

2.8.2.7. Glass

Before the Syrian crisis, glass was exported via Syria to Lebanon for recycling in local furnaces. This practice ended with the start of the Syrian civil war and the consequent closure of the border with Syria.

Nowadays, glass is reported to offer too little value to be considered for recycling, and therefore there is no glass recycling taking place in Amman and Zarqa, nor in the rest of the country. Weak internal demand has led to the absence of glass factories in Jordan, with most manufacturing capacity concentrated on treating and processing imported glass, rather than producing the material. High transport costs in relation to the very low profit margins are another major constraint to glass recycling, a factor accentuated by the absence of regional alternative destinations to Lebanon.

2.8.2.8. Construction & Demolition waste

Most excavation material and debris are dumped at the side of the streets, in illegal dumps, or simply next to the construction sites, with steel rods and wood being systematically recovered. Steel bars are either directly re-used after manual re-processing or sold as scrap to local scrapyards. Wood is recovered as fuel, or shredded and then sold as bedding to chicken farms. Any recoverable items in a house, such as doors, door and window frames, windowpanes, roof tiles, bathroom fixtures and so on are systematically recovered and bought by the specialised second-hand trade.

2.8.2.9. Electrical and Electronic Equipment (WEEE)

The quantity of WEEE amounts to approximately 30,000–50,000 pieces per year which are recycled and exported from Jordan (InSEIS TA2 Assessment Report Jordan, 2015), this includes PCs, white goods, batteries, CRTs and flat screens. The approach to WEEE management adopted by the Jordanian government is likely to impact current disposal and recycling practices for WEEE. The inclusion of the private sector in the drafting of the proposed legislation, along with the introduction of a new WEEE regulation, should lead to the establishment of an e-waste collection network through cell-phone boutiques and other electric appliance retail stores. This will, in turn, increase the collection rates of waste electronics, specifically targeting those appliances currently not collected by the informal sector, such as mobile phones. At the same time, e-waste should be diverted from scrap dealers and recycled in state-of-the-art facilities, ultimately reducing detrimental dismantling and recycling practices commonly found within the informal sector.

2.8.2.10. Tyres

Approximately 2.5 million waste tyres per year are recycled and utilised in product fabrication and energy recovery in Jordan (JGBC, 2016). The main end-markets for scrap tyres are Tyre-Derived Fuel (TDF) and civil engineering applications; ground rubber applications; and cut, punched and stamped rubber products. Similarly, machine and repair workshops, scrap car dealers and construction firms operate the collection of the scrap tyres produced. Depending on the quantities produced, these are then sold either to itinerant waste brokers or directly brought to small and specialised scrap dealers. Before using tyres in cement kilns, the steel cords are usually removed from the tyres and used for other purposes.

Tyre-derived fuels are used as a source of fuel instead of conventional fuels such as coal and petcoke. It can be used shredded (chipped) or burned whole. Processing tyres into TDF involves two physical processing steps: chipping/shredding and removal of the steel cords. The energy-intensiveness of cement production processes and increasing fuel prices, combined with a fuel deficit, have forced the cement industry in Jordan to search for technologies based on waste-derived and alternative fuels, for example but not limited to, scrap tyres (TDF). The conditions in rotary kilns, such as high temperature, the high speed of the gas stream and the long particle-storage period, guarantee that the use of alternative fuels is ecologically safe.

2.8.2.11. OTHER RECYCLING OPTIONS

Refuse Derived Fuel (RDF) utilisation

Among many WtE strategies, RDF is a solid fuel recovered from the MSW materials that can be used as a substitute for conventional fossil fuel and as renewable energy for industries. Refuse-derived fuel is an alternative fuel produced from energy-rich MSW materials diverted from landfills. The utilisation of RDF as a supplementary source of fuel in the cement industry is an environmentally conscious and sustainable way to reduce dependency on fossil fuels and provide clean and renewable energy for the extreme high temperatures required within the rotary kiln during the clinker production process. It also allows the utilisation of waste streams of a high calorific value as a fuel substitute.

Accordingly, two of the three main cement manufacturers in Jordan (Lafarge and Al Manaseer) were interviewed as part of the market analysis survey to assess their willingness to use RDF as a substitute fuel in their cement factories (JGBC, 2016).

Landfill gas utilisation

Landfill gas (LFG) collection and utilisation for power generation is also a proven technology to deal with landfill sites in a sustainable manner. The recovery and use of LFG for electricity generation has been piloted at the older Russeifeh dumpsite site near Amman. It has a 3.5 MW gas engine capacity and supplies the national grid. The LFG system and utilisation is still working but the electricity generation has dropped off to 1MW. The Energy and Mineral Regulatory Commission (EMRC) has established feed-in tariffs for renewable energy in Jordan. Pursuant to Article (2) of the Renewable Energy and Energy Efficiency Law No. (13) 2012, the established price for the electricity produced from waste incineration is 90 Fils/kWh and 60 Fils/kWh for electricity produced from biogas (1 Fils = 0.001 JD).

A long-term municipal infrastructure project for MSW management was implemented by GAM and co-financed with the World Bank (2008–2014). It aimed to strengthen the operational, financial and environmental performance of MSW management in Amman in a total investment of 25 million USD including the construction of three sanitary cells at Al-Ghabawi and an LFG recovery and power generation system of 6MW electrical capacity. So far, three cells have been completely closed and the LFG collection system was installed in 2014. The project is still ongoing, and the power generation will be commissioned in the next year. In 2015, GAM received funding from the European Bank for Reconstruction and Development (EBRD) to upgrade the LFG project at the Al Ghabawi landfill site through a $13 million loan.

2.8.3. SOLID WASTE DISPOSAL

Nowadays, landfilling, as practised in Jordan, is simply dumping the waste in trenches or cells with levelling and compacting by trash compactors to reduce the size and the thickness of the layers, and finally cover the waste with soil (Aljaradin and Persson, 2014). Landfills in Jordan are operated by Joint Service Councils (which usually serve more than one municipality in the same governorate), with dual supervision of the Environment and Municipalities Ministries. Disposing of waste occurs in open dumpsites with no lining, management or biogas collection. There are 21 landfills in Jordan (one of them is a sanitary landfill and the other 20 are designated dumping sites), of which seven are closed sites (UNDP, 2015).

The location of these landfills was not chosen according to the international standards, but was chosen according to population density, so as to serve the largest possible number of municipalities. Except for one landfill, the locations have not been based on feasibility studies for proper site selection. The exception is the Al Ghabawi landfill of GAM, which receives more than 50% of the volume of the solid waste generated in Jordan. The location of this landfill was selected after conducting an environmental impact assessment for best site selection (Al-Tarazi et al., 2008). Its construction was also designed and engineered according to international standards. The remaining landfills receive 40%–50% of the volume of waste in the Kingdom and are not designed according to international standards for landfills in terms of health or environmental requirements. Linings are lacking and the methods of dumping practised could lead to contamination of groundwater, soil and air (Abu Qdais 2007a).

Open combustion is still practised in the old municipal landfills. For more than 35 years, MSW was open combusted at the biggest landfill site in Jordan. After that, the total landfill area of 4–5 km^2 was covered with a soil layer of 30–50 cm depth, but the combustion of the solid waste was not completed. Therefore, the burning process and pyrolysis still continues in an oxygen depleted atmosphere, highly suitable for the formation of environmentally problematic toxic substances such as dioxin, furans and polycyclic aromatic hydrocarbons (PAHs). In Jordan, the contaminates present in most of the landfills used have not yet been identified or quantified, and the influence of seasonal variations on the contaminant concentrations with time is not acknowledged; their public health implications are unknown (Aljaradin and Persson, 2014).

2.9. RECYCLING/ SOURCE SEPARATION EXPERIENCE IN JORDAN

The MSW recycling industry in Jordan, and particularly in Amman, remains untapped. Most of the different existing and operational solid waste recycling and waste-picking activities are informal and limited to related private entities, community-based organisations (CBOs) and non-governmental organisations (NGOs). As an estimate, 5–10% of Jordan’s recyclable solid waste is being collected and recycled at the moment, which mainly comprises plastics, papers, cardboard and metal materials. This low number is attributed to the lack of government policies encouraging recycling and the absence of large-scale and effective government-run MSW sorting practices or recycling systems. Instead, there is a private recycling sector, including both formal and informal entities, which collects recyclables from the waste containers in the streets, and some cities have contracts to scavenge on the local dumpsites.

In the absence of national and formal recycling structures in Jordanian Governorates, past recycling and source separation experiences implemented outside Amman are characterised by small-scale pilot projects targeting specific types of recyclables, mainly cardboard and plastics. These initiatives belong to both donors and the private sector, and were mainly focused on urban centres such as Irbid, Zarqa, Mafraq and Karak. Moreover, an informal waste recycling sector consisting of local waste-pickers and individual scavengers has developed during the last twenty years that usually collects waste fractions of high market value directly from the MSW collection containers placed within the cities. Alternatively, MSW delivered to the official landfill sites is sorted by local waste-pickers through a form of contractual framework. The past recycling and source separation experiences (Figure 2-8) implemented in Jordan can be summarised as follows:

Key Donor	Project	Outline	Present Status
GAM	Dirty MRF	Process municipal solid waste in order to recover recyclables.	Ongoing
GAM	Resource recovery	Introducing recycling & sorting practices to the local community.	Ongoing
BE	Recycling programs	Establish in-house waste recycling programs include training, awareness sessions, auditing, and collection.	Ongoing
DEG/ INFA	Recycling & source separation	Introducing MSW separation-at-source and recycling activities within household and commercial clusters.	Completed
DEG/ INFA	Recycling & source separation	Introducing sorting and separation-at-source practices within low income residential dwellings.	Completed
UNDP/ EU	Dirty MRF	Construction of a pilot MRF in Zarqa as a comprehensive project aiming to improve SWM in the city.	Completed
MoMA	Formal waste picking activities	MSW recycling by leasing the rights to scavenge on on MOMA landfill sites for contractors at a fixed fee.	Ongoing
BMZ	Waste Recycling	A pilot project in Al-Karak aimed at raising awareness by establishing a recycling centre for paper and cardboard.	Ongoing
OXFAM	Waste Recycling	A recycling project to improve livelihoods and create jobs for Syrian Refugees living in Za'atari Camp.	Ongoing
UNDP	Manure composting plant	Manure treatment facility at the Al-Hussainiyat landfill site to improve the local community's sanitation.	Ongoing
GIZ	Waste Sorting and Recycling	Projects targeting the separation of waste at source and manual sorting throughout several local municipalities.	Ongoing

Figure 2-8. *Recycling and source separation experiences were implemented in Jordan*

2.9.1. Dirty Material Recovery Facility of Tadweer MRF, Amman

In 2005, GAM signed an agreement with the private company "Tadweer" with a 15-year contract to build, operate and transfer 600 tonnes per day maximum capacity in a dirty material recovery facility (MRF) to process MSW and recover recyclables. Basically, this kind of waste processing had been initiated by GAM in order to control the informal scavenging activities being practised at the city level with safer working conditions. In addition, it would increase the waste sorting efficiency by involving the local private sector in managing the MSW treatment and recovery in terms of recycling and sorting. The MRF facility was built next to the Al Ghabawi landfill in 2006 to recover plastics, metals, papers and cardboard expected to be marketed to both local and international markets. Unfortunately, the project was suspended in 2008 due to legal disputes with Tadweer. According to the contract, GAM was not to be charged if Tadweer decided to receive MSW up to 1,000 tonnes/day and Tadweer was permitted to dispose of residue from the facility at the Al Ghabawi Landfill at no charge. Tadweer was obliged by the contract to have a revenue share with GAM of 5% of gross revenue in the first three years and 10% of gross revenues for the following 12 years. The contract was to start once the MRF was properly operational and was subject to renewal for an additional 15 years.

In 2016, and after many years of suspension, Tadweer MRF resolved the legal disputes with GAM and decided to renovate the entire sorting line and related machinery needed to operate the MRF facility and receive MSW from GAM with a daily intake capacity up to 1,000 tonnes/day. The facility started trial operations in August 2016. Preliminary data indicates that it will be very difficult to reach design capacity due to operational problems.

2.9.2. Jordan Environment Society (JES) recycling projects

The JES's waste recycling programme is the first pilot programme in Jordan. The project was initiated in 1995 in cooperation with GAM and the Ministry of the Environment. The project is ongoing as a resource recovery project. The waste recycling programme is constantly expanding with more collection sites in Amman, such as in Shmeisani District, which include indoor and outdoor waste containers. This ongoing experience has demonstrated the potential feasibility of collecting paper and other selected materials.

The JES has contracted with many local institutions, companies, organisations, societies, banks and shopping malls to recycle paper and plastic waste produced from their premises. The project produces recycled paper and sells it to local industries to be used for different stationary and publications. Over the years, the project has positively contributed to raising environmental awareness among various sectors as well as the provision of trained personnel in the recycling industry. Another school paper recycling project was launched by a Jordanian telecom company, namely Zain, in 2010, in a partnership with the "Madrasati" initiative, JES. The project is still ongoing and targeting 80 public schools around Jordan. It creates awareness among students about how to save the environment by collecting papers from schools before sending them to the JES recycling facility.

2.9.3. BE Environmental recycling project

BE Environmental Services ("Entity Green" up until 2012) has worked closely with many local institutions and organisations in Jordan, particularly in Amman, to establish in-house waste recycling programmes. The recycling programmes include training, awareness sessions, auditing and collection. In 2010, BE Environmental Services established its waste recycling centre in Amman jointly with COZMO marketing stores, where hundreds of individuals and companies bring their recyclables to the recycling centre placed in Sahab, east of Amman.

The recycling centre was provided with orange-coloured recycling bins donated by the Netherlands Embassy Recycling Program-Amman. The recycling centre also receives different types of recyclables, such as paper and metal of any kind, PET and all plastics including wrappings, bags, containers, boxes, Styrofoam, wood scraps, old bread, used cooking oil, printer and copier toner cartridges and batteries. The project is still ongoing.

2.9.4. GAM recycling and separation at source project in Um Uthaina

In 2011, GAM initiated a pilot project to introduce MSW separation-at-source and recycling activities considering the household and commercial clusters situated in Um-Uthaina, a neighbourhood located in Wadi Al Sir District on the western side of Amman. The project was conducted in the framework of the German Public Partnership Project funded by DEG and a private German company named INFA. The project aimed to encourage household waste sorting at source with medium to high-income areas and provide a separation collection for the recyclables with a market value.

The scope of the project was to encourage the citizens to sort their waste into wet and dry fractions using small plastic bins that were collected regularly by designated solid waste collection (SWC) vehicles before hauling it to a pilot manual sorting facility placed in the Al-Shaer Transfer Station. The participants used to dispose of their residual waste in the municipal bins. The project included distributing small and medium-sized plastic bins of 120 litres and 770 litres over the targeted areas and streets and engaged more than 1,000 people. GAM, through a fund received by DEG, utilised two different coloured plastic bins. A green bin was used for wet fractions (mainly food waste, etc.) and a blue bin was used for dry fractions (plastics, cardboard, paper, aluminium, glass, metals, etc.).

The project began with an environmental awareness campaign conducted throughout the neighbourhood of Um Uthaina. Volunteers went door-to-door and provided residents with brochures and a short verbal explanation of how to sort waste at source and the benefits of doing so. More than 4,000 tonnes of recyclables were collected throughout the project implementation period and the majority of fractions were plastics and papers. The pilot project was discontinued in 2013 upon the completion of the funding.

2.9.5. GAM RECYCLING AND SEPARATION AT SOURCE PROJECT IN MARKA

In 2009, GAM conducted a small pilot project to introduce sorting and separation-at-source practices within low income residential dwellings in the Marka District, east of Amman. The project was implemented through the framework of a PPP German project in cooperation with the Ministry of Environment funded by DEG and the German company INFA. The project targeted households in multi-storey buildings as well as commercial clusters and public authorities' offices situated within the designated pilot area.

Intensive awareness projects and campaigns were conducted within the local community in order to inform them about the benefits of sorting waste at source. During these campaigns, awareness materials such as brochures and posters that encouraged the waste separation and recycling practices were distributed. Recyclable waste was sorted into two different coloured plastic bags of 50 litres: blue for paper and cardboard and green for plastics and metals. The scope of the project did not include organic materials, which were disposed in the municipal bins as usual. The analysis results of the total MSW collected showed that a total of 3.9 tonnes of recycled waste were obtained, the majority of which was cardboard and paper. It was concluded that GAM should conduct intensive and creative awareness programmes for the households, provide sorting tools needed at the collection sites, and specify SWC vehicles of different capacities for the recycling projects in order to ensure the sustainability of the recycling and sorting at the household level.

2.9.6. PILOT MRF FACILITY IN ZARQA

In 2000, a pilot MRF was built in Zarqa. This facility was constructed as part of a comprehensive project aimed to improve SWM in the city. It was supported jointly by the UNDP and the European Union. It was estimated that recycling would produce annual revenues of nearly 200,000 JD in Zarqa, assuming 20% of the recyclables were recovered from the MSW stream. Unfortunately, the MRF facility was closed in 2002 after the donor phased out from the project.

2.9.7. FORMAL WASTE PICKING ACTIVITIES AT THE OFFICIAL LANDFILL SITES

The MoMA and its JSCs have implemented MSW recycling by leasing the rights to scavenge on their dumpsites to companies (contractors) at a fixed fee. There are MSW recycling activities that have recently started in several cities as follows:

- Irbid at the Al Ekaider dumpsite
- Mafraq at the Al-Hussainyyat dumpsite
- Karak city at the Al Lajoun dumpsite
- The Aghwar (Al Shouna)
- At the Deir Alla dumpsite,
- The Balqa area at the Al Hamrah dumpsite

- Zarqa city at the Al Tleil dumpsite
- Al-Aghwar Janoobiyah at the Al Samar dumpsites.

The assigned contractors or 'small enterprises' have a high potential for classifying various recyclable materials according to their market values and, accordingly, the fluctuation of the market prices have affected their interest from time to time. These formal waste-picking activities are still ongoing at most landfill sites operated by MoMA. Waste picking does not take place at the Al Ghabawi Sanitary Landfill.

2.9.8. JOUHD AND DVV INTERNATIONAL RECYCLING PROJECT IN KARAK

Within the framework of the project "Protection of the Environment and Biodiversity in Jordan" funded by BMZ Germany in cooperation with the Ministry of the Environment, the German entity DVV International launched a pilot project in Al-Karak aimed at raising awareness amongst the population and encouraging people to actively protect their environment by establishing a recycling centre for paper and cardboard. This was done in 2015 in cooperation with the Greater Municipality of Al-Karak and operated by a local CBO called the Jordanian Hashemite fund for Human Development (JOUHD).

The manual recycling facility has improved the recycling sector in the targeted municipality by purchasing the paper and cardboard recyclables being collected by the informal waste pickers and individual scavengers with reasonable prices. The initial receiving capacity is up to 6 tons/day and the facility includes pressing units with a capacity of 3 tons/day and an open airspace for stockpiling the recyclable bales. The facility receives plastics (mainly Nylon) and metals (mainly aluminium cans). The current prevailing prices per tonne of the non-pressed paper, pressed cardboard and shredded plastics are 60, 35 and 500 JD, respectively. The plastic recyclables should be shredded in order to improve their market value. The project is still ongoing.

2.9.9. OXFAM RECYCLING PROJECT AT AL-ZA'ATARI SYRIAN REFUGEE CAMP

Since 2015, Oxfam GB has been implementing a recycling pilot project to improve livelihoods and create employment opportunities for Syrian refugees living in Za'atari Camp, Mafraq Governorate. The project includes different recycling and waste separation schemes in six districts of the Za'atari camp. The scope of this project is to introduce a functional waste separation and recycling scheme to produce an income generation source for Syrian refugees, reduce the waste accumulation within the camp, minimise the volume of the solid waste sent to landfill and utilise a Jordanian partner organisation for the re-use or re-sale of recyclable waste materials.

The size of the targeted population in the pilot phase is about 7,000 Syrian refugees. The project includes distribution of waste containers and elaboration of organised picking activities through cash-for-work labour schemes, as well as the construction of a sorting and storage area. The project targets plastics, paper, cardboard and metals and the initial capacity of the separation site is 10–20 tonnes/day.

Oxfam has assigned a private contractor to purchase the recyclables being collected in the project on a monthly basis based on their market value and local prices. To create sufficient returns from the sale of recyclable materials in Za'atari, and to stabilise the fluctuations in the price of recyclables during the pilot phase, the project was expanded beyond the pilot district to create economies of scale to realise more profits. The project is ongoing and may be expanded in the near future to target the Mafraq Governorate including the whole refugee camp.

2.9.10. UNDP MANURE COMPOSTING FACILITY AT AL-HUSSAINIYAT LANDFILL SITE

In 2017, UNDP Jordan established a manure treatment facility at the Al-Hussainiyat landfill site in the northern town of Khaldiya, Mafraq Governorate. The project aims to reduce the local waste problem and improve the community's sanitation. The composting facility receives 40 to 45 tonnes/day of manure, 60 percent of which comes from the local dairy farms while the remaining 40 percent comes from the local poultry farms. The treatment process needs about 60 to 90 days to treat 40 tonnes of manure through composting methods before it is safely repackaged and resold to the community. The facility is operated by a local NGO body, namely Future Pioneers. The establishment of the facility has helped many of the refugees and low income Jordanians to earn a small amount of wages and improve their livelihoods. The project is still ongoing.

2.9.11. GIZ WASTE RECYCLING FACILITY PROJECTS

According to the German International Cooperation Agency (GIZ), new pilot recycling projects targeting the separation of waste at source and manual sorting are being implemented throughout several local municipalities in Jordan targeting mainly the commercial clusters. The GIZ is currently in the process of constructing sorting facilities in Wasatiyyah, Irbid, Ramtha, Mafraq, Dair-Alla, Jerash, Madaba, Karak and the Za'atari refugee camp. The project aims to provide the municipalities concerned with the infrastructure needed to practice sorting and recycling in order for it to be integrated later as part of their municipal services and system. The project includes the construction of nine manual sorting facilities over the designated municipalities each with an initial intake capacity of 6 tonnes/day. The sorting facility will be furnished with long manual sorting tables, different sized bins, sorting tools, two pressing units and balers for cardboard and metals. A plastic shredder and a small workshop for handicrafts might be fabricated from the delivered waste. The project includes the civil construction works required for land preparation (2,000 m^2) and steel hanger buildings (350 m^2). A minimum of 25 cash-for-work job opportunities should be ensured by each sorting facility during the pilot operation phase. It is expected that sorting activities will be effectively initiated during this year (2019) once the relevant civil construction works are completed. Accordingly, each municipality will operate the project by installing the recycling bins, collecting dry recyclables and hauling them daily to their respective sorting facilities for the final sorting. The sorted recyclables would be stockpiled in large quantities so that these can then be sold easily on the local market.

International donors will provide the funds for the project's implementation within the municipalities, as well as monitor the operation and performance in the pilot phase, and coordinate for optimisation of the waste separation and collection. The project is a new approach and will be implemented as a pilot project for one year in cooperation with the respective municipalities. The scope of the project is mainly to engage with the informal sector. It is likely that future, labour-intensive cash-for-work programmes will guarantee high participation from vulnerable Jordanians and Syrian refugees and will target the commercial clusters at the city levels, where the cardboard and packaging plastics could be sorted and separated in larger amounts and better quality.

Separation-at-source will be approached by considering the shops and markets placed within the commercial hub of the cities that formulate big commercial clusters like the midtown areas and mega malls. The concept includes the allocation of a 120-litre plastic bin for each licensed shop to sort non-organic recyclables (paper and plastics) generated during the day. The waste will be collected in a timely manner to avoid the informal scavenging practices and loss of the separated recyclables. The main recyclables that would be sorted in the project include corrugated paper, cardboard, plastic, foil, nylon, packaging material, PE and PET bottles, aluminium cans and copper.

2.10. ACTUAL PROJECTS IN THE FIELD OF SOLID WASTE MANAGEMENT IN JORDAN

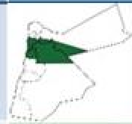
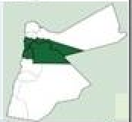
Due to political instability in the Middle East, Jordan has received several influxes of refugees since decades. Recent waves of refugees from Syria have led to a noticeable increase in the country's population: from 6.99 million inhabitants in 2011 to 9.5 million in 2015. The number of Jordanians is around 6.6 million, while the number of non-Jordanians who reside in the country is around 2.9 million, representing 30.6 % of overall population. The number of Registered Syrian Refugees according to the UNHCR is 655,344 individuals. However; the actual number of registered and non-registered Syrian refugees is about 1.265 million (Abu Qdais, 2017).

An attempt to cope with this situation has been made in recent years; international donors mobilized efforts and resources to enable the municipalities to offer the basic solid waste services to meet the increasing demand. Several projects have been carried out by international bodies and organizations (Figure 2-9a, b and c) aimed at improving the system of waste management and treatment in Jordan (GIZ, 2019).

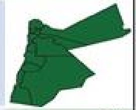
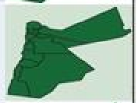
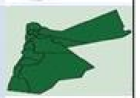
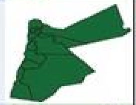
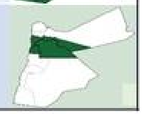
Overall, the projects that were implemented aimed to:

1. Provide emergency support to the Municipalities to cope with the pressures placed on waste infrastructure following the influx of refugees by funding specialist equipment, compactors, etc.
2. Improve municipal solid waste services and hygiene conditions in the Northern and Central regions, directly affected by the influx of Syrian refugees.
3. Rehabilitate and develop the landfills such as the installation a landfill gas (LFG) system at Al-Ekaider and an additional cells at Al Ghabawi landfill.

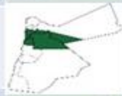
4. Establish an environmental friendly concept of recycling solid waste addressing the entire waste chain
5. Increase the institutional and technical capacities of Ministry of Municipal Affairs (MoMA), Ministry of Environment (MoEnv) and Joint Services Councils (JSCs)
6. Strengthen the capabilities of MoMA, the Joint Services Council in Irbid, Mafraq & in Northern Shouneh in the solid waste management sector for enhanced capacity of service delivery, emergency response, women empowerment & local economic development.
7. Improved job and market opportunities in Irbid, Mafraq and Amman governorates in recycling, green technology, renewable energy (RE), water and energy efficiency (WE/EE) sectors.
8. Create job opportunities during the construction and operation phases.

Key Donor	Project	Objective	Budget	Duration	Location
BMZ	SWM for Greater Amman Municipality (GAM)	Establishing an concept of recycling solid waste.	42,000,000 EUR 34,960,000 JOD	13/06/2014 13/06/2020	
	ADHOC 1 – Supporting SWM in Refugee Hosting Communities	Improve SWM services (collection, transfer & disposal) in the cities of Irbid, Ramtha, Karak & Mafraq.	3,000,000 EUR 2,465,000 JOD	01/07/2014 31/12/2018	
	ADHOC 2 – Supporting SWM Refugee Hosting Communities	Improved implementation of municipal tasks in SWM in selected municipalities.	3,000,000 EUR 2,465,000 JOD	01/08/2017 30/06/2020	
	CIRCLE - Climate and Resource Conservation through Recycling	Establishment of conditions for a climate friendly circular economy in Greater Amman Municipality.	4,000,000 EUR 3,287,000 JOD	01/07/2017 30/06/2020	
	Support for UNRWA SWM Strategy	Selecting appropriate (effective, cost saving, accepted) SWM solutions for individual camps (Irbid & Talbieh).	1,500,000 EUR 1,250,000 JOD	01/09/2015 31/01/2019	
	Waste to Positive Energy	Reduce conflicts and relieves the burden on the environment in Jordan's host communities.	46,000,000 EUR 37,800,000 JOD	01/09/2015 31/10/2020	
UNICEF	SWM in Zaatari and Azraq Refugee Camps	Provide solid waste management services for the communities of Zaatari and Azraq Refugee Camps.	704,225 USD 500,000 JOD	01/01/2014 31/12/2018	
JICA	Improvement of SWM in Northern Region Hosting Syrian Refugees	Enhance waste management in Northern region hosting Syrian refugees.	1,631,000,000 JPY 10,600,000 JOD	01/05/2018 31/12/2022	

(a)

Key Donor	Project	Objective	Budget	Duration	Location
EU	Support to SWM in Jordanian Communities Hosting Syrian Refugees	Improve solid waste management services (collection and disposal) in the governorates of Irbid & mafraq.	9,850,000 EUR 8,094,000 JOD	01/01/2015 31/12/2018	
	Sustainable Food Security for Refugees through Environmentally Responsible SWM	Enhancing food security/resilience for Refugees by sustainable Cash for Work (CfW) income from SWM.	2,589,336 EUR 1,998,242 JOD	01/02/2016 31/01/2019	
	EU Support to the Implementation of the National SWM Strategy	Ensure in the coming five to seven years, the safe and sanitary disposal of municipal solid waste.	40,000,000 EUR 33,157,120.26 JOD	01/01/2018 31/12/2023	
	National Monitoring Information System for MSW	Design, develop & implement a National Monitoring Information System for MSW (NMIS-MSW).	3,800,000 EUR 3,072,890 JOD	01/11/2017 31/12/2019	
	Support MoMA in Upgrading SWM Facilities	Improve MSW services conditions in the Northern & Central regions, affected by the of Syrian refugees.	53,000,000 EUR 43,500,000 JOD	15/07/2018 16/07/2023	
	Enhancing Employment Opportunities in Jordan Energy and Environment Sectors E4	Improved job & market opportunities in Irbid, Mafraq & Amman cities in Energy & Environment Sectors .	3,340,009.89 EUR 2,742,916.32 JOD	01/02/2016 31/01/2019	
AFD	Technical Assistance to MoMA-Implementation of SW Strategy	Support MoMA and the inter ministerial technical committee in implementing the SWM strategy.	500,000 EUR 400,000 JOD	15/08/2016 31/12/2018	
GEF	Reduction & Elimination of POPs & Other Chemical Releases.	Protection of human health & the environment by reduction & elimination of POPs, & other chemicals.	5,090,000 USD 3,603,720 JOD	31/05/2018 31/05/2022	
DIFD	Greater Amman Municipaility Solid Waste Crisis Response	Provide emergency support to Greater Amman Municipality to cope with the pressures placed on waste infrastructure following the influx of refugees.	15,000,000 GBP 14,100,000 JOD	01/12/2016 31/03/2019	

(b)

Key Donor	Project	Objective	Budget	Duration	Location
USAID	Jordan Cities Implementing Transparent, Innovative, and Effective	Support to decentralization and improvement municipal services.	Small part of budget for SW	22/09/2016 21/09/2021	
World Bank	Municipal Service and Social Resilience Project (MSSRP)	Support Jordanian municipalities affected by the influx of the refugees.	30,000,000 USD 21,290,000 JOD	31/12/2017 31/12/2020	
Italian Gov.	Global Facility for Disaster Risk Reduction Facility Technical Assistance Activity	Improving Urban Resilience in Cities Impacted by the Syrian Refugee Crisis in Jordan.	500,000 USD 350,000 JOD	30/06/2017 30/06/2019	
DFAT	Livelihoods Project for Syrian Refugee Response in Jordan	Provide Syrian refugee households with access to improved livelihood .	1,823,054 AUD 912,830 JOD	01/01/2018 30/06/2019	
	Sustainable Job Opportunity Creation for Refugees and Host Communities.	Creating job opportunities for refugees and host communities in Jordan in the SWM sector.	3,000,000 AUD 1,502,145 JOD	01/01/2018 31/12/2019	
EBRD	EBRD Greater Amman Municipality Solid Waste (LFG) Project	Install a landfill gas (LFG) system at Al Ghabawi landfill.	18,000,000 USD 12,780,000 JOD	15/05/2015 31/12/2020	
	EBRD Greater Amman Municipalities Crisis Response SW Programme	Improve solid waste infrastructure & associated services, components.	100,000,000 EUR 83,400,000 JOD	24/11/2016 31/12/2022	
GAC	Improving SWM and income creation in host communities	Improve the SWM cycle by complimenting the efforts undertaken by the government.	19,822,672 CAD 10,695,000 JOD	23/03/2015 30/04/2019	
	Jordan Valley Links Project	Improved entrepreneurial and business acumen of women and youth in targeted sectors.	19,000,000 CAD 10,000,000 JOD	03/04/2016 30/04/2021	
	Jordan Municipal Support Project (JMSP)	Strengthen the resilience of Jordanian municipalities in Central and Southern Jordan.	20,600,000 CAD 10,690,000 JOD	01/06/2017 31/05/2022	

(c)

Figure 2-9. (a), (b) and (c) *Actual projects in different waste management areas were implemented in Jordan (GIZ, 2019)*

3. TRENDS AND DEVELOPMENT OF SUSTAINABLE SOLID WASTE MANAGEMENT

Nowadays, there is much interest in SW production, management and disposal. This is attributed to the observation that waste generation is a side effect of consumption and production and it tends to increase with the economic development of the society (Beolchini et al., 2012). Furthermore, there is an increasing awareness of the environmental, health, economic and social problems associated with SW disposal. Particular attention should be given to the treatment and management of SW and more effort and capacity are needed to manage it in an environmentally safe manner due to its abundance and impact on the environment (Vasudevan et al., 2012). This scenario poses an immense challenge considering the lack of adequate capacity, institutional and financial capabilities and skilled resources in the collection, transportation, processing and final disposal of waste (Bundela et al., 2014). Several options associated with the supply chain for implementing a SWM system are available. However, to determine the optimal solution several technical, economic, environmental and social aspects must be considered (Santibanez-Aguilar et al., 2013), as follows:

- Realistic and actionable laws.
- Establishing organisational structures in the ministries and municipalities.
- Scaling up for the education and training of local people.
- Regulation of finances for covering the costs in households, commerce and industry.
- Separate collection of valuable materials, starting with test and pilot projects.
- Integrating the recycling industry achieved by the private sector with the governmental sector.
- Ban of landfilling for organic matter and combustible materials.
- Regulation of collection and disposal of hazardous waste from households, commerce and industry.
- Flexible and long-term planning of treatment facilities.
- National and international cooperation in the disposal of special material (e.g. hazardous waste) flows.

3.1. THE CONCEPT AND ELEMENTS OF SUSTAINABLE SOLID WASTE MANAGEMENT

Solid waste consists of both solid and liquid waste but not wastewater. According to the WHO (World Health Organization), solid waste can be defined as useless, unwanted or discarded materials arising from domestic, trade, commercial, industrial and agricultural activities as well as from public services with insufficient liquid content to be free flowing (Das, G and Aich, 2014; Elnaas, 2016).

Municipal waste is the waste that is generated by citizens and civil work and similar waste from small businesses and industry (Christensen, 2011). Solid waste management refers to the collection, transfer, treatment, recycling or resource recovery and disposal of solid waste in urban areas (Sasikumar and Krishna, 2009). Today, nearly half of the world's growing population lives in urban areas, placing great pressure on local environments. Inadequate waste management is the cause of serious urban pollution and health hazards. Sustainable management of waste, with the overall goal of minimising its impact on the environment in an economically and socially acceptable way, is a challenge for the coming decades (Ludwig et al., 2003).

Waste management is about all the options that society has to manage the transition of the value of goods and materials from positive value to negative value to be considered at the end as waste. Ideally, waste management will ultimately turn waste into a zero-value good, i.e. appropriately treated residue that can be left in a safe landfill or recycled by transforming it physically and/or chemically so that it becomes valuable again as a raw material for new products (Ludwig et al., 2003). A simple definition of SWM is the supervision of SW from the source of generation through collection, recovery and treatment to disposal (Sasikumar and Krishna, 2009). According to Uriarte (2008), SWM should focus on all administrative, financial, legal, planning and processing functions that lead to finding solutions to all problems of solid waste.

3.2. INTEGRATED SOLID WASTE MANAGEMENT (ISWM)

Integrated solid waste management (ISWM) can be defined as the selection and application of suitable techniques, technologies and management programmes to achieve specific waste management objectives and goals in a way that favours the best interests of public health and takes into consideration environmental concerns (Elnaas, 2016). The hierarchy's main purpose is to make waste management practices as environmentally sound as possible. The goal of ISWM is the recovery of more valuable products from waste with the use of less energy and a more positive environmental impact. Integrated solid waste management involves evaluating local needs and conditions and then selecting and combining the most appropriate waste management activities for those conditions. It is also evolving in response to the regulations developed to implement the various laws. The implementation of ISWM for MSW typically involves the use of several technologies (Chandrappa and Das, 2012).

There is no universally applicable SWM system. Every community must plan a system based on the quantity and character of its waste, its financial capability, its technical expertise and manufacturing capability, and energy and wage costs (Uriarte, 2008).

Integrated solid waste management lacks a clear and widely accepted definition. A hierarchy is sometimes used to define ISWM. An integrated approach to waste management consists of a set of actions that will result in minimum energy use, minimum environmental impact and minimum landfill space at an affordable cost to the community. It will take into account community and region-specific issues and needs, and formulate an integrated and appropriate set of solutions (Elnaas, 2016).

Some waste management practices are more costly than others, and integrated approaches facilitate the identification and selection of low-cost solutions. Some waste management activities cannot bear any charges; some will always be net expenses, while others may produce an income. An integrated system can result in a range of practices that complement each other in this regard (UNEP, 2005). This means that the hierarchy cannot be followed strictly since, in particular situations, the cost of a prescribed activity may exceed the benefits, when all financial, social and environmental considerations are taken into account.

3.3. Technological Concepts of Solid Waste Treatment

Nowadays, one of the priorities for municipalities is the collection, recycling, treatment and disposal of increasing quantities of SW. The potential impacts caused by waste on the environment, the use of valuable space by landfills and poor waste management that causes risks to public health are significant obstacles to handling the problem. The effective management of SW involves the application of various treatment methods, technologies and practices. All applied technologies and systems must ensure the protection of public health and the environment. There are a wide variety of alternative waste management options and strategies available to deal with mixed SW to limit the residual amount left for disposal to landfill. With proper MSW management and the right control of its polluting effects on the environment and climate change, SW has the potential to become a precious resource and fuel for future sustainable energy. Waste-to-Energy (WtE) technologies are able to convert the energy content of different types of waste into various forms of valuable energy resources (Rechberger, 2011; Rotter, 2011).

3.4. State-of-the-Art for Solid Waste Utilisation and Disposal in Germany

3.4.1. Solid waste management policy

Waste management in Germany is constantly changing due to new political and legal requirements as well as technical and organisational developments and has developed into a large and powerful economic sector. Thus, modern waste management is the result of a long development process. Figure 3.1 summarises this development along a time axis.

The legal foundations for proper waste management were provided far back in history. With the Prussian Local Tax Act of 1893, municipal finances were reorganised and the prerequisite for the establishment of municipal cleaning facilities was created. Municipalities were henceforth entitled to levy charges for waste disposal. Later, in 1935, the German municipal authorities established the general principle of collection and use of the waste system. This ensured the collection of all waste and forbade all illegal disposal routes. In the mid-1960s, cities and municipalities were finally identified as waste disposal authorities, and thus as responsible for waste disposal. During the same period, the first bulletins were drafted on the issues of waste disposal, which were the guidelines for dealing with waste (Nelles et al., 2017).

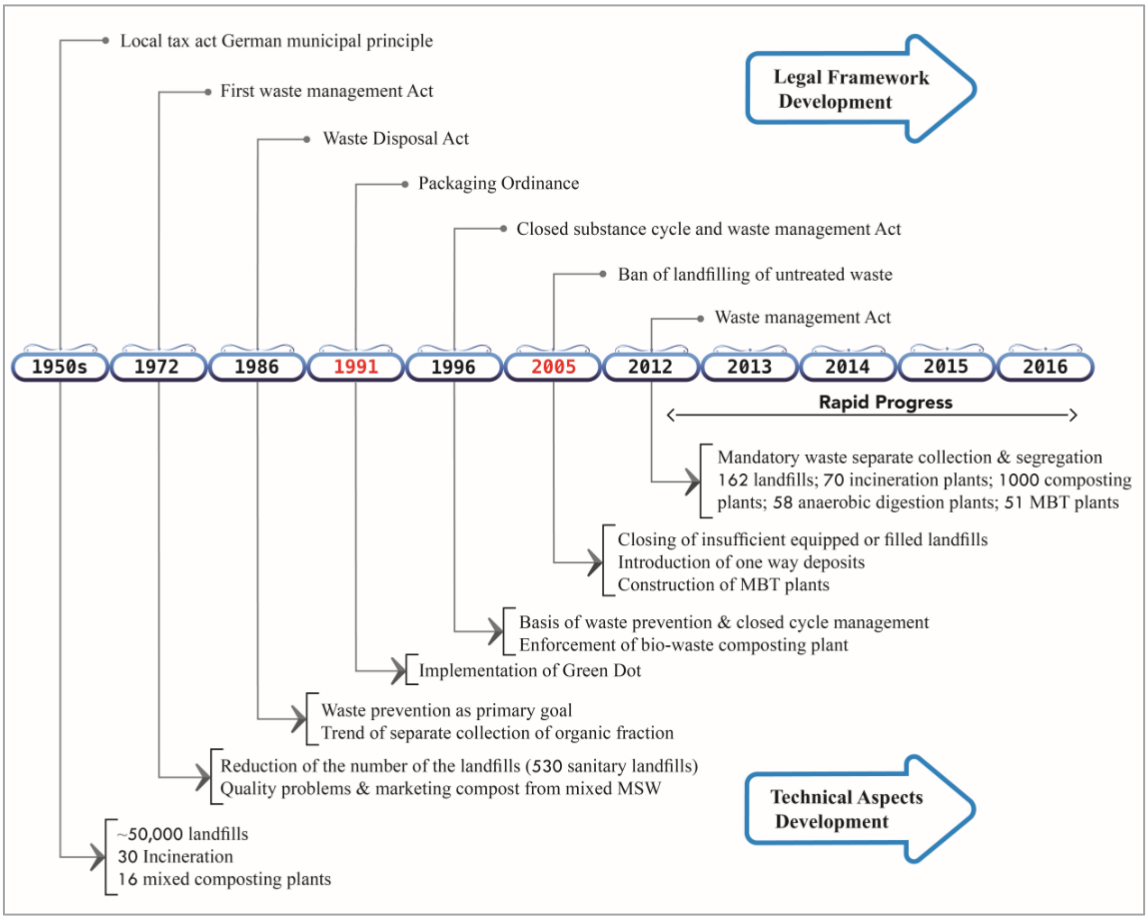


Figure 3-1. *Summary of the legal (up) and technical (down) development of waste management in Germany along the time axis*

The waste management policy, which has been adapted in Germany over the past 20 years, is based on closed cycles and assigns disposal responsibilities to manufacturers and distributors of products. This has made people even more aware of the necessity to separate waste, led to the introduction of new disposal technologies and increased recycling capacities. Article 4 of the revised EU Waste Framework Directive (Directive 2008/98/EC) sets out five steps for dealing with waste, ranked according to the environmental impact – the "waste hierarchy". The waste hierarchy gives top priority to preventing the creation of waste in the first place. When waste is created, it gives priority to preparing it for re-use, recycling, other recovery (such as energy recovery) and disposal (landfill after pre-treatment) in descending order of environmental preference. The waste hierarchy has been transposed into German law (Fischer, 2013).

A new obligation has been included to draw up a national waste prevention programme (Article 33 KrWG). The programme formulates waste prevention targets, presents and evaluates existing waste prevention measures, and develops new measures on this basis. The aim is to strengthen waste prevention policies and make them more transparent to the general public. The Federal Ministry of the Environment formulated a waste prevention programme for the first time in 2013. The Closed Cycle Management Act has also created the opportunity to introduce an obligatory, nationwide “uniform recycling bin”. With this collection system, households should not only dispose of packaging, but also other waste of the same materials, e.g. plastics or metal, in a new recycling bin. This means that recyclables from domestic waste can be collected that are of better quality and in larger quantities. It is proposed to regulate further details of the collection of recyclables in a separate law in the near future (Nelles et al., 2016).

Since 1 June 2005 waste cannot longer be landfilled without pre-treatment. This takes place in incineration plants or mechanical-biological treatment plants. Waste must be treated so that it cannot degrade inside a landfill. Recoverable substances have to be separated before landfilling and the energy from the waste has to be utilised. The German waste management system is totally financed by fees. There are no subsidies. There is a polluter-pays principle, which means that the producer has to pay for waste treatment or disposal (Fischer, 2013).

Various groups of main stakeholders are working in waste management including both municipal and private waste management companies (waste collection, recovery and disposal). Municipal waste management companies are responsible for bio-waste and residual waste (domestic waste); private waste management companies are responsible for the waste recycling in terms of domestic waste, trade waste and commercial waste (Morscheck and Nelles, 2014).

3.4.2. Development and further targets of the solid waste management

Waste management in Germany has evolved substantially since the early 1970s. The first independent Waste Disposal Act was adopted in Germany in 1972 and its primary aim was to shut down uncontrolled refuse dumps and replace them with central, regulated and supervised landfill sites, which fall under the responsibility of the regional and local governments (Schnurer, 2002). Instead of creating new landfill sites and incineration plants, the new Waste Avoidance and Management Act of 1986 was introduced and stipulated, by the principle of avoidance, that the recycling of waste was given precedence over waste disposal (EEA, 2009; Fischer, 2013).

Germany has had landfill restrictions for municipal waste since 1993, for residual municipal waste that cannot be recovered from both separately collected waste materials and unsorted municipal waste, and the part of municipal waste that can be recovered. The restrictions are to ensure that the waste being landfilled does not pose a danger to soil, groundwater, air or the climate. Residual municipal waste must be treated prior to landfill, because of its significant biodegradable content, in order to comply with the landfill criteria. The deadline for total compliance with the landfill ban was set for 2005, thus allowing for an overall transition period of 12 years.

Despite a slow start, the waste management industry began to invest more actively in additional treatment facilities after 2001, when the landfill restrictions were made legally binding. As a result of this, the proportion of municipal waste sent directly to landfill without treatment went from 39% of total municipal waste in 1997 down to 1% in 2006 (BMU, 2006; EEA, 2009; Weissenbach, 2007).

3.4.3. Elements and responsibilities of waste management

Germany is a federal republic consisting of sixteen federal states (Bundesländer). Responsibility for waste management and environmental protection is shared between the national government, the federal states and local authorities (Figure 3-2). The National Ministry of the Environment sets priorities, participates in the enactment of laws, oversees strategic planning, information and public relations and defines requirements for waste facilities. Each federal state adopts its own waste management legislation containing supplementary regulations to the national law, e.g. concerning regional waste management concepts and rules on requirements for disposal. There is no national waste management planning in Germany. Instead, each federal state develops a waste management plan for its area (EEA, 2009).

Germany was the first country in the EU to introduce producer responsibility with a packaging waste regulation in 1991. According to this principle, which is a core tenet of German waste legislation, the producer of a product is generally responsible for the product when it becomes waste. However, this principle has been implemented only for some product types such as packaging, waste electric and electronic equipment, vehicles, solvents, waste oil and batteries.

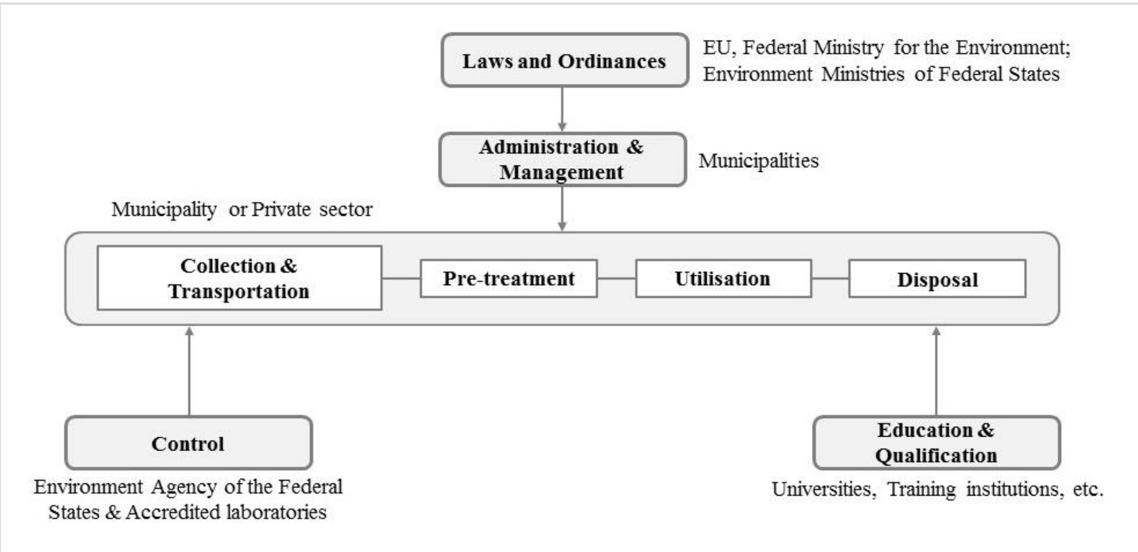


Figure 3-2. *Elements and responsibilities of waste management in Germany*

For waste generated by households, the Recycling Management and Waste Act assigns responsibility to the local public waste disposal authorities (in most federal states these are districts and towns). Their responsibility covers collecting and transporting waste, measures to promote waste prevention and recovery, and planning, constructing and operating waste disposal facilities. Municipalities have more practical tasks such as providing sites for waste collection (EEA, 2009).

3.4.4. Handling of solid waste streams

3.4.4.1. Waste streams arising

In Germany, the amount of waste currently produced is still too high. In particular, in the field of municipal waste, further efforts towards resource efficient consumption are needed in order to prevent waste from arising. The German waste prevention programme, launched in 2013, will contribute to developing advice, support and incentive measures. In 2016, there were only minor changes in waste composition. Furthermore, in the same year, 626 kg per inhabitant of municipal waste including the share of household waste of 462 kg per inhabitant were produced (BMU, 2018, 2016).

As illustrated in the figure above, in 2016, the total German generation of SW was around 412 million tons. From this amount, Germany's waste recovery rates were very high (Table 3-1). This demonstrates how the solid waste management industry contributes to sustainable economic production in the country through saving raw materials and primary energy.

Table 3-1. *Waste balance in 2016 in Germany (DEStatis, 2018).*

Type of waste	Total waste amount generated	Of which: waste deposited in waste treatment plants with					Recovery rate
		disposal operations			recovery operations		
		landfilling	thermal disposal	treatment for disposal	energy recovery	recycling	
	Million tons						%
Total	**411.5**	69.6	5.9	4.0	44.4	287.6	81
Municipal Waste	**52.1**	0.12	2.00	0.80	14.30	35.00	94
Mining Waste	**28.1**	27.06	0.00	0.028	0.02	1.04	4.0
Commercial Waste	**55.9**	13.00	2.80	1.50	12.20	26.40	69
C&D Waste	**275.4**	29.50	1.00	1.70	18.0	225.20	88

Overall, in 2016, there were 411.5 million tons of waste; the recycling rate was 81%. The total comprised 225.2 million tons of construction and demolition waste (88%); 26.4 million tons of waste from production processes and commercial waste (69%) and 35 million tons of MSW (94%) (DEStatis, 2018).

3.4.4.2. HANDLING OF MUNICIPAL SOLID WASTE

Since 2005, municipal solid waste (MSW) has to be pre-treated prior to landfilling. Generally, there are two technologies available: incineration and Mechanical-Biological Treatment (MBT). Waste must be treated so that it cannot degrade inside a landfill site. Recoverable substances have to be separated before landfilling and the energy from the waste has to be utilised. Germany has reported to the European Commission that zero tons of Biodegradable Municipal Waste (BMW) were landfilled in 2006, 2007, 2008 and 2009 (Fischer, 2013). Two basic techniques can be applied for the treatment of municipal waste. One is thermal treatment; the other is mechanical treatment of municipal waste, which is combined with biological and thermal processes (the main concept of each method is described in Table 3.2). The goals of these processes are:

- To break down the organic substances biologically or thermally to stabilise the waste before landfilling
- To obtain recyclable material
- To minimise the mass sent to landfill

Table 3-2. *Processes of municipal waste before landfilling (Doneit, 2012).*

Concept	Preparation (MBT/MPS)	Thermal treatment
Target	Production of defined material flows for recovery or an environmentally friendly landfilling	Reduce waste quantities for landfill, inert, sanitation and utilisation of the energy content
Process	Mechanical aerobic biological treatment Mechanical anaerobic-aerobic biological treatment Mechanical biological stabilisation (Drying) Mechanical physical stabilisation (Drying)	Incineration of municipal waste in incineration plant Pyrolysis in combination with the burning of the pyrolysis products for power generation Mono combustion for the use of alternative fuels
Result	Material flows for recycling (approx. 5-10% metal, plastic, etc.) Alternative fuels (approx. 30-50%, depending on the treatment) Material for disposal (approx. 20-30%, depending on the treatment)	Material flows for recycling (approx. 5% metal) Power (electricity and heat) Material for disposal (approx. 30%, depending on the composition of the waste)

Thermal treatment

Regarding the thermal treatment method, incineration is mainly used for the reduction of the quantities of inert and sanitation materials for disposal and for the utilisation of energy. The creation of energy is not the main goal of incineration. Nevertheless, it is a proven technology in industrialised countries, and it has been used in waste disposal for many years. Flue gas cleaning is a very important process for the environment. The incineration process could be applied to the treatment of MSW. It is an effective MSW treatment option that contributes to waste stabilisation and maximum reduction of waste volume, as well as to sanitation and energy recovery (Liu, 2005). Waste combustion is an attractive treatment option that has some major drawbacks (Brinkmann, 1999), which are:

- Relatively high cost, higher than that of other technologies for the management of municipal waste.
- High level of maintenance, higher than that of other technologies for the management of municipal waste.
- Demand for high quantities of waste.
- Skilled labour required for operations.

Mechanical biological treatment

Mechanical biological treatment (MBT) is an increasingly popular option in Europe, either as a pre-treatment before landfilling or as a pre-treatment before combustion. Processes can be classified into two groups according to the role of free oxygen, either as aerobic or anaerobic systems. The practical experience in Western European countries has shown that the following groups of substances can be produced and utilised by the mechanical-biological/physical treatment processes:

- Approximately 5–10% recyclable materials for marketing in local and international markets.
- 40–60% alternative fuels for thermal utilisation in the cement industry and power plants. The price of the fuels is dependent on energy prices in the country.
- 20–30% inert/stable substances for landfill material, where less leachate and no landfill gases are produced.

The primary function of the mechanical treatment is to break down the waste and to screen the relevant material flow, taking into consideration the properties and further processing (Beckmann and Ncube, 2007; Siefert, 2010). Usually, this consists of different mechanical processes such as:

- Storage and loading facilities
- Removal of impurities and foreign matter
- Pre-shredding
- Several screening techniques for the separation of the organic fraction

- Metal separators for ferrous and non-ferrous metals
- Sorting technology ‘near infrared technology’ for PVC, polyethylene terephthalate (PET) and polypropylene. Grading technology for light and heavy fractions
- Secondary granulators

With the support of MBT, municipal solid waste can be safely disposed of because the treatment permanently reduces the potential reactions and risks induced by the waste. The mechanical biological treatment process is very flexible and can adapt to the change of the composition of the waste very easily, which makes it productive. The core of mechanical biological waste treatment is the treatment of the biodegradable fractions in the biological stage (Weissenbach, 2007).

Recycling of municipal solid waste

The development of recycling of MSW in Germany is divided between recycling material, such as metal, glass, plastic, paper and cardboard and organic recycling, such as compost and other biological treatment (Fischer, 2013). Germany had a high starting level of recycling of MSW in 2001, and the total recycling continued to increase steadily over the period from 2001 to 2008 from 48% to 64%. Nevertheless, the total and consistent increase of MSW recycling covers different trends for material recycling and organic recycling. The amount of material recycled increased during the period from 2001 (34%) to 2010 (45%). In the period from 2001 to 2010, organic recycling increased very little, from 15% to 17%. In fact, an increase has taken place during the last three years, in particular (EEA, 2009; Fischer, 2013).

The ban on non-pre-treated MSW in 2005 has had a huge impact on the amount of MSW landfilled. The total amount of MSW for recycling has increased from 2005. First, this relates to the amount of MSW sent to incineration, which has increased from 13.2 million tonnes in 2005 to 18.0 million in 2010 (Fischer, 2013). However, this increase of incineration does not necessarily reflect the real actual amount of MSW incinerated. According to the German report to Eurostat, “incineration of MSW (without energy recovery) includes ‘treatment for disposal’, mostly referring to mechanical biological treatment (MBT)” (Eurostat, 2012). Furthermore, the waste generated during the pre-treatment process, such as sorting or mechanical biological treatment, will also include waste ending up partly in incinerators and in landfills, and the latter part of this waste is not necessarily reported as landfilled but as incinerated. According to a study of the flows from MBT in Germany, 22% of the input of approximately 6.4 million tonnes into MBT plants ended up in landfills in 2007 (Thiel and Thomé-Kozmiensky, 2011).

3.4.4.3. Handling of commercial solid waste

Commercial waste is defined as all types of solid waste generated by for-profit or non-profit retail stores, offices, restaurants, warehouses and other non-manufacturing activities, excluding residential, industrial, and institutional waste, or other municipal solid waste generated by home-based businesses. The properties and composition of commercial waste (i.e. commercial and industrial waste) are similar to those of household waste. Such waste can be collected separately from household waste (in swap containers) or together with household waste as so called "business waste" (UBA, 2011).

The commercial waste contains a high portion of recyclable material indicating that not all businesses are separating recyclable fractions but dispose of those materials as conglomerate in pre-treatment plants. The Commercial Waste Ordinance (GewAbfV) regulation governs the handling of this waste and lays down the requirements that must be met for high-quality recycling of it (UBA, 2013). According to the Federal Ministry for the Environment report issued by the Federal Statistical Office (2013), in 2010 around 3.45 million tons of mixed commercial municipal solid waste were trucked to waste processing facilities (Figure 3.3). Recyclable paper and board, wood, plastic and metal accounted for 52% of mixed commercial waste.

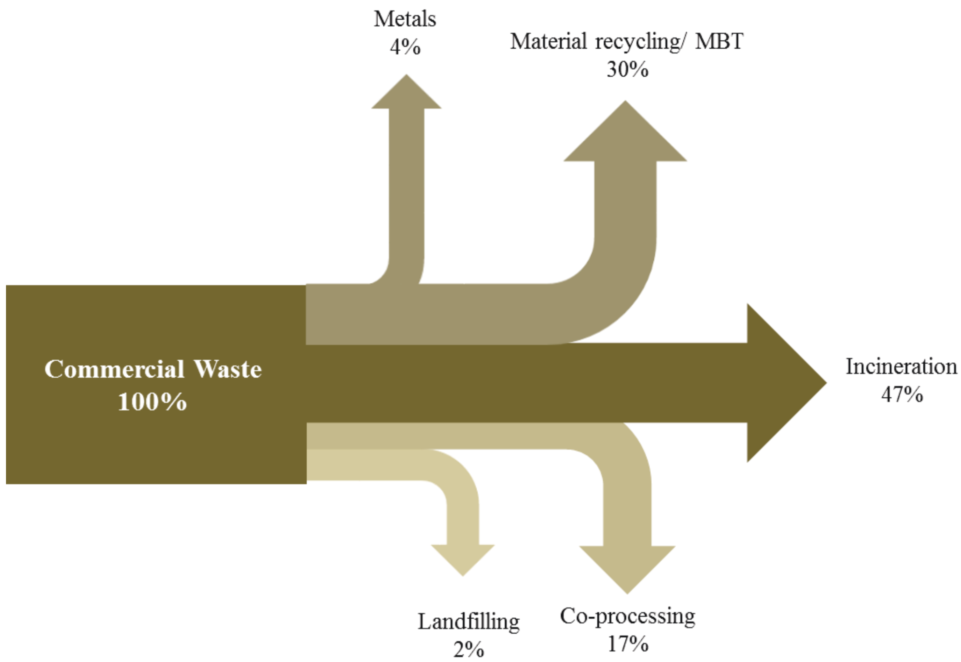


Figure 3-3. *Handling paths of commercial waste in Germany*

As illustrated in Figure 3-3, the biggest amount of mixed commercial municipal waste (app. 60% by weight) is directly treated in waste incineration plants without pre-treatment, only 30% by weight is treated in sorting plants. In contrast, approx. 70% by weight of mixed packaging waste is treated in sorting plants (UBA, 2011).

3.4.4.4. Handling of construction and demolition solid waste

In Germany, construction and demolition (C&D) waste mainly consists of excavated earth, construction and demolition debris, road construction waste, gypsum-based construction material and construction waste. The existence of C&D is strongly influenced by the economic development of the construction industry (Li et al., 2013).

Every year, Germany generates around 200 Mt of C&D waste, of which the majority is constituted of soil and stones. After removing this major category, the total remaining is estimated at around 80 Mt per year. In 2012, a monitoring report stated that around 200 Mt of mineral construction waste was generated in Germany, in line with what is reported in the official statistics of the Federal Statistical Office.

According to the monitoring report, soil and stones also constituted the majority of C&D waste generated (EC, 2015). While soil and stones were responsible for more than half (57%) of the total C&D waste generated, demolition waste amounted to 27% of the reported volume. With 14.6 Mt, construction waste represented around 8% of the total C&D waste, the same share as road construction waste. Construction waste of gypsum-based material made up only a relatively small share with 0.6 Mt (EC, 2015). Furthermore, according to the Federal Statistical Office, the total generation of C&D in 2014 was 209,538 Mt. From this amount, 183.407 Mt (88%) was recycled, see Table 3-3 (UBA, 2014). From the table, it can be observed that the number of landfills in use decreased significantly in the last decade in Germany. This is because landfill sites that could not be feasibly upgraded to tighter regulations were shut down in July 2005.

Table 3-3. *Amount and treatment of C&D waste in Germany, 2014.*

Treatment	**Disposal operations**			**Recovery operations**	
	Landfilling	Thermal disposal	Treatment for disposal	Energy recovery	Recycling
Tons (x 1000)	23,478	130	1,055	1,467	183,407
Total amount					209,538
Recovery rate %					88%

Since constructors have quality concerns, C&D products still have reputational issues when it comes to choosing between primary resources and recycled C&D. Moreover, they are in general not much cheaper than primary resources and can even be more expensive, depending on the market situation and geography. In some states, backfilling of C&D is also allowed (EC, 2015).

3.4.4.5. Handling of hazardous solid waste

The term "hazardous waste" refers to various types of waste with defined hazardous properties that are harmful for the environment and/or human health. Among the waste generated in Germany in 2014, some 21.8 million tons (5.6% of the total waste generated) were classified as hazardous waste. This was equivalent to an average of 250 kg of hazardous waste per inhabitant in Germany (Eurostat, 2017). Depending on the kind of facility, hazardous waste can be composed of a broad range of materials including chemical, medical, radioactive and material with high a heavy metal concentration (Hansen et al., 2014).

Mineral and solidified waste (mainly soils, construction and demolition waste) accounts for half (51%) of the total weight of hazardous waste composition followed by chemical and medical waste (mainly laboratory chemicals, solvents, spent disinfectants, fixatives, formalin, cytostatics or material with high heavy metal content), which accounts for almost 30% of total waste. While mixed ordinary waste (mainly household and similar waste) accounts for 8% of total waste. Recyclable waste (metal, wood, paper/cardboard, glass, plastics, rubber and textiles) accounts for 5% (Eurostat, 2017).

In total, 20.5 million tons (94% of the total) of hazardous waste were treated in Germany in 2014 (Figure 3-4). More than half (57%) of this total was recovered or sent to recovery operations other than energy recovery and backfilling; in other words, this is called recycling (recycled or used for backfilling). Around 23% of the total hazardous amount treated was subject to disposal operations or deposited through land treatment and released into water bodies (disposal other than incineration); for simplification this is called landfilling. Some 6.0% of all hazardous waste was incinerated without energy recovery and a further 14% with energy recovery in 2014 (Eurostat, 2017).

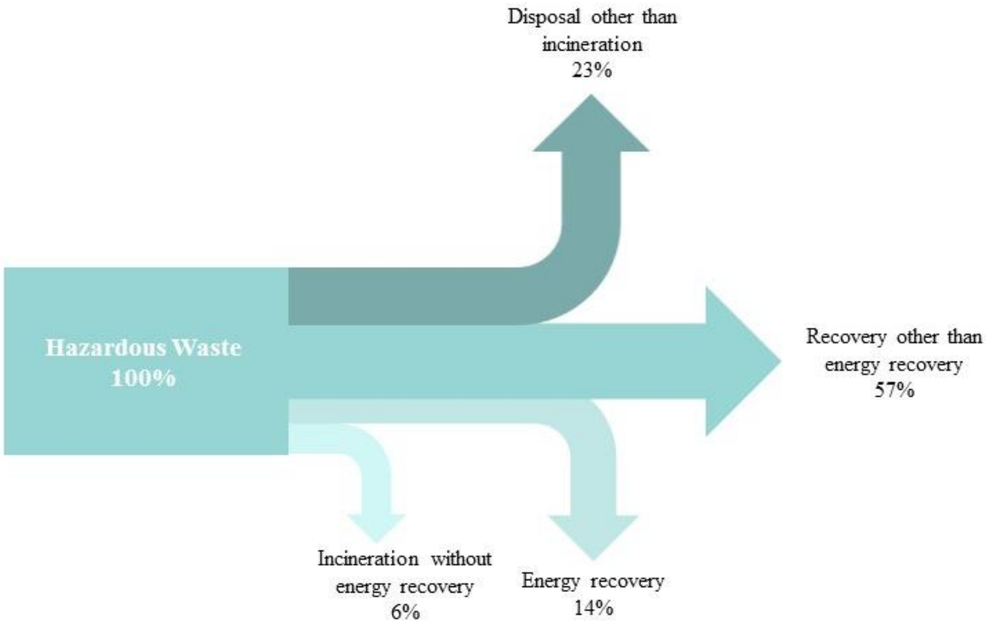


Figure 3-4. *Hazardous waste treatment in Germany, 2014*

4. Research Approach

In this research, based on the results of the review of the status of the waste management system in Jordan, different areas of waste management have been studied through experimental projects (Figure 4-1). Then, based on the results of these studies, a complete environmentally sound, affordable and financially viable sustainable waste management solution (treatment and disposal) has been devised for Jordanian cities, adapting the technical requirements to the local conditions.

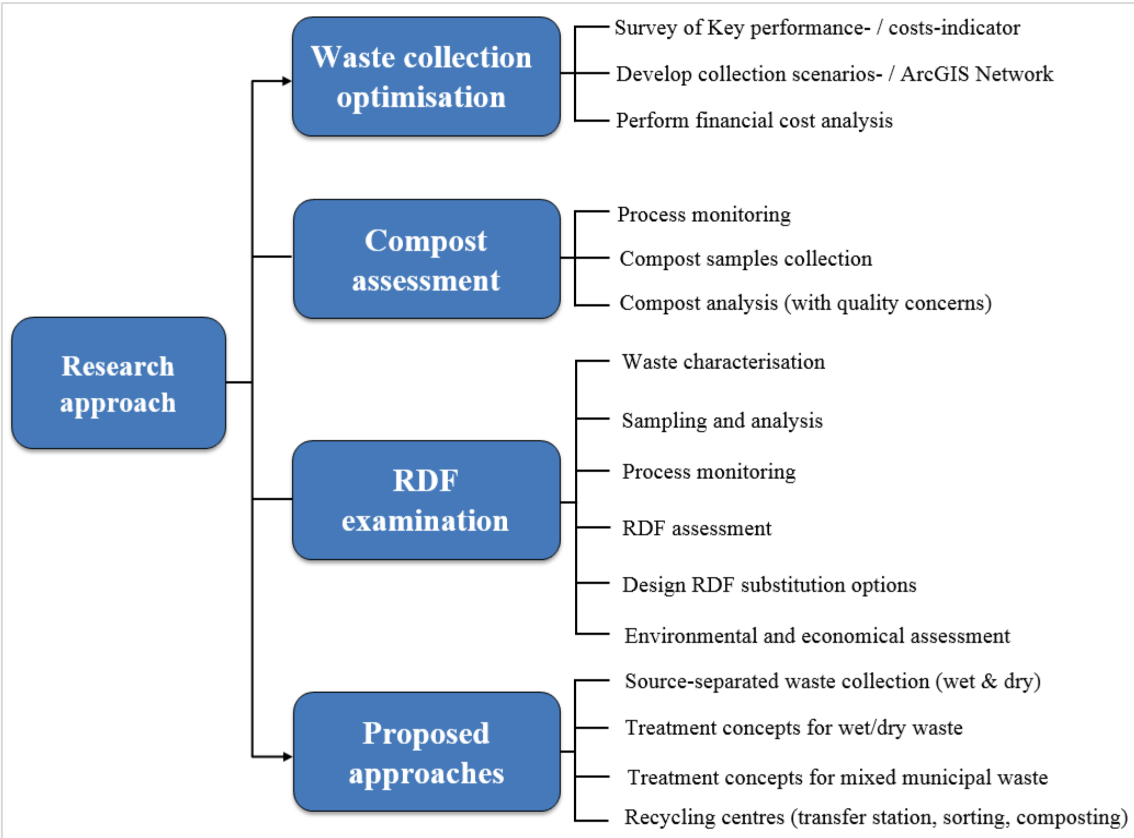


Figure 4-1. *Research approach implemented*

These approaches were selected to be the core of this research, and considered the critical obstacles for the waste management sector in Jordan. In the search for sustainable solutions, as mentioned in the national strategic study of Jordan, this research could represent a key factor to matching the theoretical solutions proposed in the strategic study and the real situation of waste management in Jordan. However, different areas in the field of waste management have been addressed, including improvement of waste collection, assessment of compost production (with quality concerns) and investigation of RDF production from mixed MSW as an alternative fuel. Furthermore, based on the results obtained, different sustainable solutions with different strategies have been proposed.

A research study was carried out using the ArcGIS Network Analyst tool in order to improve the efficiency of waste collection and transportation in the cities of Irbid, Karak and Mafraq, Jordan. A Geographic Information System (GIS) has been created based on data collection involving GPS tracking (collection route/bin position). Both key performance and key operational costs indicators of the actual state (Scenario S0) were evaluated, and by modifying particular parameters, other scenarios were generated and analysed to identify optimal routes.

A small-scale segregated bio-waste composting pilot project conducted in A-Mafraq city proved that a good quality final product can be achieved, which can be recovered and used as compost for agricultural purposes. The study was conducted to explore the physical and chemical properties of compost made from different segregated bio-waste raw materials. Four experimental windrow piles, constructed from different types of organic waste (fruit, vegetable and garden waste) were initiated and then temporally monitored. Plant residues and sawdust were used as bulking agents to provide the required C/N ratio needed for efficient decomposition. The compost produced was monitored in terms of moisture content, bulk density, pH, EC, total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and compost respiration. Final product quality was examined and assessed against the quality specifications of the German End of Waste Criteria for bio-waste which has been subjected to composting, aimed to specify whether the different types of organic waste that have undergone recovery cease to be waste and can be classified as high quality compost.

A pilot project conducted in Amman aimed to investigate the potential for Refuse Derived Fuel (RDF) production and utilisation as an alternative fuel for the Jordanian cement industry by using the biodrying process as a solution for the conditions in Jordan to overcome some of its MSW management problems. During this study, laboratory analysis of RDF samples was carried out to evaluate the RDF quality and compare it with criteria and limits set by some European countries. The biological drying process of solid waste by aerated windrow composting was used as a method of pre-treatment of mixed MSW prior to landfill, in order to produce high calorific RDF material and recover valuable material from the waste stream. Furthermore, the performance of the biological drying process of solid waste by aerated windrow composting was investigated in a pilot scale experiment carried out in Jordan. A further objective was to investigate both the economic feasibility of the production and utilisation of RDF (for cement kilns) and the environmental impact in the context of Jordan's integrated solid waste resource management plan in terms of examining the prospects of greenhouse gas emission reduction and the calculation of CO_2 feasibility upon replacing petcoke with RDF.

Based on the evaluation of the results obtained recommendations were able to be made for a solid waste management system in Jordan. In fact, three approaches have been proposed: introducing separated wet/dry waste collection, treatment concepts for separated wet/dry and treatment concepts for mixed municipal waste. Two strategies were considered: Strategy one is based on the recovery of RDF and metal after the biodrying of raw waste, while in strategy two, the raw waste is processed into RDF, metal is recovered and the fine fraction is further stabilised before landfilling. Two technical models were also suggested: establishment of recycling centres (transfer station, sorting and composting plant) at the municipal level and a technical treatment model including the installation of an incineration plant for the city of Amman in particular. (Please refer to section 8.)

5. Evaluation of Key Indicators of Waste Collection using GIS Techniques as a Planning and Control Tool for Route Optimisation

The need for solid communal waste management is inevitable, just like its generation. Economically developed countries have adopted integrated waste management systems which have all the functional elements defined in their inter-relations, harmonised in terms of efficiency and sustainability. In developing and transition countries, however, which currently do not invest the necessary funds in the development and improvement of their SWM systems, these are only based on elementary elements: waste collection, transport and disposal (Minoglou and Komilis, 2013; Das and Bhattacharyya, 2015; Xue et al., 2015). Specifically, these three elementary functional elements represent activities that generate the highest costs even in highly developed systems, whereas in less developed systems they represent the majority of waste management costs (Malakahmad et al., 2014).

Many authors have based their research on increasing the efficiency of SW collection and transport processes because they were identified as being the most expensive functional elements in the entire SWM process, reaching as high as 85% of all costs in the system (Ohri and Singh, 2010). Waste collection route optimisation is the principal component for achieving the best savings in the entire SWM process (Khan and Samadder, 2014). Therefore, in the SWM optimisation process, equal attention should be paid to both the collection process and the process of waste transport to the final waste treatment or disposal location (Xue et al., 2015).

The implementation of these low-cost processes is significant, especially in developing countries. For this reason, the application of operative level and optimisation in the planning process are frequently the only possibility for improvement in a time-limited period. At this level, the central issues of optimisation are: problems with waste-transporting vehicle movement routing (which is directly connected with the area creation problem) and determining waste collection spots (Apaydin and Gonullu, 2011).

5.1. Introduction

How to collect and dispose of the booming amounts of SW has become a topic of serious interest (Xue et al., 2015). With rising fuel, labour and vehicle maintenance costs, and the increased volume of solid waste from population and consumption growth, this continues to challenge planners to find innovative solutions to reduce overall costs. Solid waste collection has posed many operational problems for local authorities in many cities involving tasks such as determining the optimal fleet size, type and scheduled routes (Taveres et al., 2009). This has forced many municipalities to initiate research into such aspects as route optimisation aimed at cost effectiveness (Kinobe et al., 2015).

Route optimisation is one of the most commonly studied aspects in terms of optimisation problems in transportation research, consisting of the design of the optimal and cheapest distribution patterns aimed at serving scattered customers (Badran and El-Haggar, 2006;

Bosona et al., 2013). The common objective of route optimisation is to minimise travel distances and reduce the fleet size used so as to reduce operational costs and minimise emissions (Nuortio et al., 2006; Ljungberg et al., 2007; Apaydin and Gonullu, 2008).

Optimising the collection route with advanced routing software is a common approach to reducing travel costs. In this light, Geographical Information Systems (GIS) provide network-based spatial analysis. The application of ArcGIS Network Analyst allows the user to dynamically model realistic network conditions, including turns and height restrictions, one-way streets, speed limits and variable travel speeds based on the local traffic (Sumiani et al., 2009; Malakahmad et al., 2014). More specifically, ESRI's ArcGIS Network Analyst extension allows users to perform complex calculations to solve vehicle routing problems. The program performs analysis over a network of connected edges and decides on fleet routing, travel directions, closest facility, service area and location allocation. In the application for route optimisation, network dataset edges represent the road network being traversed (ESRI, 2011).

There have been many previous case studies which have examined routing optimisation using different methods and programs. A review of the literature shows the popularity of GIS for route optimisation studies. It was found to be a suitable tool for these kinds of studies as it is designed to store, retrieve and analyse a large amount of data as well as provide output visualisation in a reasonable duration. Overall, research shows that implementing a route-solving solution using advanced ArcGIS Network Analyst software can lead to substantial overall operational cost savings and additional benefits related to reducing the vehicle operating times and CO_2 emissions (Karadimas et al., 2008; Taveres et al., 2008; Sumiani et al., 2009; Chalkias and Lasaridi, 2009; Chalkias and Lasaridi, 2011; Jovicic et al., 2011; Rada et al., 2013; Malakahmad et al., 2014).

Route optimisation of SW collection as a management sphere has not yet been launched in Jordanian municipalities, where the existing waste collection systems have been developed based on limited data. The aim of this study was to develop optimised scenarios using the ArcGIS Network Analyst tool in order to improve the efficiency of waste collection and transportation in the cities of Irbid, Karak and Mafraq, Jordan. A Geographic Information System (GIS) has been created based on data collection involving GPS tracking (collection route/bin position). Both key performance and key operational costs indicators of the actual state (Scenario S0) were evaluated, and by modifying particular parameters, other scenarios were generated and analysed to identify optimal routes. The benefits of the proposed strategy were assessed in terms of minimising collection time, distance travelled and man-effort, and consequently allowing a comparison of the financial and environmental costs of the current collection system and the one proposed.

5.2. STUDY AREA AND EXISTING WASTE COLLECTION SYSTEM

Parts of Jordan, including the three cities of Irbid, Karak and Mafraq, were selected for a pilot study. In Jordan, SWM is one of the most complex activities due to the wide variety of SW types. It involves many different competent entities depending on their relevant area of interest. Jordan lacks a complete range of integrated practices in terms of street cleaning, collection, transportation, transfer, treatment and disposal of solid waste (Abu Qdais, 2007). The existing solid waste collection system is considered to be adequate in urban centres, but services tend to be poor or non-existent in small towns and rural areas (Al-Hamamre et al., 2014).

In the three cities involved in this study, as is the case in other Jordanian cities, municipalities are responsible on a day-to-day basis for municipal cleaning, waste collection and disposal of the mixed household waste generated. Due to the geographical area and population, the cities concerned in this study were divided into zones or districts for effective SW collection, which can be summarised as consisting of 25, 18 and 17 zones for the cities of Irbid, Mafraq and Karak, respectively.

Under the Deputy City Manager, the Directorate of Environmental Affairs in each municipality oversees waste collection and manages the transport of waste from the collection areas (districts) to the landfill. The waste disposal is managed by the landfill site and treatment department. Each of the aforementioned districts are responsible for their waste collection and for transport to the transfer station (if any) or the landfill. The districts all have a SWM organisation under which drivers, waste collectors and street sweepers are coordinated.

A very general observation is that overall the system works as desired, as it does keep the cities mostly clean. The system is not always overly efficient. Many containers are in poor condition, making it time consuming to move and empty them. Given the cities' numerous narrow streets and the prevalence of (illegally) parked cars, access to containers is often difficult, making waste collection a slow process. Traffic jams are common within the city, lengthening the transportation times to and from the landfill in daytime. Hence, with all containers in good condition, easy access to all bins, and an absence of traffic congestion, waste collection would be considerably faster and costs would be reduced.

The SW collection and cleaning service is organised by the human resource department and the environmental directorate of the municipalities involved as a separate waste collection service in each of the municipalities' districts. Work in municipality districts involves using four shifts, A, B, C and D, as indicated below:

- Shift A (Early morning shift): 6:00 to 12:00, about 60–75% of the service,
- Shift B (Late morning shift): 12:00 to 18:00, about 10–15% of the service,
- Shift C (Evening shift): 18:00 to 00:00, about 10–20% of the service, focusing on commercial areas in all districts,
- Shift D (Night shift): 00:00 to 6:00, about 5–10% of the service, focusing on cardboard and sacks collection in commercial areas in all districts.

The collection of SW is carried out seven days per week using different types of vehicle. It includes the collection of residential area waste as well as bulky waste produced within industrial areas, shopping complexes and shops. The SW collection and cleaning services are carried out in four shifts in the cities of Irbid and Mafraq, while the collection of SW is carried out in the city of Karak in three shifts. A typical SW collection crew consists of a driver and two loaders. The type of vehicle to be used depends on the type of collection bin and width of road.

Metallic containers with a 1.1m^3 volume are predominantly used for waste collection. There are currently 3,500, 1,500 and 2,000 such containers in service within the cities of Irbid, Karak and Mafraq. Frequently, due to physical constraints (narrow streets, people not wishing for containers to be sited close to their residence, etc.) there are considerable distances between the containers or the groupings of containers. This means that only some of the waste is placed directly into the containers by the citizens. The bulk of the waste is left in plastic bags on the kerb for the street sweepers to pick up and transport to the container.

There are insufficient containers, so these often overflow, despite the fact that those in densely populated areas are emptied around the clock. Some districts, especially in the city of Karak, are very hilly, and it is obvious that this creates problems with wheeled containers, resulting in the widespread use of containers with skids, which are obviously quite difficult for the collectors to move around.

The SW is collected as mixed without any separation of recyclables. The emptying of the 1.1m^3 containers is done using pre-specified waste collection routes. The collection trucks start from the depot in each of the districts of the city concerned and collect waste along their route prior to travel to the final disposal sites, which are located some 34km, 30km and 22km from the depots of the cities of Irbid, Karak and Mafraq, respectively. They usually manage to collect all the waste within their area. At times waste is not collected due to equipment breakdown and the lack of a replacement.

Existing equipment for collecting the waste consists of compactor trucks of various sizes, as well as a smaller number of Rotopress vehicles. The waste collection is a challenge: many streets are narrow and parked cars often obstruct access to the containers, making life difficult for the waste collection team. In these areas, waste is collected by the use of small vehicles with a capacity of 2–3m^3 which are normally allocated for sack and cardboard waste material collection.

All SW collected from the city districts is transported directly to their landfills, except in Irbid municipality, where around 80% of the SW collected is transported directly to the landfill and the remaining 20% is carried by small vehicles to a transfer station which is located some 3km from the Irbid municipality depot. In general, the three cities studied are relatively clean, although windy and dry conditions often create dust problems and thin plastic (bags) are blown around.

5.3. MATERIALS AND METHODS

5.3.1. FIELDWORK STUDY AND DATA COLLECTION

The study was conducted in June 2015 and lasted six months. Three Jordanian cities, namely Irbid, Mafraq and Karak, were selected for a pilot scale study. In order to efficiently manage the SW collection system, detailed spatial information is needed (Malakahmad et al., 2014). This information is related to the geographical background of the area under investigation, as well as to data specifically related to the waste collection procedure.

In co-operation with the municipalities concerned, a large database of waste management data for the period January 2014 – December 2015 was collected and statistically analysed. This involved the static and dynamic data of each existing collection programme: population density, road networks and related traffic; waste generation rate for mixed waste and for specific waste streams; the current routing system of the collection vehicles; number and distribution of the existing collection routes over time and districts; time schedule for the collection process; number, costs and distribution of the existing collection staff over time and districts; number, type, history and costs of vehicles; vehicle capacities and their characteristics; vehicle fuel consumption, maintenance and repairs and spare parts costs; number, type, capacity and position of waste containers; and the geographic borders and characteristics of the waste collection districts.

Thus, for the optimisation of the collection process, the data collected was designed, implemented and statistically analysed using a standard commercial GIS environment (ESRI, ArcGIS) as described below. This choice ensured compatibility with the available data from the Nikea municipality and access to many network analysis routines available from the software.

5.3.1.1. SURVEY OF KEY PERFORMANCE INDICATORS

The inspection of the waste amount collected per vehicle per day [t / (veh. * d)], container units per vehicle per day [cu/ route*d], vehicle capacity utilisation, time spent at the containers for clearance of the waste, distance travelled/time between containers, waste collection/transportation duration, total distance travelled, breaks/set-up time, overtime, incentive time, time spent at the landfill, productive time and quantity of refuse handled, all yielded data from which cost and efficiency analyses were made.

The reliability of these data was checked by joining most of the trips, as shown in Table 5-1, and by observing the same activities within the garage and outside. The traffic volume, street width, direction of traffic flow and characteristics of each street were obtained from observation and measurement.

Table 5-1. *An overview of the waste collection routes analysed.*

Study area	Sampling distribution					
	Collection vehicle/ crew	Shift A	Shift B	Shift C	Shift D	Total
The city of Irbida	3-axle					
	Two persons	7	3	0	0	10
	2-axle					
	Two persons	12	6	1	1	20
	One person	3	4	1	1	9
	Small vehicle					
	Two persons	2	1	0	2	5
	One person	1	0	0	0	1
	Total	25	14	2	4	45
The city of Mafraq	3-axle					
	Three persons	0	0	3	0	3
	Two persons	1	2	1	2	6
	2-axle					
	Two persons	10	5	2	0	17
	Total	11	7	6	2	26
The city of Karak	3-axle					
	Two persons	2	0	1	0	3
	2-axle					
	Two persons	4	1	0	0	5
	Small vehicle					
	Two persons	6	0	0	0	6
	Total	12	1	1	0	14
Total routes analysed for the three cities						87

[a]There were additional staff in collection areas (street workers)

5.3.1.2. ANALYSIS OF KEY OPERATIONAL COST INDICTORS AND ORGANISATION DATA

To be able to propose suitable possible scenarios for waste collection with regard to travel distance and time as well as cost, tracking the overall operational cost for collection, transfer and transportation of solid waste including cost analysis was required. To this end, detailed operational data from the related work areas was collected, analysed and evaluated. Moreover, financial feasibility was studied to estimate the total and operational cost for each scenario or option, and compared to the current situation.

Table 5-2 summarises the detailed operational data that has been touched upon and obtained. This yielded the basic calculations from which cost analyses were made.

Table 5-2. *The basis of calculation addressed during the study*

Basis of calculation	Data Analysed
Analysis of staff	• number of employees (head of department; observer; driver; loader; street worker) • personnel costs (monthly staff salaries; overheads; reserves)
Analysis of vehicles	• number of vehicles (vehicles for container collection; vehicles for bulky waste; vehicles for transfer station; other vehicles) • vehicle costs (capital costs; fuel costs; oil costs; maintenance costs)
Analysis of routes	• number of routes (container collection, bulky waste, transfer station) • routes per day • numbers of drivers, loaders and workers per vehicle and route
Analysis of containers	• number of containers • container costs (capital costs; maintenance costs)

Background spatial data for road networks, existing routes, bins and building parcels were obtained from the various municipalities. These data were updated with field work and other non-spatial data such as road names, road types, vehicle average speed, time travelled, distance travelled, fuel consumption, maintenance and repair costs, road slopes, bin numbers, bin type/capacity, bin collection time, all of which were added. Furthermore, special attributes of road networks such as traffic rules, traffic marks, topological conditions and special restrictions (e.g. turn restrictions) were registered in order to model the real world road network conditions efficiently.

5.3.2. METHODOLOGY

The key feature of the proposed analysis is GIS technology. According to Ghose et al. (2006) and Chalkias and Lasaridi (2009), GIS is an important tool for solving complex routing problems with regard to waste transport, from the collection spot to the waste landfill with the aim of minimising costs. The effectiveness of this tool is well documented in the literature; for example, Santos and Rodrigues (2003), Tarantilis et al. (2004), Armstrong and Khan (2004), Ghose et al. (2006), Viana (2006), Ericsson et al. (2006), Salhofer et al. (2007) and Taveres et al. (2009). The structure of the methodology that was followed in this work, shown in Figure 5-1, comprised of three general steps. Step 1 established the spatial database of the study area as described previously. Step 2 was dedicated to the research for different optimisation versions with the use of GIS analysis functions. Finally, Step 3 consisted of the waste collection routing optimisation in terms of minimum time, distance and fuel consumption.

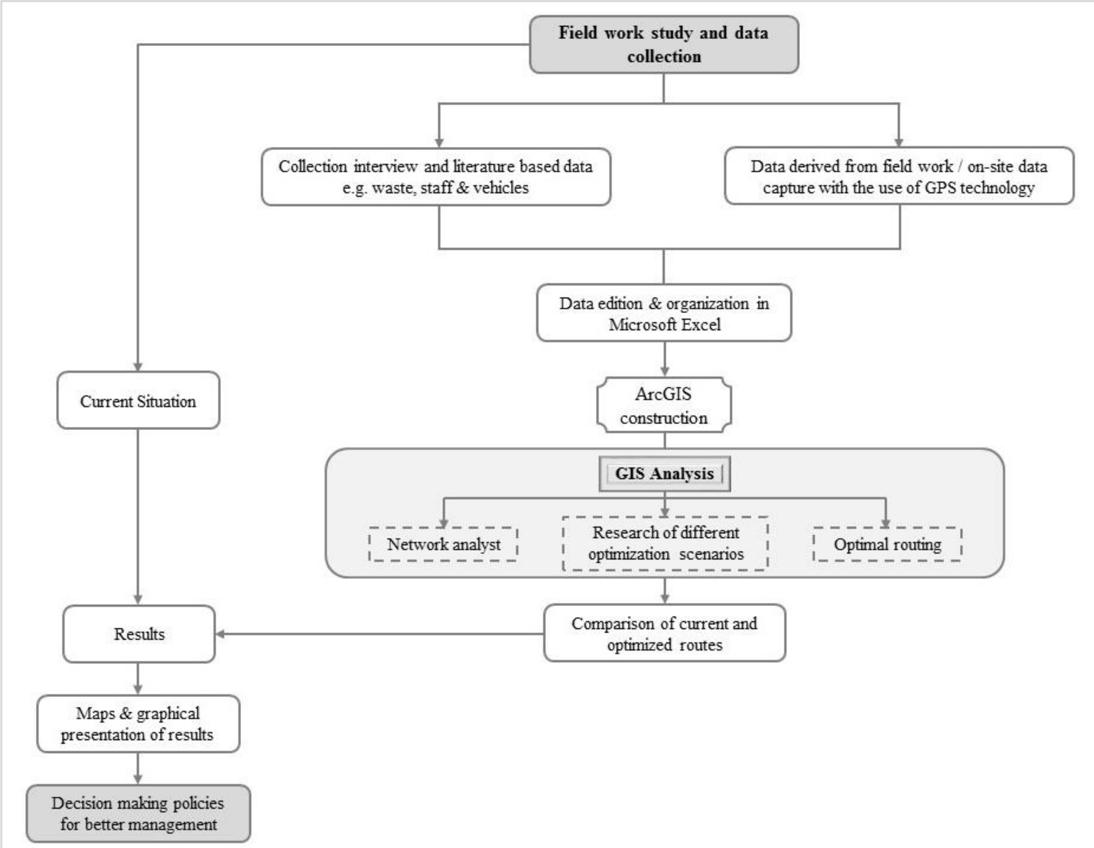


Figure 5-1. *Flow chart of the adopted methodology*

5.3.2.1. FIELDWORK STUDY AND DATA COLLECTION

In order to analyse the spatial data for the optimisation of the waste collection scheme in the study areas, a spatial database (SDB) within a GIS framework was constructed. The description of this database is provided in section 3.1. The main sources of the SDB were (a) analogue maps from the municipalities involved, (b) digital data from various official providers (e.g. National Statistical Service) and (c) data derived from field work/on-site data capture with the use of GPS technology.

5.3.2.2. GIS ANALYSIS

For the purpose of efficiently managing the SW collection and transport system through a reduction in haul distance, time and cost, balancing the distribution of waste collection in all the zones, and ensuring equitable involvement of all assigned vehicles in waste hauling, GIS techniques were used to optimise the collection routes in the study areas involved. Since, by using ArcGIS, it is possible to plan routes for an entire fleet, calculate drive-times, locate facilities and solve other network related problems (Son, 2014), it was used together with the Network Analyst extension to develop an optimisation module to calculate the shortest distances.

The GIS software took into account parameters in solid waste management such as the location of dumpsites, truck capacities and the road network, as well as the waste generation volumes of the area (Son, 2014; Kinobe et al., 2015).

In the identification of the existing practice with regard to municipal waste materials collection, where the main objective was to identify existing collection routes of bins, the receivers of the Global Positioning System (GPS) technology were used to collect data on dumpsites and routes. A Magellan® Triton 1500 model GPS was used to collect and store data that was later integrated into, and managed by, GIS software.

With the aim of mapping the current situation, the existence of a complete road network, satellite images of the area from the Google Earth application (Figure 5-2), descriptive information of roads such as one-way streets, average speeds, street names, street types and dead ends, were required.

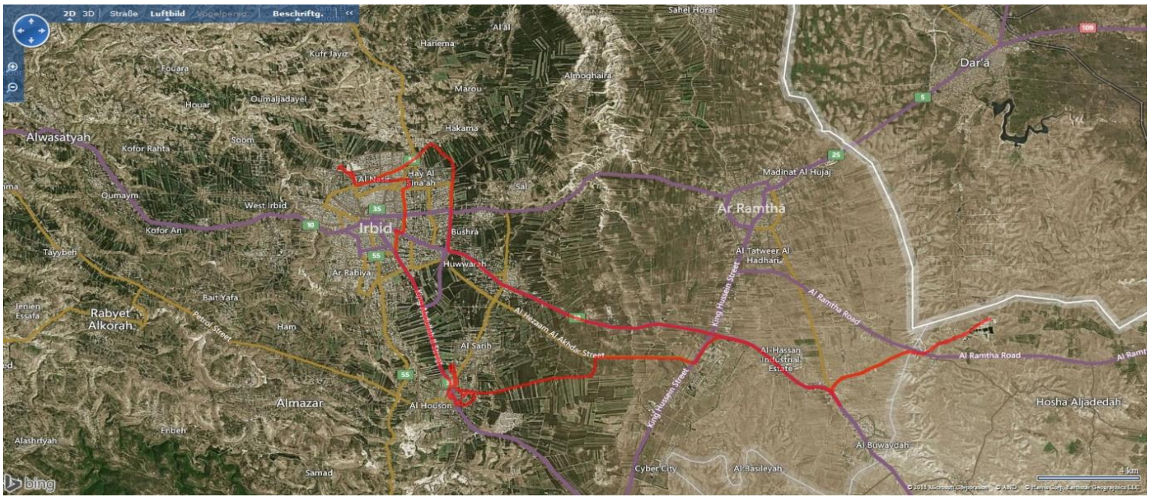


Figure 5-2. *Satellite image for one of the areas studied (Irbid city) using Google Earth application*

Another very crucial point for the routing application development was the identification of the municipal solid waste vehicles' routes, including landfill sites and garages, the positions and types of containers per sub-region, container density per route, and finally a set of additional information such as the number and type of bins, capacity, district they belong to, etc. After determining the itinerary's start and end points, the route was determined. Finally, another category of primary data was created related to the existing routes of the waste trucks which are operated by the municipality. Figure 5-3 illustrates an example of one collection route tracked using GIS data.

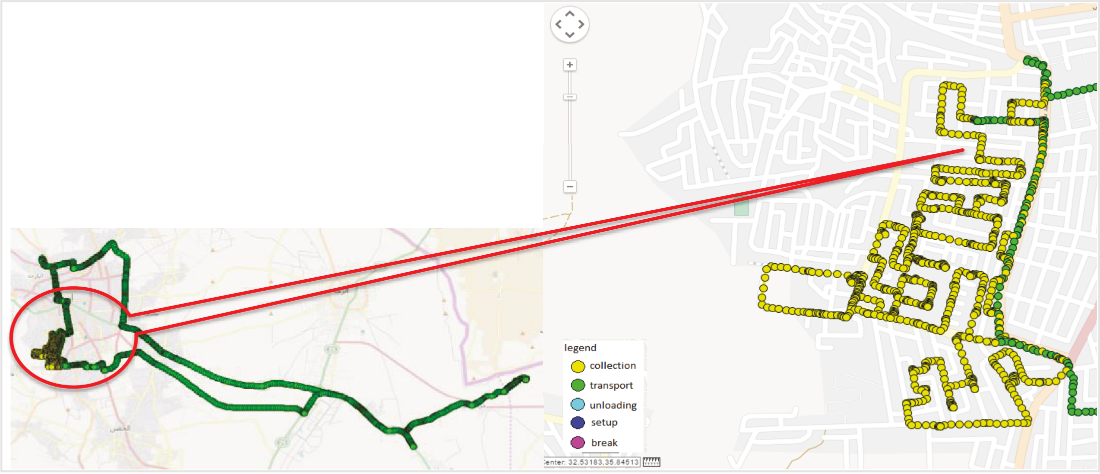


Figure 5-3. *A sample of one collection route tracked with GIS Network Analyst data.*

For the evaluation of the performance of the existing collection routes, which were identified in the previous phase, the total mileage was estimated for each route, as was the corresponding collection time. Then, the calculations were utilised for a comparison with the suggested routes, as well as for the adjustment of parameters for the simulation by which the optimal routes were identified. These parameters are related to the average time spent on each bin, the maximum number of bins which can be collected by a waste truck on a route, vehicles' payload utilisation, staff needed per route and/or vehicle, the waste truck's average speed, distance travelled, breaks/set-up time, overtime, incentive time, time spent at the landfill, etc. In order to understand how efficient the existing routes were, the recorded routes were re-created (Figure 5-4) using the ArcGIS analyst tool with the optimised (shortest distance) option.

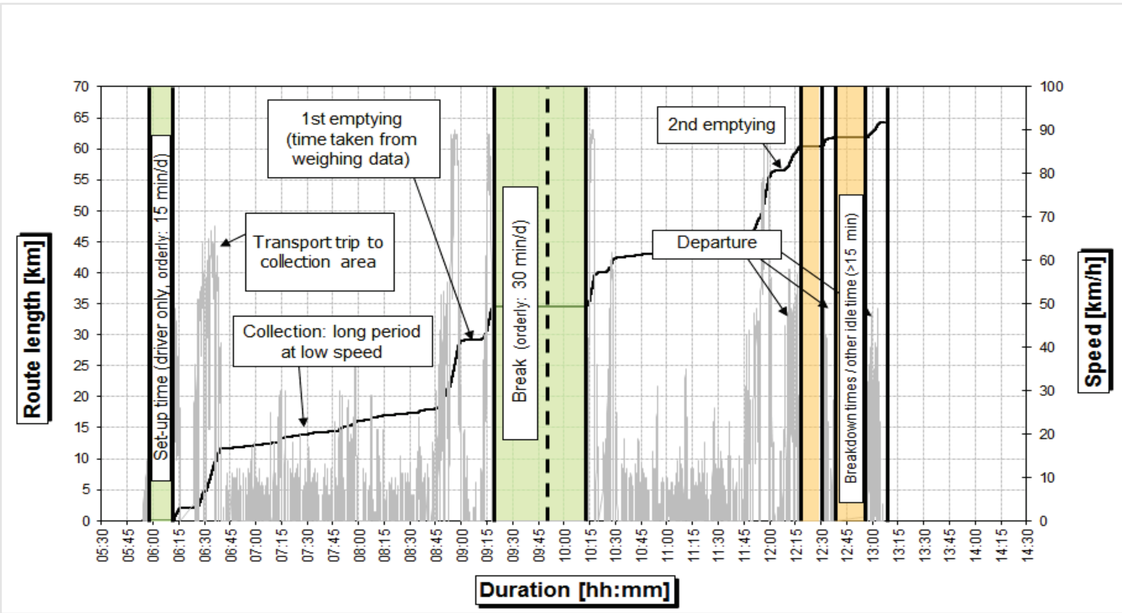


Figure 5-4. *Evaluation of route tracking data*

Tracking the overall operational cost of solid waste collection and transportation was one of the main goals of this study. The main objective was to optimise the cost of solid waste collection and transportation. Consequently, the costs of handling solid waste in the form of the cost of staff (staff type, amount and costs), vehicles (number of vehicles, capital costs, fuel costs, oil costs and maintenance) and containers (capital costs and maintenance) were input and analysed using Microsoft Excel. Detailed data were obtained from the three cities concerned.

The third phase was the main objective of this study because it had, as the final derivative, the development of a methodology to optimise the waste trucks' routes utilising GIS technology. The routing application of the routing in the study area was undertaken using the Network Analyst tool, which is an extension of ArcGIS software that provides network-based spatial analysis including routing, travel directions, closest facility and service area analysis. The Network Analyst tool is able to identify efficient travel routes for the trucks during solid waste collection.

In order to solve the route optimisation problem, distance criteria and collection time by the truck (regardless of time spent in traffic) were generated and considered. By considering the speed formula ($v = \Delta d/\Delta t$), the duration taken for each truck travelled throughout the solid waste collection procedure was obtained. The final output was an optimal solution in terms of distance criteria. After setting the stop points, the optimised routes for solid waste collection were produced.

5.3.2.3. Route Optimisation

The final stage of the implementation included the calculation of the optimal route which would be followed by the waste truck for the collection of bins in the study area, in order for the waste collection process to be undertaken in the most efficient way, and subsequently to compare the results of the implementation with the current waste collection situation in the municipalities under consideration. Next, the best possible scenarios for solid waste collection routes were identified based on the information obtained with the help of the GIS regarding the possible routes, and having taken into account the restrictions in terms of road conditions and topography. The routes were chosen in such a way that the resources used for collection, the length of the route and the time taken to complete the collection, is minimised.

5.4. Results and discussion

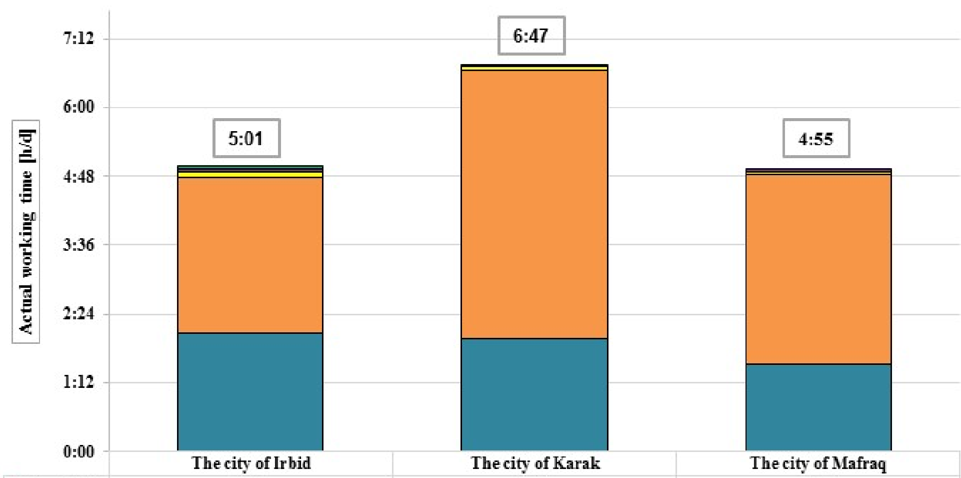
Three cities were chosen to carry out this study, namely the cities of Irbid, Mafraq and Karak. Returnable collection bins with capacities of $1.1m^3$, cardboard and sacks were considered in the calculations. Some of the collection points contain more than one bin. All three allocated types of vehicles (three and two-axle compaction trucks, small vehicles) started a trip at the garage, collected the waste from the returnable bins at predefined locations, and moved to the final destination (landfills or transfer stations), making a closed loop circuit. Only one landfill and one garage in each city were chosen for the present study.

5.4.1. EVALUATION OF KEY PERFORMANCE INDICATORS WITH REGARD TO WASTE COLLECTION

The experimental results obtained were based upon supportive field data relating waste collection statistics of the three cities such as daily work time utilisation; containers emptied per route and per vehicle; container filling level; time spent on emptying the containers (S/Cu); payload per route; vehicle payload utilisation (%) and distance travelled per route.

5.4.1.1. DAILY WORK TIME UTILISATION

One of the most important objectives of this study was to reduce the operating time of the vehicles compared to the amount of transported waste. To this end, the required time for waste collection and transportation was estimated. On the basis that the average daily working time in the city of Irbid and Mafraq was five hours per day and seven hours per day in the city of Karak (Figure 5-5), the results revealed that the time spent to transport waste was very high in the three cities; 41%, 29% and 24% of the daily working time in the cities of Irbid, Mafraq and Karak, respectively. Moreover, the time spent on waste collection, depending on the amount of waste collected and distance travelled, was also very high; 49%, 70%, 68% of the daily working time in the cities of Irbid, Mafraq and Karak, respectively. Therefore, there is usually one disposal trip per shift.



	The city of Irbid	The city of Karak	The city of Mafraq
Stand still	0:03	0:00	0:00
Break	0:00	0:00	0:00
Set up time	0:02	0:02	0:02
Unloading	0:06	0:05	0:04
Collection	2:43	4:40	3:18
Transport	2:04	1:58	1:31

Figure 5-5. *Daily work time utilisation in the study areas [h/d]*

In addition, the long time spent on waste haulage, in turn, results in an unbalanced utilisation of the collection routes (working time, container units per route, tonnage per route). With reference to the abovementioned, the usage/renewal of the transfer station would be the most optimal solution. The direct benefits from using a transfer station include the reduced mileage haul distance, time and cost. This reduction (estimated at about 30%) includes environmental and economic benefits (reduced fuel, reduced emissions from the waste trucks, reduced traffic and reduced noise pollution).

5.4.1.2. Tonnage per vehicle and route

From the vehicle payload point of view, three types of vehicles were used to manage solid waste, namely three-axle vehicles with a capacity of 12 m^3, two-axle vehicles with capacities of 8 and 10 m^3 and small vehicles with a capacity of 2–3 m^3. In the city of Irbid, as set out in Figure 5-6, the results have shown good payload utilisation for all the vehicles that were used, in that the payload utilisation was found to be 89%, 85% and 70% for 3-axle, 2-axle and small vehicles, respectively. By contrast, in Mafraq city, the utilisation of the vehicles' payload was poor and there is an urgent need for improvement.

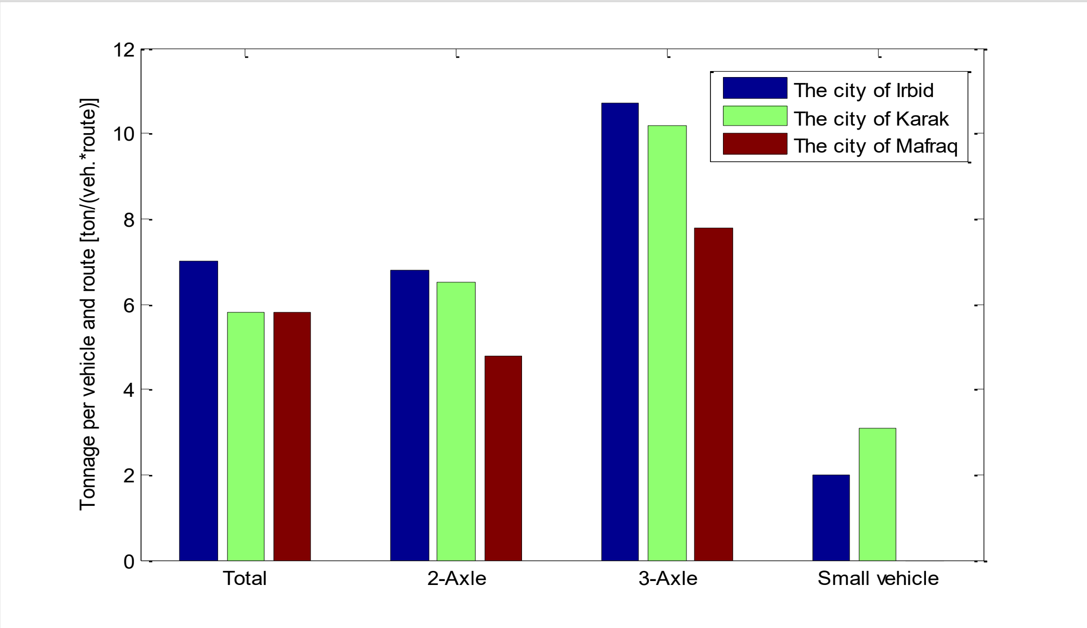


Figure 5-6. *Tonnage per vehicle and route [ton/ (veh. route)]*

Regarding Karak city, due to its good payload utilisation, it can be concluded from the results that the use of two-axle vehicles (8 and 10 m^3) would be the most viable. However, in order to increase the amount of waste collected, 10 and 12 metric ton trucks are proposed. There would be a significant improvement in terms of reduction in the number of trips made and distance covered with an increase in the vehicle capacity that would reduce the fleet vehicle number, which in turn would reduce fuel consumption as well as emissions.

5.4.1.3. Number of container units per vehicle and route

As the number of waste containers was one of the main indicators of performance parameters during the survey, where the main objective was to evaluate the existing practices of the municipal waste collection systems of the cities involved, the container units collected according to the vehicle type used were estimated. In this context, in order to determine the collection unit amount per vehicle and per route, it was necessary to develop the following weighting factors:

- 2-wheel containers: factor 1
- 4-wheel containers: factor 4
- Sacks and cardboard: factor 0.25

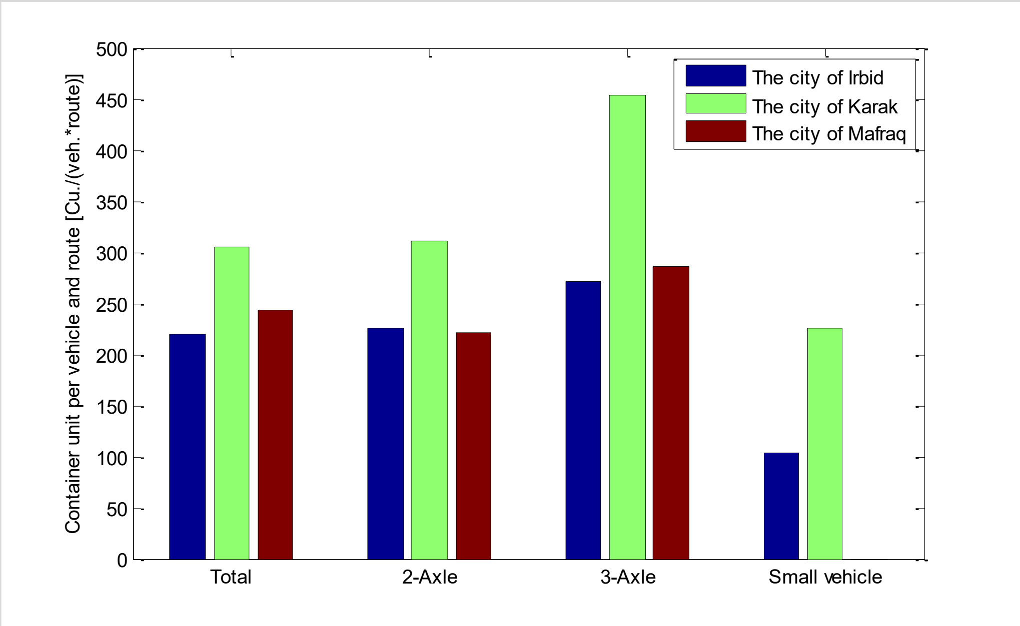


Figure 5-7. *Container unit per vehicle and route [cu/ (veh. route)]*

It is clear from Figure 5-7 that the city of Karak has the highest number of waste containers collected per unit (305 units). In the same framework, the container filling ratios for the city of Irbid, Mafraq and Karak were found to be 97%, 92% and 85%, respectively. Therefore, despite the fact that the city of Karak has the highest number of containers collected, and also the highest daily working time (7 h/d), the city of Irbid is still at the forefront in terms of the amount of waste collected, followed by the city of Mafraq.

5.4.1.4. Time required for collection of waste disposal containers

It is a fact that the time spent on each bin directly affects collection costs, where the lower this time is, the greater the number of collection points passed per unit of time, the higher the quantity of waste collected per route, the higher the service's performance, the lower the cost per ton and the lower the emissions (Apaydin and Gonullu, 2011). To this end, the best performance among the three cities concerned in terms of the time required for the collection of waste disposal containers was determined (Figure 5-8), and a comparison between the experimental results obtained from those cities was undertaken.

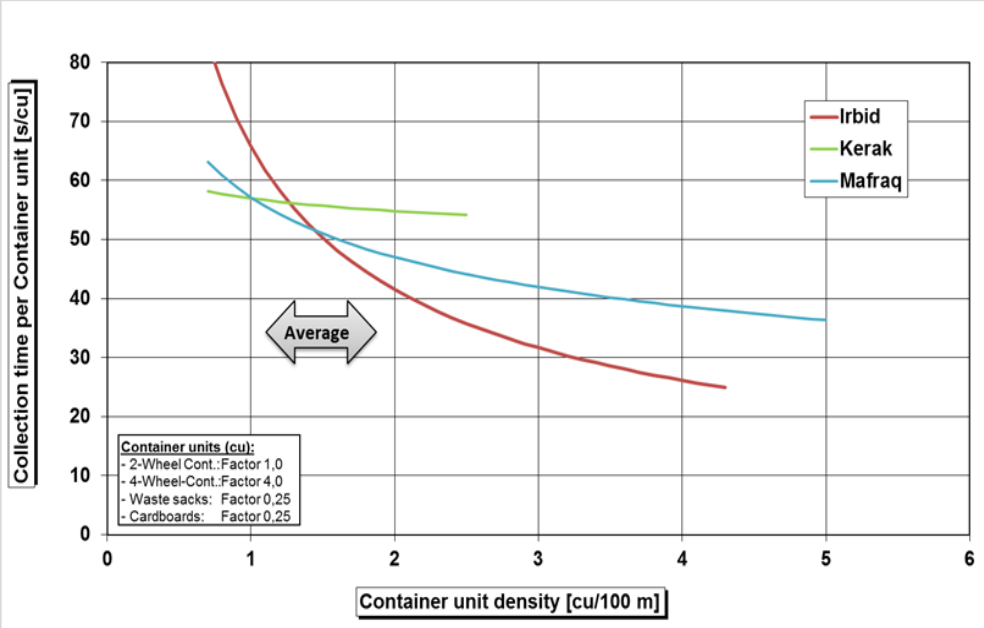


Figure 5-8. *The waste collection services performance of the study areas*

As the figure shows, despite the insufficient daily working time in Irbid (5 h/d), the city of Irbid has the best performance regarding managing the solid waste collection services in terms of the total amount of collected waste, containers collected per vehicle and route, utilisation of vehicles, payload, travelling distances and the operational time.

5.4.2. Evaluation of key operational cost indicators

Among the different waste management operations, waste collection is the most aggravated due to the high costs that are involved. Many studies have reported that waste collection costs represent over 70% of the solid waste management budget of many municipalities in developing countries (Rotich et al., 2006) and about 60% or less for developed countries (Brunner and Fellner, 2007).

It is therefore crucial to provide an overview of the typical costs of the municipal solid waste collection system implemented. For this purpose, towards the end of the process of gathering data from the study areas under consideration, an estimation of the overall operational cost for solid waste collection and transportation was made.

Furthermore, based on the results of the evaluation of the current situation, and the strengths and weaknesses of the waste collection system, three scenarios were developed, and a cost analysis was performed for each suggested scenario. This was then compared with the current empirical collection scheme. Bear in mind that the costs were estimated in Jordanian dinars (1 € equals about 1 JD in 2015).

5.4.2.1. Estimation of existing staff costs for waste collection services

It is well-known amongst those close to waste collection activities that crew size is an important component of waste collection, and can have a great effect on overall collection costs (Bohm et al., 2010). For this reason, the existing staff involved in waste collection services and their associated costs were estimated, analysed and evaluated (Table 5-3). It is clear from Figure 5-9 that the city of Mafraq suffers from a severe shortage of dedicated staff to manage the process of waste collection. It was found that only one person managed the process, which in turn adversely affected the effectiveness of the combined process. Here, an increase is urgently needed. In the same framework, the balance of staff in the city of Irbid, depending on the task, is realistic and can be used as an indicative figure for other cities in Jordan.

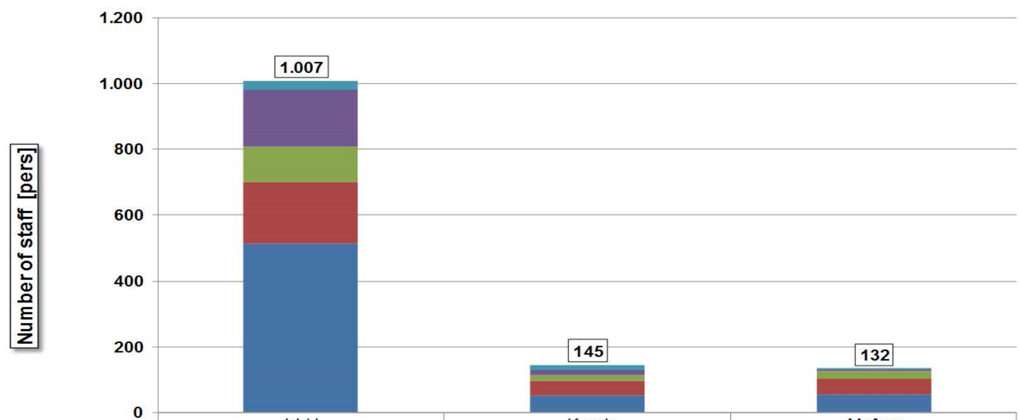
Table 5-3. *The existing staff involved in waste collection services and associated costs.*

Study area	Job Title	Number of staff	Number of staff/ route	Monthly Salary/JD[c]	Personnel cost/route	Personnel cost %
The city of Irbid[a]	Head of Department	25	0.3	508.50	5.15	3
	An observer	173	1.8	395.50	27.70	19
	Drivers (incl. reserve)	107	1.1	395.50	17.06	12
	Loader	190	2.0	339.00	26.08	18
	Workers	512	5.4	339.00	70.27	48
	Total	1,007	10.6	1977.5	146.25	100%
The city of Karak[b]	Head of Department	15	0.9	508.50	17.26	14
	An observer	17	1.0	395.50	15.21	13
	Drivers (incl. reserve)	17	1.0	395.50	15.21	13
	Loader	45	2.6	339.00	34.51	28
	Workers	51	3.0	339.00	39.12	32
	Total	145	8.5	1977.5	121.31	100%
The city of Mafraq[a]	Head of Department	1	0.0	508.50	0.81	1
	An observer	6	0.3	395.50	3.80	5
	Drivers (incl. reserve)	22	0.9	395.50	13.94	19
	Loader	48	2.0	339.00	26.08	35
	Workers	55	2.3	339.00	29.88	40
	Total	132	5.5	1977.5	74.51	100%

[a] Daily working time 6 h/d

[b] Daily working time 7 h/d

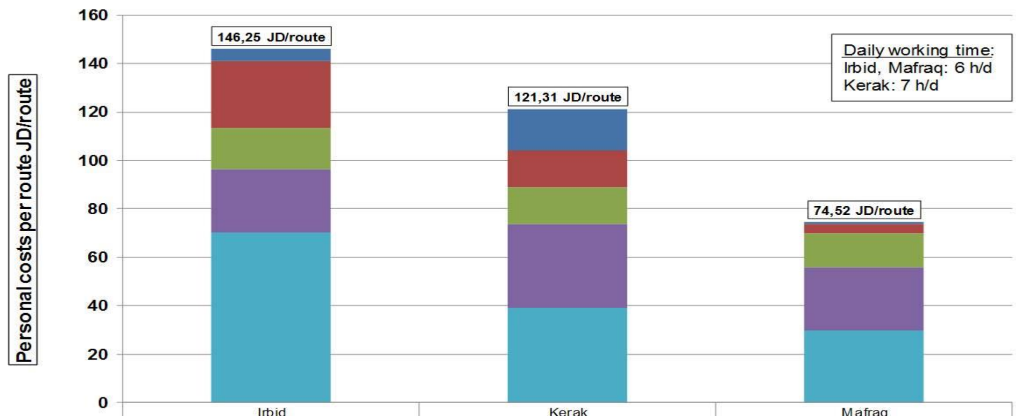
[c] Salary includes 13% insurance



	Irbid	Kerak	Mafraq
Total	1.007	145	132
Head of department	25	15	1
Observer	173	17	6
Driver (incl. reserve)	107	17	22
Loader	190	45	48
Worker	512	51	55

Figure 5-9. *Breakdown of the existing waste collection staff*

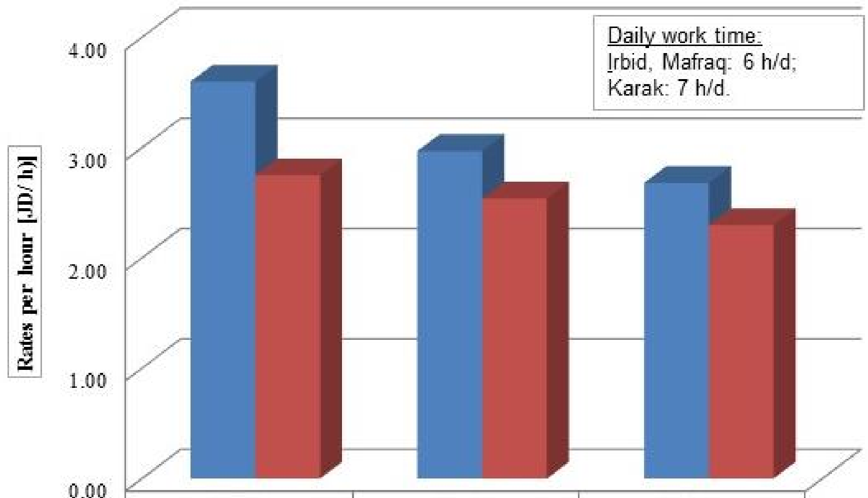
Moreover, as shown in Figure 5-10, the personnel costs per route (JD/route) in the study areas involved were also estimated. In the present study, a daily routine of waste collection was considered, where after fuelling each vehicle was assumed to leave the start point, i.e. the garage, then move to the collection area or district where full containers were located with constant stops at temporary collection sites until it filled and departed to the landfill and back to the garage.



	Irbid	Kerak	Mafraq
Total	146,25 JD/route	121,31 JD/route	74,52 JD/route
Head of department	5,15 JD/route	17,26 JD/route	0,81 JD/route
Observer	27,70 JD/route	15,21 JD/route	3,80 JD/route
Driver (incl. reserve)	17,06 JD/route	15,21 JD/route	13,94 JD/route
Loader	26,08 JD/route	34,51 JD/route	26,08 JD/route
Worker	70,27 JD/route	39,12 JD/route	29,88 JD/route

Figure 5-10. *Personnel costs of waste collection per route (JD/route)*

The results revealed that the personnel costs per route were found to be 146.25, 121.31 and 74.52 JD in the city of Irbid, Karak and Mafraq, respectively. In the city of Mafraq, it is clear that the personnel costs are low because no street workers are employed among the narrow streets for collecting the waste and transporting it to the collection points. Therefore, the vehicle crews carry out these tasks, which in turn increases the time required for waste collection and thus leads to an increase in costs. Another way of looking at the cost of personnel for waste collection is to estimate it per hour. The previously obtained data, contained in Table 5-3, were used as the main inputs for performing the cost analysis in order to estimate the personnel costs of waste collection per hour (Figure 5-11).



	Irbid	Karak	Mafraq
Drivers	3.60	2.97	2.68
Loader and workers	2.75	2.54	2.30

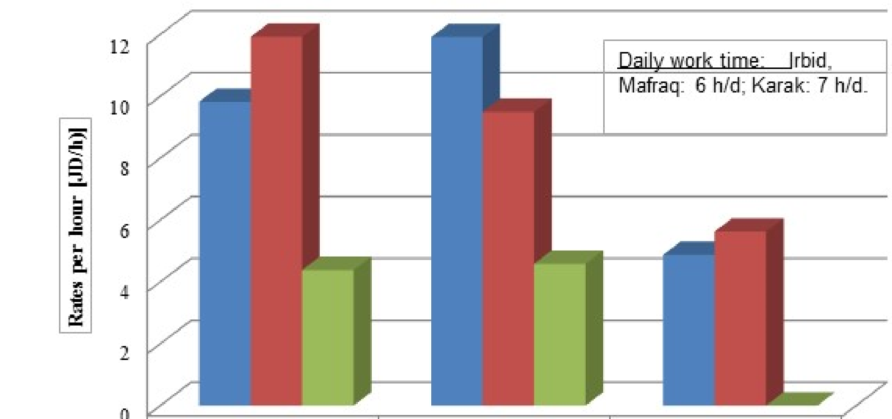
Figure 5-11. *Personnel rates of waste collection per hour (JD/hour)*

The results reported in Figure 5-11 provide the cost per hour for the drivers, loaders (for lifting up, discharging the container at the back the vehicle) and workers (street workers). In each route, the workers consisted of a driver, two loaders and three to five street workers, depending on their availability on a particular day, because they were taken on as casual labourers for loading the waste. The results show that the driver costs per hour were 3.60, 2.97 and 2.68 JD in the cities of Irbid, Karak and Mafraq, respectively. In the same light, the loader and worker costs were found to be 2.75, 2.54 and 2.30 JD in the city of Irbid, Karak and Mafraq, respectively.

5.4.2.2. ESTIMATION OF THE VEHICLE COSTS PER HOUR

In a collection routing context, the collection vehicles are the resources. In essence, the collection of waste is a Vehicle Routing Problem (VRP) (Aringhieri et al., 2004). In the present work, the rates per hour were estimated for the three types of vehicles used to manage solid waste collection (Figure 5-12). As the results show, the heavy duty vehicles (3-axle) had the highest costs. This can be interpreted as the effect of vehicle load, where the lower the vehicle weight, the less the load demanded from the engine, the less fuel consumption, and vice versa (Salhofer et al., 2007).

Furthermore, the effect of road gradient plays an important role in determining costs. The road gradient increases (when positive), or decreases (when negative), the resistance of the vehicle to traction. This is due to the different engine power output that is needed to travel uphill vs. downhill. Therefore, the power required from the engine during driving is the key factor that determines vehicle fuel consumption. Because of their larger masses, the gradient effect is considerably greater in the case of heavy duty vehicles than for any other category (Taveres et al., 2009).



	Irbid	Karak	Mafraq
2-axle	9.82	11.91	4.87
3-axle	11.92	9.49	5.62
Small vehicle	4.38	4.58	0.00*

* No small vehicle in operation

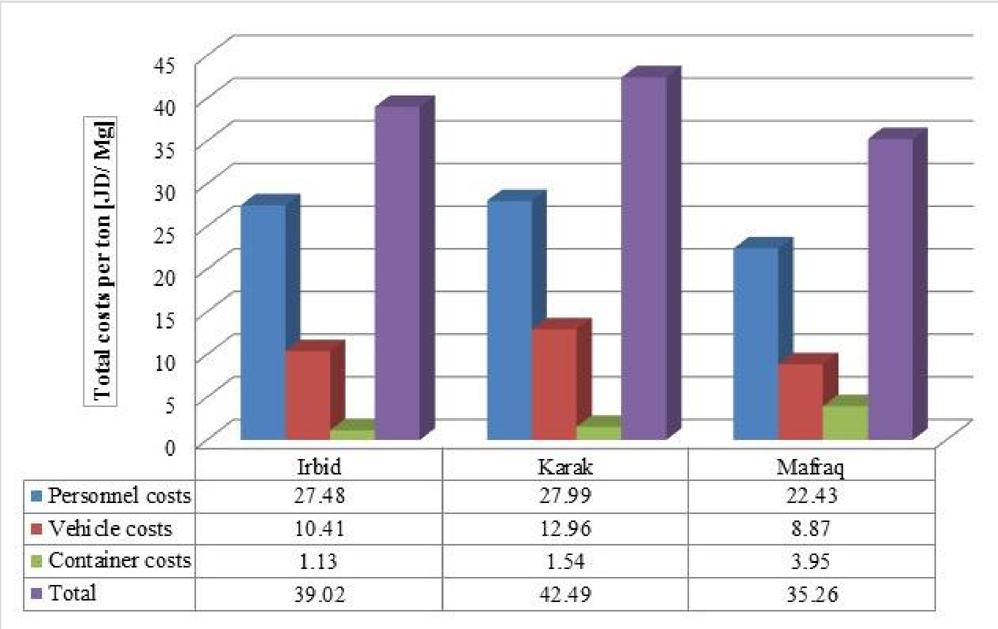
Figure 5-12. *Vehicle rates of waste collection per hour (JD/hour)*

Another factor that affects the cost per vehicle is the number of workers accompanying the vehicle during the waste collection rounds. Usually, the heavy duty vehicles (3-axle) are accompanied by two workers, and sometimes three, which in turn increases the cost of such large vehicles, while small vehicles are usually accompanied by one worker, which reduces the cost.

5.4.2.3. Estimation of the waste collection costs per ton

To obtain an insight into the actual costs of solid waste collection services in Jordan, an attempt was made to analyse the extensive cost data of solid waste collection. Two separate cost studies were performed as part of this work. One was to provide an insight into the (1) per ton costs (i.e. personnel costs per ton) and the other was to gain an insight into the (2) per vehicle costs (i.e. 3-axle vehicle costs per ton).

One can think of many factors that could possibly affect total expenditure. However, only selected socio-economic variables for which data were available from the study areas involved were used in this analysis. The following variables that were thought to have an influence on total costs were used: population density, waste density, waste generation amounts, number of vehicles used for collection and transportation, average trips per vehicle per day, total number of staff employed, frequency of collection, repair and maintenance, fuel consumption and finally whether or not medical waste is collected and disposed of separately. The cost estimates and future planning is based on past data during the year 2015 (Figure 5-13). The dataset used in this work covers a sampled waste generation of 158, 23 and 26 thousand tons in 2015 in the cities of Irbid, Karak and Mafraq, respectively.



	Irbid	Karak	Mafraq
Personnel costs	27.48	27.99	22.43
Vehicle costs	10.41	12.96	8.87
Container costs	1.13	1.54	3.95
Total	39.02	42.49	35.26

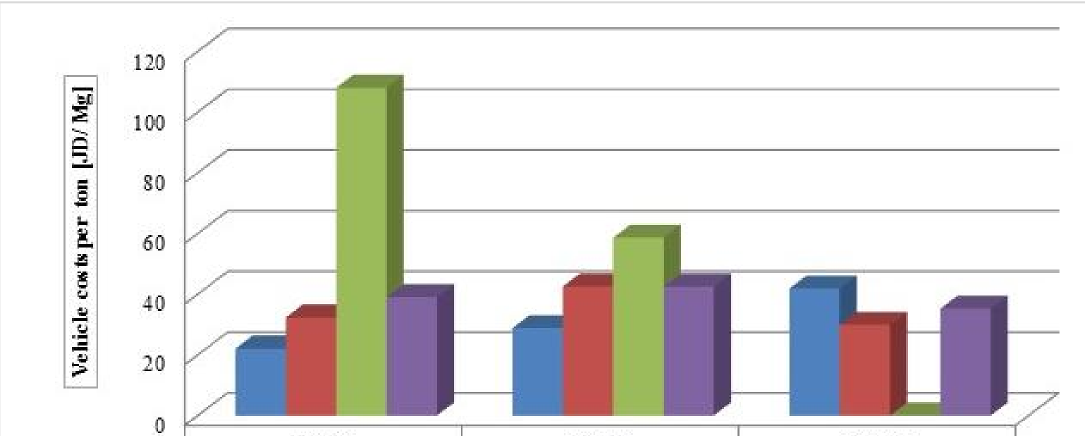
Figure 5-13. *Total cost of waste collection per ton [JD/ Mg]*

The sampled cities and towns in turn represent the entire country. Figure 5-13 plots the cost per ton per year in Jordanian Dinars (JD) across these cities. It was observed that the cost per ton per year varies from as low as 35 JD to 43 JD between cities. Such a comparison serves to highlight the vast variation in the costs per ton between cities, even with a constant waste generation rate (i.e. only those cities that generate 0.9kg/person/day). Keeping these data issues in mind, one can imagine the challenges that a SWM planner could face in these regions.

From Figure 5-13, it can be seen that the total cost for collection and transportation were found to be 39.02, 42.49 and 35.26 JD per ton in the cities of Irbid, Karak and Mafraq, respectively. Only about 10–20% will be covered by waste charges which are levied from the electricity bills. The remaining 80–90% is paid by the municipal revenues from the Ministry of Municipal Affairs. From a vehicle cost point of view, the results have shown that the average fuel consumption of the compactor vehicles used for waste collection was found to be 0.40, 0.45 and 0.42 L of diesel per kilometre in the cities of Irbid, Karak and Mafraq, respectively. Furthermore, fuel costs account for 10% of the total vehicle costs per ton for the cities of Irbid and Karak and 8% for the city of Mafraq, which in turn highlights the urgent need to optimise the routing network in order to reduce the distance travelled and, consequently, reduce fuel consumption, together with emissions.

Regarding the vehicle costs in the city of Mafraq, these were found to be low because the vehicles used are new and no maintenance costs were incurred in 2015. In the city of Mafraq the staff costs are also low because no street workers are employed on the roads for transporting the waste to the collection points. Therefore, the vehicle crews carry out these tasks, which in turn increases the time required for waste collection and thus leads to an increase in costs.

Furthermore, the waste collection cost per ton was investigated, according to the type of vehicle used in the area studied (Figure 5-14). The calculation and analysis reveal that the road container scheme (using 2-axle and 3-axle vehicles) leads to high captures of waste, with lower specific costs for the municipal waste fraction. This can also be seen and proven from the results obtained from the cities of Irbid and Karak for the small vehicles with a capacity of 2–3 m^3, where the costs of the small vehicle were found to be very high.



	Irbid*	Karak	Mafraq
3-axle	22.11	28.81	41.85
2-axle	32.33	42.54	29.86
Small vehicle	108.01	58.63	0.00
Total	39.02	42.49	35.26

Figure 5-14. *Vehicle costs of waste collection per ton [JD/ Mg]*

Actually, these small vehicles are dedicated to the collection of commercial waste from the front of malls and shops (small vehicles usually collect waste cardboard) in addition to collecting waste sacks located on the narrow streets from the front of houses and scattered randomly on both sides of the road. This could be explained by the fact that cardboard and sack collections require more time for uploading of the waste materials to the vehicles, the limited vehicle capacity (their maximum payload) and more frequent trips (the higher this number is, the higher the cost) to the transfer station site. This is because with larger waste volumes per collection, the collection costs are expected to increase for a decreasing collection rate.

Also, the amount of fuel consumption plays an important role in vehicle costs, in that fuel consumption depends on the type of vehicle, the distance travelled and the condition of the vehicle. The increase in truck capacity generally reduces the number of trips made, and consequently the distances travelled and time, which in turn reduces the total fuel consumption which subsequently reduces emissions.

Many studies have reported that by using trucks of 10 metric tons capacity instead of 6 metric tons, improvements of 41% on trips, 39% per km and 20% in terms of hours have been obtained. Similarly, improvements of 44% on trips, 34% per km and 9% in terms of hours have been realised with an increase in truck capacity from 10 to 18 metric tons. The benefit is more significant when the increase is from 6 metric ton to 18 metric ton trucks, in which case the benefit realised is 67% on trips, 60% per km and 27% in terms of hours (Kinobe et al., 2015).

5.4.2.4. Description of the strengths and weaknesses of the waste collection process

Currently, in the municipalities involved, as is the case in other Jordanian municipalities, solid waste collection was carried out without analysing demand, and the construction of the routes is left to the drivers.

Current routes are designed by the city authority based on where waste is deposited, and the drivers also follow routes depending on their experience and knowledge of the area. In other words, the trucks do not work on a scheduled route or timetable. Most of the waste collection trucks in the city are loaded manually. When the truck is full to capacity, it goes to the landfill to dispose of the waste. Each truck can normally make more than one trip per day to the landfill. During this work, many strengths and weaknesses were identified in the areas covered by this research (Table 5-4).

Generally, the areas covered by this research demonstrate a good knowledge of municipal solid waste collection. However, their weaknesses lie in route planning performed on the basis of experience as there is no structured key data-oriented route planning, no/hardly any adjustments to changing situations, lack of reporting and documentation, use of inappropriate collection vehicles, an inadequate number of containers, inefficient daily work time utilisation and inefficient and expensive waste collection processes.

Table 5-4. The main strengths and weaknesses of the areas studied.

Study area	Strengths	Weaknesses
The city of Irbid	• frequent usage of 3-axle vehicles • good utilisation of vehicle payload • good utilisation of container volume	• 5 h/d average daily working time • very high transport time percentage • usually just one disposal trip per shift • unbalanced utilisation of the collection routes (working time, container units per route, tonnage per route) • no structured route planning (traditional structures)
The city of Karak	• 3-shift working hour model • 7 h/d average daily working time • frequent usage of 3-axle vehicles • good utilisation of vehicle payload • good utilisation of container volume	• high transport time percentage (esp. small vehicles) • large number of sacks • usually just one disposal trip per shift • unbalanced utilisation of the collection routes (working time, container units per route, tonnage per route) • no structured route planning (traditional structures)
The city of Mafraq	• frequent usage of 3-axle vehicles • good utilisation of container volume	• 5 h/d average daily working time • high transport time percentage • usually just one disposal trip per shift • bad utilisation of vehicle payload • unbalanced utilisation of the collection routes (working time, container units per route, tonnage per route) • no structured route planning (traditional structures)

5.4.2.5. Proposed scenarios for waste collection

In order to evaluate the output using the proposed methodology, three different waste collection scenarios were examined and their results were compared with the measured data of the existing collection scheme (Scenario 0). The proposed scenarios, as reported in Table 5-5, mainly focused on introducing longer shifts, relocating and/or introducing new transfer stations, combining scenarios of introducing longer shifts and relocating and/or introducing new transfer stations. Moreover, the cost analysis that has been performed for the different scenarios were made for the different parameters involved in the cost calculation that fit the cities' situations (see Table 5-6 and Figure 5-15). The figure shows the cost projections for the scenarios proposed providing savings for the city of Irbid, while the cost projections for the scenarios proposed for the cities of Karak and Mafraq are given in Appendix I.

Scenario S0: Current Route

Scenario S0 describes the daily routine of waste collection, where each vehicle, after fuelling, was assumed to leave the starting point, i.e. municipal garage, before moving into the division for pickups characterised by constant stops at temporary collection sites until it is full and departs to the landfill. Usually, the collection is made by a team of five people: the driver and two collectors accompanying the compactor, and two collectors with hand carts. The distance travelled by truck from the starting point (the municipal garage) to the landfill station ranged between 28 and 37km and the daily work time ranged from between 5 to 7 hours including around 2.5 hours of driving, 4.5 hours for loading/unloading bins and 0 minutes break. The utilisation of payload for all vehicles is around 90 to 95%.

The results obtained show that the current total cost of waste collection per year, compared to the amount of waste collected in the same period, was found to be very high; accounting for around 6.18, 0.98 and 0.92 million JD in the cities of Irbid, Karak and Mafraq, respectively. It can obviously be seen that personnel costs are pre-eminent, followed by vehicle costs with an average of 65% and 27% of total costs, respectively. Therefore, this fact is important as a small percentage of route optimisation for this scenario, as a reduction in the number of workers, working time, distance travelled, number of trips and fuel consumption, will result in a significant saving for the waste collection/transportation operation time and for overall costs.

Scenario S1: Optimisation of working time

This scenario maintained the same work method as in S0 (route, equipment and number of workers) and therefore the same stop points. Only the daily work hours per shift differ. Scenario S1 focuses on increasing the daily working hours per shift in conjunction with reducing the number of shifts. The scenario modelled here was for each crew to work six hours per shift in the cities of Irbid and Mafraq, and eight hours in the city of Karak, including a 30 minute break. The utilisation of payload for all vehicles is assumed to be 85%. This scenario allows an increased work area to be dealt with by the same team for the same work session. Additionally, when the length of the daily working hours per shift was increased, total costs savings of 15%, 6% and 11% and personnel costs savings of 16%, 10% and 12%, were found in the cities of Irbid, Karak and Mafraq, respectively. The results modelled suggest that vehicle distance and time taken would decrease, mainly due to the decrease in the number of trips required to the depot to swap crews.

Scenario S2: Use of a transfer station

In this scenario, the same daily working time per shift as in S0 was maintained. Only relocating and/or introducing new transfer stations differ. Scenario S2 assumes using transfer stations for all vehicles in parallel with providing new vehicles with a larger capacity (6-axle vehicles). Optimisation of this scenario results in significant savings in personnel costs with reductions of 20%, 8% and 16% and total cost savings of 13%, 3% and 6% in the cities of Irbid, Karak and Mafraq, respectively. In this scenario, remarkable savings in fuel consumption would be obtained, mainly due to fewer vehicles being on the road, as the number of trips required to the landfill would be decreased and this would subsequently reduce CO_2 emissions.

Scenario S3: Optimisation of working time and use of a transfer station

Scenario S3 is a combination of S1 and S2. It suggests increasing the daily work time per shift as mentioned in S1 in parallel with relocating and/or introducing new transfer stations. This scenario results in significant gains for the collection/transportation operation with personnel cost reductions of 31%, 17% and 23% and total cost savings of 23%, 8% and 13% in the cities of Irbid, Karak and Mafraq, respectively. Moreover, vehicle operating time was seen to decrease by 30%, in addition to other extra benefits related to CO_2 emissions, fuel consumption, wear/maintenance of vehicle, and so forth.

Table 5-5. *The proposed scenarios for solid waste collection.*

Scenarios	Target	Descriptions		
		The city of Irbid	**The city of Karak**	**The city of Mafraq**
S0	Initial situation (working time as current situation)	• daily working time: 5:00 h/d • set-up time / paid breaks: < 0:15 h/d • utilisation of payload: 90 to 95 % for all vehicles	• daily working time: 6:45 h/d • set-up time / paid breaks: < 0:15 h/d • utilisation of payload: 90 to 95 % for all vehicles	• daily working time: 5:00 h/d • set-up time / paid breaks: < 0:15 h/d • utilisation of payload: 70 to 75 % for all vehicles
S1	Optimisation of working time	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles	• daily working time: 8:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles
S2	Use of a transfer station (working time as current situation, no investment costs for building considered)	• transfer station at Truck City outside of Irbid for 2- and 3-axle vehicles • current transfer station for small vehicles at same place • reduction of distances for unloading 2-, 3-axle vehicles • more 6-axle vehicles for transfer stations	• transfer station outside of Karak for 2-, 3-axle and small vehicles • reduction of distances for unloading 2-, 3-axle and small vehicles • new 6-axle vehicles for transfer stations	• transfer station outside of Mafraq for 2- and 3- axle vehicles1) • reduction of distances for unloading 2- and 3-axle vehicles • new 6-axle vehicles for transfer stations
S3	Combination of scenarios S1 and S2	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles • transfer station at Truck City outside of Irbid for 2- and 3-axle vehicles • current transfer station for small vehicles at same place • reduction of distances for unloading 2-, 3-axle vehicles • more 6-axle vehicles for transfer stations	• daily working time: 8:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles • transfer station outside of Karak for 2-, 3-axle and small vehicles • reduction of distances for unloading for 2-, 3-axle and small vehicles • new 6-axle vehicles for transfer stations	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilisation of payload: 85 % for all vehicles • transfer station outside of Mafraq for 2- and 3-axle vehicles • reduction of distances for unloading for 2- and 3-axle vehicles • new 6-axle vehicles for transfer stations

Table 5-6. *Estimation of the total costs per year for the proposed scenarios.*

Study area	Specific costs [JD/ Mg]					Total costs [JD/ a]				
	Key figures	Initial situation	Scenario S1	Scenario S2	Scenario S3	Key figures	Initial situation	Scenario S1	Scenario S2	Scenario S3
The city of Irbid	Personnel	27.48	23.11	22.01	19.02	Personnel	4,352, 325	3, 661,030	3, 486,005	3, 013,548
	Vehicles	10.41	8.86	10.86	10.07	Vehicles	1, 648,783	1, 402,670	1, 720,842	1, 594,405
	Containers	1.13	1.13	1.13	1.13	Containers	179,531	179,531	179,531	179,531
	Total	39.02	33.10	34.00	30.22	Total	6, 180,640	5, 243,232	5, 386,379	4, 787,484
	savings in the total cost compared to the initial situation (JD/ a) in %		15%	13%	23%	savings in the total cost compared to the initial situation (JD/ a) in %		15%	13%	23%
The city of Karak	Personnel	27.99	25.07	25.66	23.31	Personnel	644,977	577,658	591,161	537,010
	Vehicles	12.96	13.15	14.12	14.47	Vehicles	298,551	303,077	325,258	333,416
	Containers	1.54	1.54	1.54	1.54	Containers	35,403	35,403	35,403	35,403
	Total	42.49	39.76	41.31	39.32	Total	978,931	916,138	951,822	905,829
	savings in the total cost compared to the initial situation (JD/ a)		6%	3%	8%	savings in the total cost compared to the initial situation (JD/ a)		6%	3%	8%
The city of Mafraq	Personnel	22.43	19.82	18.81	17.19	Personnel	582,264	514,417	488,412	446,352
	Vehicles	8.87	7.55	10.26	9.45	Vehicles	230,365	196,082	266,368	245,410
	Containers	3.95	3.95	3.95	3.95	Containers	102,598	102,598	102,598	102,598
	Total	35.26	31.32	33.03	30.60	Total	915,228	813,098	857,378	794,361
	savings in the total cost compared to the initial situation (JD/ a)		11%	6%	13%	savings in the total cost compared to the initial situation (JD/ a)		11%	6%	13%

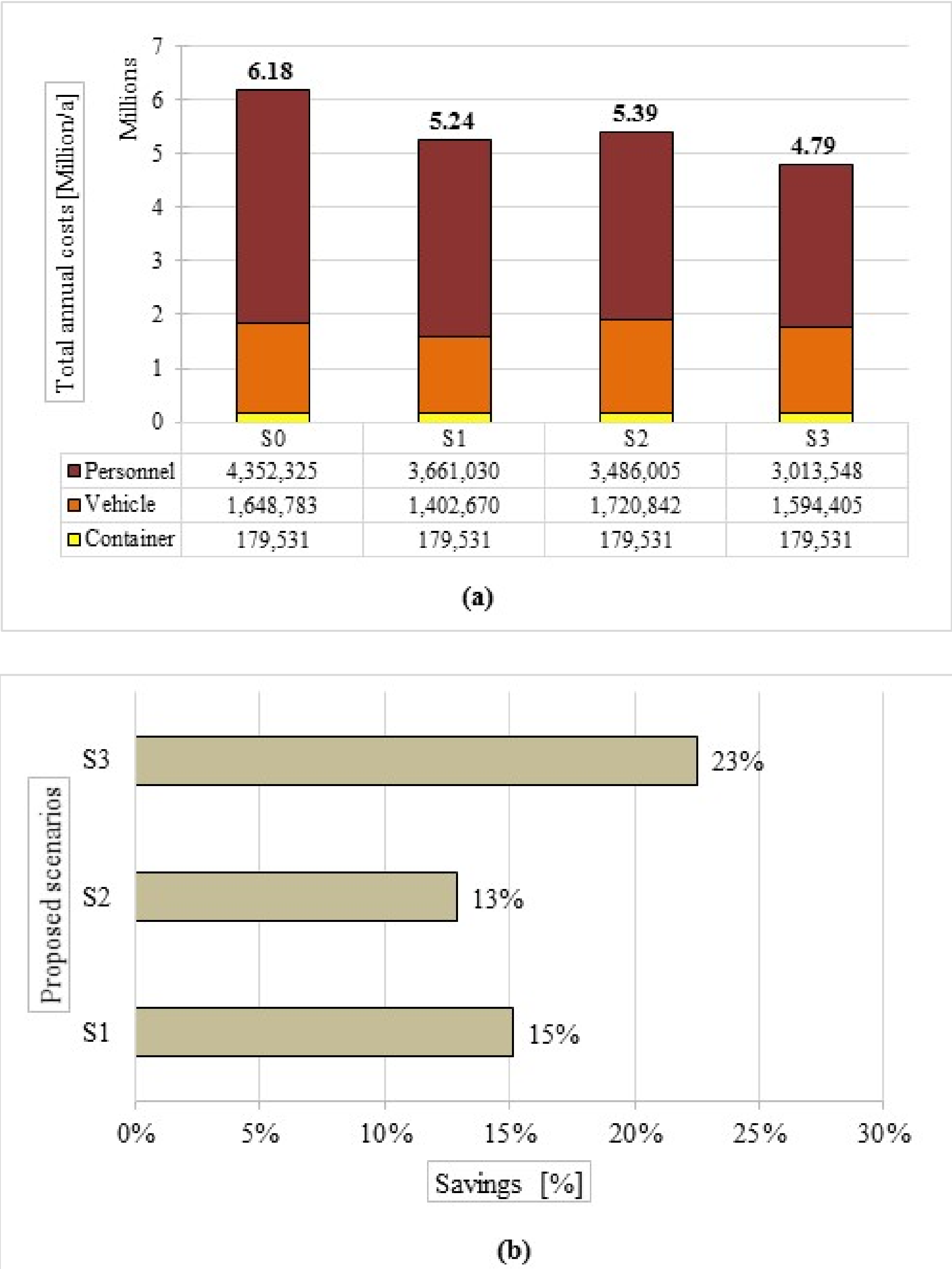


Figure 5-15. *The (a) annual collection costs projections [JD/a] and (b) savings [%] for the proposed scenarios & compared with the initial situation in the city of Irbid*

The results indicate that the GIS-based optimised scenario is flexible and can provide reasonable and significant improvements to the collection and transportation system of solid waste, and consequently to its financial and environmental costs. Therefore, GIS-based models can be tested in any waste collection compactor travel route; thus, any waste collection authority could implement the method to improve their waste collection management with considerable financial and environmental savings. The remarkable savings obtained from the proposed scenarios or models encourage expanding the scope of the study to cover other entire cities and international ones as well, since it has a similar configuration for waste management.

Globally, urbanisation as well as the steady rise in the human population has resulted in the generation of a large quantity of waste. These waste streams have led to a number of challenges (environmental, social and economic) especially in the developing countries (Awasthi et al., 2014; Sukholthaman and Sharp, 2016). To overcome these concerns, effective management strategies for these waste streams should be adopted. Among the various waste treatment options, composting has gained wide popularity owing to its associated benefits such as hygienization of waste, cost effectiveness and conversion of waste to value-added products (Qian et al., 2014; Onwosi et al., 2017). In accordance with the latest trend of environmental policies, composting is a valuable way of solid waste treatment that contributes to reducing organic waste destined to landfill disposal or incineration (Storino et al., 2016).

Composting remains the most widespread method of organic waste recycling worldwide. It is traditionally defined as the aerobic biological decomposition and stabilisation of organic substrates, under conditions that allow the development of thermophilic temperatures as a result of biologically produced heat, to obtain a final product that is stable, free of pathogens and viable plant seeds, and can be beneficially applied to land (Oazana et al., 2017). Composting methods are generally classified into two main categories: closed systems (vertical and horizontal flow reactors) or open systems (windrows and forced aerated static piles). Windrow composting is still the most common due to its low capital investment and operating costs, simplicity of operation and design, and relatively high treatment efficiency (Aspray et al., 2015).

Composting can be beneficial in the recycling of the organic fraction of the solid waste, reducing as much as 30% of the volume of organic matter entering the already overcrowded landfill sites (El-Sayed, 2015). Diverting municipal solid waste organic material from landfills by composting has many environmental benefits, such as reducing greenhouse gas emissions and decreasing leachate quantities once discarded in landfills (Wei et al., 2017), and increasing the calorific value of feedstock in the case of energy recovery applications, co-processing, incineration, etc. (Zhou et al., 2014).

6.1. INTRODUCTION

Composting is a biochemical as well as heterogeneous process involving the mineralisation of organic matter to CO_2, NH_3, H_2O and incomplete humification resulting in a stabilised final product with reduced toxicity and pathogenic organisms (Das et al., 2011). It constitutes a series of techniques towards organic waste treatment that is in total agreement with sustainable agriculture (Adbrecht et al., 2011).

Composting is a reliable waste treatment option that could be useful in the reduction of the negative effects that may arise due to the application of organic waste to soil. This is because it provides sanitised and stabilised products which could be utilised as potential sources of organic fertilisers or in soil amendments (Qian et al., 2014). It is a continuous process which reduces the organic substances into smaller volumes (Raut et al., 2008). This occurs under natural or controlled conditions that involve the decomposition of organic matter to a useful product (compost) through microbial activities (Onwosi et al., 2017). Therefore, the composting process is influenced by physico-chemical parameters such as temperature, pH, particle size, moisture content, aeration and electrical conductivity (Li et al., 2013; Juárez et al., 2015).

Considering the benefits of composting, it can be used to transform organic matter into useful products using the degradative attributes of both macro and micro-organisms found in the contaminant matrix. It is a widely used technology for transforming organic waste to organic manure (compost), and thus recycles mineral nutrients (nitrogen (N), phosphorus (P) and potassium (K)) that could be utilised for agricultural purposes (Wang et al., 2015). This makes compost a serious competitor in the fertiliser market (Proietti et al., 2016). Thermophilic conditions associated with composting provide room for total hygienisation of compost by destroying pathogenic organisms present in waste (Kulikowska, 2016; Pandey et al., 2016). The composting process results in organic matter decomposition and humification (i.e. humic acid and humic substances formation). Therefore, if it is used as a bioremediation option, it plays significant role as a stabiliser (immobilises metal in the soil) and as a washing agent, since it is a good source of humic substances that could be deployed in the treatment of soil contaminated with heavy metals (Kulikowska et al., 2015).

From an economic point of view, composting can bring reductions in the cost of disposing of organic residues, as well as providing an income by virtue of compost being used as a substitute for other materials (chemical fertilisers and peat) that may be quite expensive (Proietti et al., 2016). Nevertheless, these merits attendant with composting procedures can only be achieved if the process is effectively managed (Storino et al., 2016). This implies that there should be adequate planning during composting to produce useful or value-added products (Awasthi et al., 2016). Therefore, successful operation involves the use of the right mixing ratios (Zang et al., 2016); optimisation of the various process parameters such as aeration rate, bulking agents, C/N ratio and moisture content (Azim et al., 2014; Kazemi et al., 2016); the use of adequate bulking agent (Chowdhury et al., 2014); and the use of mathematical models for effective simulation of the composting process (Petric and Selimbasic, 2008; Vasiliadou et al., 2015).

The physical and chemical properties of organic waste and the factors that affect their composting performance mean that easily identifiable and reliable methods are required to control the process in situ to enable proper decisions to be made regarding its performance (Hurerta-Pujol et al., 2010). Although the characteristics of yard waste will vary, depending upon the predominant vegetation in the area and the season in which it is collected, composted green waste typically contains low levels of heavy metals that are often present in sludge-based compost (Benito et al., 2005). This makes it environmentally sound.

Biomass residues available in Jordan may be derived from localised agriculture-related activities, the organic fraction of municipal solid waste (MSW), animal manure and organic industrial waste (Al-Hamamre et al., 2017). Therefore, composting can play a vital role in enhancing soil fertility and improving the agricultural economy. Recently, there has been increased interest in the Jordanian society for local handling and use of organic residuals that have been used as a soil conditioner and plant supporter.

In fact, composting of source-separated organic materials on an industrial scale of a larger amount of fruit, vegetables and plant residues has yet to be launched in Jordan. The way in which this model can be applied to small-scale composting and the best practices to ensure a correct and safe composting process needs to be investigated. The opportunity to use the different types of organic waste as compost requires scientific studies that endorse it and guide users concerning the aspects behind the better management of the composting operation.

To this end, in the present experimental study, it seemed appropriate to focus on (1) the monitoring and analysis of the temporal operating parameters in an aerobic composting process, (2) study some of the physical and chemical properties of the first small-scale application of source-separated bio-waste composting in Jordan and (3) the evaluation of the quality of compost products that can be obtained in practice by implementing a state-of-the-art windrow composting process to compare against established quality standards.

6.2. MATERIALS AND METHODS

6.2.1. EXPERIMENTAL SITE

The research experiments, with an annual capacity of 150 m^3, were conducted on an established composting pilot plant located at the Al Hussainiat landfill site around 25 km east of Al-Mafraq Governorate, Jordan.

The landfill site was previously described by Saidan et al. (2017). Jordan is a semi-arid country with scarce fresh water resources and relatively limited agricultural activities (Saidan, 2015; Al-Weshah et al., 2016). Currently, it ranks second in the world in water scarcity (Aboelnga et al., 2018; Saidan et al., 2018).

6.2.2. RAW MATERIALS

Based on the elementary value of compost as a natural fertiliser in agriculture, different types of organic waste, such as fruit, vegetable and plant residues, were used as the composting input material. Clippings and sawdust were used as bulking agents to provide the required C/N ratio needed for efficient decomposition.

The characteristics of the initial raw materials used in the composting experiments are presented in Table 6-1. Once the raw materials were prepared for composting, they needed to be sorted, screened and shredded if they contained large pieces, and then mixed in certain ratios to maintain nutrient content and bulk porosity.

Table 6-1. *The characteristics of initial raw materials used in composting.*

Properties	Fruit & Vegetables	Plant residues	Sawdust
Physical properties			
Bulk density Kg/m3	630.00	335.00	278.00
Moisture Content MC (%)	82.00	32.00	8.00
Chemical properties			
Dry Organic Matter (%)	60.00	61.3	91.00
Total organic Carbon (%)	33.00	45.00	52.00
Total Nitrogen (%)	1.5	1.4	0.13
C:N Ratio (w/w)	22.00	32.00	400.00
pH	6.71	6.71	5.90
EC (dS/cm)	3.60	3.1	0.42
Total P (%)	0.93	1.20	0.03
Total K (%)	0.84	1.38	0.01

6.2.3. METHODOLOGY

Four different types of compost were obtained by mixing fruit, vegetable and plant residues at different ratios to form the following:

P1: Fruit & Vegetables (100:0)

P2: Fruit & Vegetables and plant residues (75:25)

P3: Fruit & Vegetables and plant residues (50:50)

P4: Fruit & Vegetables and plant residues (25:75)

During each run, the different organic raw materials (fruit, vegetable and plant residues) were blended in certain ratios and gently mixed with bulking agents (tree clippings and sawdust) to provide the C/N ratio needed to obtain efficient decomposition (Table 6-2). Conditions to support rapid aerobic composting (moisture and aeration) were then supplied directly after mixing. The waste mixtures were aligned in long windrow piles (1.5 m high, 3 m wide and 18 m long) by a front-end loader and turned periodically, using a specialised windrow turner, to maintain adequate O_2 levels and rapidly initiate composting. Pile moisture was controlled by adding sufficient water to ensure the moisture content was 50% or higher. Overall, 84 days were required to produce the finished compost products. Differences in the input materials influenced the final C/N ratio of the pile. Typical operating parameters, such as temperature, oxygen, pH, moisture content and C/N ratio, were frequently monitored during the composting process.

Table 6-2. *Compost run ingredients and composting time.*

Compost Run 1	**Experiment Duration: 05.11.17 - 28.01.18**	**C/NM***	**Run No.**
Pile 1	100% Mixed Fruit &Vegetables**	24	P1
Compost Run 2	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	75% Mixed Fruit &Vegetables + 25% plant residues**	25	P2
Compost Run 3	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	50% Mixed Fruit &Vegetables + 50% plant residues**	27	P3
Compost Run 4	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	25% Mixed Fruit &Vegetables + 75% plant residues**	29	P4

* C/N_M is a theoretically calculated ratio for the resulting mixture.

** Mixed bio-waste means that it was mixed with 10 percent clipping and sawdust (v/v).

Samples were then taken at the end of the process to determine the chemical and physical properties. Each sample was constructed by mixing five subsamples taken from five points in the pile. These were then placed in polyethylene bags and transferred to the laboratory for analysis. All materials used in the composting processes were analysed to assess different parameters. This was carried out using the International Centre of Agricultural Research in Dry Areas (ICARDA) methods for nutrient extraction procedures (Rynk et al., 1992; Abbassi et al., 2015) and international standard methods for the examination of water and wastewater at the National Agricultural Research Center (NARC) laboratories and University of Rostock laboratories, Germany. Table 6-3 summarises the parameters that were analysed along with their corresponding standard methods. The composting method, which was based on the principle of windrow technology, was carried out by turning, which facilitated the aerobic decomposition of organic waste into odour free and stable compost. The prepared materials were therefore well-blended and aligned in long windrow piles, each of which were 18m long, 3m wide and 1.5m high, to ensure efficient mechanical turning.

Most types of bio-waste are a good source of nitrogen but, depending on the amount of bedding used, they may be low in carbon. Most materials available for composting do not fit the ideal ratio, so different materials must be blended (Abbassi et al., 2015). The proper blending of carbon and nitrogen helps to ensure that the composting temperatures will be high enough for the process to work efficiently and ensures that adequate supplies of other nutrients are available for microbes. During the four composting runs, four windrow piles comprising different types of organic waste were aerobically composted in an open site area using the windrow system. Each compost run consisted of one pile. As recommended for rapid aerobic composting, the raw materials were mixed in different component ratios (weight basis) based on theoretical calculations used to adjust the initial C/N ratios between 25 and 30.

Table 6-3. *Laboratory measurement of composting parameters and their corresponding standard methods.*

Parameter	Method	Reference
Moisture Content (MC)	Using electronic oven by drying at (105 º C for 24 hours) (w/w).	(Ryan et al., 2003)
EC	(1:10 w/v sample: water extract) by an EC meter with a glass electrode.	(APHA, 2005)
Ash Content	Muffle furnace by ignition at (550 o C for 6 hours).	(APHA, 2005)
Total Organic Carbon (TOC)	TOC (%) = ((100 - Ash %) ÷1/8)	(Mercer and Rose, 1968)
C/N Ratio	Expressed as ratio of (TOC / TKN) %	(Abbassi et al., 2015)
Total kjeldahl-N (TKN)	Regular Kjeldahl Method (automatic analyser)	(APHA, 2005)
Total P and K	Atomic absorption spectrometric methods	(Ryan et al., 2003)
Respiration Activities (AT4)	Soil quality-laboratory methods for determination of microbial soil respiration (ISO 16072:2002)	(Artola et al., 2009)
Heavy Metals	Inductively Coupled Plasma-Mass Spectrometer, Thermo-Elemental ICP-MS-X Series.	(Elmaslar-Özbaş and Balkaya et al., 2012)

The initial C/N ratios were calculated according to the following formula (Amlinger et al., 2005; Abbassi et al., 2015):

$$\mathbf{C/N_M = \frac{\Sigma\,(C/N_{1\ldots n} \times t_{1\ldots n})}{\Sigma\, t_{1\ldots n}}} \qquad \mathbf{(1)}$$

where,

C/N_M : C/N ratio of resulting mixture.

$C/N_{1\ldots n}$: C/N ratio of individual components of the mixture (from 1 to n).

$t_{1\ldots n}$: mass of individual components of the mixture in tons (from 1 to n).

The composting system adopted in this pilot plant was based on the principles of windrow technology. The composting piles were turned mechanically using a special compost turner (MENART 4719 SPM turning machine, Belgium) according to the following schedule: 1) 3–4 turnings in first week, 2) 2–3 turnings in second week, 3) 2 turnings in 3rd week, 4) one turning per week in the fourth and fifth weeks, and 5) from the sixth week onwards, one turning every two weeks if heating still occurred.

Water was continuously added to the piles to achieve the required moisture content of 50 – 60% (wet basis). The temperature was expected to increase due to the microbial activity and should be noticeable within a few hours of forming a pile as easily degradable compounds will be consumed. The temperature was measured using a digital probe one metre (three feet) long.

The composting process was expected to finish eight weeks from the first turning. However, the compost remained in the pile for four additional weeks for the purpose of curing. Each pile therefore required a total of twelve weeks to accomplish complete composting. However, to avoid prolongation of the research, the four runs were carried out in the same time interval. During the implementation of composting runs, a continual monitoring programme was conducted on a daily basis and permanent control of the piles was maintained. This programme contained direct in-situ measurement of the operating parameters of the composting process, such as temperature, pH, oxygen and the percentage of carbon dioxide (v/v) inside the windrow piles. These parameters helped to schedule the frequency with which the piles were turned.

To facilitate data interpretation during the composting process, regular sampling was carried out during the different stages of composting. In-situ measurements of the parameters, conducted to ensure a proper composting process was taking place and to indicate composting maturity, are tabulated in Table 6-4. The table also shows the frequency of parameter analysis. The ambient temperature and temperature within each pile were measured daily. The temperature of the pile was measured by dividing it into five equal sections and taking readings at five locations in each section (at the bottom, 0.25cm from the bottom, in the middle, 0.25cm from the top, and at the surface). From these, an average reading was then taken. The CO_2 and O_2 percentages inside each pile were measured directly using digital meters (Models 115 and 117 Testoryt Compost Systems) and before each turning operation (twice per pile). The pH values were measured using a pH meter with a glass electrode (1:10 w/v compost: water extract).

Table 6-4. *In-situ measurements of operating parameters during the composting process.*

Test	Method	Frequency
Temperature	Using a digital dry bulb thermometer (Compost Systems)	Daily
O_2 (v/v)	Using an Oxygen meter (Testoryt O_2 Compost Systems, Model 117)	Once a week
CO_2 (v/v)	Using a Carbon Dioxide meter (Testoryt CO_2 Compost Systems, Model 115)	Once a week
pH	(1:10 w/v sample: water extract) by a pH meter (GPRT 1400) with a glass electrode Redox-Electrode GE 105	Once a week

Representative samples were collected by dividing the pile into five equal sections and taking samples from three locations in each pile (0.25cm from bottom, in the middle, and 0.25cm from the top). The collected samples were analysed at NARC laboratories for the following parameters: moisture content (oven drying 105°C for 24hr), ash content (expressed as a percentage of residues after muffle furnace ignition at 550°C for 6 hr), and Total Kjeldahl Nitrogen (TKN) (using the regular Kjeldahl Method by FOSS Kjeltec™ 2300 Analyser Unit). Because the NARC laboratories were unable to analyse the stability (AT4) and heavy metal concentrations within the samples, the samples were sent to Rostock University laboratories, Germany, for analysis. The frequency with which the parameters were analysed is listed in Table 6-5.

Table 6-5. *Frequency of analysis of composting parameters in the laboratory.*

Laboratory Test	**Frequency**
Moisture Content (MC)	Once a week
EC	Every two weeks
Ash Content	Every two weeks
Total Organic Carbon (TOC)	Every two weeks
C/N Ratio	Every two weeks
Total Kjeldahl Nitrogen (TKN)	Every two weeks
Total P and K	Start and end
Total organic matter	At the end
AT4	At the end
Heavy Metals	At the end

The total amount of organic carbon was estimated from the ash content, using the following formula developed by Mercer and Rose (1968):

$$\textbf{TOC (\%)} = \frac{\textbf{VS (\%)}}{\textbf{1.8}} = \frac{\textbf{100 – Ash(\%)}}{\textbf{1.8}} \quad \textbf{(2)}$$

Where,

TOC (%): percentage of total organic carbon.

VS (%): percentage of volatile solids.

Ash (%): percentage of ash content.

The C/N ratio was calculated using the following formula:

$$\frac{\textbf{C}}{\textbf{N}} = \frac{\textbf{Carbon Content \%}}{\textbf{Nitrogen Content \%}} = \frac{\textbf{TOC (\%)}}{\textbf{TKN (\%)}} \quad \textbf{(3)}$$

Total phosphorus (P) was measured calorimetrically (Olsen et al., 1954; Abbassi et al., 2015) while total potassium (K) was measured using flame photometry (APHA, 2005). To evaluate the stability of the final composted product and determine the optimum C/N ratio, a compost respiration index (biological activity) was estimated using soil quality laboratory methods for determining microbial soil respiration (ISO 16072:2002) (Artola et al., 2009). The AT4 analysis and the measurement of concentrations of heavy metal were carried out at Rostock University Laboratories, Germany.

6.3. RESULTS AND DISCUSSION

This section presents the experimental data collected during the composting experiments. All the tables and figures in this chapter were constructed from these results. The experiments were carried out during four runs that contained four compost mixtures. The parameters of temperature, moisture content, pH, oxygen, carbon dioxide, C/N ratio, volume reduction, bulk density, nutrient content and water consumption were controlled and monitored during composting. The main operating parameters, which were controlled and monitored directly during composting, are discussed in the following sections and given in Appendix II.

6.3.1. CHARACTERISTICS OF THE RAW MATERIALS

As mentioned previously, there were four compost runs; P1, P2, P3 and P4, each consisting of different ratios of three mixtures. P1 was formed from four portions of fruit and vegetables (4F&V: 0 plant residues), P2 from three portions of fruit and vegetables and one portion of plant residues (3F&V: 1 plant residues), P3 from one portion of fruit and vegetables and one portion of plant residues (1F&V: 1 plant residues) and P4 from one portion of fruit and vegetables and three portions of plant residues (1F&V: 3 plant residues).

Three components are required to build a compost mixture: the primary substrate, amendment and bulking agents (Graves et al., 2000). In this study, fruit and vegetables and plant residues were the primary substrate. Sawdust was mainly used to balance the C/N ratio or modify the pH value by mixing fresh bio-waste with approximately 10% sawdust. Clippings or branches and woodchips were used as bulking agents to provide structure and porosity for the compost piles.

The mixing ratios were calculated based on the formula developed by Amlinger et al. (2005) to achieve a C/N ratio that ranged from 25 to 30 for mixtures depending on their weight. The windrow piles were then mechanically turned according to a periodic schedule to maintain effective aerobic decomposition. Water was added to provide optimum moisture, which is critical for the function of microorganisms during the composting process. The moisture content for prepared piles was adjusted to range from 50–60% (w/w). Monitoring of the temperature, moisture content and oxygen supply was carried out to ensure the composting process was effective.

The blended ratios for the compost mixtures are listed in Table 6-2, and the initial physical and chemical characteristics of the raw materials in the composting piles are listed in Table 6-6. The composting process was carried out in ambient conditions at an open site and the windrow piles needed twelve weeks to produce biologically stable and heat sterilised compost.

Table 6-6. *The initial physical and chemical characteristics of composting piles.*

Parameter	**P1**	**P2**	**P3**	**P4**
Ash Content (%)	56.1	64.4	57.2	55.1
Volatile Solids (%)	43.9	35.6	42.8	44.9
TOC (%)	25.4	27.4	30.0	33.3
TKN (%)	1.06	1.09	1.11	1.15
C/N Ratio (w/w)	24.0	25.1	27.0	29.0
Moisture Content MC (%)	28.0	26.0	25.0	23.0
pH	6.84	7.36	7.71	7.97
EC (dS/m)	2.43	2.45	3.01	3.36
Total P (%)	1.12	1.27	1.44	1.48
Total K (%)	1.29	1.37	1.41	1.47
Initial Pile Volume m^3	36.0	38.0	36.0	40.0
Initial Bulk Density Kg/m^3	521.0	472.0	371.0	295.0

6.3.2. PHYSICAL PROPERTIES

Temperature

An increase in the temperature was clearly observed during the early phase of composting for all piles (see Figure 6-1). An internal temperature profile, characterised by an initial increase followed by a decrease before finally approaching ambient temperature, can be traced back to the typical rise and fall in temperature within the time expected in traditional windrow composting.

As Figure 6-1 shows, all piles exhibited typical composting temperatures, achieving thermophilic temperatures of more than 55°C and reaching approximately 67°C within two weeks, especially in pile P2 (thermophilic phase). Thereafter, the temperature declined slightly to around 60°C and remained above 50°C from week six to week eight (active phase), before dropping further during the second phase of composting (curing phase).

The addition of a bulking agent allowed for good aeration during composting, favouring microbial respiration and augmenting the exothermic activity of the decomposition process. As reported by Smith and Jasim (2009), the ideal thermophilic temperatures during a small-scale composting process are sometimes difficult to attain if only vegetable residues are composted.

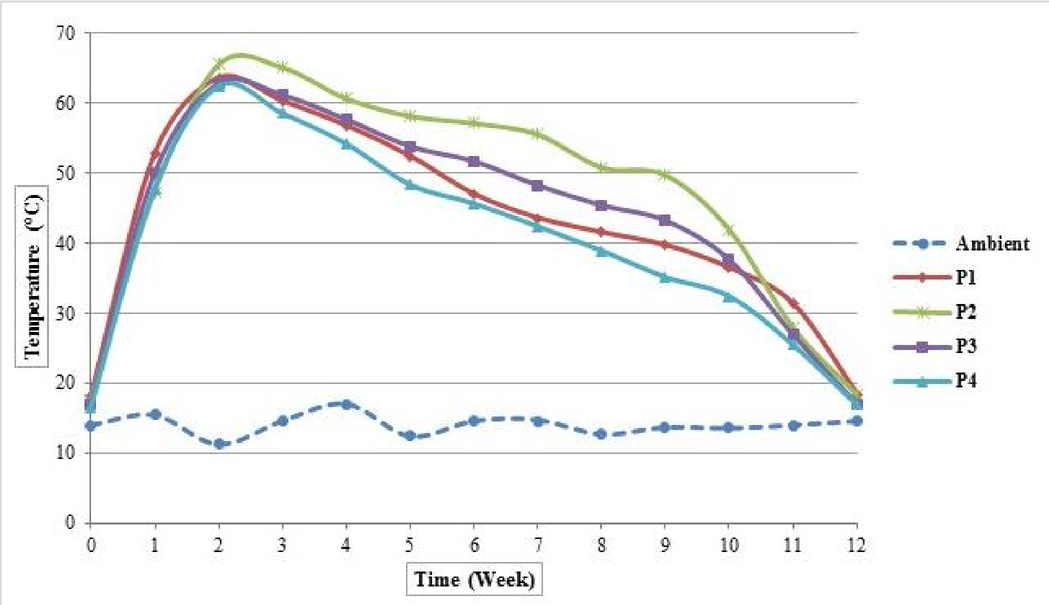


Figure 6-1. *Average temperature profiles during composting runs*

As the process progressed, the temperature began to decrease gradually after five weeks and, with an ambient temperature, reached a constant level after twelve weeks. Notably, in P4 the short thermophilic development and continual temperature decrease indicated high initial C/N ratios (low nitrogen content) which indicates the carbonaceous degradation of raw compost material (Rynk et al., 1992;WSU, 2016).

In windrow composting, windrow size, turning frequency, initial C/N ratio, ambient temperature, moisture content and oxygen supply are among the variables that can affect the temperature (USEPA, 1985). According to USEPA guidelines for pathogen control, the thermophilic period for all piles was achieved during the active process (Tchobanoglous et al., 1993; Abbassi et al., 2015).

As the organic matter became more stable, the microbial activities and decomposition rate declined, and thus the temperature gradually decreased to the ambient level, marking the end of the active phase. The reduction of the pile temperature to that of the ambient temperature was evident in the last four weeks, indicating that the maturation of organic materials into biologically stabilised products was efficiently accomplished.

Oxygen and carbon dioxide concentrations

Under aerobic conditions, emissions of carbon dioxide are a good indicator of the amount of degraded organic carbon. Therefore, the key factor in the composting process (i.e. aerobic biological activity) can be monitored and optimised through the continuous measurement of oxygen levels. If the oxygen supply is limited, micro-organisms favour anaerobic conditions that have high odour potential (Haug, 1993; Abbassi et al., 2015). The concentration of O_2 and CO_2 was used as an indicator for turning the piles, regardless of the turning schedule previously discussed in the research methodology. If the O_2 concentration was found to be close to zero in any sampling location, turning was immediately applied to provide the microorganisms in the pile with the required oxygen.

As Figure 6-2 clearly shows, the initial concentration of oxygen within the body of the piles was very low due to the high rate of biological activity. This was also evident from the results of CO_2 concentrations in the initial phases, which were very high. As the composting process progressed, the oxygen concentration increased and CO_2 concentrations decreased. This is attributed to the decreasing rate of biological degradation (Haug, 1986; Abbassi et al., 2015).

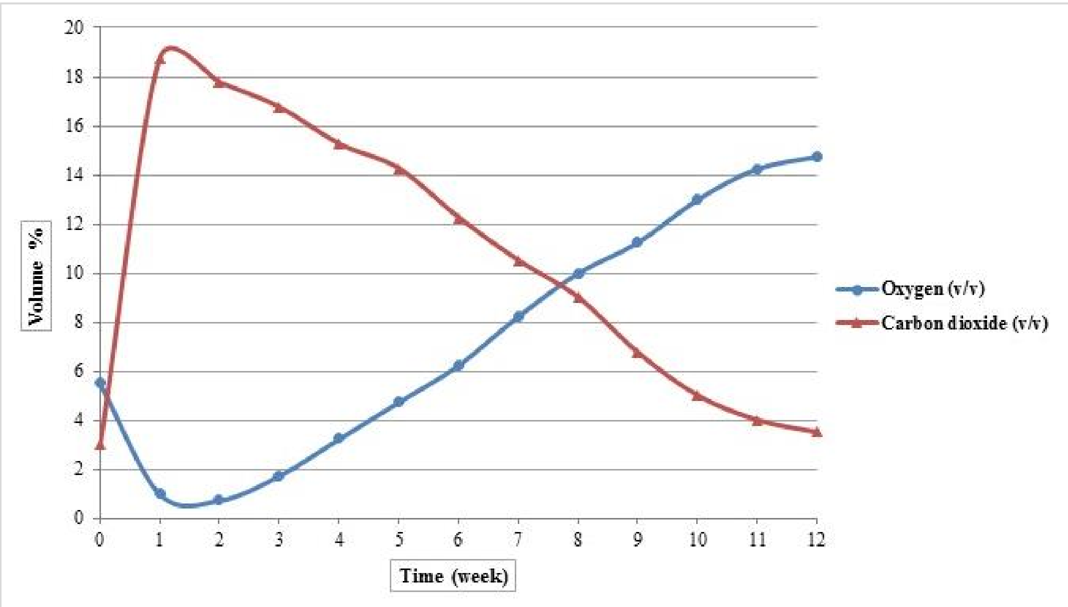


Figure 6-2. *Average O_2 and CO_2 concentrations for all piles during composting runs*

As shown in Figure 6-2, CO_2 concentrations inside the entire pile immediately increased to around 20% (v/v) during the first week of composting. O_2 concentrations exhibited the opposite trend, declining rapidly to the lowest level (0%) from the start of composting. Thereafter, O_2 concentrations gradually increased as the composting process progressed, reaching their highest levels during the curing phase. The change in trends regarding O_2 and CO_2 concentrations is attributable to vigorous microbial activity during aerobic composting. Therefore, concentrations of O_2 and CO_2 in an aerobic process serve to monitor the provision of sufficient oxygen to the piles via windrow turning practices.

Bulky materials, such as woodchips, are often used to maintain structure and porosity because they decompose at a much slower rate than other carbon sources, such as sawdust. Furthermore, the structure of the plant residues used in P2, P3 and P4 were better than those of fruit and vegetables (P1). This was critical in providing porosity and, hence, aeration. Well-aerated mixtures result in low turning frequencies and high-quality products (Willson, 1993). The concentration of CO_2 in the final curing phase of composting (approximately 3%) clearly demonstrates that existing biological degradation proceeds at a very low rate.

Moisture content

Moisture content (MC) is a critical parameter in the composting process. It influences the oxygen uptake rate, free air space, microbial activity and temperature of the process (Petric et al., 2012). According to Bernal et al. (2009), the optimal MC for effective composting depends on the waste type or form. They opined that the feedstock MC should be at 50–60%. To this end, moisture content levels inside the composting piles remained close to 50% to ensure high organic matter degradation with sufficient porosity and proper aeration and, consequently, aerobic degradation and composting throughout the entire experiment. Water was added to maintain the moisture levels at around 50% for the first eight weeks. This ensured optimum microbial activity and a sufficient oxygen supply. In general, the moisture content decreased gradually during composting, causing slow decomposition and low temperatures. The moisture content values ranged from 33 to 38% for different types of compost (see Figure 6-3). The lowest value of moisture content (33%) was found for fruit/vegetables with plant residues (1:0) compost while the highest value of moisture content (38%) was obtained for fruit/vegetables with plant residues (1:3) compost.

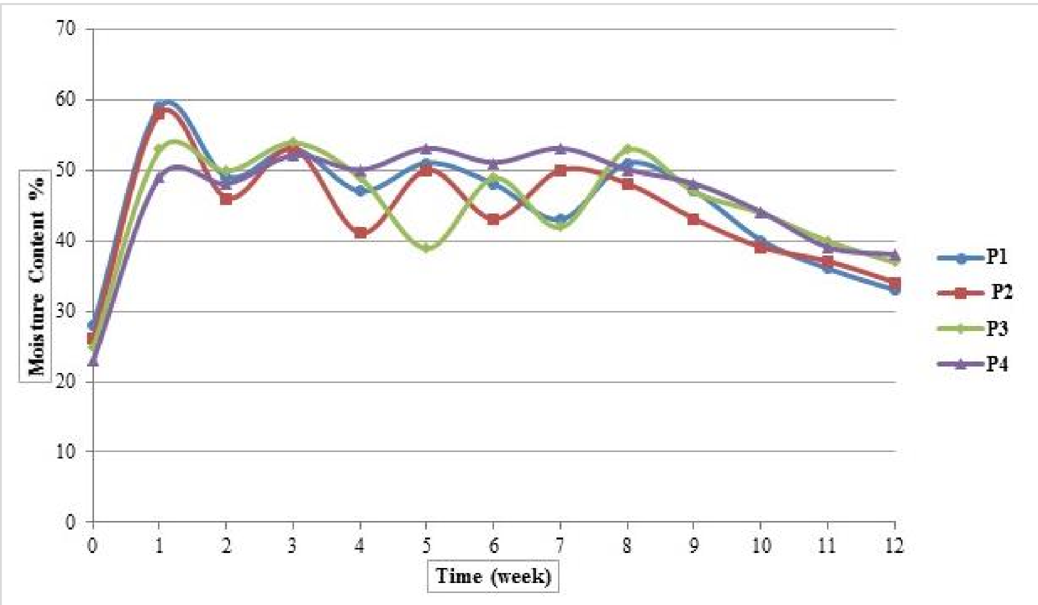


Figure 6-3. *Average moisture content during composting runs*

Large variations in the moisture content during the active composting phase, especially between week two and week eight, were attributed to the thermophilic temperatures caused by vigorous microbial activity, as well as the excessive frequency of turning which reduced the existing moisture content inside the piles. Moreover, higher porosity and aeration led to greater sensitivity in the variation of moisture (Abbassi et al., 2015). When the moisture of the compost decreased, limiting the process, the temperature decreased, which was especially evident in the treatment with the high bulking agent ratio (P3 & P4) where the highest decrease in temperature was observed; similarly, the temperature in P3 and P4 increased quickly when enough moisture was provided by watering once again.

When the curing phase began at the end of week eight, the moisture content in all piles gradually decreased to around 30%, especially in P3. By the end of composting, the highest water content, around 38%, was found in P4. This was attributed to the high initial C/N ratios (high carbon content) within the raw materials used, which reduced the rate of decomposition (Lynch and Cherry, 1996).

Bulk density, volume of piles and water consumption

As a result of the biological activities, organics in the composting material (substrate) were mineralised and transferred into stable materials and carbon dioxide. The consequence was a reduction in the piles' volume (Figure 6-4). These results were found to be in agreement with the findings of Yue et al. (2008) and Abbassi et al. (2015). The pile volumes decreased in the range of 22–30% by the end of the composting processes (after twelve weeks), which was attributed to vigorous microbial activity within the pile (see Figure 6-4). This is crucial in further justifying the use of composting, as it means a 30% reduction in transportation requirements for composted material compared to non-composted and unstable organic material.

The results indicate that the bulk density value ranged from 340 to 603 kg m^{-3} for different types of compost. The highest bulk density (603 kg m^{-3}) was found for P1, which was formed from one portion of fruit and vegetables and zero portions of plant residues (1F&V: 0P). The lowest value of bulk density (340 kg m^{-3}) was found for P4, which was formed from one portion of fruit and vegetables and three portions of plant residues (1F&V: 3P). Hurerta-Pujol et al. (2010) found that bulk density values ranged between 350 and 502 kg m^{-3} for different compost types, results supported by those of Raviv et al. (1987), Larney et al. (2000), Mohee and Mudhoo (2005) and Romeela et al. (2008).

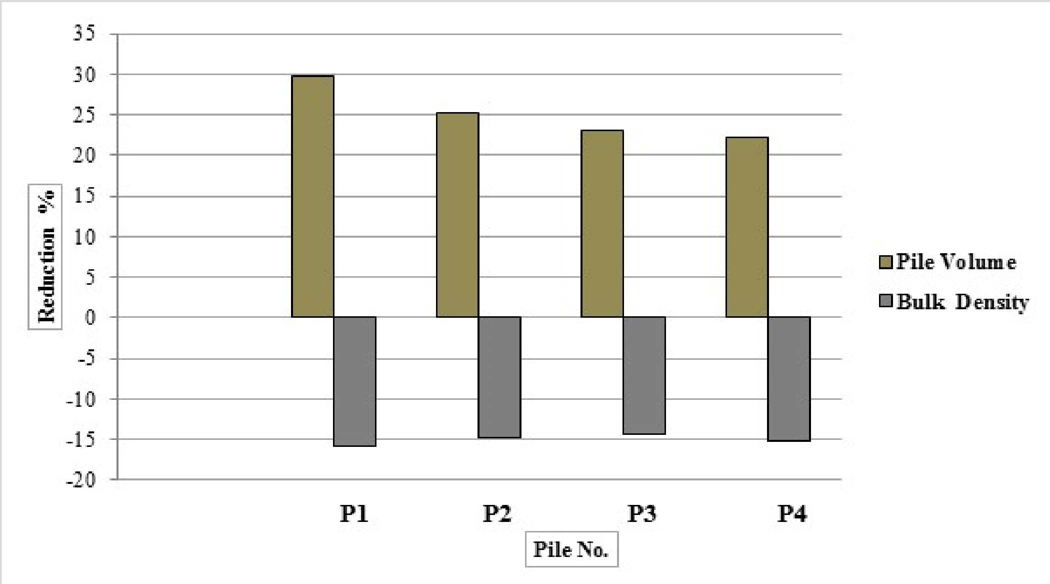


Figure 6-4. *Pile volume and bulk density during composting runs*

This reduction in the volume of material was offset by an increase in bulk density, where an approximate 15% increase was observed (Figure 6-4). This can be attributed to the fact that the bulk density of compost increases as total organic matter decreases (Figure 6-5). Conversely, the bulk density of compost decreases as the total organic matter increases. For instance, bulk density increases from 340 to 603 kg m^{-3} when the total organic matter decreases from 39.7 to 24.3%.

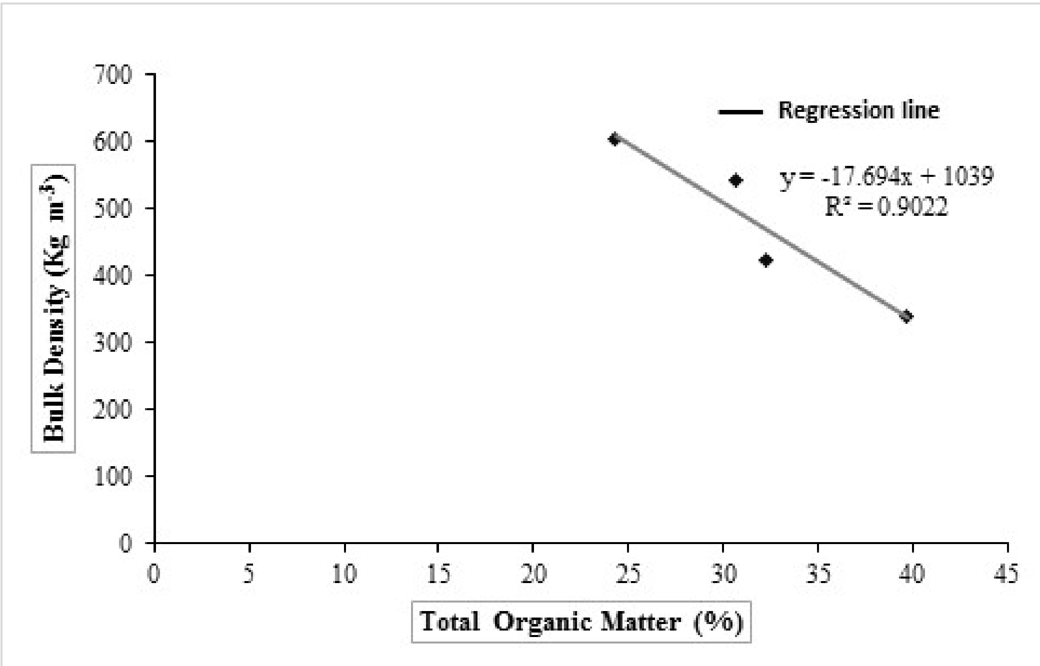


Figure 6-5. *The relationship between bulk density and total organic matter*

The relationship between the bulk density of compost and the total amount of organic matter within the compost is shown in the following equation:

$$\mathbf{BD = -17.694\ TOM + 1039 \qquad R^2 = 0.90 \qquad (4)}$$

Where:

BD is the bulk density (kg m^{-3})

TOM is the total organic matter (%)

The internal heat generated due to microbial activity and the ambient environment affected the provision of optimum moisture levels inside the composting piles. A summary of the initial volume of organic material, final composting volume and water added volume is shown in Figure 6-6. This shows that the amount of added water (in volume) was more or less equal to the amount of organic fertiliser produced (in volume), therefore a 1:1 ratio can be assumed. This means that the ratio of water added in relation to the amount of raw composting material was about 60% for the four piles, which is in line with Abbassi et al.'s (2015) findings.

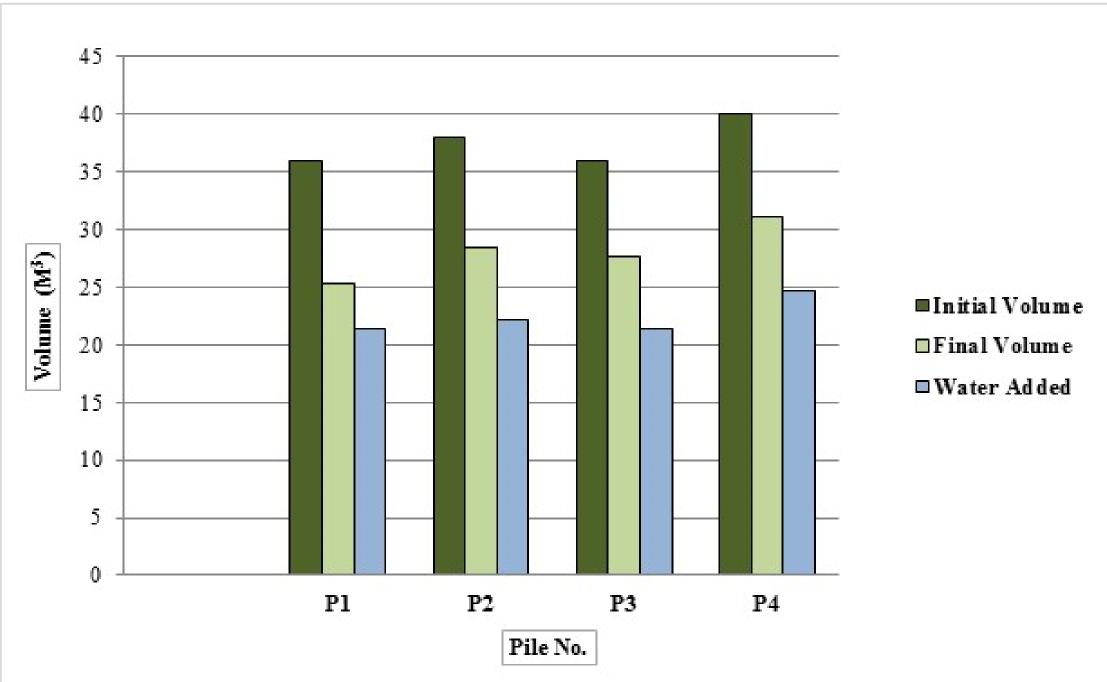


Figure 6-6. *Pile water consumption during composting runs*

6.3.3. CHEMICAL PROPERTIES

C/N ratio

The C/N ratio is an important parameter to determine the maturity and quality of the compost product (Pandey et al., 2016). On average, microorganisms use 30 carbon atoms per nitrogen atom; therefore, the optimal C/N ratio for the start of the process is generally between 25 and 35; higher values act as an obstacle to the development of microorganisms, due to the relative shortage of nitrogen; lower values cause loss of nitrogen, as ammonia or nitrous compounds, with the consequent generation of bad smells and a negative environmental impact (Proietti et al., 2016).

In this study, the C/N ratios obtained during composting at different time intervals are shown in Figure 6-7. This shows that the four piles had different initial C/N ratios. These ratios ranged from 24 to 29 across all the piles, which all exhibited similar C/N ratio reduction profiles and trends. However, Figure 6-7 shows that the C/N measures of the experimental composting windrow piles clearly decreased overall in relation to the weekly composting time, which is qualitatively consistent with the C/N reduction generally expected in the evolution of the composting process (Rynk et al., 1992). The C/N ratio clearly decreased in the second phase of composting (after eight weeks) in comparison to the first phase (up to eight weeks). This, however, was expected due to the lower degradation rate in the second phase. The final C/N ratio ranged from 14.4:1 to 18: 4 for all the piles. The lowest C/N ratio (14.4: 1) was found for P1 and the highest (18.4: 1) was found for P4. These results are in accordance with the results obtained by Rosen et al. (1993); Dougherty (1999) and Pandey et al. (2016) who reported that the C/N ratio of matured compost is to be less than 20, which is ideal for ready-to-use compost.

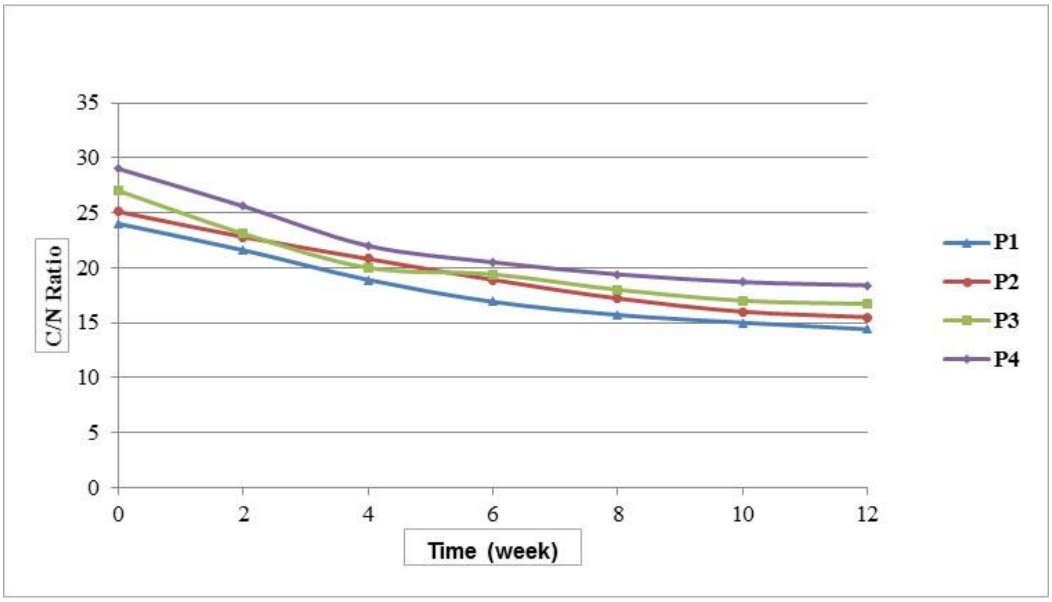


Figure 6-7. *Average C/N ratio profiles during composting runs*

Regarding the reduction of C/N ratios, the highest reduction of C/N ratio took place in the P1 pile, where more than a 40% reduction was achieved (see Figure 6-8). This high level of reduction can be attributed to the degradation process, as well as the low initial C/N ratio (Rynk et al., 1992; Abbassi et al., 2015). Furthermore, piles P2, P3 and P4 exhibited C/N ratio reductions of approximately 39, 38 and 36%, respectively.

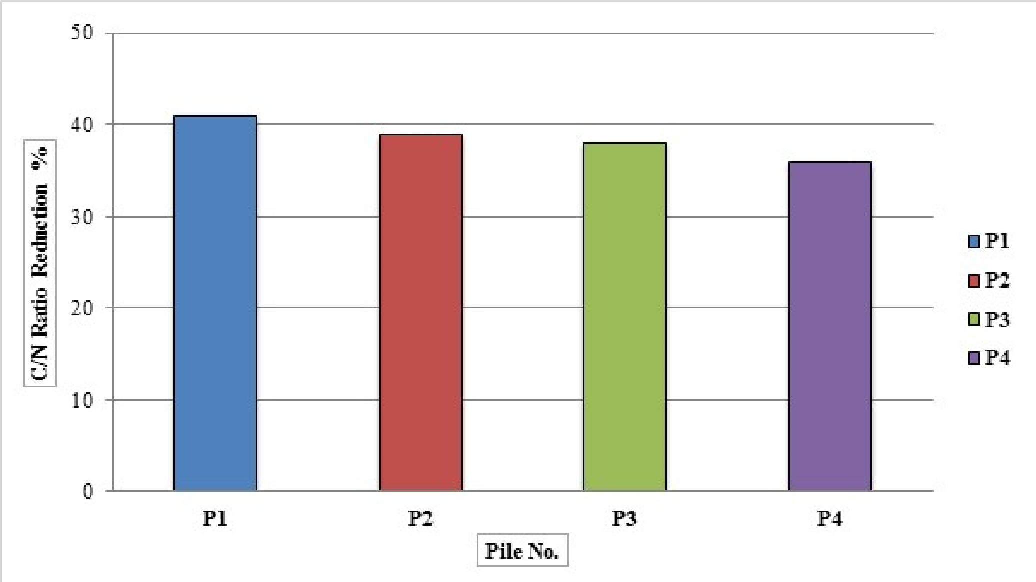


Figure 6-8. *C/N ratio reduction profiles during composting runs*

The total amount of organic carbon ranged from 26.9 to 47.9% for different types of compost. The lowest value (26.9%) was found for P1, which was formed from one portion of fruit and vegetables and zero portions of plant residues (1F&V: 0P) and the highest value (47.9%) was obtained for P4, which was formed from one portion of fruit and vegetable and three portions of plant residues (1F&V: 3P). These results are supported by those of Batjes (1996) who found the optimum value of total organic matter to be higher than 10%.

For total nitrogen, the experimental composting windrow piles exhibited pronounced overall increases in measured content in relation to weekly composting time. This increase in nitrogen appears to be in accordance with the concentration effect generally expected in the composting process due to the gradual decomposition of organic matter. This causes weight loss and, consequently, a relative increase in concentration (in terms of dry matter) provided that a possible concurrent nitrogen loss is relatively less than the weight loss (Dougherty, 1999). However, as decomposition proceeded, the nitrogen content of the piles generally increased. The total nitrogen values ranged from 1.87 to 2.61% for the different types of compost. The lowest value (1.87%) was found for P1, which was formed from one portion of fruit and vegetables and zero portions of plant residues (1F&V: 0P) and the highest value (2.61%) was found for P4, which was formed from one portion of fruit and vegetables and three portions of plant residues (1F&V: 3P).

These results are in accordance with those obtained by Benito et al. (2005) who found that the total nitrogen rate ranged from 0.99 to 3.01%. Accordingly, the carbon ash content slightly decreased due to high microbial activity during composting as large amounts of carbon were transformed via microbial respiration to CO_2 (Dougherty, 1999).

pH

The pH value of the compost is important because applying compost to the soil can alter the pH of the soil which, in turn, can affect the availability of nutrients to plants (USCC, 2001; CIWMB, 2007). The pH is a measure of the active acidity in the feedstock or compost and most finished compost will have pH values ranging from 6 to 8; these ranges may substantially differ depending on the kinds of feedstock used. Microorganism growth and gaseous loss of ammonia are influenced by variations in pH during composting; therefore, the optimum pH for microbes involved in decomposition lies between 6.5 and 7.5 (Rynk et al., 1992).

After a possible initial drop that most likely occurred during the first two weeks of composting (CIWMB, 2007), the changes in pH presented in Figure 6-9 appear to be in qualitative agreement with the typically expected pH-time profile of the composting process. In particular, the experimental windrow piles exhibited a similar temporal sequence with a phase of increasing pH followed by a decreasing phase (although with a final increased value in the sixth week).

The pH profiles of the pile materials during the four runs are shown in Figure 6-9. This shows there was a decrease in pH during the first two weeks of composting and that the pH of decomposition lay between 6 and 7.5. The decrease in pH values is attributed to the biological activities of aerobic decomposition, which produces hydrogen atoms (acid) (Poincelet, 1977).

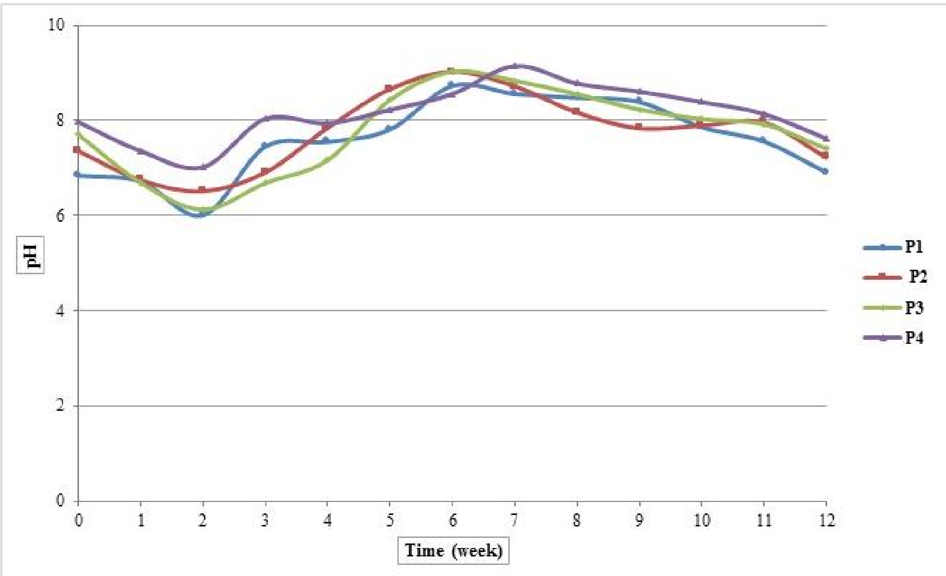


Figure 6-9. *Average pH profiles during composting runs*

Despite the high rate of biological activity during the initial phase of composting, pH values were never less than 6. This can be explained by the high buffering capacity of the composting material, which prevents a sharp decrease in pH values (Willson, 1993). As the composting process progressed, pH values increased up to 9, and had generally stabilised between 6.9 and 7.6 by the end of the second composting phase. This pH range is within the optimum range for growing media which, according to Bunt (1988), is from 5.2 to 7.5.

Electric Conductivity (EC)

Johnson et al. (2005) defined electrical conductivity (EC) as a numerical expression of the conduction of electrical current by an aqueous solution. Electrical conductivity reflects the salinity of an organic amendment (Lazcano et al., 2008). During composting, the concentration of salts increases unavoidably due to the decomposition of complex organic matter (Chan et al., 2016). The EC indicates the total salt content of compost reflecting the quality of compost to be used as a fertiliser (Jiang et al., 2015; Awasthi et al., 2014).

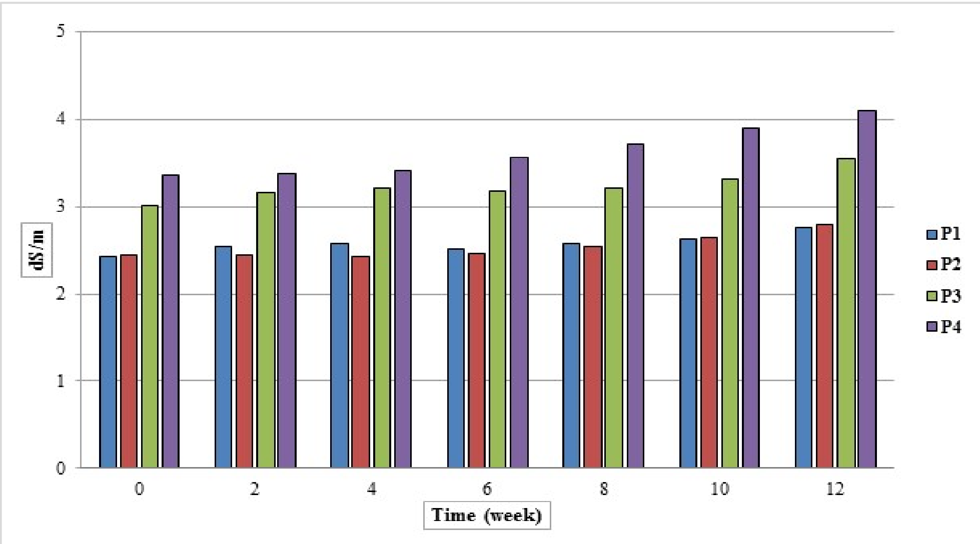


Figure 6-10. *Average EC values during composting runs*

As shown in Figure 6-10, measures of electrical conductivity in the experimental piles increased overall in relation to weekly composting time. In general, an increase in electrical conductivity, which parametrically reflects the salinity of the matrix, is an additional indication of progress in the composting process as the gradual decomposition of organic matter is usually accompanied by the increased relative concentration of different mineral ions (Hanlon, 2012). The electric conductivity (EC) of the compost samples varied from 2.76-4.1 dS/m, with a median value of 3.17. This EC range is within the optimum range (2.0 to 4.0) for growing media (Hanlon, 2012). Compared to the initial values, the final ECs for all runs showed an increase of 11.9, 12.5, 14.9 and 17.8% in P1, P2, P3 and P4, respectively. This can be attributed to mineralisation in the organic material of the waste and the EC content of added water.

Nutrient content

Organic waste supplies balanced nutrients to plant roots, stimulating growth, increasing the organic matter content of the soil (including the 'humic substances' that affect nutrient accumulation) and promoting root growth. Thus, they improve all the physical and chemical properties of the soil (Bombatkar, 1996). They also add useful microorganisms and provide food for existing soil microorganisms, increasing their biological properties and capacity for soil fertility self-renewal. Actually, one ton of compost may contain 10lbs of nitrogen (N), 5lbs of phosphorus (P_2O_5) as well as 10lbs of potash (K_2O) (Ouédraogo et al., 2001).

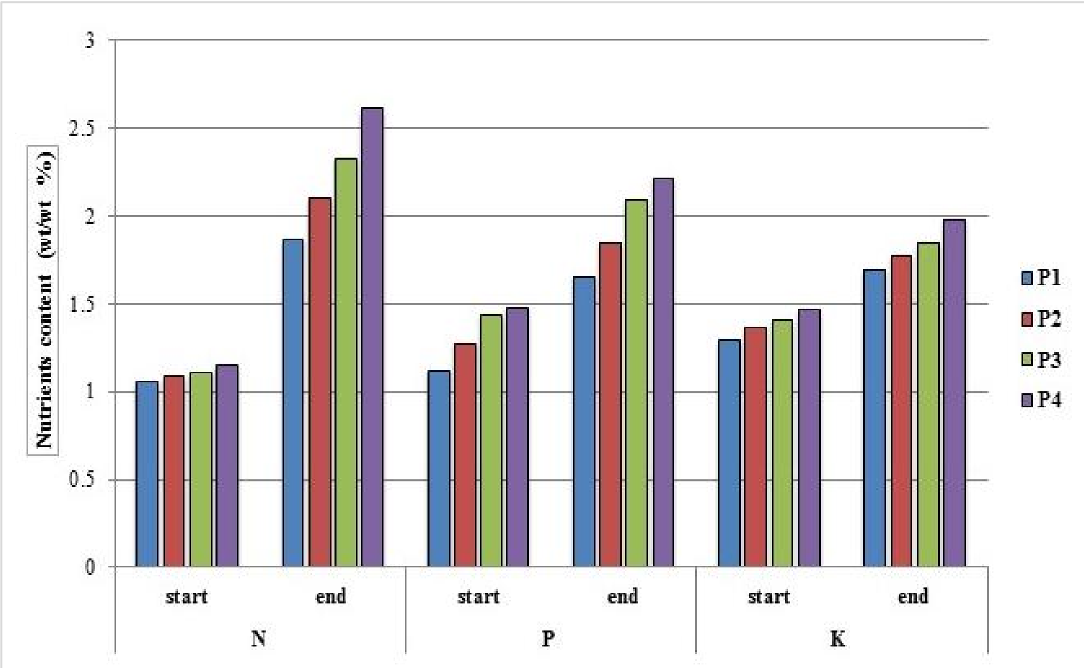


Figure 6-11. *Nutrient content wt/wt (%) during composting runs*

The temporal evolutions in the experimental windrow piles of extractable nitrogen, phosphorus and potassium are reported in Figure 6-11. This shows that all the experimental windrow piles exhibited overall increases in measured N, P_2O_5 and K_2O content in relation to weekly composting time, with final values (by the end of twelve weeks) of 1.87, 2.1, 2.33 and 2.61% for N concentrations; 1.65, 1.85, 2.09 and 2.21% for P concentrations; and 1.69, 1.77, 1.85 and 1.98% for K concentrations, which were exhibited in P1, P2, P3 and P4, respectively.

As Figure 6-11 shows, there was an increase in the agriculturally beneficial fertilising elements of nitrogen, phosphorous and potassium. Overall, 43, 48, 52 and 56% increases in N concentrations; 32, 31, 31 and 33% increases in P concentrations, and 24, 23, 24 and 26% increases in K concentrations were exhibited in P1, P2, P3 and P4, respectively. This increase was due to the reduction in composting volume and the increase in pile bulk density (Bombatkar, 1996; Ouédraogo et al., 2001).

Organic matter

Four samples (one sample from each run) were tested in n=3. Organic matter (OM) in the samples ranged from 19% to 40% (see Figure 6-12). The organic matter content of all the compost samples was lower than the value set by the German standard, which is between 15–45% (BioAbfV, 2017).

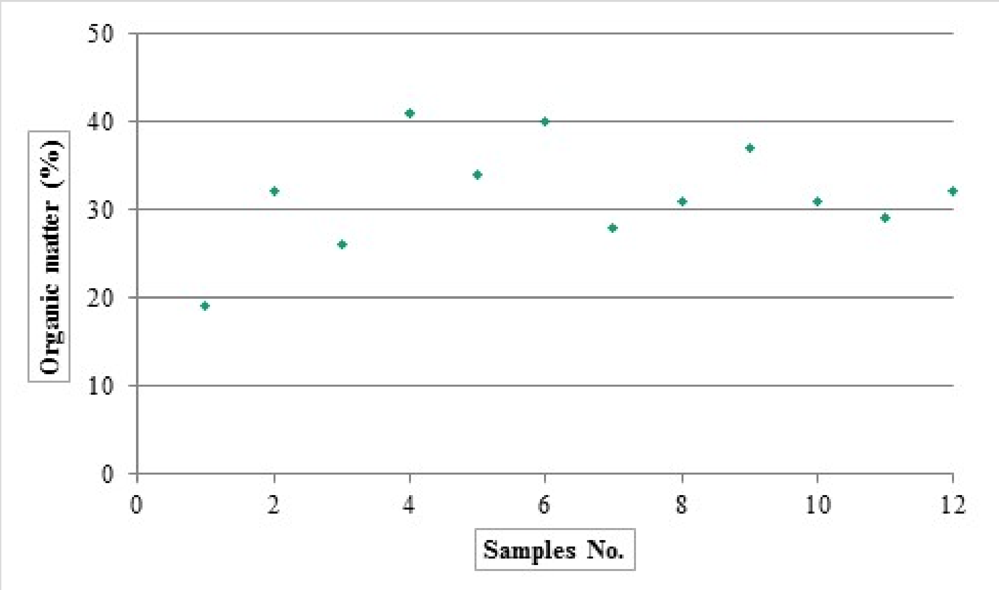


Figure 6-12. *Organic matter content in the analysed compost samples*

The results are averages, with the lowest average value for total organic matter (24.3%) found in P1, which was formed from one portion of fruit and vegetable waste and zero portions of plant residues (1F&V: 0P). The highest average value of total organic matter (40%) was found in P4, which was made from one portion of fruit and vegetable waste and three portions of plant residues (1F&V: 3P). These results are in accordance with those of Benito et al. (2005) who found that the highest value of total organic matter to be around 45%.

Heavy metals

High levels of heavy metals represent an obvious concern when the compost is destined to be applied to food crops (Bhattacharyya et al., 2001; Papadimitrou et al., 2008). Heavy metals do not degrade during the composting process and always become more concentrated due to microbial degradation.

Heavy metals in compost products are sourced from the raw materials that have been subjected to composting. Thus, the method of waste collection (i.e. source-separated or mixed collection) and composition characteristics of the raw materials significantly affect the quality of the compost product (Wei et al., 2017). In terms of heavy metal concentrations, the samples analysed showed that the resulting content in the four windrow piles monitored during the twelve weeks of composting were below the respective upper limits of Table 6-7.

Table 6-7. *Heavy metal concentrations of compost compared with German standards.*

Parameter	Range	German standard (BioAfV, 2017)	
		Class A	Class B
Pb mg/kg	12.22 – 53.65	**150**	**100**
Cd mg/kg	0.19– 0.39	**1.5**	**1.0**
Cr mg/kg	12 – 17	**100**	**70**
Cu mg/kg	21 –57	**100**	**70**
Ni mg/kg	11 - 14	**50**	**35**
Hg mg/kg	< 0,05	**1.0**	**0.7**
Zn mg/kg	152 – 268	**400**	**300**

Source separation is generally regarded as the most effective and promising method for improving compost quality in terms of metal content (Veeken and Hamelers, 2002). The content of the metals (Pb, Cd, Cr, Cu, Ni, Hg and Zn,) in source-separated compost is shown in Table 6-7, which clearly indicates the effectiveness of source-separated collection on the control of metal content as the concentrations of all seven heavy metals were significantly lower in the source-separated compost.

Respiration activities

Respiration is directly related to the metabolic activity of a microbial population. Microorganisms respire at higher rates in the presence of large amounts of bioavailable organic matter, while the respiration rate is slower if this type of material is scarce. In the composting process, respiration activity has become an important parameter for determining the stability of the compost. Additionally, it is also used to monitor the composting process and is an important factor when estimating the maturity of the material (Komilis and Ham, 2003).

A wide range of respirometric protocols have been reported in the literature, based either on CO_2 production, O_2 uptake or the release of heat. The most common methods are those based on O_2 uptake. Respirometric assays are affected by a number of parameters including temperature, humidity, and both incubation and pre-incubation conditions. In drafts of European legislation (European Commission 2001), stabilisation means a reduction in the decomposition properties of bio-waste to the extent that offensive odours are minimised and respiration activity after four days is below 10mg O_2/gm dm (Tiquia, 2005; Gea et al., 2007; Barrena et al., 2008). A high value on the Maturity Index (MI) indicates high potential efficiency of the composting process due to high temperature generation, lingering thermophilic condition, prolonged composting and high C/N reduction.

Therefore, this test contributes to an understanding of stability and maturity from a microbiological basis. Its measurement is used to estimate the biological activity in a sample and refers to a specific stage of organic matter decomposition, during or after composting, that is related to the type of organic compounds remaining and the resultant biological activity in the material.

Table 6-8. *Classification of the compost samples analysed for the AT4 test (Kehres, 1998).*

Rotting class	AT4 (mg O2/g DM)	Classification of the samples tested	Product description
I	>40	0 %	Compost raw materials
II	40-28	0 %	Fresh compost
III	28-16	0 %	Fresh compost
IV	16-6	50 %	Finished compost
V	<6	50 %	Finished compost

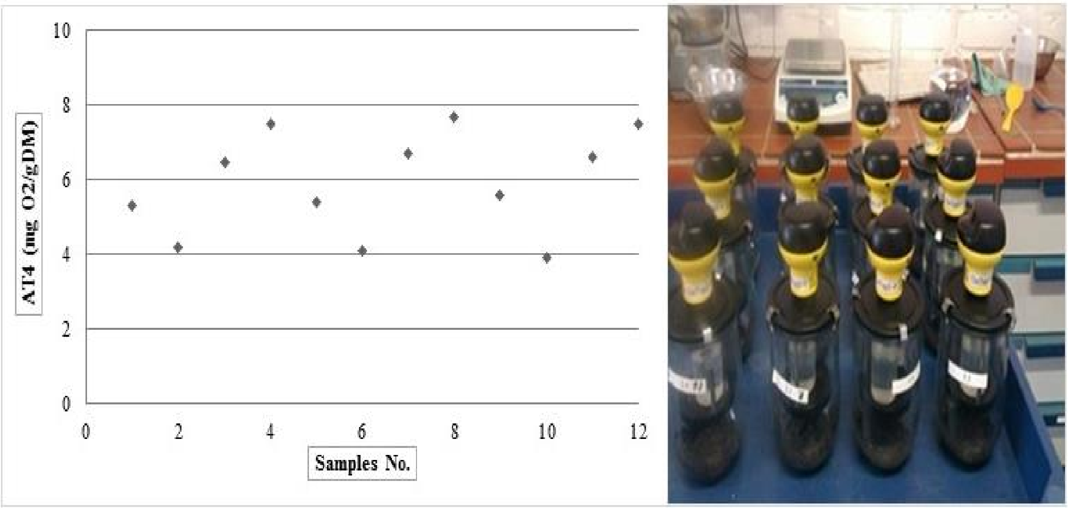


Figure 6-13. *Results of the AT4 test for all compost samples included in the study*

The stability or maturity of the final product is of vital importance in ensuring successful agricultural application. However, an unstable compost product indicates that microbial activity is high enough to cause adverse effects (Garcia et al., 1992). Because compost has traditionally been used agriculturally, this implies that plant growth will be negatively impacted. Therefore, mature compost will exhibit characteristics that indicate the completeness of the composting process. The stability of any given compost is important in determining the potential impact of the material on the nitrogen available in the soil. Most uses of compost require a stable to very stable product that will prevent nutrient tie-up and maintain or enhance oxygen availability in the soil. As shown in Table 6-8, compost respiration in the samples varied from 3.9 to 7.7 mgO_2/g dm (see Figure 6-13). Accordingly, all of the compost samples appeared to be stable and thus can be rated as IV and V finished products (see Figure 6-14).

Figure 6-14. *Distribution of compost samples according to their rotting degree/class*

The results indicate that the compost produced was stable and there was no more biological activity. This means the organic material had been destroyed to form a new stable material (soil) that can be used for agricultural purposes. This also indicates that the compost production process was performed successfully, under ideal conditions and within a relatively short time (84 days), which, in turn, reduces the costs. Table 6-9 summarises the results achieved at the end of all runs.

Table 6-9. *Final physical and chemical characteristics of composting for all runs.*

Parameter	P1	P2	P3	P4
Ash Content (%)	40.1	43.8	39.2	39.4
Volatile Solids (%)	59.9	56.2	60.8	60.6
TOC (%)	26.9	32.6	38.8	47.9
TKN (%)	1.87	2.10	2.33	2.61
Total Organic Matter (%)	24.3	30.7	32.3	40.7
C/N Ratio (w/w)	14.4	15.5	16.7	18.4
Moisture Content MC (%)	33.0	34.0	37.0	38.0
pH	6.91	7.22	7.41	7.62
EC (dS/m)	2.76	2.80	3.54	4.09
Total P (%)	1.65	1.85	2.09	2.21
Total K (%)	1.69	1.77	1.85	1.98
Final Pile Volume m^3	25.3	28.4	27.7	31.1
Volume Reduction %	29.7	25.3	23.1	22.3
Final Bulk Density Kg/m^3	603.0	542.0	424.0	340.0
Bulk Density Increase %	15.74	14.83	14.29	15.25
Water Added m^3	21.4	22.1	21.4	24.6
m^3 water / m^3 manure	0.59	0.58	0.59	0.62
Heavy metals mg/kg				
As	< 5	< 5	< 5	< 5
Pb	38.30	19.30	53.65	12.22
Cd	0.39	0.28	0.32	0.19
Cr	17.0	16.0	16.0	12.0
Cu	57.0	42.0	42.0	21.0
Ni	14.0	13.0	13.0	11.0
Zn	268.0	167.0	166.0	152.0
Hg	< 0,05	< 0,05	< 0,05	< 0,05

Overall, the results of the experiment showed that compost with acceptable chemical properties (OM, TOC, TKN, total P, total K, heavy metals) and physical properties (bulk density, moisture content, etc.) was produced. These findings indicate that composting was carried out successfully under optimised conditions. The findings show that the quality of the compost produced depends largely on the level of the C/N start-up ratio and the quality of constituents within the mixture.

7. Potential Production and Utilisation of Refuse Derived Fuel (RDF) as an Alternative Fuel for the Cement Industry in Jordan

Municipal solid waste (MSW) disposal and management is one of the most significant challenges facing urban communities around the world. The effective management of solid waste involves the application of various treatment methods, technologies and practices to ensure the protection of public health and the environment. Solid waste management (SWM) over the years has utilised many sophisticated technologies and smart strategies (Reza et al., 2013). There is a wide range of alternative waste management options and strategies available for dealing with mixed MSW to limit the residual amount left for disposal to landfill (Adani et al., 2002).

Solid waste landfilling, composting, recycling and incinerating are usually used as solid waste disposal or treatment methods. Landfilling is the most commonly used waste disposal method worldwide, despite all the significant environmental, health and economic impacts of this method (Uso´n et al., 2013). However, the disposal of MSW is challenging in many areas, mainly because landfill space is becoming scarce, and there is a growing public environmental awareness. Therefore, recent MSW management strategies encourage material recycling, energy recovery and the stabilisation of MSW prior to landfill. Thus, combustion and biological processes, yielding thermal power, refuse-derived fuel (RDF), compost and stabilised products have attracted increasing attention. Therefore, MSW can be a viable source of energy rather than being a source of pollution, if properly managed and utilised (Al-Hamamre et al., 2017).

A good alternative for the region is the waste-to-energy (WtE) concept by which mixed MSW is converted to RDF (Madlool et al., 2011). This alternative mainly involves the reduction of the moisture content of the waste, which increases the calorific value of the resulting product and decreases the production of leachate in the case of landfilled material if no further stabilisation of organic material is applied. It also includes the possibility of converting the waste into energy, the recovery of recyclable material and the reduction of pollutants emitted into the environment (Velis et al., 2010).

7.1. Introduction

As in many developing countries, solid waste is a major environmental problem in Jordan. Population growth in urban centres, lack of strategic planning, lack of proper disposal facilities, limited collection services, use of inappropriate technology and inadequate financing are considered the main problems facing solid waste management systems (Diaz et al., 1999; Saidan et al., 2017).

In the case of Jordan, there are various factors that contribute to making waste and waste management processes one of the most serious environmental problems in line with population growth, current modern standards of living, rapid economic growth, the expansion of urbanisation, the lack of suitable and well-designed sanitary landfills and, finally, political reasons, which include the massive influx of refugees caused by the conflicts in neighbouring countries (Nassour et al., 2011; Al-Awad et al., 2018; Alrabie et al., 2018). According to Jordan's Ministry of Municipal Affairs, in terms of the generation and collection of MSW, about 2.7 million tons is produced by a population of 6.7 million (MOMA, 2014), while in 2009 it was about 1.9 million tons for a population of 5.8 million (MOMA, 2009). However, the massive influx of refugees is the main reason for the remarkable increase in the recent generation rate with regard to MSW in Jordan. Therefore, waste and waste management has become one of the major challenges for the hosting regions (Saidan et al., 2017; Al-Hamamre et al., 2017). In this context, it is worth mentioning that Jordan is non-oil producing country with 96% of energy supply in the country imported (Saidan, 2012). Moreover, Jordan is a semi-arid country with scarce fresh water resources and relatively limited agricultural activities (Saidan et al., 2015; Al-Weshah et al., 2016). Currently, Jordan is ranked second in the world in water scarcity (Aboelnga et al., 2018; Saidan et al., 2018).

Due to a high proportion of food waste (>50%), the MSW of many developing countries, such as Jordan, has a high water content, which lowers the recovery of material and increases the operational cost of combustion (Bezama et al., 2007; Hazra and Goel, 2009). Some processes could be applied to mixed MSW to overcome these problems, and to improve the material and energy recovery from the waste stream. Composting and other bio-stabilisation processes result in the degradation of easily degradable organic matter while biodrying processes dry the waste while increasing its heating value by reducing its water content (Sugni et al., 2005; Bezama et al., 2007; Zhang et al., 2008; Rada et al., 2009). However, RDF is an alternative fuel produced from energy-rich MSW materials diverted from landfills. It is a solid recovered fuel that can be used as a substitute for conventional fossil fuels in industrial sectors, for example, but not limited to, the cement industry (Reza et al., 2013).

The cement manufacturing industry is considered one of the greatest energy consumers in the world. Moreover, it currently faces several economic and environmental challenges. Therefore, there is a great potential for using solid waste as alternative fuel in this sector. The cement subsector uses approximately 12–15% of the total industrial energy worldwide (Madlool et al., 2011) in order achieve a consumption level of 120 kWh/t of cement (Uso´n et al., 2013). Regarding carbon dioxide (CO_2) emissions, 5–7% of human-generated CO_2 emissions are contributed by the cement manufacturing industry globally (Reza et al., 2013). However, several studies have shown that these figures have been reduced by up to 5% worldwide in the last few years as a result of improved energy efficiency and the use of alternative fuels.

Jordan is faced with a shortage of available landfill space and difficulties in constructing new landfills. Additionally, Jordan is a country which lacks natural resources with regard to fuel or energy. Accordingly, using RDF as an alternative fuel in the cement industry would significantly reduce greenhouse gas (GHGs) emissions, energy consumption, as well as raw material consumption. In this sense, the cement industry in Jordan has a great potential to use RDF produced from MSW as an alternative/substitute for fuel. Therefore, the RDF approach is a potential solid waste treatment option which is suitable for Jordan.

The potential for RDF production and utilisation as an alternative fuel in the Jordanian cement industry as a solid waste management sphere has not yet been launched, given that most of the previous studies were conducted on a small pilot scale and/or consisted of case studies for the area of interest, and have been developed based on limited data. Therefore, the aim of the present study was to investigate the potential for RDF production and utilisation as an alternative fuel for the Jordanian cement industry by using the biodrying process. A further objective was to investigate both the economic feasibility of the production and utilisation of RDF (for cement kilns) and the environmental impact in the context of the Jordanian integrated solid waste resource management plan in terms of examining the prospects of greenhouse gas emission reduction and the calculation of CO_2 feasibility upon replacing petcoke with RDF.

7.2. MATERIALS AND METHODS

7.2.1. STUDY AREA

The pilot project, with an annual capacity of 52Mg, was conducted in the Greater Amman Municipality (GAM), the city of Amman, Jordan. An established materials recovery facility (Tadweer Company) was selected to be the site of the research experiments. The Tadweer Company is located opposite the Al-Ghabawi landfill site around 40 km east of Amman, Jordan. The site is characterized by a continental climate, in that its climate is semi-arid, with hot dry summers and cool wet winters. This site is used as a recovery spot for recyclable materials, compost production, and energy retrieval from non-recyclable substances, such as RDF. It has been serving Amman city since 2003.

7.2.2. INPUT MATERIALS (MSW)

In Amman, as is the case in other Jordanian cities, municipalities are responsible on a day-to-day basis for municipal cleaning, waste collection and the disposal of the mixed household waste generated. Due to the geographical area and population, Amman city is divided into six (6) regions or districts for effective solid waste collection.

The waste under consideration has the typical characteristics of most waste in developing countries, such as high moisture content and a large organic fraction. Organic material represents the highest portion of the waste stream, about 60.2%. It contributes to the high moisture content, and hence leads to a low calorific value. However, in order to obtain a representative sample of the waste generated by the city of Amman, the input raw waste material was taken from the six regions of Amman over a period of six days from the Al-Ghabawi landfill (see Table 7-1).

__Table 7-1.__ The quantity of raw waste materials used for each trial in Kg.

Trials	Region	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Total
Trial 1	**R1**	870.3	890. 5	865.3	890.4	860.9	840.8	5.22
	R2	1080.7	1200.6	1180.5	1221.9	1189.4	1300.1	7.17
	R3	580.4	576.1	740.6	566.4	670.7	578.1	3.71
	R4	900.9	890.3	865.4	970.4	950,9	940.9	5.52
	R5	470.4	566.2	634.6	480,5	570.1	478.9	3.20
	R6	53	60	50	30	45	50	288
Total								**25000 Kg**
Trial 2	**R1**	980.9	980.4	758.8	870.5	788.7	860.1	5.240
	R2	1100.8	1150,6	1190.3	1190,2	1211,6	1298,9	7.142
	R3	590.4	666.3	790.4	656.1	550.7	580.3	3.834
	R4	795.1	840.6	970.4	975.1	985.7	978.6	5.546
	R5	577.3	534.5	595.3	522.5	467.2	468.7	3.166
	R6	63	50	45	35	50	40	283
Total								**25000 Kg**

For each district, according to the proportion of its participation in the total amount of waste generated annually (in 2017), sub-samples were taken from different waste trucks to achieve a representative sample for each trial. A total amount of 50 tons of municipal waste was collected as a sample from the targeted regions and unloaded at the test site (Appendix III).

7.2.3. Methodology

After delivery of fresh waste, about 50 tons of mixed MSW, a screening unit was used to categorise it according to size in the form of fractions of >100, >150, <100, <150 and <10 mm. For each trial, the waste fractions <100 mm during trial 1 and the fractions < 150 mm during trial 2, were subjected to a biodrying phase (the self-draining of waste) for a three week period to enable an effective screening of waste for separation of recyclable materials and those of high calorific value made up of components of fine organic fraction (see Figure 7-1).

Two biodrying trials were carried out over the same time period. Both trials were spread over nearly three months, and during this period municipal waste characterisation, sampling, and physical and chemical analyses were carried out. The method of biodrying, which was based on the principle of windrow composting technology, was carried out by means of turning the material in such a way that it allowed the aerobic decomposition of organic waste into odour-free and stable compost. The prepared materials were well-blended and aligned in two long windrow piles (2m high, 3m width and 25m long), by a front-end loader, and turned periodically using the loader to ensure efficient mechanical turning and to maintain adequate O_2 levels in order to ensure rapid decomposition.

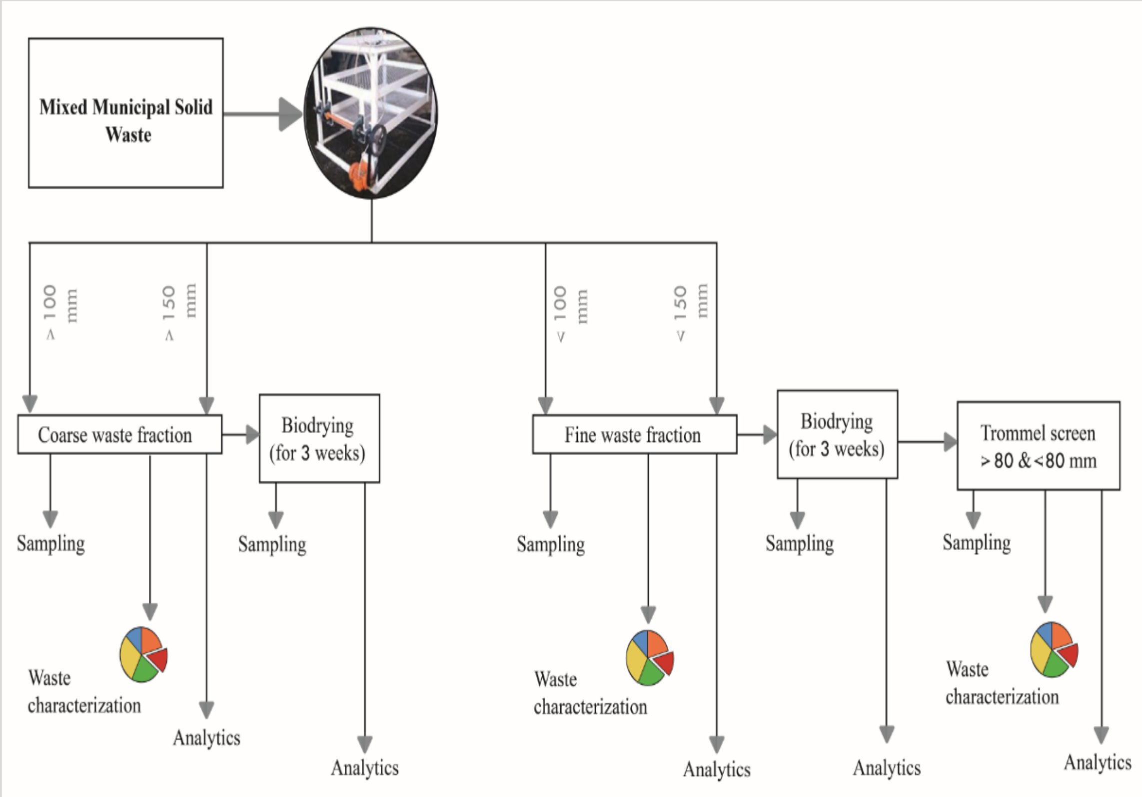


Figure 7-1. *The adopted methodology*

The biodrying process of the windrows so formed was monitored continuously. Typical operating parameters – temperature and moisture content – were monitored on a daily basis. A temperature thermometer probe was used to measure the temperature, and samples were taken weekly to examine the moisture content of the windrow piles. After three weeks, the process was finished, and the waste should have been dry. The waste, derived from trial 1 and trial 2, was separately screened at 80 mm using a drum screen (trommel screen). Accordingly, the split between > 80 and < 80 mm was determined on the site. Afterwards, the total RDF was weighed using a weighbridge in the closed dumping site in order to estimate and calculate the mass balance. The schedule of the two trials is listed in Table 7-2 below. The sampling was carried out during the different steps of the process as follows:

- Sampling for the characterisation of waste received at the site
- Sampling the dried waste during screening (at 80 mm) after three weeks (output)
- Sampling during the weekly turning of waste in order to monitor biological reactions.

All the samples passed three times through preparation and shredding at 20mm to reduce their size before analysis. The main parameters were: the dry matter content, ash content, chlorine content, heavy metals content and calorific value.

Table 7-2. The schedule of both trials during the pilot project period.

Trials	Quantity of waste (t)	Number of windrows	Beginning of trial	End of trial
1	25	1	02.01.2018	22.01.2018
2	25	1	02.01.2018	22.01.2018

7.2.3.1. Biodrying concept

In biodrying, the main drying mechanism is convective evaporation. This uses heat from the aerobic biodegradation of waste components, and is facilitated by a mechanically-supplied airflow. The moisture content of the waste is reduced through two main processes: water evaporates from the surface of the waste into the surrounding air, and the evaporated water is then transported through the waste by the airflow and removed with the exhaust gasses. A limited amount of free water may leak through the waste and be collected at the bottom in the form of leachate. The appropriate control of aeration operational parameters (e.g. air-flow rate and direction) and temperature can achieve a high biodrying efficiency (66.7% of initial water eliminated) (Adani et al., 2002; Sugni et al., 2005). However, the principle of aerobic biodrying is to drive evaporation with energy from organic matter degradation. Consequently, the capacity for water removal is limited by the amount of biodegraded organics.

Temperature is the key parameter for water evaporation and organic degradation during biodrying. The aeration of waste is critical for biodrying in that it provides a mass and energy flow medium and enables water content removal, heat-transfer redistribution, the removal of excessive heat, adjusting the windrow temperature and ensuring O_2 delivery for aerobic decomposition. The thermometer probe was set to maintain an average windrow temperature of around 40˚C to 70˚C. The air supply was controlled through the turning schedule. Waste was turned daily by the loader machine to avoid poor air distribution and uneven composting of the waste in the windrow, and also to maintain a good structure in order to maintain porosity throughout the entire composting period.

The resulting dry material was afterwards screened in order to separate the oversize fraction characterised by high net heating value from the smaller fraction, the biodried MSW fine fraction (MSWFF) that is characterised by low heating values (Velis et al., 2010; Tambone et al., 2011).

7.2.3.2. Characterisation of MSW

Waste Categories: Material classification was based on the "Methodology for the Analysis of Solid Waste" of the European Commission (European Commission, 2004). The waste fractions were divided into 18 primary categories (Table 7-3). A screen unit with a 100 and 150 mm screen was used to screen the waste to fractions < 100 and > 100 in the case of trial 1 and fractions < 150 and > 150 mm in the case of trial 2 to record the size distribution of the waste.

The characterisation method followed is described in the manual of the pilot project. A screening unit machine with a screen of 100 and 150 mm was used for the first screening. The entire waste sample was screened. After separating the waste into the initial four categories (< 100, > 100, < 150 and > 150 mm), waste bigger than 100 and 150 mm was then placed on a table and sorted. Before the first screening step at 100 and 150 mm, plastic bags containing materials were opened to make the contents available for screening/sorting.

Table 7-3. *Sorting fractions of waste samples (the manual of the pilot project).*

#	Sorting fractions	Examples
1	Organic "garden"	Grass clippings, leaves, weeds, tree and shrub cuttings.
2	Organic "kitchen/canteen"	Food waste, spoiled food, coffee and tea filters, kitchen waste, etc.
3	Wood	Painted and treated wood, wood covered with plastic, untreated wood
4	Plastic film	Plastic bags, freezer bags, cling wrap, covering and packaging films.
5	Plastic 3D	Plastic buckets, bottles, containers, etc.
6	Composite materials	Drink cartons for milk, juice, wine, soups, coffee vacuum packaging, toys, mobiles, chairs.
7	Fe-metals	Magnetic drink and foods cans, other magnetic metals.
8	Non Fe-metals	Non-magnetic drink and foods cans, other non-magnetic metals such as aluminium.
9	Glass	Bottles, jars for jam fruit and vegetables, jars for chocolate, drinking bottles, windows.
10	Inert	Porcelain, clay pottery, tiles, stone, brick, concrete.
11	Paper	Newspaper, magazine, catalogues, writing paper, envelopes, advertising, tissue paper.
12	Cardboard	Carton, boxes.
13	Textiles, shoes, bags	Clothes, covers, curtains, leather and plastic shoes, handbags, backpacks.
14	Hygiene products	Nappies, sanitary pads, bandages.
15	Batteries	Batteries, rechargeable batteries.
16	Electronic goods	Electrical and electronic goods.
17	Miscellaneous combustible	Rubber, hazardous materials, undefined materials.
18	Fines < 10mm	Screened materials (not further specified).

In addition, large particles (e.g. large pieces of cardboard, plastic film, etc.), which may disturb the screening process and could reduce the quality of the screening, were separated by hand and specified according to the defined sorting fractions. The sorted fractions were then weighed. From the waste which was fed to the first screening step of 100 mm and 150 mm, about 10% was separated as a sample for lab analysis.

The screen overflow > 100 mm and 150 mm was then sorted by hand into the sorting fractions defined in Table 7-3. The sorting fractions were then weighed. According to the waste sorting guidelines, about 10% of the complete fine fractions (<100 and <150 mm) was then manually sorted on a sorting table into up to 18 individual waste types.

Sorting was performed until a fraction size of about 20 mm was obtained; smaller fractions were not feasible. However, the complete fine fractions <100 and <150 mm were weighed and then a proportionate quantity of at least 40 litres (40 l) was taken for further investigation. The procedure to obtain this sample of 40 l was performed as follows: the materials <100 and <150 mm, separately, were piled on an even surface into a cone. This cone was turned once into a new cone to further homogenise the material. The homogenised cone was flattened to a uniform truncated cone and divided into four equal sections. Each of the diagonally opposite portions was combined to a new subset. The entire process was repeated until the desired quantity of about 40 l was obtained.

As mentioned previously, the waste was divided into 18 primary categories as shown in Table 3. The final category mentioned is all waste material particles passing the smallest screen, e.g. parts smaller than 10 mm. For this work, two primary categories – plastics and metals – were subdivided. Secondary categories of plastics were chosen – plastic film and 3D plastic. Metals were subdivided into ferrous and non-ferrous (aluminium). However, the individual waste types were largely separated during sorting. Plastic bags were emptied to obtain their contents. Even though one plastic bag itself does not represent a large mass fraction, it can still alter the calorific value of a sample, for example.

7.2.3.3. Sampling and analytical methods for input material

During biodrying, the samples of fresh waste were collected from each windrow for the fresh input of waste and during each turning of the windrows. Four 80 l buckets were filled from different places along the windrow; all of the samples went through shredding at 20 mm three times to reduce their size before analysis. The sampling procedure for input material and during the biodrying is illustrated in Figure 7-2. The main parameters are the dry matter content, the ash content, the chlorine content, heavy metals and calorific value.

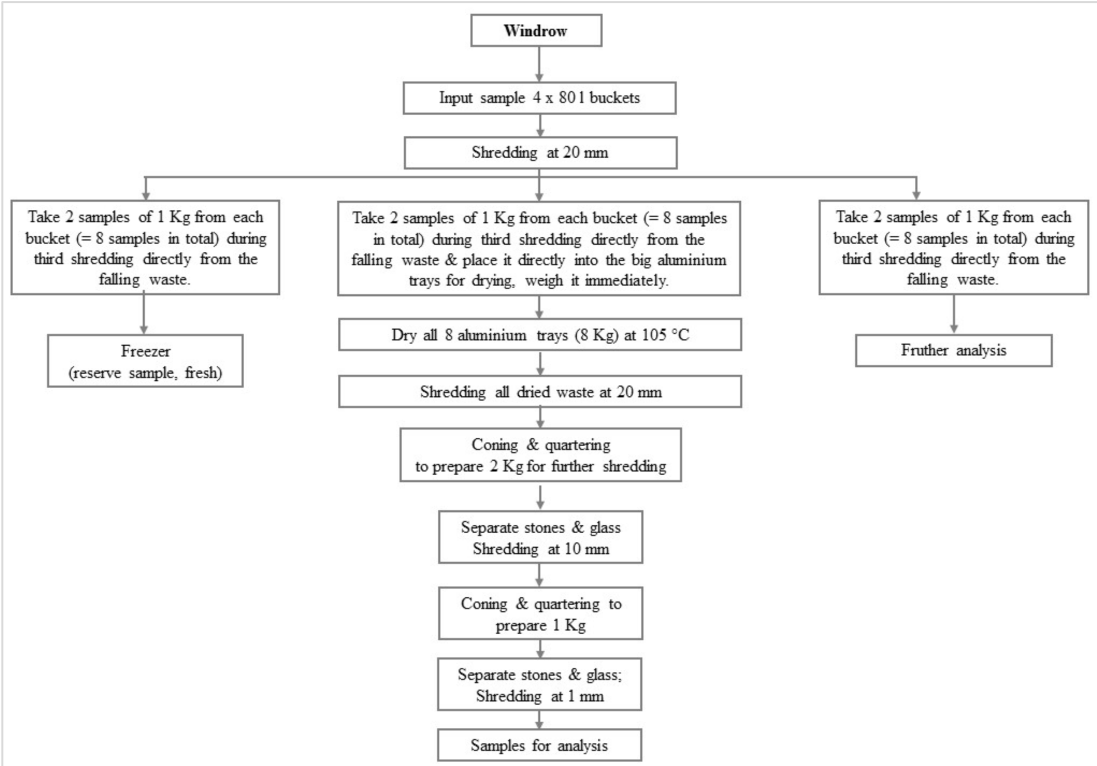


Figure 7-2. *Sampling and analytical methods for input material*

7.2.3.4. Sampling and analysis for the coarse fraction (>80 mm)

After three weeks, the biodrying process was finished and the material should be dried. The waste was screened at 80 mm using the drum screen. Samples were taken from the total waste, the coarse fraction >80 mm (RDF) and the fine fraction <80 mm. During the screening and sampling processes, the split between >80 and <80 mm was determined.

A total of four RDF samples were sorted manually, two samples during trial 1 (the main input screened at 100 mm) and two samples during trial 2 (the main input screened at 150 mm). Sampling for coarse fraction characterisation and analysis was done by collecting at least 15 buckets of 80 l during screening, parallel to the sampling of <80 mm for the determination of the screening split.

As shown in Figure 7-3, 11 buckets were used for the waste characterisation by hand sorting, the various components of the RDF were weighed, and the results are presented as percentages on a weight/weight basis. The other four buckets were used for the lab samples which went through various sample preparation processes such as shredding and drying.

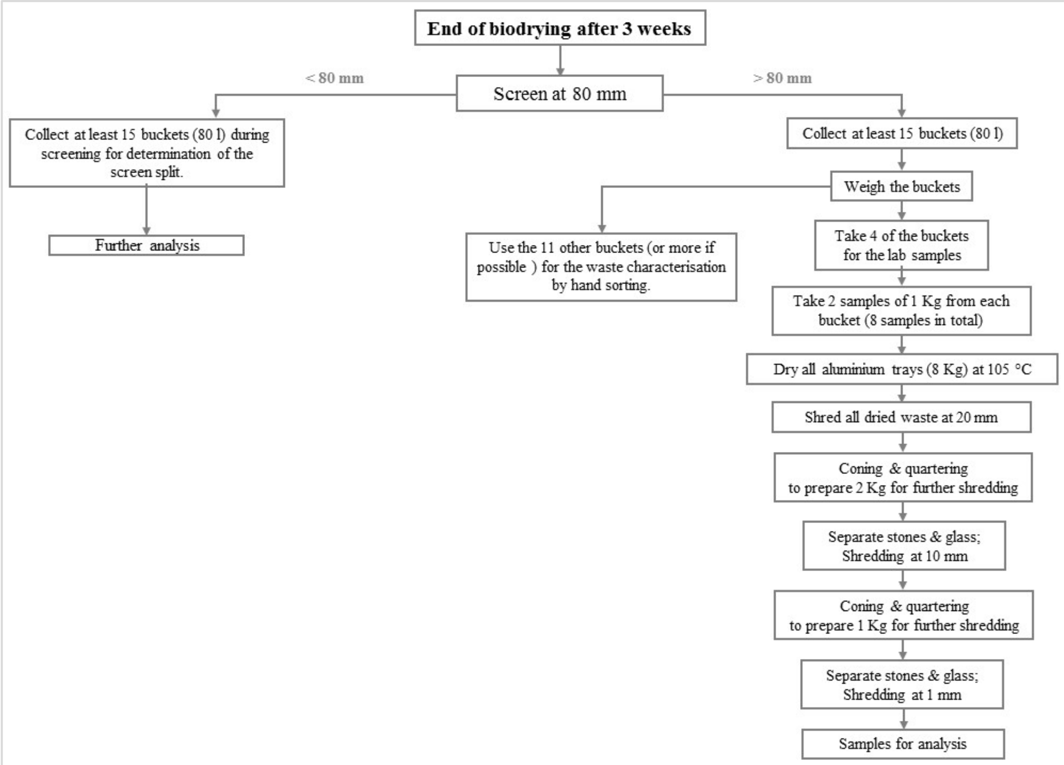


Figure 7-3. *Sampling and analysis for the coarse fraction; >80 mm*

Refuse-derived fuel is one of the products of recycling combustible waste fractions from MSW. It can be used as a fuel for steam or electricity production. To produce RDF, the heat value and chemical constituents, especially the presence of heavy metals and chloride, are normally taken into account to ensure the RDF has the appropriate quality in order to avoid the environmental problems that may result from the co-combustion (Rotter, 2004).

7.3. RESULTS AND DISCUSSION

7.3.1. CHARACTERISATION OF THE MSW

Waste characterisation was based on the "Methodology for the Analysis of Solid Waste" of the European Commission (European Commission, 2004). Waste was divided into 18 primary categories. The results for each sample and the overall results of the waste characterisation and screening during the project, are described in Table 7-4. The waste of the area under consideration had the typical waste characteristics of most developing countries, such as high moisture content and large organic fractions, both of which contribute to the production of leachate and landfill gasses with the additional problem of the presence of an unpleasant odour.

The composition of the total waste delivered shows that the fresh matter in the waste for both trials was strongly dominated by organics. The results of the analysis show that the overall waste composition consisted of four main parts in the form of organic matter

(55.1%), paper and cardboard (11%), plastics (9%) and hygiene products (8.9%). The remainder accounted for 14.9 % of the total and contained textiles (4.7%), metal (3%), glass (2%), composite materials (2.5%) and others. The average results of the waste characterisation of each and both trials are summarised in Figures 7-4 and 7-5. Further, the results waste composition and the related analysis performed over the pilot project duration are given in Appendix III.

Table 7-4. *Overall results of waste characterisation and screening during the project*

Sample area	Trial 1						Area under investigation		Trial 2						Area under investigation	
Particle size	> 100mm		80-100 mm		< 80mm		Total result		> 150mm		> 80-150mm		< 80mm		Total result	
Total sample wight	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%
	126	28	140	31	187	41	**453**	**100**	65	18	127	36	164	46	**356**	**100**
Sorting fractions	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%	Kg	%
Organic "garden"	10	8	7	5	19	10	**36**	**8**	5	8	7	5	11	6	**23**	**6**
Organic "kitchen/ canteen"	0	0	13	9	39	21	**53**	**12**	0	0	12	9	36	22	**47**	**13**
Wood	2	2	2	1	2	1	**6**	**1**	1	2	2	1	2	1	**5**	**1**
Plastic film	26	20	27	19	12	7	**65**	**14**	12	19	24	19	11	7	**48**	**13**
Plastic 3D	5	4	6	4	6	3	**17**	**4**	2	4	6	4	6	4	**14**	**4**
Composite materials	4	3	7	5	2	1	**12**	**3**	1	2	6	5	1	1	**9**	**2**
Fe-metals	2	2	8	6	4	2	**15**	**3**	1	2	8	6	4	3	**13**	**4**
Non Fe-metals	1	1	1	1	2	1	**4**	**1**	1	1	1	0	2	1	**3**	**1**
Glass	4	3	1	1	5	3	**9**	**2**	2	3	1	1	5	3	**7**	**2**
Inert	2	2	2	2	3	2	**8**	**2**	1	2	2	2	3	2	**6**	**2**
Paper	23	18	10	7	9	5	**42**	**9**	12	18	9	7	8	5	**29**	**8**
Cardboard	16	12	9	6	5	3	**30**	**7**	8	13	8	6	5	3	**21**	**6**
Textiles	18	15	28	20	2	1	**49**	**11**	11	16	26	20	2	1	**39**	**11**
Hygiene products	4	3	15	11	28	15	**46**	**10**	2	3	13	10	25	15	**40**	**11**
Batteries	0	0	1	0	5	3	**5**	**1**	0	0	0	0	4	3	**5**	**1**
Electronic goods	3	2	1	0	1	1	**5**	**1**	2	3	1	0	2	1	**4**	**1**
Miscellaneous combustible	6	5	3	2	5	2	**14**	**3**	5	7	3	3	3	2	**11**	**3**
Fines < 10mm	0	0	0	0	39	21	**39**	**9**	0	0	0	0	36	22	**36**	**10**
Control	126	100%	140	100%	187	100%	453	100%	65	100%	127	100%	164	100%	356	100%

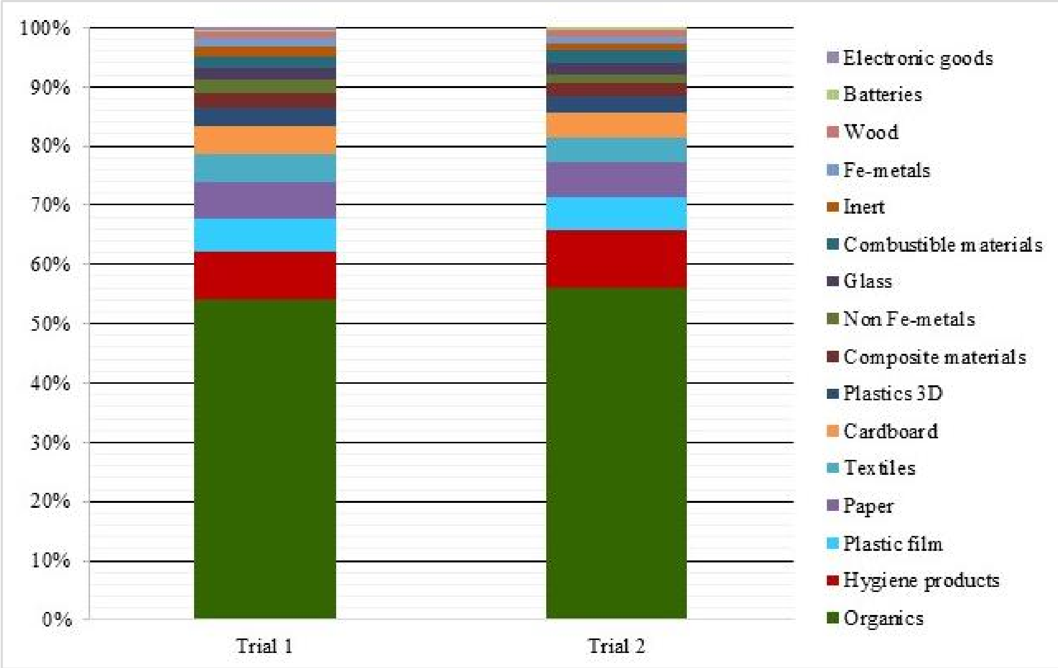


Figure 7-4. *Composition of municipal waste from Amman city, average of each trial analysis*

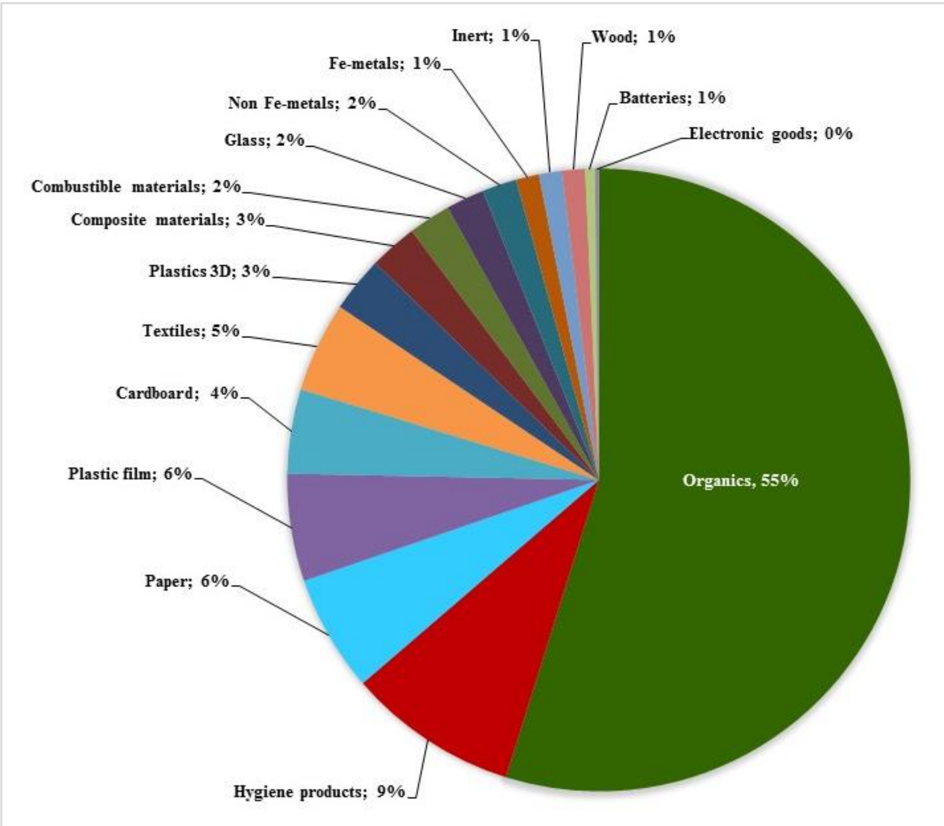


Figure 7-5. *Composition of municipal waste from Amman city, average of total analysis during both trials*

7.3.2. SIZE DISTRIBUTION OF FRESH WASTE

The screening of the waste received at the site showed that most of the waste was 10-100 mm in size in trial 1 and 10-150 mm in size in trial 2 (see Figure 7-6). In terms of the size distribution of the solid waste, approximately 30% of the total solid waste screened could be recovered as a large fraction (> 100 and > 150 mm), whereas 10% of the waste had sizes of < 10 mm.

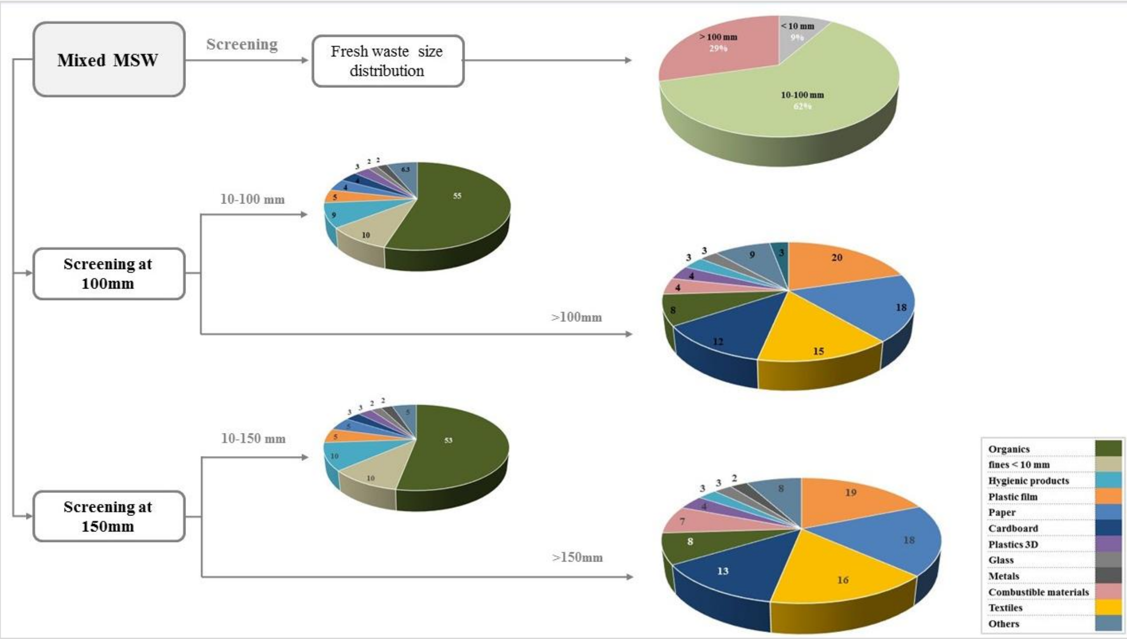


Figure 7-6. *Size distribution and composition of fresh waste*

From the sorting analysis it was assumed that about 80% of the fine fraction (<10 mm) was organic material. The additional classification of waste composition found that about 55.2% and 52.5% of the total organic materials were included in the waste fraction of 10-100 and 10-150 mm, respectively (see Figure 7-7). In the case of waste of size 10-100 mm, the results of the analysis show that the overall waste composition consisted of two main parts – organic matter (55.2%) and combustible material (29.8%). The remainder accounted for 15% and contained inert materials. In terms of waste fractions of 10-150 mm in size, approximately 52.5% of the waste was organics, while combustible material accounted for around 30.2%. The small fractions were textiles (0.6%), metals (2.4%) and cardboard (3.1%). The results revealed that 29.8% of waste of size 10-100 mm and 30.2% of waste of size 10-150 mm can be recovered from waste as RDF. Moreover, for the large fraction > 100 and > 150 mm, the waste included 8.4% and 8.1% organics and 79.9% and 76.5% combustible material, respectively, which are considered as RDF.

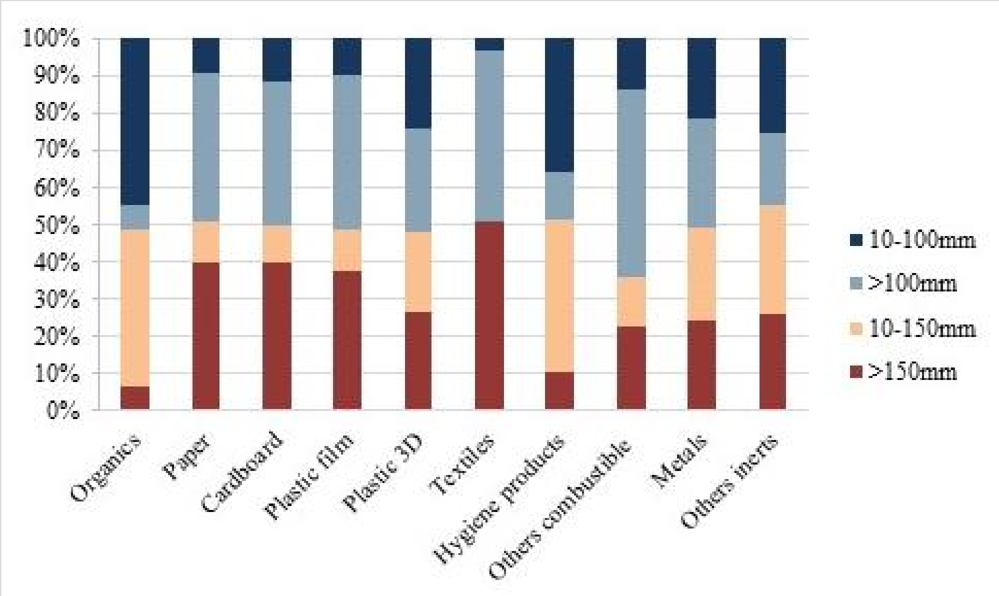


Figure 7-7. *Size distribution of each waste component of the received waste (Input)*

7.3.3. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF MSW

7.3.3.1. DRY MATTER (DM)

The unsorted waste was sampled and dried for dry matter analysis. The initial dry matter (DM) obtained from the input raw waste material was in the same range – 48–49% – for the two windrows formed during each session (see Table 7-5).

Table 7-5. *Dry matter results with regard to raw waste during the biodrying process.*

Trials	**Dry matter**			
	Input	Week 1	Week 2	Week 3
Trial 1	49%	65%	64%	62%
Trial 2	48%	62%	66%	64%

The average DM during trial 1 was about 49%, while the average DM during trial 2 was 48%. Figure 7-8 illustrates the results of the DM for the input material with regard to the biodrying process up to the end of the process (three weeks) before the screening at 80 mm to separate the fine and coarse fraction to produce RDF.

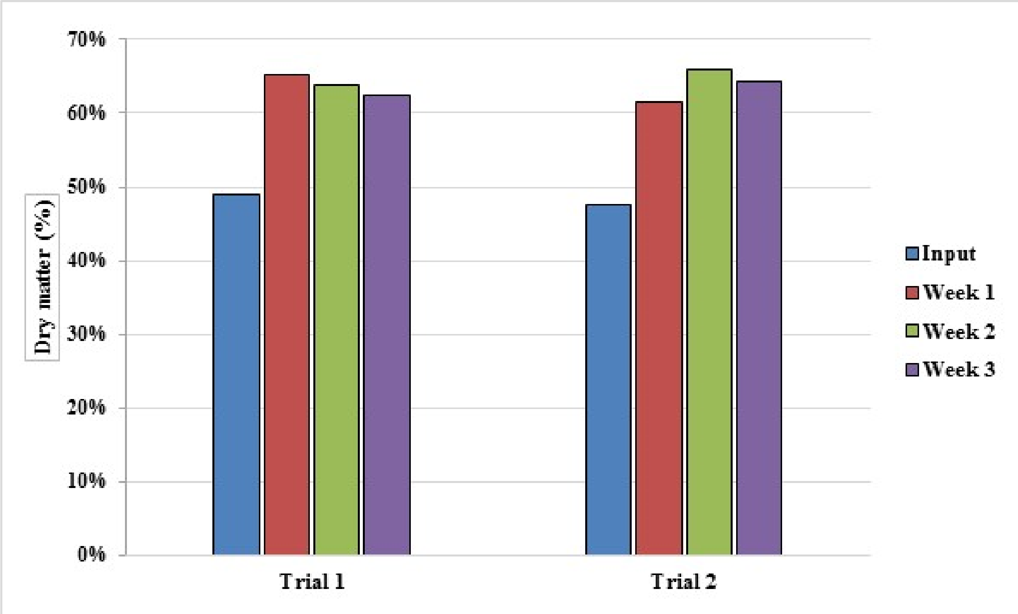


Figure 7-8. *Dry matter results of the input material up to the end of the biodrying process*

This implies that the moisture content during both trials can support a bio-stabilisation process, in that for this process to be successful the water content should be no less than 50%, while for thermal treatment, the moisture content of the waste should be less than 45% (Shukla, 2000). This means that the high moisture content of the waste generated in the study would reduce the efficiency of its energy recovery, as well as the feasibility of the mechanical separation of different fractions for beneficial utilisation.

7.3.3.2. Screening at 80 mm and mass balance

After three weeks of composting and drying, the waste can be efficiently screened into a coarse fraction with high calorific values, which can be used as a basis for the production of substitute fuel, for example, for use in cement kilns or combustion facilities. However, the screening splits, and the fresh and dry weight of each fraction after screening during both pilot project trials, were identified (see Table 7-6).

At the end of the biodrying process, the mass of waste was reduced on average by approximately 35% when the dried waste was directed to landfill without the recovery of material (see Figure 7-9). In the case of RDF utilisation from the dried waste, the mass of waste to be landfilled was reduced by approximately 69%. Furthermore, when dumping the dried waste in the landfill, leachate would not be produced if the landfill was carefully covered and protected from rainfall.

Table 7-6. *Results of screening and the fresh and dry weight of each fraction after screening.*

Trials							
Trial 1		**The split of fractions (%)**	**Fresh materials**		**Dry matter content (%)**	**Dry material**	
			Mass (t)	**% of total mass**		**Mass (t)**	**% of total mass**
	Input	N.A.	25	100%	48,91	12,2	49%
	> 100 mm	28%	6,3	25%	75,07	4,8	19%
	80-100 m	31%	4,2	17%	70,68	3,0	12%
	< 80 mm	41%	6,4	26%	63,68	4,1	16%
	Mass loss during 3 weeks drying	N.A.	8,0	32%	N.A.	0,4	2%
Trial 2		**The split of fractions (%)**	**Fresh materials**		**Dry matter content (%)**	**Dry material**	
			Mass (t)	**% of total mass**		**Mass (t)**	**% of total mass**
	Input	N.A.	25	100%	47,63	11,9	48%
	> 150 mm	18%	4,4	18%	71,19	3,2	13%
	80-150 m	36%	4,6	18%	69,89	3,2	13%
	< 80 mm	46%	6,6	26%	64,75	4,2	17%
	Mass loss during 3 weeks drying	N.A.	9,4	38%	N.A.	1,3	5%

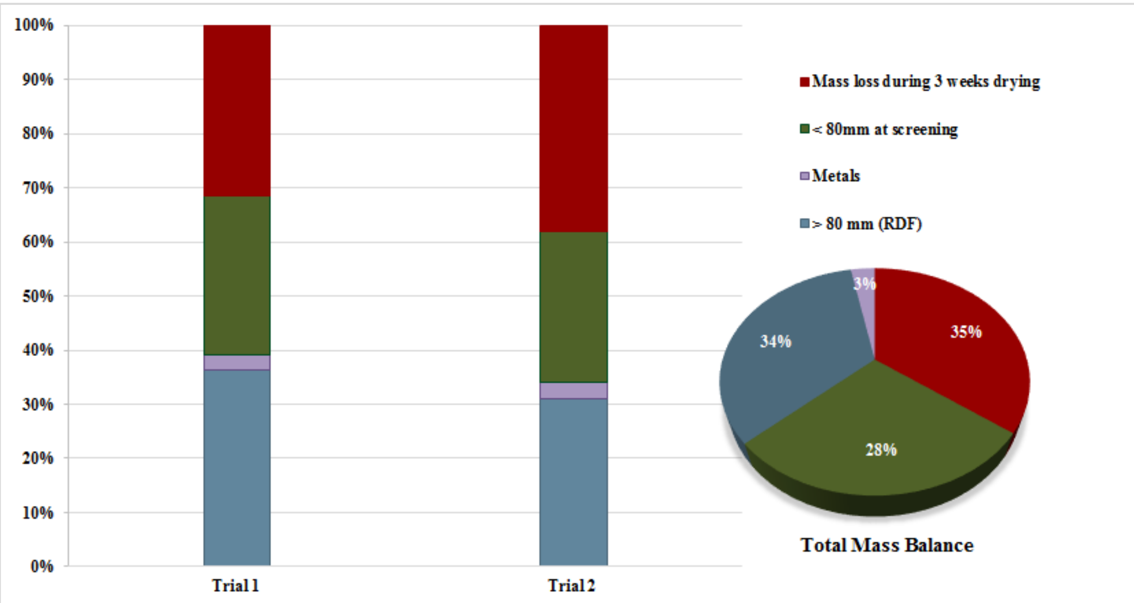


Figure 7-9. *The percentage of output fractions after screening at 80 mm for each trial and for the total*

On average, for trials 1 and 2, biodrying removed 29% of water, and 7% of solid waste mass was lost from the input material weight (see Table 7-7). In total, the weight of MSW decreased by 32% during trial 1 and 38% during trial 2.

Table 7-7. *Mass balance after the biodrying process during the pilot project.*

Trials											
Trial 1	**Input material %**		**Output of biodrying 3 weeks %**							**Mass loss %**	
	Dry matter	Water content	> 100 mm		80-100mm		< 80 mm		Water	Dry matter	Water
			fresh	dry	fresh	dry	fresh	dry			
	49	51	25	19	17	11	26	16	22	4	28
Trial 2	**Input material %**		**Output of biodrying 3 weeks %**							**Mass loss %**	
	Dry matter	Water content	> 150 mm		80-150mm		< 80 mm		Water	Dry matter	Water
			fresh	dry	fresh	dry	fresh	dry			
	48	52	18	12	19	12	25	14	24	9	29
Avg.	**48**	**52**	**22**	**16**	**18**	**12**	**25**	**15**	**23**	**7**	**29**

The efficiency of the biodrying process is apparent through a consideration of the reduction in the mass of raw waste by the end of the three (3) week biodrying period (Figure 7-10). Up to 30% of water was removed by biodrying and, on average, up to 35% of RDF materials produced.

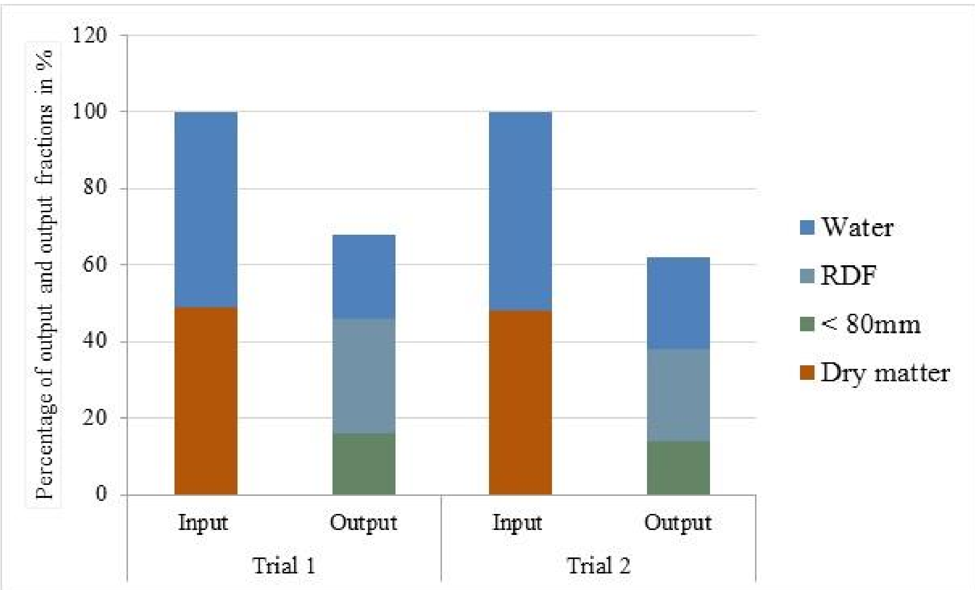


Figure 7-10. *The mass balance after the biodrying process for both trials*

7.3.3.3. CHARACTERISATION OF THE COARSE FRACTION

An 80 mm drum screen was used to separate the coarse fraction > 80 mm from the fine fraction < 80 mm. Approximately 39% of the waste input material was found to be >80 mm. Material samples were taken from this, both for lab analysis and for waste characterisation (by means of hand sorting). Sorting analysis of the coarse fraction, at the end of the biodrying process, was conducted for each trial during the pilot project. The results of the RDF percentage composition of each trial are presented in Table 7-8. The average characteristics of the coarse fraction for both trials are illustrated in Figure 7-11.

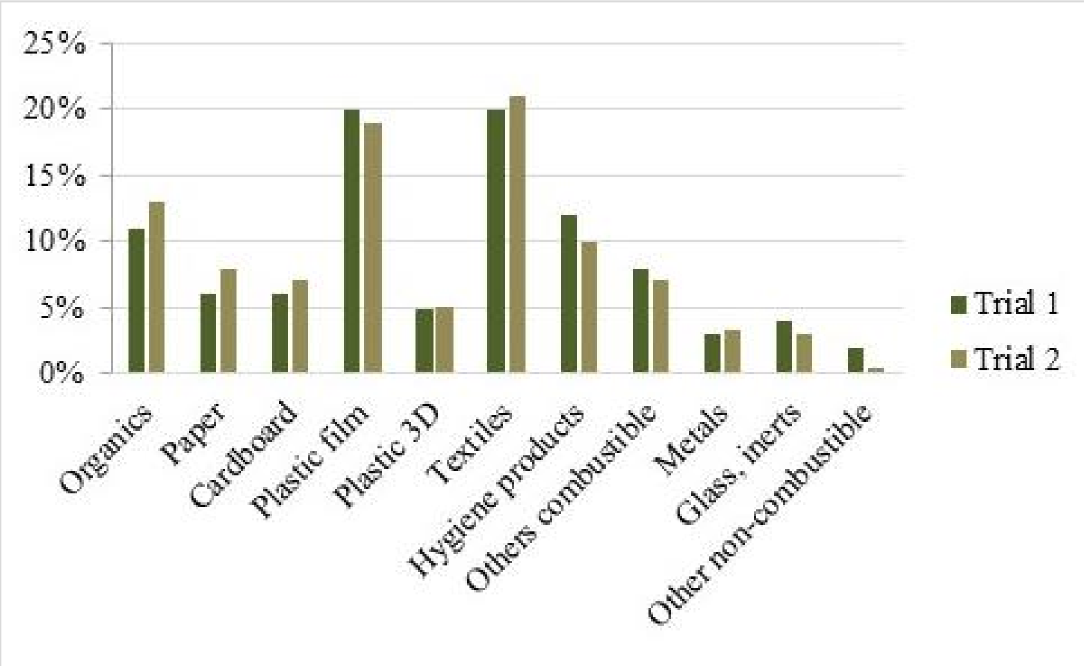


Figure 7-11. *The average characteristics of coarse fraction for both trials*

On average, for both trials (see Figure 7-12), the major components of RDF were textiles (20.6%), plastic films (19.7%), hygiene products (10.8%), paper (7.7%) and cardboard (6.5%) Other combustible materials present included paper (15.4%), other plastics (4.5%) and organics (14.8%).

Table 7-8. *Characterisation analysis of output material > 80mm (RDF) during the pilot project.*

Sample area	**Trial 1**		**Trial 2**		**Area under investigation**	
Date of collection	**23.01.2018**		**23.01.2018**		**Total result**	
Particle size	**> 80mm**		**> 80mm**		**> 80 mm**	
Total sample weight	Kg	%	Kg	%	Kg	%
	140	100	127	100	**267**	**100**
Sorting fractions	Kg	%	Kg	%	Kg	%
Organic "garden"	6.3	4.5	5.9	4.6	**12.2**	**4.6**
Organic "kitchen/ canteen"	10.9	7.8	9.6	7.6	**20.5**	**7.7**
Wood	1.8	1.3	1.7	1.3	**3.5**	**1.3**
Plastic film	27.9	19.9	24.8	19.5	**52.7**	**19.7**
Plastic 3D	6.2	4.4	5.6	4.4	**11.8**	**4.4**
Composite materials	6.8	4.9	6.0	4.7	**12.8**	**4.8**
Fe-metals	1.5	1.1	1.6	1.3	**3.1**	**1.2**
Non Fe-metals	2.5	1.8	4.4	3.5	**6.9**	**2.6**
Glass	0.8	0.6	0.7	0.6	**1.5**	**0.6**
Inert	6.4	4.6	3.1	2.4	**9.5**	**3.6**
Paper	9.8	7.0	8.9	7.0	**18.7**	**7.0**
Cardboard	8.8	6.3	8.1	6.4	**16.9**	**6.3**
Textiles	29.2	20.9	27.0	21.3	**56.2**	**21.0**
Hygiene products	16.7	11.9	15.3	12.1	**32.0**	**12.0**
Batteries	0.5	0.4	0.4	0.3	**0.9**	**0.3**
Electronic goods	0.5	0.4	0.6	0.5	**1.1**	**0.4**
Miscellaneous combustible	3.4	2.4	3.2	2.5	**6.6**	**2.5**
Fines < 10mm	0.0	0.0	0.0	0.0	**0.0**	**0.0**
Control	140	100%	127	100%	267	100%

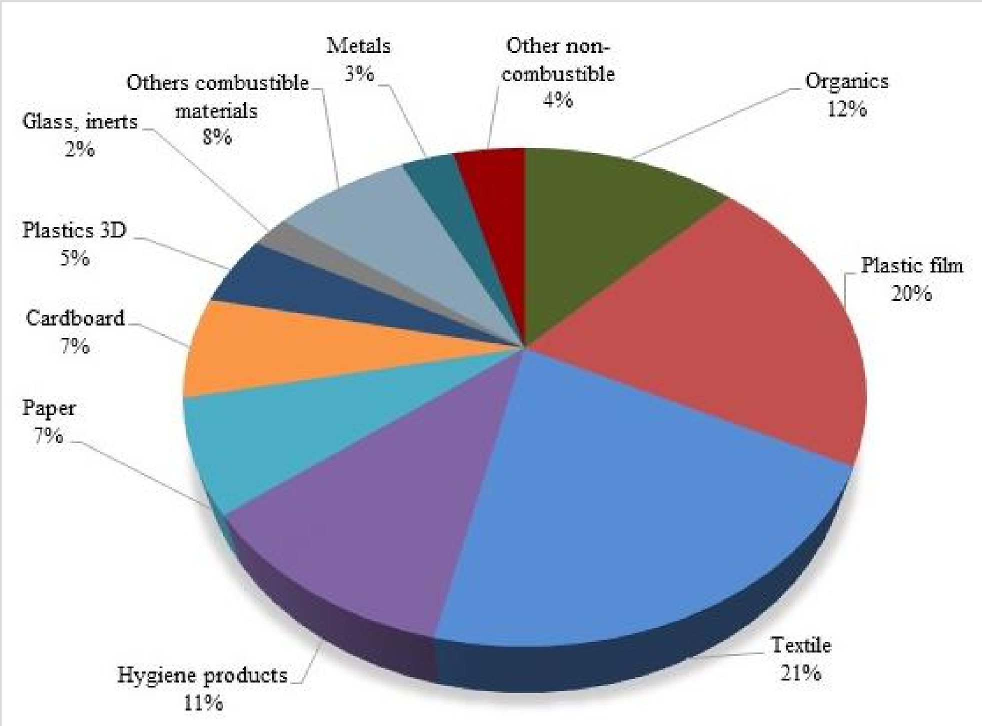


Figure 7-12. *Average total composition of coarse fraction characteristics*

The proportion of plastics, textiles, nappies and paper/cardboard were seen to have increased compared to the fresh waste composition, as shown in Figure 7-13. There were still some organics in the coarse fraction, but this could be further reduced by optimisation measures. Impurities in the RDF comprised non-combustible materials, namely metals (3%) and glass and inert materials (2.3%).

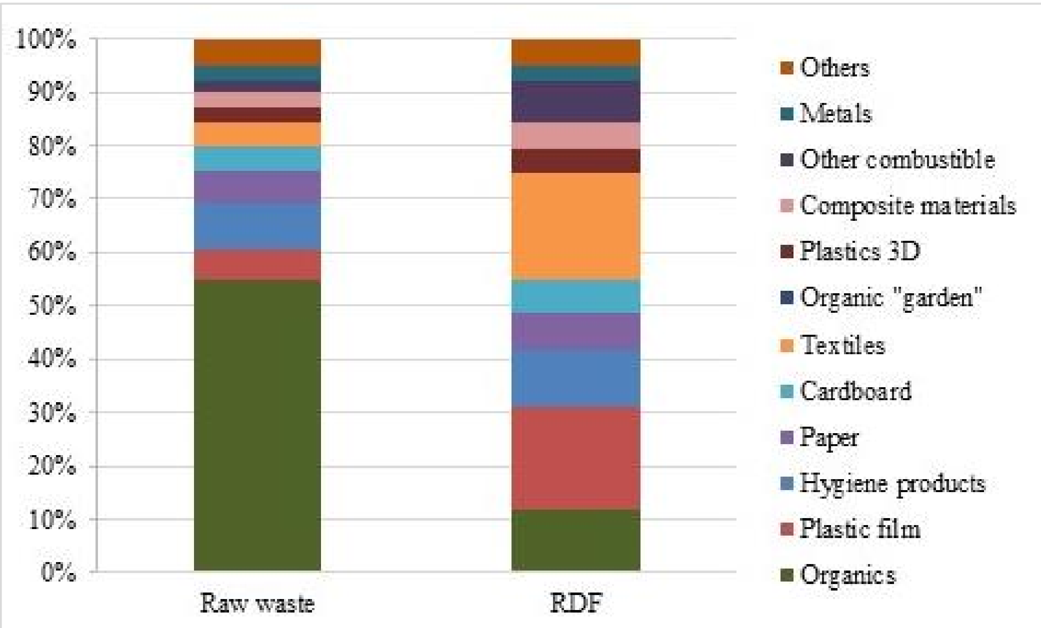


Figure 7-13. *The average characteristics of fresh waste (input) and the coarse fraction >80 mm after the end of the biodrying process (three weeks).*

Refuse-derived fuel (RDF) presents several advantages as a fuel over raw MSW. The main advantages are higher calorific values, which also remain fairly constant, more uniformity of physical and chemical composition, ease of storage, handling and transportation, lower pollutant emissions and reduction of excess air requirements during combustion (Caputo and Pelagagge, 2000).

7.3.4. CHEMICAL PROPERTIES OF THE RDF

The results of the basic chemical features of RDF are discussed in the current section. In addition to the heating value, other important fuel properties such as moisture content/dry matter, chlorine content and ash content were measured (see Table 7-9).

Table 7-9. *The basic chemical features of RDF produced in the study.*

Parameter		Trial 1	Trial 2	Average
Dry Matter$_{Input}$ (%)		49	50	49,5
UHV$_{Input}$ (MJ/Kg) dry sample		15,51	16,12	15,82
UHV$_{Input}$ (MJ/Kg) wet sample		7,34	7,59	7,47
LHV$_{Input}$ (MJ/Kg)		6,21	6,45	6,33
Dry Matter$_{Output}$ (%)		73	76	74,5
UHV$_{Output}$ (MJ/Kg) dry sample		20,43	20,90	20,67
UHV$_{Output}$ (MJ/Kg) wet sample		15,85	16,70	16,28
LHV$_{Output}$ (MJ/Kg)		14,83	15,58	15,21
Ash$_{Output/RDF}$ (%)		19,6	16,7	18,15
Chlorine$_{Output/RDF}$ (%)		1,03	0,95	0,99
Heavy metals$_{output/RDF}$(mg/Kg)	Cd	2,90	3,00	2,95
	Cr	62	70	66,00
	Ni	53	64	58,50
	Hg	< 0,03	< 0,03	< 0,03
	Zn	280	260	270,00
	As	0,89	1,1	0,99

Dry matter showed great variability, ranging from 50% to 75%. Figure 7-14 presents the DM of the RDF produced in each trial compared with the DM of the input material for each trial. The climatic conditions were one of the main factors that may have influenced the moisture content of the incoming MSW, and therefore of the RDF produced.

The moisture content significantly lowered the fuel value. As the moisture increased, there was less combustible material per unit. In addition, a significant amount of high heat energy was used to heat and evaporate the water in the waste (Rhyner et al., 1995).

The biodrying process studied in this work allowed an increase of the waste calorific value (LHV) of about 58%, as a consequence of the waste moisture reduction. The calorific value of unprocessed MSW ranged between 6.21 and 6.45 MJ/Kg. The calorific value of the RDF produced during the pilot project ranged from 14.83 to 15.58 MJ/kg, which made it suitable as a fuel (see Figure 7-15). The ash content of the RDF produced in Amman city appeared to be in a low range of between 16% and 19%.

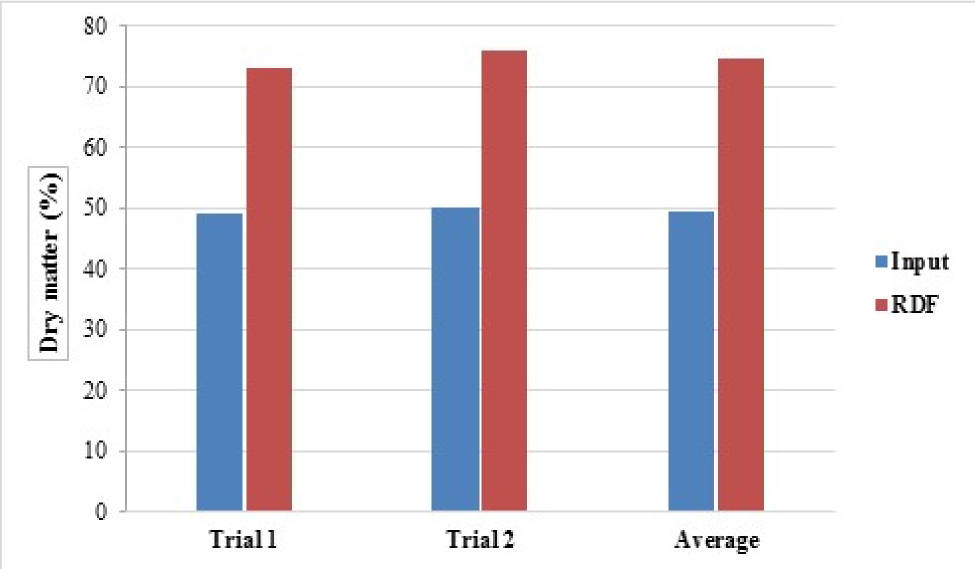


Figure 7-14. *The dry matter of the input waste and the RDF produced after the biodrying process*

Chlorine was also a limiting factor for RDF quality, not only for ecological reasons, but also for technical ones. The concentration of chlorine was in the range of 0.56–1.20%w/w, because of the existence of plastic material in the RDF production. This required more attention because it is considered to be a source of acidic pollutants, and an important reactive element in the formation of dioxins (Watanabe et al., 2004).

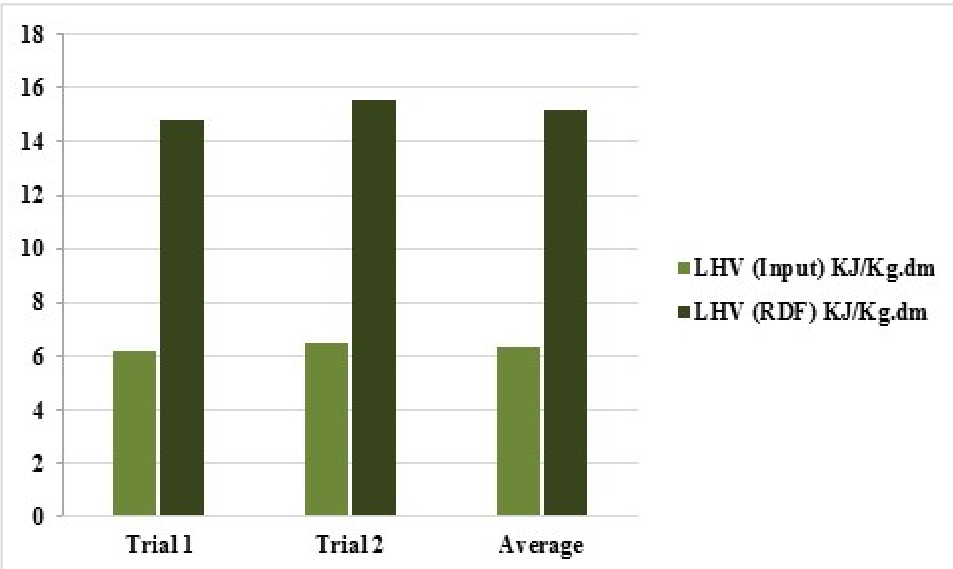


Figure 7-15. *Low heating value (LHV) of the input material and the RDF produced after the biodrying process*

As Table 7-9 shows, the RDF samples showed concentrations of heavy metals. The values of the heavy metals could be explained by the high content of organic material and by the fine particles in the RDF produced, given that they may have high concentrations of heavy metals.

The advantage of RDF over raw MSW is that RDF can be considered as a homogeneous material, with little pollutant content and with a good calorific value, which can be used for energy production in different plants or for replacing conventional fuels. However, due to the high moisture content, low calorific value and high ash content of raw MSW, it is necessary to segregate the raw MSW and to produce RDF. The important characteristics of RDF as a fuel are its calorific value, water content, ash content and chlorine content. The values of these parameters will vary according to the raw waste characteristics and to the processes applied to produce the RDF.

A better quality RDF will be obtained after further shredding and screening/sorting. Despite this, the quality of the RDF produced did not differ from the RDF quality obtained by some European countries. The required quality of RDF should have a high calorific value and a low concentration of toxic chemicals, especially in terms of heavy metals and chlorine. Due to the different points of view of RDF producers, potential RDF customers and the respective authorities, the suggested RDF quality varies from one group or country to another (Rotter et al., 2004).

Although many European countries and organisations have already set specifications and quality criteria for the chemical characteristics of RDF, limited work exists on the actual measurements of the chemical parameters on RDF samples. This is particularly true for data on heavy metal concentrations, which refer mostly to the specific components of MSW (Scoullos et al., 2009).

In Tables 7-10 and 7-11, the results with regard to the RDF produced in Amman are compared with the available data on the chemical characteristics of RDF reported from a number of European countries.

Table 7-10. *Chemical properties of the RDF produced in Amman compared with quality criteria set by various European countries (Gendebien et al., 2003).*

Parameter	Finland	Italy	UK	Amman
Calorific value (MJ/Kg)	13-16	15	18.7	12.84-15.82
Moisture content %	25-35	25 max	7 to 28	25-34
Ash content %	5 to 10	20	12	16.0-19.0
Chlorine %	<1.5*	0.9	0.3-1.2	0.56-1.2

*standard class III RDF

__Table 7-11.__ Heavy metals content of the RDF produced in Amman compared with quality criteria set by European countries (Gendebien et al., 2003).

Parameter	EURITS[a]	Italy	Finland	Amman
Cd (mg/kg)	N/A	10	5	1.6-3.0
Cr (mg/kg)	200	100	N/A	36-87
Ni (mg/kg)	200	40	N/A	18-150
Hg (mg/kg)	2	N/A	0.5	< 0.03
Zn (mg/kg)	500	500	N/A	130-280
As (mg/kg)	10	9	N/A	0.6-1.4

a: European Association of Waste Thermal Treatment Companies for specialized waste

It becomes clear from the results that the RDF produced in Amman was of high calorific value, low moisture content and acceptable chlorine content compared to the RDFs produced in the other countries. Concerning heavy metal content, it is interesting to note that although the Amman RDF showed different ranges of heavy metal concentrations in the samples, as shown in Figures 7-16 and 7-17, in all cases they were lower than the reported ranges from the other countries.

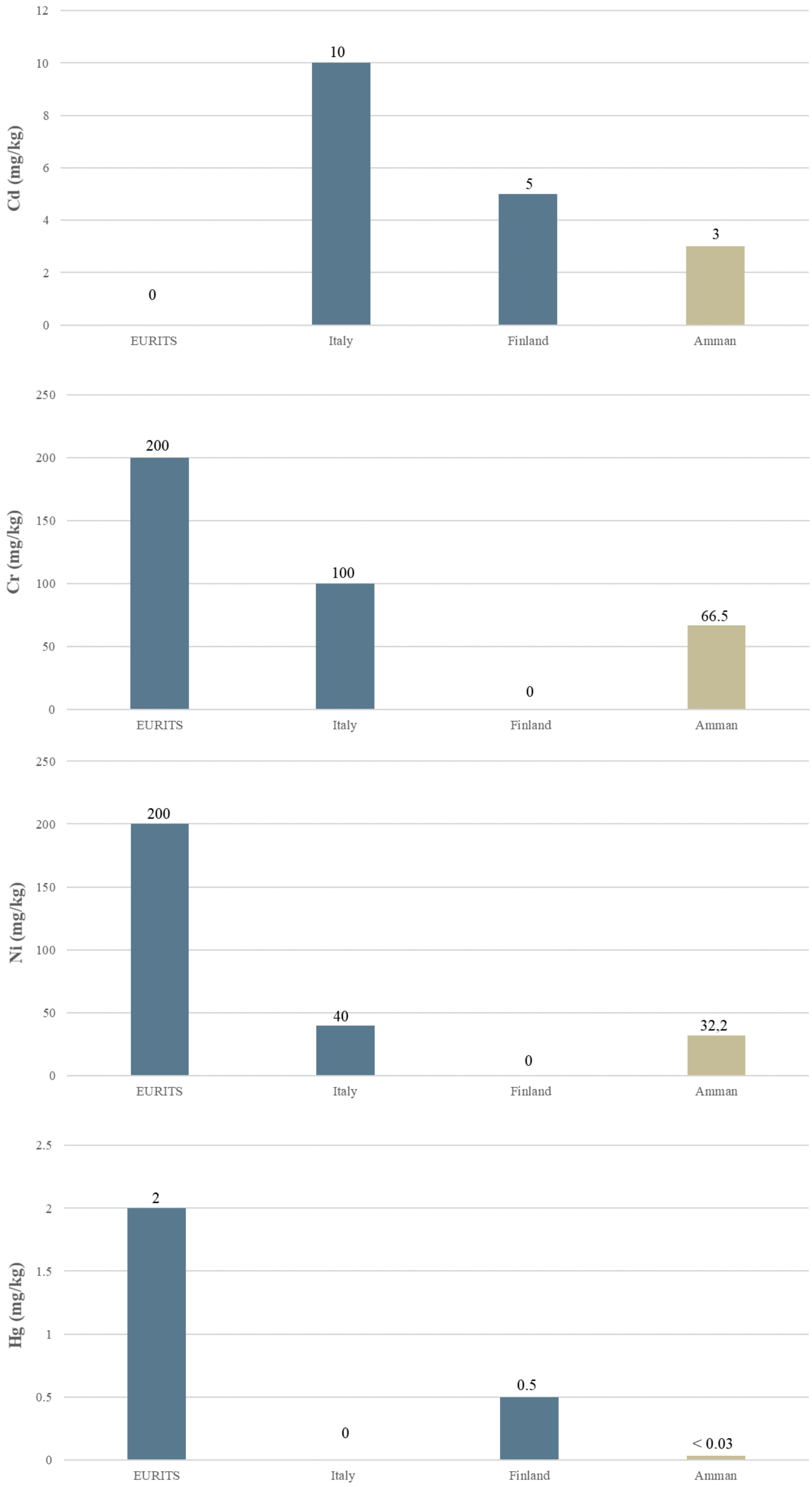


Figure 7-16. *Heavy metals concentrations (Cd, Cr, Ni & Hg) of RDF produced in Amman compared with criteria and values set by European countries*

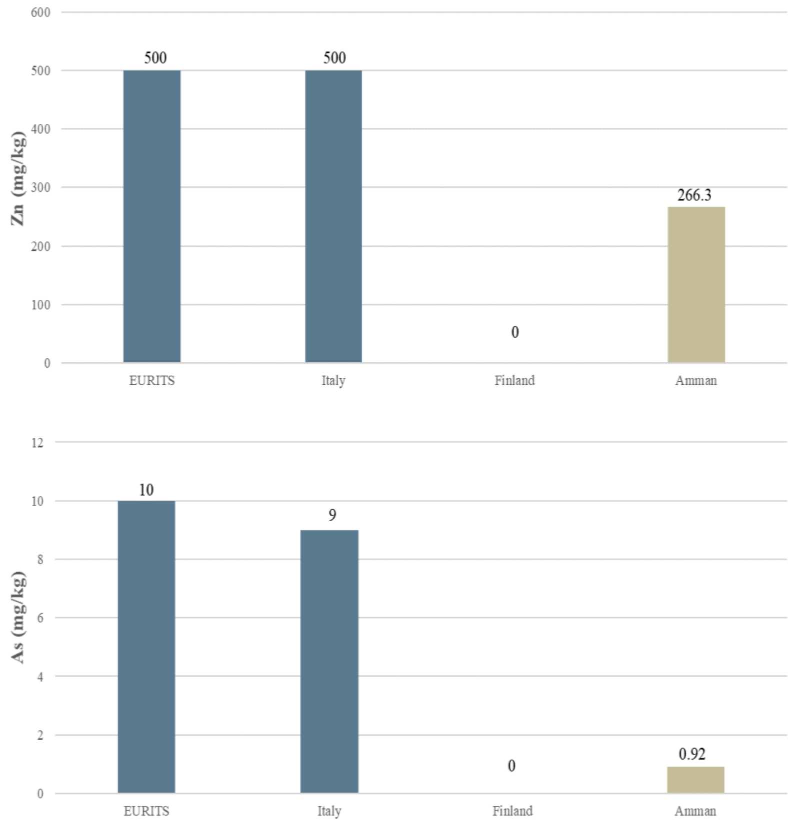


Figure 7-17. *Heavy metals concentrations (Zn & As) of RDF produced in Amman compared with criteria and values set by European countries*

7.3.5. Feasibility of using RDF

As observed during the experimental studies, the use of 15% RDF as a supplemental fuel in cement production did not cause any disadvantages in terms of clinker quality and stack gas emission values. 840 kcal energy is consumed for the production of 1 kg clinker. Previous studies have found that 6030.77 kg/h petcoke is equivalent to 13,440 kg/h RDF (Directive, 2000/76/EC, 2000; Kara, 2012).

Several studies show that various combinations of potential environmental benefits and impacts are associated with RDF production and utilisation in cement factories. On the one hand, RDF production impacts on the environment through energy and material consumption, while, on the other hand, replacing traditional fossil fuel with RDF in industrial plants leads to energy recovery and emission reduction (Reza et al., 2013). In this context, the aim of this section was to evaluate the feasibility of producing RDF materials for use as an alternative fuel in cement kilns. This feasibility study involved examining the proportion of CO_2 in GHG emissions and determining the energy demand by replacing petcoke with RDF.

In order to assess the economic benefits of RDF utilisation, an economic model was proposed. The model proposes six distinct scenarios resulting from adding RDF as a substitute fuel for the fuel currently used in Jordanian cement factories – Petcoke. The scenarios of this model were based on the literature, previous studies, publications (Kara, 2012; Al-Zu'bi, 2017), real data and the requirements and assumptions that have been obtained from Manaseer Cement Industry, Jordan. Six distinct scenarios were considered for the economic assessment of the addition of RDF to the main fuel (Petcoke) in ratios of 5%, 10%, 15%, 20%, 25% and 30%. The proposed scenarios represent the results based on the following assumptions:

1. The daily kiln production quantity: 4000 ton/day (24 hours) (Manaseer Cement Industry, 2018).
2. Total operating hours: 7200 h/year (Manaseer Cement Industry, 2018).
3. Daily petcoke consumption: 381 ton/day, which equals 15.9 Kg/hr (Manaseer Cement Industry, 2018).
4. Total energy consumption: 715 kcal/kg.cl. (Manaseer Cement Industry, 2018).
5. Total energy consumption for clinker stage: 46 kWh/t (Manaseer Cement Industry, 2018).
6. Calorific value of petcoke equals 8000 kcal/kg (Uso´n et al., 2013).
7. 1 ton of petcoke currently costs 150 USD (Kara, 2012).
8. Production cost of 1 ton RDF is accepted as 24.24 USD (Kara, 2012).
9. The calorific value of RDF produced in this study is 15.21 MJ/kg which is equal to 3632 kcal/kg.
10. 70% of 1 kg petcoke is emitted as CO_2 (Kara, 2012).
11. Emission of 1 ton CO_2 is accepted as 15 USD (Lechtenberg, 2008).
12. Energy efficiency of the facility using RDF is accepted as 97% (EU Directive, 2008; Kara, 2012).

Many studies have shown that if RDF is used as a substitute fuel in the cement industry it should not exceed 15% of the original fuel, because of the effects that this may have on the physical properties of the cement produced. Furthermore, previous studies have shown that there is a maximum net saving that can be obtained by adding RDF to traditional fuel with a ≤15% substitution ratio and without any adverse impact on final cement product quality (Kara, 2012; Al-Zu'bi, 2017). Therefore, the following part will interpret the results of Scenario 3 in detail. However, as can be seen in Table 7-12, if the RDF value is taken as 15% (Scenario 3), the remaining 85% petcoke corresponds to the consumption of 12.66 ton/h. In other words, 3.24 ton/h petcoke energy consumption will be saved.

The energy consumption of petcoke to produce 4000 ton/day is:

$$4000 \text{ ton/day} \times 1000 \times 715 \text{ kcal/kg.cl.} = 286\times10^{7} \text{ kcal/kg.cl.} \qquad \textbf{(5)}$$

So, when 15% RDF is used as a supplementary fuel, the petcoke energy consumption saving is:

$$286\times10^{7} \text{ kcal/kg.cl.} \times 0.15 = 429\times10^{6} \text{ kcal/kg.cl.} \qquad \textbf{(6)}$$

The RDF amount to be substituted per hour to achieve the required energy of 429×10^{6} kcal/kg.cl is:

429×10^6 kcal/kg.cl / 3632 kcal/kg.cl. /1000 /24 hours per day = 4.92 ton/h. **(7)**

The petcoke amount per hour to achieve the required energy of 2431×10^6 kcal/kg.cl is:

2431×10^6 kcal/kg.cl. / 8000 kcal/kg.cl /1000 /24 hours per day = 12.66 ton/h. **(8)**

Quantity of RDF needed to substitute 1 ton of petcoke is 4.92 ton/h / 3.24 ton/h = 1.52 ton

Adding 15% RDF is used as a supplementary fuel, the annual petcoke saving is:

3.24 tons/h × 24 h/day × 300 day/year = 23,328 ton/year. **(9)**

The cost of 1 ton petcoke to the cement factory is 150 USD on the basis of current market prices, thus the annual income is:

23,328 ton/year × 150 USD/ton = 3,499,200 USD/year. **(10)**

As RDF consumption is 4.92 tons/h, when 15% RDF is used as supplementary fuel, the annual consumption of RDF becomes:

4.92 tons/h × 24 h/day × 300 day/year = 35,424 tons/year. **(11)**

The cost of 1 ton RDF to the cement factory is 24.24 USD on the basis of current market prices, thus the annual cost is:

35, 424 tons/year × 24.24 USD/ton = 858, 677 USD/year. **(12)**

In this situation, the real financial saving will be:

3,499,200 USD/year – 858, 677 USD/year = 2,640,522 USD/year. **(13)**

This calculation explains only the savings obtained by using RDF in the cement industry. Because RDF is obtained from waste, savings in waste collection, sorting, processing and storing will be also achieved.

CO_2 is a by-product of a chemical conversion process (calcination) that is used in the production of clinker, a component used in producing cement. During the cement production process, calcium carbonate ($CaCO_3$) is heated in a cement kiln at a temperature of about 1300°C (2400°F) to form lime (i.e. calcium oxide or CaO) and CO_2. This process is known as calcination or calcining. The process releases carbon dioxide into the atmosphere. The lime reacts with silica, aluminium and other materials to produce clinker, which is ground into a fine power and combined with small amounts of gypsum to create Portland cement. CO_2 emissions may also be emitted from cement kiln dust (CKD) that is not recycled into the production process. Cement kiln dust is composed of the raw materials fed into the kiln that are lost to the system, or do not become part of the clinker.

Typically, CKD is collected and recycled back into the system. Any CKD that is not recycled for other purposes (such as in construction works or paving of roads) is disposed of in landfills. CKD is generated in all cement kilns; however, the quantity generated is reliant on the specific operating conditions of plant. In general, the amount of CKD produced can be estimated to be about 1.5–2% of the weight of clinker production (Direct

Emissions from the Cement Sector, 2003; Kara, 2012). The savings achieved in terms of petcoke consumption and the CO_2 emissions when using RDF are given in Table 7-12. It is accepted that 1 kg petcoke emits 70% of CO_2. The emission cost of 1 ton CO_2 is accepted as 15 USD. The production cost of 1 ton RDF is estimated to be 24.24 USD (Lechtenberg, 2008).

Table 7-12. *The economic model for the use and savings associated with RDF & Petcoke.*

Parameter	S0	S1	S2	S3	S 4	S5	S6
RDF substitution ratio (%)	0	5	10	15	20	25	30
Petcoke consumption ratio (%)	100	95	90	85	80	75	70
Petcoke consumption (t/h)	15.9	14.15	13.41	12.66	11.92	11.17	10.43
RDF consumption (t/h)	0	1.6	3.28	4.92	6.56	8.20	9.84
Replacement ratio to substitute 1 ton of petcoke (t)	0	1:1.1	1:1.32	1:1.52	1:1.65	1:1.73	1:1.80
Petcoke saving (t/year)	0	12,600	17,928	23,328	28,656	34,056	39,384
Petcoke saving (USD/year)	0	1,890,000	2,689,200	3,499,200	4,298,400	5,108,400	5,907,600
CO_2 emission saving in petcoke[a] (t/year)	0	8820	12,550	16,330	20,059	23,839	27,569
CO_2 emission saving in petcoke[b] (USD/year)	0	132,300	188,244	244,944	300,888	357,588	413,532
RDF production cost[c] (USD/year)	0	279,245	572,452	858, 677	1,144,904	1,431,130	1,717,356
Net savings[d] (USD/year)	0	1,690,763	2,235,842	2,798,902	3,350,753	3,913,812	4,465,663

[a] 70% of 1 kg petcoke is emitted as CO_2 (Kara, 2012).
[b] Emission of 1 ton CO_2 is accepted as 15 USD (Lechtenberg, 2008).
[c] Production cost of 1 ton RDF is accepted as 24. 24 USD (Kara, 2012; Al-Zu'bi, 2017).
S: Scenario
S0: Initial situation

As the cost of 1 ton petcoke is 150 USD, and 15% RDF is used as a supplementary fuel, the financial saving achieved on petcoke is:

3.24 tons/h × 24 h/day × 300 day/year × 150 USD/ton = 3,499,200 USD/h. **(14)**

The annual CO_2 emission saving in petcoke (quantity) is:

3.24 tons/h × .70 ×24 × 300 = 16330 tons/ year. **(15)**

CO_2 emission savings in petcoke (financial) is:

16330 tons/ year × 15 USD/tons = 244,944 USD/year. **(16)**

Efficiency loss is 20% × RDF% consumption × 100 = (0.20 ∗ 0.15) × 100 = 3%.

Therefore, based on the above-mentioned equations the Net Cost Saving is:

[(Petcoke saving + CO_2 emission saving in petcoke − RDF production cost) × (100 − efficiency loss)]/ 100 **(17)**

[(3,499,200 USD/year + 244944 USD/year − 858, 677 USD/year) × (100 − 3)]/ 100 = 2,798,902 USD/year. **(18)**

From the net cost savings point of view, based on the above calculations, it is clearly shown that it is feasible to take the RDF value as 15%, with the remaining 85% petcoke (Scenario 3). The scenario achieved 3,499,200 USD annual petcoke cost savings after adding 35,424 tons/year of RDF to the traditional fuel, while the current cost of using petcoke on an annual basis is about 17,172,000 USD. The net cost savings calculations which take CO_2 cost savings and RDF cost and efficiency losses into account shows that the net annual saving is about 2,798,902 USD/year USD.

Nowadays, one of the priorities for municipality planners and decision makers is to collect, recycle, treat and dispose of the increasing quantities of solid waste. The potential impacts caused by waste on the environment, the use of valuable space by landfills and poor waste management that causes risks to public health are the obstacles to handling the problem. The problem has to do with the quantity of solid waste generated and effective ways of management; while the solution lies in the policy established or conceptual framework, configured as '3Rs' or 'RRR', that is, 'reduce, reuse and recycle' (Peprah et al., 2015).

With proper SWM and the right control of its polluting effects on the environment and climate change, SW has the opportunity to become a precious resource and fuel for future sustainable energy. Alternatives should be examined so that waste is put to the use which is most beneficial in resource and environmental terms, rather than accepting a simple hierarchy, thus pursuing integrative strategies (Silva et al., 2017).

In Jordan, the unprecedented population growth, rise in community living standards (changing lifestyle) and urbanisation have left most municipal authorities seeking to find viable solutions to their waste management problems. While improper waste management is attributed to the systemic failure of policy makers and municipal authorities to identify the most sustainable approach to dealing with it so as to meet environmental and socio-economic aspirations. This chapter aimed to find new approaches by identifying the resource potential of waste streams and the extent of waste utilisation as a resource in order to achieve efficient and cost effective waste management.

8.1. ASPECTS TO BE CONSIDERED IN SOLID WASTE MANAGEMENT

When considering a strategy for waste management it has to be considered that this does not only imply the selection of a technical solution, but much more the development of a waste management system including other aspects interconnected with the technology. Such a system needs to consider the management and administration entity, the legislation, financial aspects, monitoring and technology as core elements of the overall system. Furthermore, all the stakeholders involved need to be taken into account: waste producers, but also the informal sector and personnel working in solid waste management, etc. Figure 8-1 illustrates the aspects and stakeholders to be considered in a SWM system.

Legislation is an important element in solid waste management since the different laws, ordinances and standards are essential to define and regulate the responsibilities, timeframes, environmental protection limits, product quality, etc. The legal framework should also specify what actions need to be taken in case of non-compliance with any regulation. If there are regulations missing, the strategy might not work, and likewise if some aspects in the SWM strategy are not clear. Ministries are mostly in charge of enacting the legal framework.

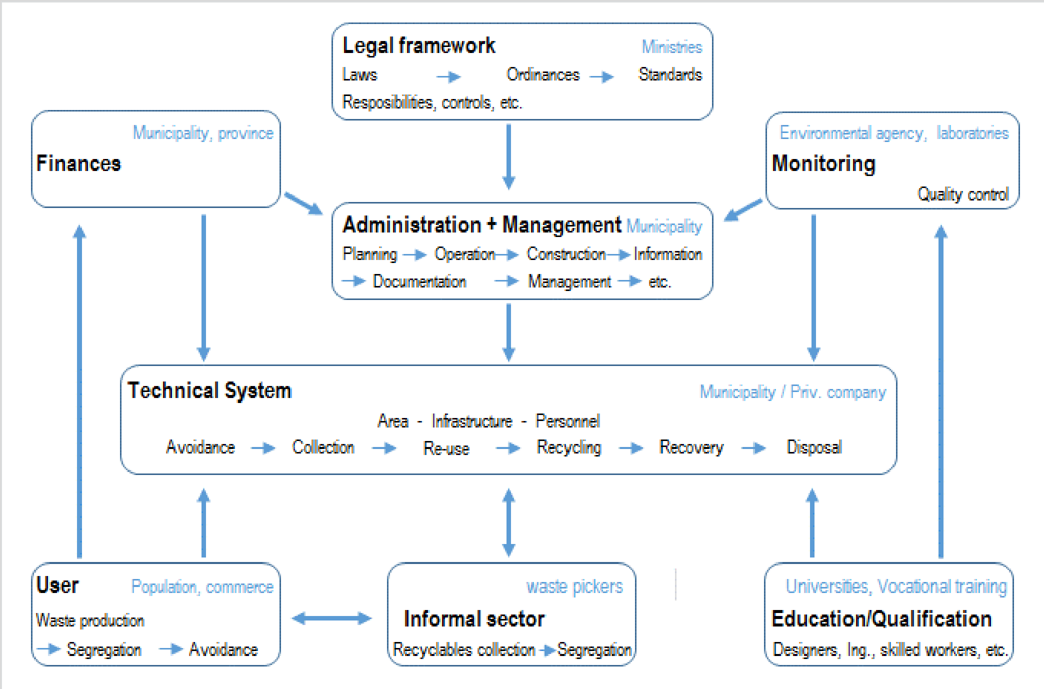


Figure 8-1. *Aspects and stakeholders to be considered in a waste management system*

Further, the financial and monitoring aspects should not be forgotten. A waste management system comprising collection, operation, equipment, facility construction, etc. is a costly activity. In Germany, the population, commerce and industry pay for these services. The introduction of a fees-system is, however, a difficult matter, since the population needs to understand the need to pay for a service that was previously "free" or cheap. Therefore, when introducing a new funding system, an improvement of the service should be noticeable.

In Germany, municipalities are the entities responsible for waste management. This does not only mean for performance of the waste collection and treatment, but much more and includes the development of a SWM plan for their areas, the design, construction and operation of facilities, the documentation of related data as well as giving information to the public and administration of these duties. These duties are strongly interlinked with the technical system in place. The technical system includes all areas of SW: from avoidance to disposal. Often, the municipalities are responsible for the management and administration of SWM activities, but they can make use of third parties (private companies) to execute some of their duties. Therefore, private companies might perform the collection or operate a SW facility.

Two stakeholder groups are most important for the development and implementation of an advanced SWM strategy. First, the users: they are the waste producers, but also the main performers of segregation and avoidance. It is crucial to consider public information in SWM issues to gain the cooperation of the population. It has to be taken into account that public information is not a one-time issue but a periodic task, which needs substantial effort. The second stakeholder involved is the informal sector, which in many countries performs very good segregation and recycling rates, contributing to resource and climate protection. Their contribution is, however, seldom recognised and documented. When improving a SWM system, the informal sector should be considered so that people working in this sector do not lose their livelihoods and the recyclables do not end up in the residual waste.

Furthermore, the qualification and education of the personnel is an aspect seldom considered in SWM but is of great importance. Lack of knowledge, experience and knowledge could result in missed planning, bad decisions, improper operation of facilities, resulting in severe damage for the environment and higher costs to repair the damage caused. Here, it would be beneficial if universities and also other educational institutions like vocational training centres would consider SWM in the curriculum for engineers, electricians and other workers needed in SWM. Additionally, there should be participation in international conferences to benefit from the experiences of developed countries in the field of waste management and knowledge transfer.

Finally, the monitoring of solid waste management is crucial to make sure the existent regulations are followed and therefore SWM contributes to resource and climate protection instead of further damaging the environment.

Figure 8-2 and Figure 8-3 summarise all of the above aspects that need consideration in a SWM strategy for Jordan. The legal framework in Jordan has been described in Chapter 2. However, even though there are already existing regulations and laws concerning the waste management in Jordan, the real life implementation or reinforcement of them has a great deal of room for improvement. What is needed for the legal frameworks is to devise specific standards from waste definitions and parameters, to waste classifications and separations, until the final treatment and disposal processes.

In Germany and Europe, the segregated collection and the landfill ban of untreated waste and energy-efficient WTE are the basis for sustainable waste management. Thereby, each country has found its own suitable way of implementing sustainable waste management. However, waste segregation is always an important part of it, since it lowers the cost of landfill.

If a similar strategy were to be followed in Jordan, the legal framework might need to be extended and the monitoring of the existing as well as new regulations should be strengthened. For the separate collection of the organic fraction of solid waste there are no guidelines, neither are there any for the treatment of the segregated fractions of its products. Therefore, a packaging ordinance must be issued before, or coincide with, the implementation of separation of waste at source. Also, standards and limits for the treatment and utilisation of different SW fractions need to be defined.

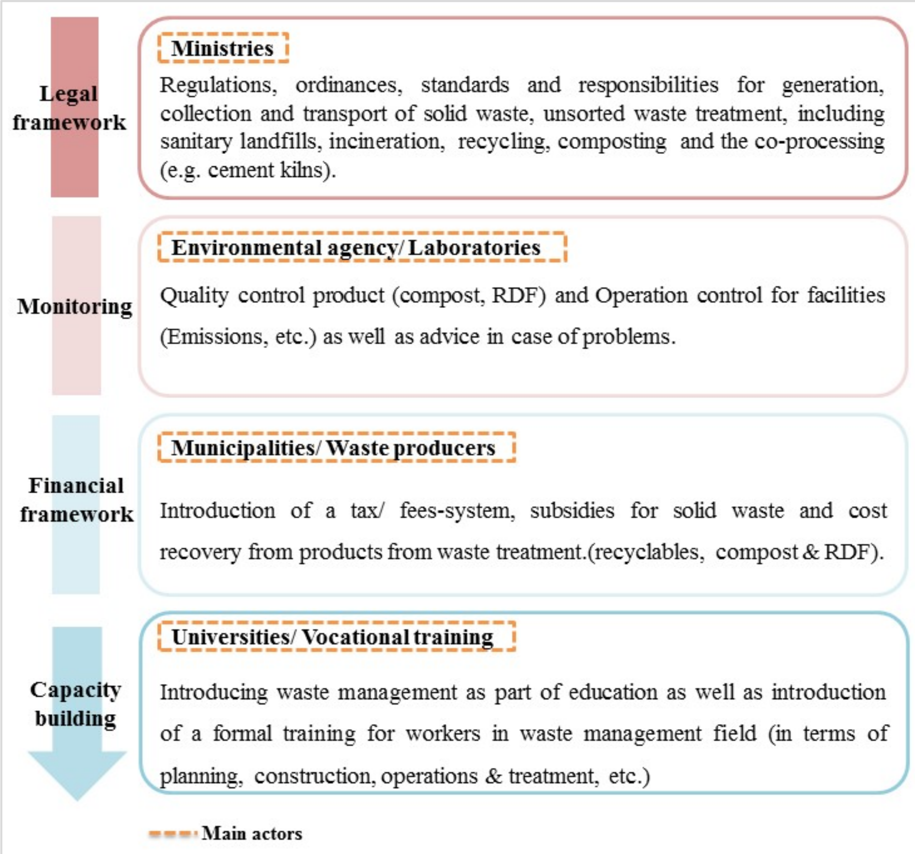


Figure 8-2. *General aspects to be considered in the solid waste management strategy for Jordan*

According to the experience of the German companies, it is difficult to find skilled workers for the solid waste facilities. Therefore, new professional education with an SWM subject might need to be introduced or improved.

At present, SWM in Jordan is financed through the national investment and support programme (see chapter 2.5). These consider, however, only the construction of infrastructures but not the operation costs. Therefore, for a proper operation of SWM facilities, the introduction of a tax system, subsidies for SW and possible revenues from products from waste treatment should be considered.

When considering the technical aspects of SWM, avoidance should always play an important role (see Figure 8-3). Waste avoidance is always a challenging matter, but it is the most effective, although its measurement is difficult. Due to the fact that waste collection and transportation takes over 70% of most waste management budgets, equal attention should be paid to optimise both the collection process and the process of waste transport to the final waste treatment or disposal location. If considering the wet and dry separated waste stream, the introduction of a segregated collection is indispensable to truly contribute to resource and climate protection. Only when collected and treated separately can the different waste fractions (wet/dry) be transformed to high quality products.

As for the mixed waste stream, which is inevitable, mechanical-biological treatment (MBT) can be considered as a complementary treatment before incineration. This can improve the properties of this waste stream by reducing the volume, related emissions, calorific value and increasing the recovery rate of mixed waste. It should be noted that the viability of a mixed solid waste treatment technology should be evaluated at large or medium or small city-scale or county-scale. The technical solutions dealing with the mixed fraction containing organic waste will be considered in detail in the following section.

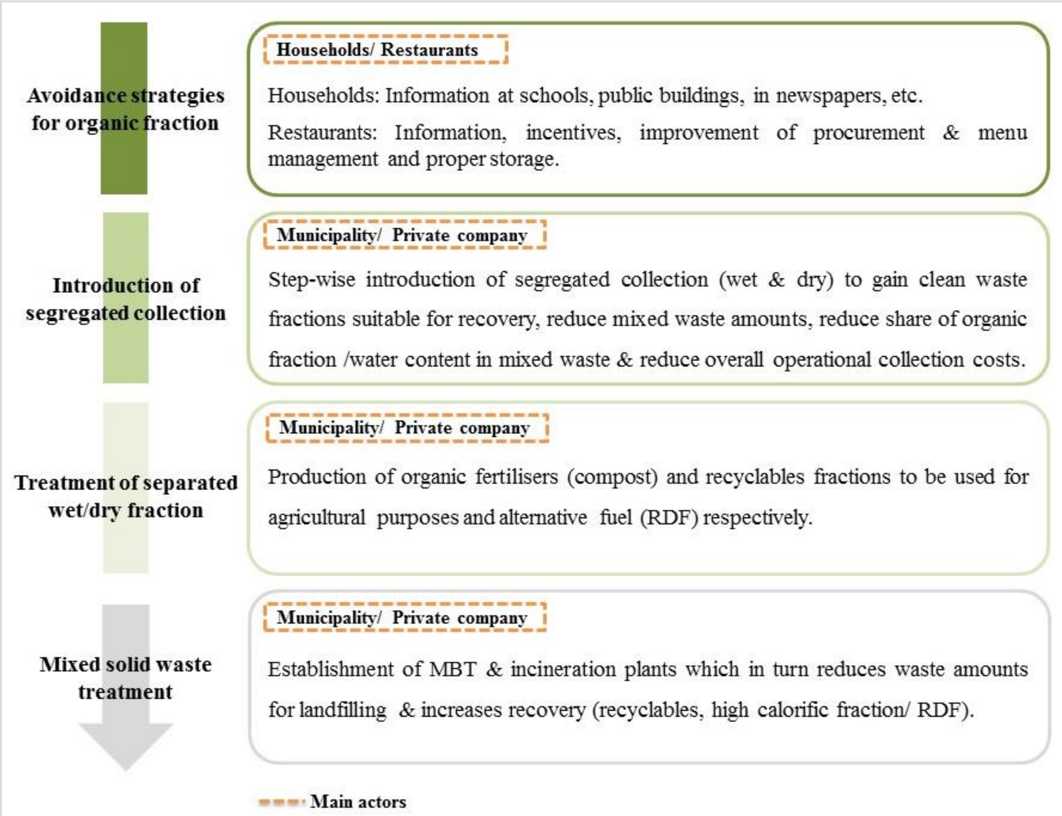


Figure 8-3. *Technical aspects to be considered in the solid waste management strategy for Jordan*

8.2. INTRODUCTION OF SEPARATED WET/DRY WASTE COLLECTION

Connected to the study undertaken (Chapter 5) and in line with its main objective (improving the waste collection system in Jordan), source-separated collection of the wet/dry waste fraction is strongly recommended and could be a viable option to reduce the overall operational collection cost. Introducing a separate collection of wet/dry fractions would not only reduce costs of manpower, time and operational costs, but would also provide environmental benefits such as reduction in greenhouse gas emissions during waste collection and transportation (Hemidat et al., 2017). Furthermore, separate collection of the wet/dry waste fractions is a pre-condition for its high quality recycling.

If a separate collection of wet/dry waste is to be introduced in Jordan, this can be carried out step-by-step. The first step must be introducing a packaging ordinance. The implementation of separation of waste at source must coincide with the issuance of the packaging ordinance, otherwise this approach cannot be applied because it will be doomed to failure.

Initially, problems can be avoided during the expansion phase of the separate collection. New procedures are often faulty and have to be continuously revised. In Germany, bio-waste has been separately collected, treated and recycled for 25 years and here new adjustments are still required from time to time (Schüch et al., 2016).

As described in section 2.8.2, there is at present no working segregated collection for wet/dry waste in Jordan. Moving towards the segregated collection of wet/dry waste from household and industrial organic waste is one of the most solutions that must be considered by municipal authorities to improve the environmental aspects arising from solid waste as well as to allow high quality recycling.

The savings from diverting food waste from the residual waste stream are sufficient to offset the additional collection costs. The removal of wet/food waste from the residual waste bin by offering, for example, a weekly separate food waste collection can be an important element of an overall waste collection service. This can influence all of the collection costs (less frequent waste collections) that are incurred when a separate food waste collection is introduced. Separate wet/food waste collections would be a precondition of achieving indirect savings, through reduced residual waste costs and increased diversion of material into the recycling stream.

Figure 8-4 illustrates the possible solutions for the implementation of the segregated collection of the wet/dry waste fraction. In institutions such as restaurants, canteens, supermarkets, food industry, etc. where large amounts of wet/food waste arise centrally, separate collection is logistically possible and applicable. The conventional kerbside collection (collection at the generation point) in waste bins could be combined with the dehydration of the waste to reduce the volume.

The major challenge is the introduction of separate collections of the wet/food fraction from households. This waste stream is produced regularly/daily but in relatively small quantities (per household) and cannot be stored for a long time. For the segregated collection of this fraction, in addition to the conventional collection by a kerbside system, a ‘bring system’ seems possible.

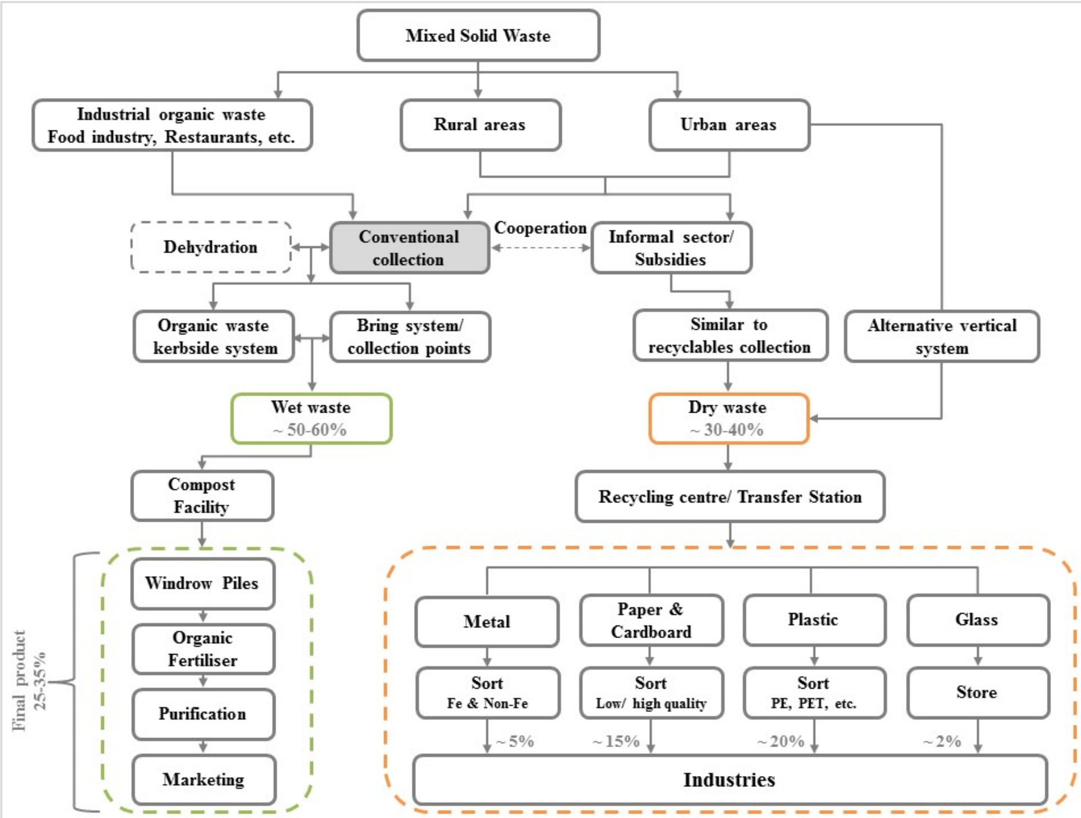


Figure 8-4. *Proposed strategy for the segregated wet/dry waste collection in Jordan*

In urban densely populated areas, alternative vertical systems for high-rise building might be found and developed. The conventional kerbside collection in these buildings, where residents bring their waste to a big container, mostly placed in the basement, is possible. But experiences in Europe show that impurities in such systems are high.

The successful separation of wet/dry waste requires an optimal design of the collection requirements for the resident more than explicit targets. Separate collection requires collection containers for which the owners of the apartments have to provide storage spaces. With regard to the amounts collected, the container volume is of crucial importance. An analysis of existing disposal areas in Germany showed that the quantity of collected bio-waste increased with the container size (UBA, 2016). This aspect is mainly in urban, highly populated areas of significance, where the collection takes place in high-rise buildings and space is rare.

The calculated capacities and bins needed to provide the required volume are set out in Table 8-1. At the same time, it has to be considered that sufficient volume for the residual waste has to be provided as well.

Table 8-1. *Assumptions and the calculated capacities and bins needed to provide the required volume for the separated wet waste.*

Parameter	Daily collection					Collection every 2 days					Unit
Targeted population	1000	2000	3000	4000	5000	1000	2000	3000	4000	5000	Persons
Generation rate	1.0										Kg/capital/ day
Total daily amount	1000	2000	3000	4000	5000	2000	4000	6000	8000	10000	kg
Wet/ bio-waste ratio	60%										%
Total wet/ bio-waste	600	1200	1800	2400	3000	1200	2400	3600	4800	6000	kg
Collected wet/ bio-waste	30%										%
Collected/ wet bio-waste	180	360	540	720	900	360	720	1080	1440	1800	kg
Wet waste bulk density	0.5										Kg/l
Required capacity	360	720	1080	1440	1800	720	1440	2160	2880	3600	l
Capacity of containers	240										l
No. of containers required	1.9	3.8	5.6	7.5	9.4	3.8	7.5	11.3	15.0	18.8	containers
	2	4	6	8	10	4	8	12	16	19	
Capacity of containers	660										l
No. of containers required	0.7	1.4	2.0	2.7	3.4	1.4	2.7	4.1	5.5	6.8	containers
	1.0	2.0	3.0	3.0	4.0	2.0	3.0	5.0	6.0	7.0	

The transport of the wet/food should be carried out in vehicles that are solely used for wet/food to avoid contamination with other waste streams. Moreover, compact trucks should be designed to handle low density (dry) and high density (wet) fractions. To this end, wet/food waste generated by Jordanian residents is very dense and does not need to be compacted. Therefore, the waste pressing system can be dispensed with when selecting waste collection vehicles or even when designing new transfer stations, which in turn reduces the cost required. Another way of looking at solutions for optimum source-separated wet/dry waste collection is to relocate and/or introduce new transfer stations as a recycling centre to receive the compostable (wet) and recyclable (dry) materials. In this approach, remarkable savings in fuel consumption would be obtained, mainly due to fewer vehicles being on the road, as the number of trips required to the landfill would be decreased and this would subsequently reduce CO_2 emissions in addition to create new jobs where manpower is needed for sorting recyclables.

8.3. Treatment Concepts for Separated wet/dry and Mixed MSW

As already discussed in the introduction to this chapter, there are two technical solid waste treatment options when dealing with fractions generated from solid waste: wet/dry clean fraction collected separately and a mixed solid fraction with a share of organic/wet waste (Figure 8-5). In this context, it is suggested that the municipalities be free to establish and operate local-scale solid waste treatment facilities (recycling centres) including composting facilities for pre-segregated wet-waste, a sorting plant for recyclables and MBT plants for mixed solid waste.

The idea behind those three options (composting, sorting and MBT plant) is to reduce energy usage, reduce volume of landfills, reduce air and water pollution, reduce greenhouse gas emissions and preserve natural resources for future use.

However, it is recommended that municipalities join forces through JSCs where possible, to construct and operate recycling centres to achieve economies-of-scale. The approach recommends that appropriate recycling centres should be established all over Jordan to reduce bio-waste and recyclables ending up in landfills and increase material and energy recovery. These recycling centres should be able to co-operate with both options of MSW collection systems for mixed collection and sorting-at-source of wet/dry waste.

The state-of-the-art technology for separated collected organic/wet waste is aerobic composting. To this end, this approach recommends installing a windrow composting plant for biological stabilisation (aerobic composting). The composting units would be sited in the framework of the local (municipal) or the regional MSWM plans, depending on their level of coverage and competent authority (municipality or JSC, respectively). They would receive pre-segregated wet/food waste material from the respective separate collection systems.

Regarding the separated collected recyclables/dry waste, all of the waste collected by the municipal utility or nominated certified contractors would be brought back to a recycling centre at the transfer station. The load would be taken into a sorting facility for onward processing. Depending on the nature of the waste, and whether it has been pre-treated, the load would pass through a primary sorting operation – either in a baling hall or in the main sorting building, dependent on each disposal location.

At the primary sorting stage large items would be removed and placed in relevant storage bays – large and bulky items such as pallets, beds, large metal items, electrical equipment and long pieces of plastic and wood. These items could cause damage if they were allowed to pass through the picking lines. It is also at this stage that the majority of the plastic and cardboard would be removed and transported to the baling hall .The remaining waste would be loaded into a feed hopper which carries the recyclables up to the picking lines. Here, smaller pieces of timber, plastic and card would be removed along with any non-ferrous metals and wire. The waste would then pass through a rotating sieve or barrel screen, which allows all of the small stones and particles of earth to fall through.

The remaining fraction would then pass under a magnet which captures the ferrous metals. Certain locations may then pass the material over a powerful air knife. The air knife blows off any remaining light fraction (mostly small pieces of card, plastic and wood together with any soiled paper and card). Because of the relatively high calorific value, this fraction would then be taken to be baled and would be used to generate energy from waste. The remaining material would be given a final inspection on the last picking line where residual and recyclables are taken out leaving clean hard-core ready to be crushed and re-used in the construction industry.

Two options have been considered for mixed municipal solid treatment.The first is based on the energy recovery (electricity and heat) after the incineration of raw waste, while in the second option the raw mixed waste is processed into RDF, and recyclable material is recovered and the fine fraction is further stabilised before landfilling. The possible alternative treatment strategies for mixed municipal solid waste will be addressed in detail in the next section.

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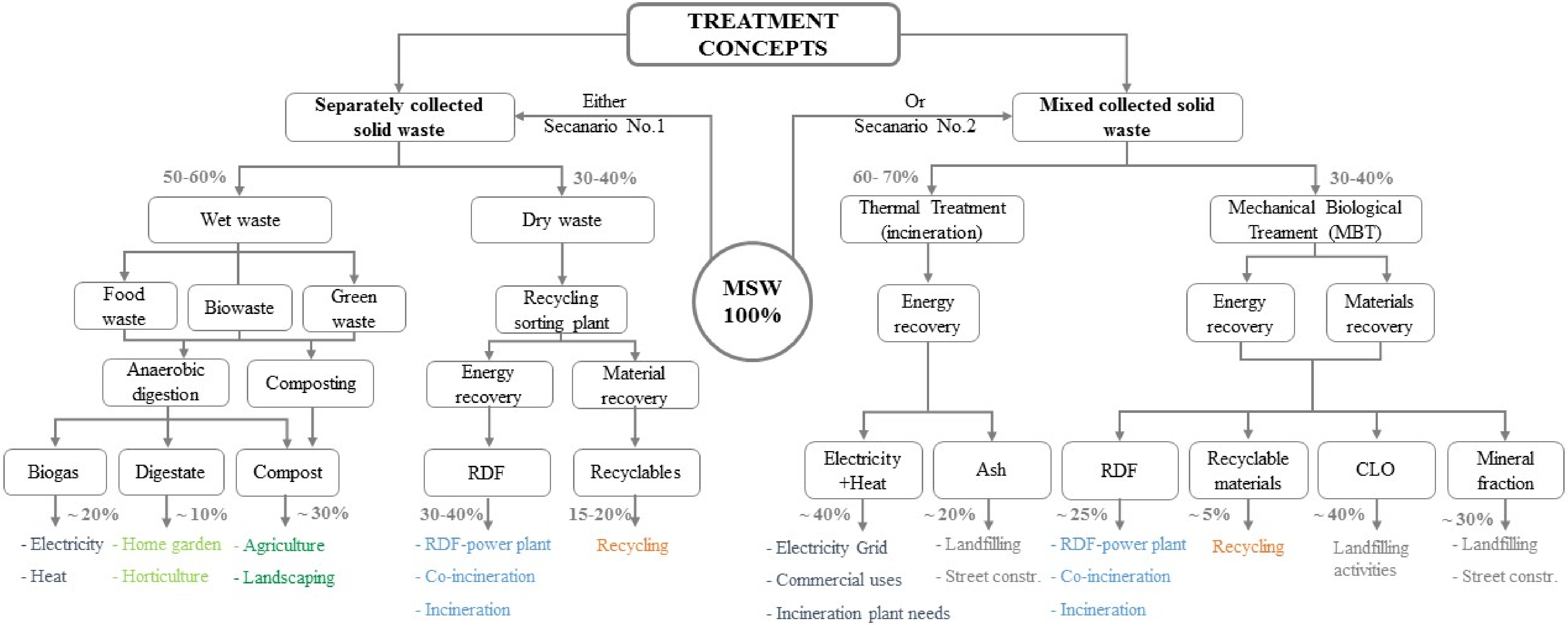

Figure 8-5. *Treatment concepts for generated solid waste streams in Jordan*

8.4. POSSIBLE TREATMENT ALTERNATIVES FOR MIXED MSW

Solid waste treatment alternatives should be examined so that waste is put to the use that is most beneficial in resource and environmental terms, rather than accepting a simple hierarchy, thus pursuing integrative strategies. Mechanical biological treatment (MBT) for waste drying and sorting and mechanical biological stabilisation (MBS) are designed for a short and hot biological treatment to dry the waste for later incineration and for sorting and sieving out usable fractions (minerals, metals). These plants produce only a small amount of material, which might be landfilled. Most components are comparable to MBTs prior to landfilling. The main product is RDF (Elnass et al., 2016).

8.4.1. MECHANICAL BIOLOGICAL TREATMENT (MBT)

Mechanical biological treatment is a residual waste treatment process that involves both mechanical and biological treatment. The first MBT plants were developed with the aim of reducing the environmental impact of landfilling residual waste. It therefore complements, but does not replace, other waste management technologies such as recycling and composting as part of an integrated waste management system (Plavac et al., 2017). Mechanical biological treatment can be classified into four process concepts: material stream separation, mechanical biological stabilisation (with a biological drying process), mechanical-physical stabilisation (with a thermal drying process) and mechanical/biological pre-treatment prior to incineration .

In MBT based on the concept of material stream separation, the mixed waste is separated by mechanical processing into different fractions: a concentrated high-calorific fraction for use as RDF, value materials (such as metals) for material recycling and a fraction with a low calorific value that is biologically treated and then landfilled. Originally, the development of MBT in the last twenty years took place in Germany and Austria, but the technology has spread all over the world. In each case, the MBT process is designed to suit the local conditions, the characteristics of the treated waste and required output. The main advantage of the MBT technology is its fundamental flexibility. The construction and layout can be adapted to the legal and technical circumstances on site (Muller and Bockreis, 2011; Elnass, 2016).

8.4.2. MECHANICAL BIOLOGICAL STABILISATION (MBS) WITH BIOLOGICAL DRYING

The aim of mechanical biological stabilisation (MBS) is to stabilise the carbon as the main source of energy contained in the biologically degradable components contained in waste by biological drying, and to transform it, as far as possible, into the high calorific fraction for use as RDF. The drying stage is an important precondition for the efficiency of the subsequent separation of the remaining waste into combustible and other value and inert materials (Thiel and Hoffmann, 2008; Thiel et al., 2011).

In different MBT systems waste passes through various processes, but the processing is generally divided into two main stages: (1) mechanical and (2) biological treatment (Plavac et al., 2017).

8.4.2.1. Mechanical Treatment

Mechanical processing of mixed municipal waste is aimed at separating fractions for material and/or energy use, and the fraction requiring further biological treatment. Waste generated in the process of mechanical treatment of residual municipal waste is processed in accordance with the waste hierarchy. The fraction of at least 0-80 mm needs to be separated and stabilised in the biological part of an MBT plant, which can be conducted under aerobic or anaerobic conditions.

Three types of biological treatment are defined: aerobic stabilisation, anaerobic stabilisation and biodrying (Elnaas, 2016). It has the following functions :

- Separation of bulky waste, to protect the machines, and homogenisation of the waste for the biological treatment (e.g. shredding).
- Separation of high calorific fractions for use as RDF by sieving (150 mm) and sometimes air separation; if the waste gets a second mechanical treatment after the biological treatment it is usually a sieving at 60 mm or smaller.
- Separation of waste components, which can be recycled (e.g. metals), by magnetic separator.

8.4.2.2. Biological Treatment

In biological treatment, processes occur in the waste which is biodegraded by drying out and similar processes. In this part of MBT, waste can be converted into compost or a secondary source of energy (RDF). Biological treatment can be carried out using one of the following processes: anaerobic digestion, composting or bio drying. In an anaerobic process micro-organisms are used to break down the waste components and produce biogas and soil improvers. Biogas can be used for the production of electricity and heat. In the composting process, the aerobic treatment occurs where the microorganisms do not produce fuel, but create carbon dioxide and compost. In the third mode, biodrying, the aerobic microorganisms produce heat and dry the waste, which then becomes convenient for further processing. The resulting heat created in biochemical reactions within micro-organisms during aerobic biodegradation of waste removes moisture and the biodegradable part of waste (Plavac et al., 2017).

8.5. Proposed Strategies for MSW Treatment with MBT Facilities

Two strategies have been considered for an RDF production facility .The first is based on the recovery of RDF and recyclables after the biodrying of raw waste, while in the second strategy the raw waste is processed into RDF, recyclable material is recovered and the fine fraction is further stabilised before landfilling. The assumptions made for the following strategies are based on the results obtained from the pilot project carried out in Amman. The main objectives of the chosen options are:

- Minimise the emissions of odours, landfill gas and leachate
- Minimise the remaining waste to be landfilled (quantity and emission)
- Recover recyclable material
- Relevant factors include recovery efficiency, costs and time needed for treatment.

8.5.1. STRATEGY ONE: BIOLOGICAL DRYING OF MIXED MSW WITH RDF PRODUCTION

The concept of this strategy is proposed for facilities with a capacity of 100,000 Mg/a (Figure 8-6). The waste would be subjected to composting (biodrying) without adding any water for 2–4 weeks. At completion of the drying process, the waste would be screened efficiently into a coarse fraction with high calorific value, which can be used as a basis for the production of substitute fuel (RDF).

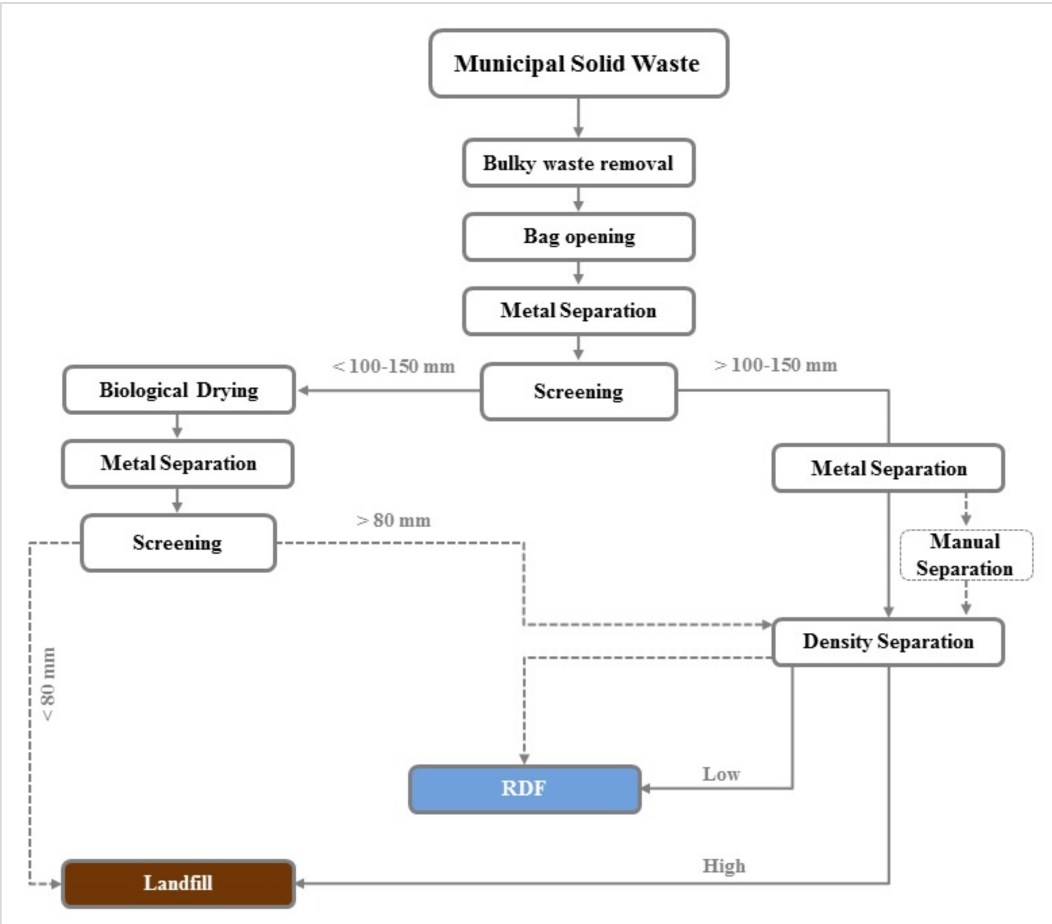

Figure 8-6*. Strategy one: biological drying with RDF production and material recovery*

Based on the results obtained for the pilot project in Amman, the mass of input waste would be reduced by approx. 65%. This means that only 35% of the input material would be sent to the landfill and 65% would be diverted from landfill. The mass balance is illustrated in Figure 8-7.

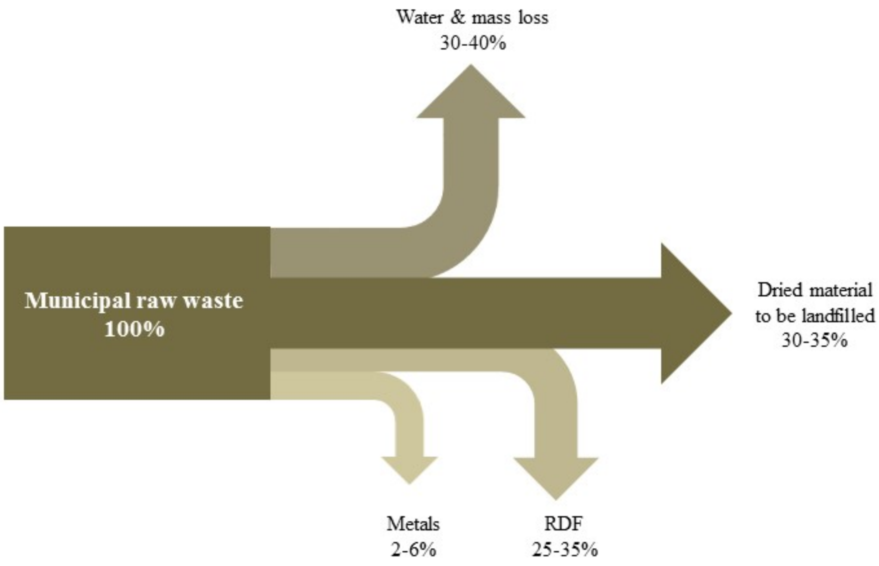

Figure 8-7. *Mass balance of strategy one*

8.5.2. Strategy Two: Biological Drying of Mixed MSW with RDF And CLO production

The concept of this strategy is the same as the concept of the previous strategy, except that at the end of the drying process the fines fraction, after screening, would go through further composting/stabilisation for further mass reduction. The composting period would be about 6–8 weeks (see Figure 8-8).

Based on the stabilisation results obtained from the pilot project in Amman, it is expected that the mass of the stabilised portion would be reduced by approx. 85%. This means that only 15% of the waste input would be sent to the landfill, while the rest would be recovered as RDF fuel, recyclable material (metals) and compost-like product with moisture content loss as a result of the biodrying and stabilisation process. The mass balance is illustrated in Figure 8-9.

The coarse fraction produced in option two may have to be further mechanically processed (e.g. air separation, shredding, etc.) to produce better quality RDF, which would be more suitable for the utilisation process. Mechanical biological treatment systems are linked to the markets and outlets for recycled materials, RDF and soil conditioners that are produced by different processes. It is likely that many of the material outputs from MBT would have a negative value. Collaborations between MBT operators and potential users of outputs should be established and care should be taken to ensure that plants could deliver materials of sufficient quality for the required market outlet.

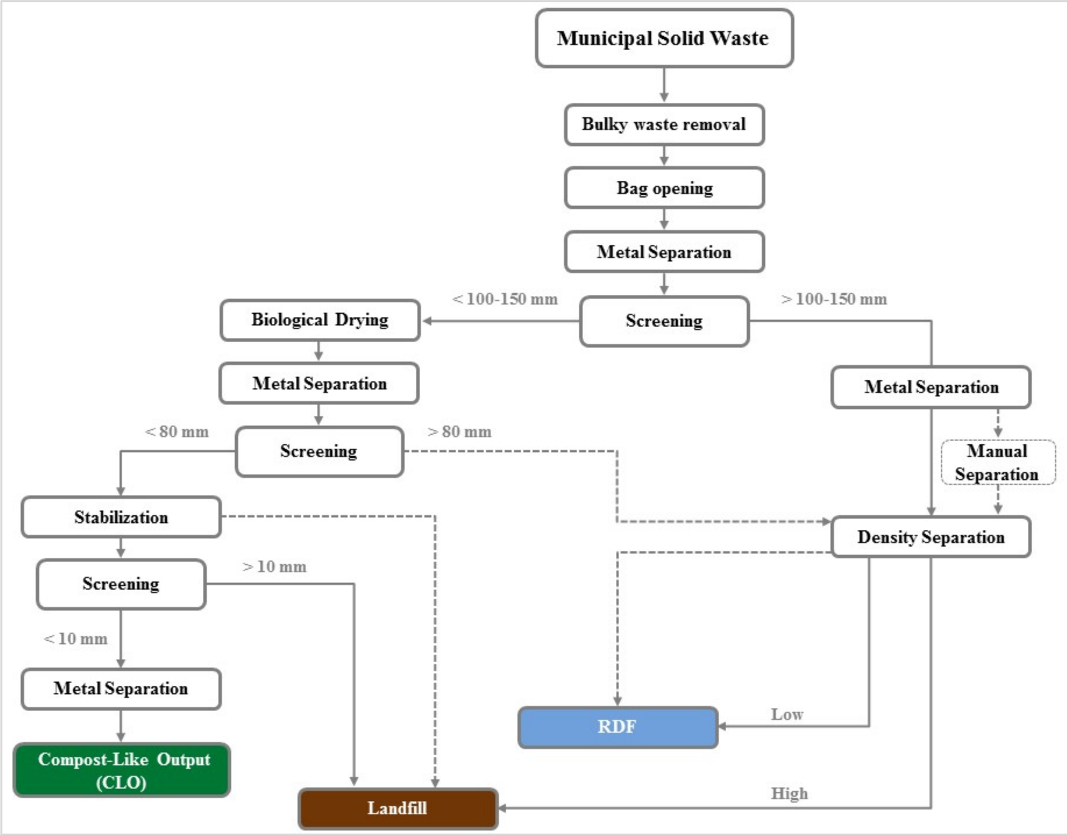

Figure 8-8. *Strategy two: biological drying with RDF, stabilised material production and material recovery*

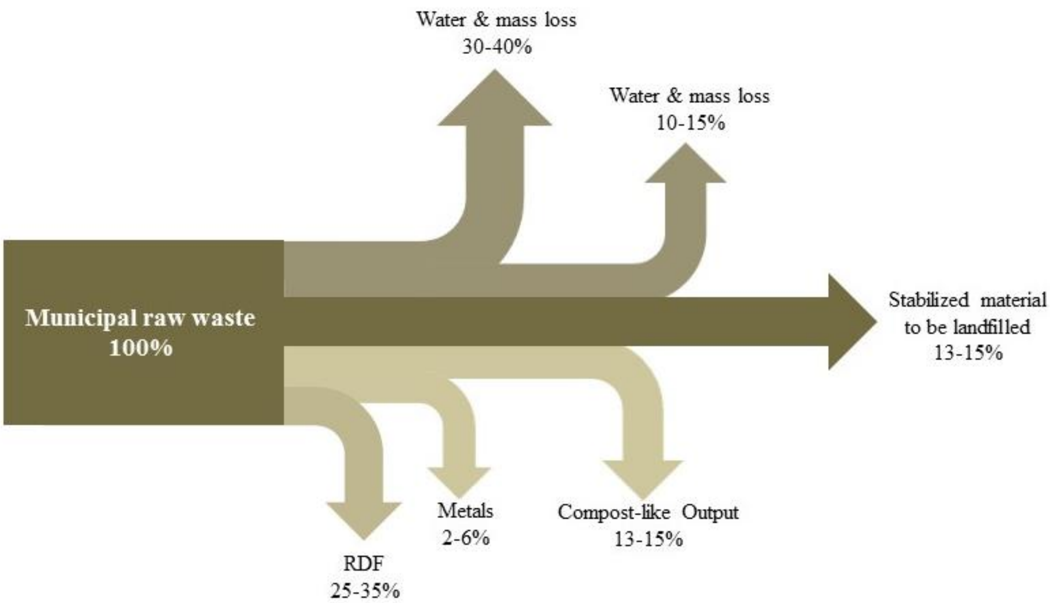

Figure 8-9. *Mass balance of Strategy two*

8.6. PROPOSED TECHNICAL MODELS FOR MIXED MSW TREATMENT

8.6.1. ESTABLISHMENT OF RECYCLING CENTRES AT THE MUNICIPAL LEVEL

The residual waste, which is discharged as mixed solid waste, still contains usable waste fractions. Depending on how intensively these recoverable waste fractions are collected, they are more or less contained in the residual waste. The mixed solid waste is thus enriched with bio-waste; up to 65% of organic components can be measured. The introduction of the separate bio-waste collections would reduce this share. One option to deal with the mixed solid waste is the installation of mechanical biological treatment plants in the framework of the local (municipal) or the regional MSWM plans depending on their level of coverage and competent authority (Municipality or JSC, respectively).

In order to properly plan the establishment of composting plant programmes and design facilities, the population numbers in each municipality is another parameter that has to be considered to make a decision on the required capacity and numbers of treatment facilities. The population number and waste amounts, mainly in Jordanian urban areas, are considerably lower and not comparable to numbers and amounts in European countries (see Figure 8-10). The population of Jordanian municipalities was estimated according to the Department of Statistics (DoS) records, 2016.

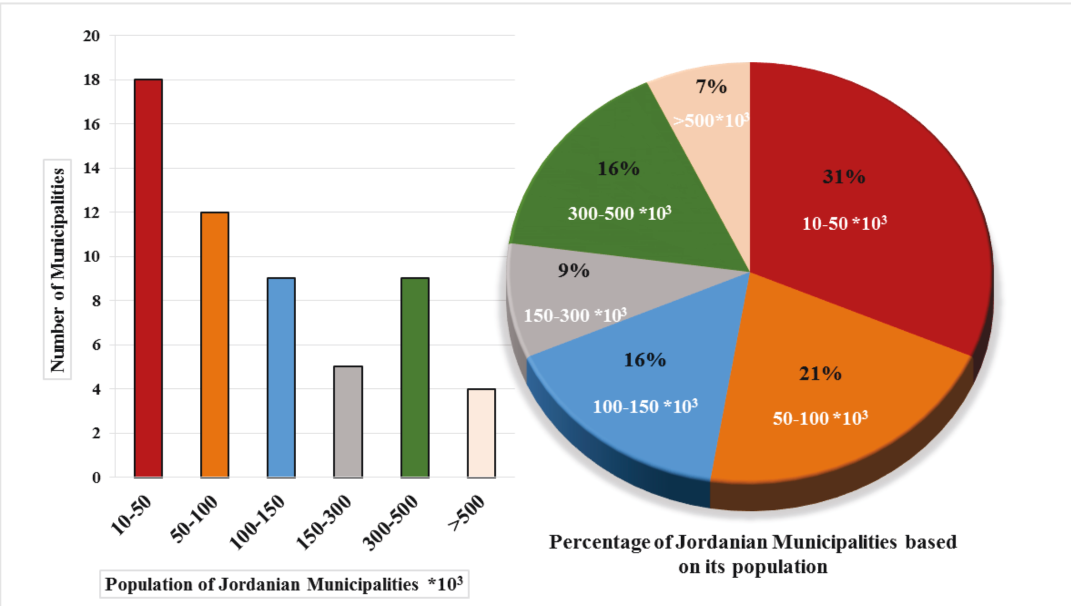

Figure 8-10. Population of Jordanian Municipalities

As the figure illustrates, more than 75% of the municipalities have a population of less than 100,000, which in turn encourages and supports the establishment of a treatment plant in each municipality of a small to medium capacity.

Aside from the population, accurate estimates of waste quantities generated and collected separately are required. Material that is already separated and diverted can be quantified through direct measurement, but in the case of organics mixed with other waste types, solid waste professionals must extrapolate quantities from known values that represent their percentage of the incoming waste stream (Figure 8-11).

In this approach, it was considered that simple waste-picking activities are normally undertaken by informal private sector workers for the recovery of recyclable materials mainly paper, glass, metals and plastics (around 7%). Furthermore, 30% of the remaining mixed solid waste would be deposited in the landfill without any treatment and the efficiency of the MBT plant of 85% were also assumed.

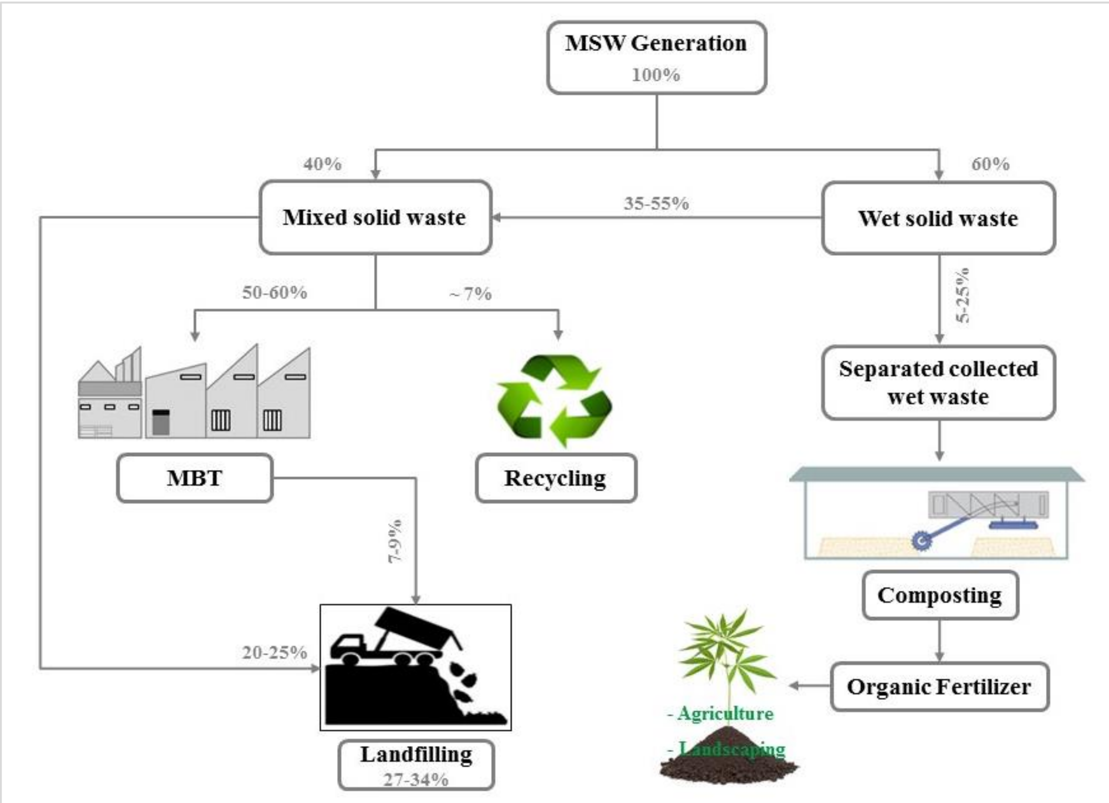

Figure 8-11. *Mass balance of the proposed strategy*

With a view to making calculations in terms of the required capacity and numbers of treatment facilities (MBT and composting plants), the amount of waste generated in each municipality was estimated based on the population of each municipality and the average waste generation of 0.9 and 0.6 kg/cap/d in urban and rural areas, respectively. Furthermore, special criteria for estimating the mass balance of the generated waste fractions, average waste content of bio-waste in household waste of 60%, amounts of organic waste generated and collected separately based on different collection rates was used (Table 8-2). For the estimation, the rates of separate collected of organic waste generation of 10, 20, 30 and 40 % were used.

Table 8-2. *Collection rates of separated organic waste.*

Urban ratio	>85 %	70-85 %	50-70 %	<50 %
Collected bio-waste rates	10 %	20%	30%	40%

Based on the above, a summary of the number of required treatment plants was calculated for each municipality as presented in Table 8-3, while the detailed calculations are given in Appendix V. At the outset phase, due to the lack of experience and knowledge, as well as the absence of qualified staff, installation of the proposed treatment plants with low capacity was considered. To this end, the projected capacity of the MBT and composting plants were assumed to be 5,000 and 50,000 ton/year, respectively.

Table 8-3. *Capacities and number of the proposed facilities of the new SWM Strategy for the Northern Region.*

Region	Governorate	Waste amount (ton/day)	Recycling (Informal)	Recycling Centre at a transfer station				Landfilling	
				Composting		MBT			
			Quantity (ton/ day)	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	%
Northern Region	Irbid	1,121	78	135	9	636	4	368	33
	Mafraq	250	18	60	4	121	1	70	28
	Ajloun	141	10	17	1	80	1	46	33
	Jerash	176	12	32	2	132	1	59	34
Central Region	Amman	2,534	177	236	12	1,485	9	859	34
	Madaba	151	11	28	2	79	1	45	30
	Balqa	406	28	75	4	211	1	122	30
	Zarqa	978	68	91	5	573	4	332	34
Southern Region	Aqaba	139	10	13	1	81	1	47	34
	Ma'an	108	8	30	2	49	0	28	26
	Karak	204	14	76	4	80	1	46	23
	Tafileh	84	6	16	1	44	0	25	30

As can be seen from the calculations depicted in the table, through the implementation of this strategy, the amount of waste to be landfilled would not exceed 30%. This reduces the environmental effects of waste dumping from pre-treatment, as happens at present, in addition to the economic aspect in terms of cost reduction dealing with waste within landfill boundaries. On the other hand, establishment of such treatment plants with low capacity has many advantages in terms of low investment costs, the possibility of securing raw materials easily and, thus, ensuring that the station is not interrupted, in addition to the ease of management and follow-up.

Consequently, the proposed technical option above must consider the lack of the required resources to enhance the environmental performance of waste disposal as one of the main challenges. Furthermore, the absence of qualified and well-trained staff is another major challenge that hinders proper management of the proposed facility.

8.6.2. A TECHNICAL TREATMENT MODEL FOR THE CITY OF AMMAN IN PARTICULAR

During the last few years, some well-developed cities in Jordan have initiated the MSW source separation programme. Amman, the capital city of Jordan, is one of the most developed cities in the country. In 2017, a total 1.3 million tons of MSW was generated, corresponding to 3,500 tons/day and 0.9 kg per capita per day.

There is one sanitary landfill site (Al-Ghabawi landfill) and one transfer station (Al Shaer transfer station) in Amman. The overloading of treatment facilities has shortened the service life of the landfill site. Therefore, MSW source-separated collection has become a key factor to achieve better waste minimisation and resource utilisation. Meanwhile, the local government also proposed several short/long-term plans to improve the MSWM system. A new incineration plant was launched to reduce the waste destined for landfill.

In addition, food waste biological treatment is under consideration, since it has been shown to have special environmental advantages and become an explicit goal in some European countries. However, no quantitative assessment has ever been conducted for the comparison of different MSWM systems. To establish an environmentally friendly integrated waste management system, assessing the effect of MSW source-separated collection and its possible improvements becomes essential.

The MSW characteristics of Amman can be summarised as follows:

- The MSW is dominated by food waste, making up the highest proportion of up to 60%. It is mainly attributable to the diet, i.e. more fresh vegetables and fruit compared to the developed countries. Since the quantity of food waste is very high, special attention is essential to its further treatment.
- The content of recyclables entering the municipal collection system is lower than developed countries. Individual collection by residents and scavengers is the dominant reason. However, there is still a considerable amount of recyclables flowing into the municipal collection system, and this will continue to increase with the growth of living standards. If these can be collected separately, a vast amount of secondary raw materials could be gained.

Currently, MSW mixed collection is the only mode in Amman and across the country. Up to 95% of the MSW goes to landfill, with the balance of 5–10 % complemented by informal recycling, where the proportion of recyclables are accumulated and sold by residents, scavengers or waste pickers, which finally flows into the recycling system for reprocessing. The remaining MSW is collected by the government. Usually, MSW from different residential communities is gathered in the Al Shaer transfer station and transported to the Al-Ghabawi landfill site. Work is underway to establish an incineration plant to treat the municipal waste generated in Amman. This has inspired the idea of this technical model, which suggests that the waste treatment process in the forthcoming incineration plant should be synchronised with the application of the waste separation system at the source: wet and dry.

As mentioned earlier, to apply source-separated raw municipal solid waste, the first step must be introducing a packaging ordinance. The implementation of separation of waste at source must coincide with the issuance of the packaging ordinance, otherwise this approach cannot be applied, because it will be doomed to failure. Once source-separated collection has started, MSW would be classified into two categories according to the policy of this proposed approach: wet/food and dry/recyclables waste.

Waste bins with different colours would be used to collect each category of MSW. Residents should be encouraged to put different waste fractions into the corresponding waste bins. Individual collection would remain the same as previously. Afterwards, food waste would be transported directly to the landfill site/transfer station, where there would be a specific area for its separated landfill. Recyclables would be classified manually into different components (paper, plastic, glass and metal) by municipal sanitation workers, followed by material recycling in reprocessing factories. The residual waste would mainly be sent for incineration, and the amount that exceeds the load of the incinerator would be diverted to landfill. Overall, the food waste and other residual waste would be collected every day, while recyclables would be collected once a week.

Four scenarios have been proposed to implement this model. In fact, as an assumption, the source-separated collection efficiency for food waste would be achieved by 15%, while the efficiency for recyclables, which are more complex to separate, are expected to reach 20%. These values were used as the calculation basis in this work. The four different MSWM scenarios that were modelled with their detailed flow chart are illustrated in Figure 8-12. Scenario 1 stands for the MSW mixed collection system which represents the current situation in Amman city. Both Scenario 2 and 3 represent the short-term MSWM plan system. Scenario 2 represents the MSWM under a source-separated collection system, in which the separation efficiency for wet/food waste and recyclables is 15 and 20%, respectively, while the initial amount of waste to be incinerated is 45% and the remaining 20% would be landfilled.

Scenario 3 suggests the same calculations for the separation efficiency for wet/food waste and recyclables (15 and 20%) while the amount of waste to be converted at the incineration plant increases to reach 65% and accordingly the amount of waste to be landfilled amounts to 15%. Scenario 4 represents a long-term plan based on Scenario 3, where food waste is expected to be biologically treated instead of separated landfill. The amount to be burned and disposed of represents 55% and 10%, respectively.

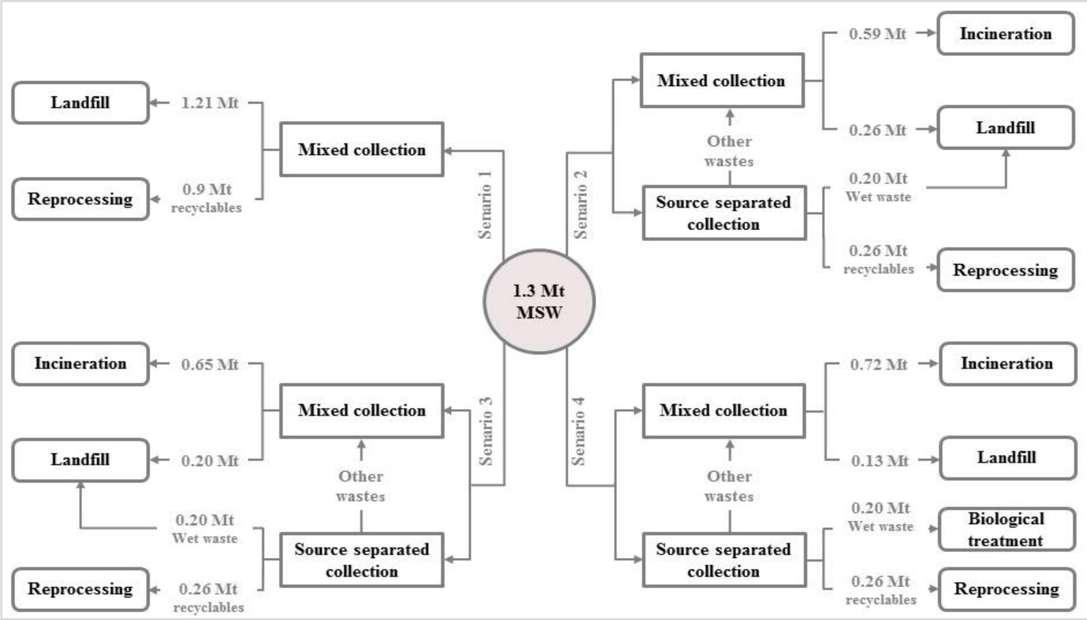

Figure 8-12. *Flowchart of different scenarios for MSWM systems in the city of Amman*

Scenarios description

Scenario 1: MSW mixed collection system (current MSWM system)

All MSW is collected mixed and 93% of the waste is deposited in landfill, with the remaining 7% of the recyclables collected by the informal sector either from containers or at the landfill site, to be sent for reprocessing.

Scenarios 2 and 3: short-term MSWM plan systems

According to the city's one-year plan, a new incineration plant, with a daily capacity of 1500 t/d, will be built 40 km away from the city centre. The yearly operation time is assumed to be 360 days, and will substitute an equal amount of MSW destined for landfill. In this scenario, both MSW source-separated collection and mixed collection exist. Food or wet waste (0.2 Mt) is landfilled separately and recyclables (0.26 Mt) are delivered for reprocessing. The residue MSW (0.59 & 0.65 for Scenario 2 & 3, respectively) is incinerated preferentially, whereas the surplus amount will be destined for landfill considering the capacity of the incineration plant.

Scenario 4: long-term MSWM plan system

According to the city plan, food waste will be diverted step-by-step towards recycling and biological treatment is under consideration. Since composting and anaerobic digestion (AD) have already been used successfully in some other countries, they are considered as Scenario 4a and Scenario 4b, respectively. The plant is supposed to be situated at the landfill site (Al-Ghabawi landfill) or the transfer station (Al Shaer transfer station) in the city. In this scenario, 0.2 Mt of wet/food waste will be biologically treated, 0.26 Mt for reprocessing, 0.72 to be incinerated and the remaining 0.13 Mt to be landfilled.

9. CONCLUSIONS

Recently, Jordan has realised that its management of solid waste does not satisfy the objectives of sustainable development. Therefore, it has decided to move away from traditional SWM options to more integrated SWM approaches. Collection and sorting, composting, incineration of medical waste and sanitary landfills are starting to be implemented, while recycling, reuse and resource recovery are still at the initial stages. Recyclable materials, such as plastic, glass, paper, metals and textiles, are not separately collected, and household waste is mixed with other types of waste when it is collected. About 5% of materials are recovered as recyclable materials: these materials are sorted by the informal sector.

Landfills and open dumps are still the common and primary disposal method in the Jordanian waste management plan. Up to 95% of generated MSW is directed to landfill for disposal without any treatment. Twenty landfill sites are available throughout the country, but there is only one sanitary landfill, which is the largest available, that receives waste from the capital city and nearby cities. About 35% of the SW is treated at the sanitary landfill site in the capital city. Over 50% of the waste generated in the entire country is placed in any of the 19 controlled landfill sites, 8% is open dumped and the remainder is unofficially recycled. Less than 5% of Jordan's solid waste is being recycled at the moment, as there is no large scale and effective government-run solid waste sorting practice or recycling system yet in place. The solid waste recycling industry in Jordan remains untapped and most of the existing and operational solid waste recycling activities are limited to the private sector and NGOs. Moreover, there is a high organic material content in MSW of 50% to 70%, and a high water content of about 60%. The technical problems and poor operation of the disposal sites will lead to environmental and acceptance problems such as leachate and landfill gas production and odour problems in the surrounding area.

Using the ArcGIS Network Analyst tool, a study was conducted in three Jordanian cities: Irbid, Karak and Mafraq, in order to improve the efficiency of the collection and transportation of waste. Three scenarios were generated and analysed for the identification of optimal routes. Compared to the current situation, the results showed a remarkable saving in the overall operational costs, where up to 23% savings were achieved. Furthermore, vehicle operating time was seen to decrease by 30%, in addition to other extra benefits related to CO_2 emissions and so forth.

A small-scale segregated bio-waste composting pilot project conducted in Mafraq city proved that a good quality final product can be achieved, which can be recovered and used as compost for agricultural purposes. Overall, the results of the experiment showed that compost with acceptable chemical properties (OM, TOC, TKN, total P, total K, heavy metals) and physical properties (bulk density, moisture content, etc.) was produced. These findings indicate that composting was carried out successfully under optimised conditions. The findings show that the quality of the compost produced depends largely on the level of the C/N start-up ratio and the quality of constituents within the mixture.

A test project conducted in Amman proved that RDF from MSW could be a strategic component of an integrated waste management system in order to achieve the recycling and reduction targets for combustible materials going to landfill. Overall results revealed that the use of RDF as an alternative fuel in cement production would be an economically viable and environmentally sound option that has the potential to result in less solid waste, reduced fuel costs, and reduce the landfill volume required and air emissions from the landfill, in particular greenhouse gases. It would lead to an environmentally sustainable future. The RDF produced was of high calorific value, low moisture content and acceptable chlorine content. It was compared with the typical composition of RDF from MSW originating in different countries. Concerning heavy metal content, it is interesting to note that although the RDF produced showed different ranges of heavy metal concentrations in the samples, in all cases they were lower than the reported ranges from the other countries considered. The quality of the RDF produced did not differ from the RDF quality set by some European countries.

The common issues for practising waste management are choosing the suitable treatment method for waste and the optimisation of disposal logistics (e.g. introduction of separate waste collection, cost reduction). Three approaches were proposed: introducing a separated wet/dry waste collection, treatment concepts for separated wet/dry and treatment concepts for mixed municipal waste. Two strategies were considered: Strategy one was based on the recovery of RDF and metal after the biodrying of raw waste, while in strategy two, the raw waste would be processed into RDF, metal recovered and the fine fraction further stabilised before landfilling. Alternatively, two technical models were also suggested: establishment of recycling centres (transfer station, sorting and composting plant) at the municipal level and a technical treatment model including installation of an incineration plant for the city of Amman in particular. The main objectives of the chosen alternatives are:

- Minimise the emissions of odours, landfill gas and leachate
- Minimise the remaining waste to be landfilled (quantity and emission)
- Recover recyclable material
- Relevant factors include recovery efficiency, costs and time needed for treatment.

The suggested options should not be considered as the ultimate solution to the problem of solid waste in Jordan. With the implementation of alternatives suitable for Jordan, other steps should be taken to improve the technologies chosen, improve the quality of the output from the waste after treatment and establish a sustainable market for the output material.

Among the various waste treatment options, composting remains the most widespread method of organic waste recycling worldwide. The benefits of composting are the recycling of the organic fraction of the solid waste, reducing as much as 30% of the volume of organic matter entering already overcrowded landfills. Diverting municipal solid waste organic material from landfills by composting has many environmental benefits, such as reducing greenhouse gas emissions, decreasing leachate quantities once discarded in landfills, and increasing the calorific value of feedstock in the case of energy recovery applications, co-processing, incineration, etc. From an economic point of view, composting can therefore bring reductions in the cost of disposing of organic residues, as well as providing an income, by virtue of compost being used as a substitute for other materials (chemical fertilisers and peat) that may be quite expensive.

Overall, a good alternative for Jordan is the WtE concept, whereby RDF is produced from energy-rich MSW materials diverted from landfills. This alternative mainly contributes to the reduction of the moisture content of the waste leading to an increase in the calorific value of the resulting product and a decrease in the production of leachate from landfilled material, if no further stabilisation of organic material is applied. Refuse-derived fuel is becoming one of the interesting alternatives to solving both global warming and MSWM problems. However, due to the high moisture content, low calorific value and high ash content of raw MSW, it is necessary to segregate the raw MSW and produce RDF. The advantage of RDF over raw MSW is that RDF can be considered a homogeneous material, with little pollutant content and with a good calorific value, which can be used for energy production in different plants or for replacing conventional fuels.

A good quality RDF is that which has a high calorific value and low concentrations of toxic chemicals, especially heavy metals and chlorine. The results showed that an efficient waste treatment could be achieved with a fairly basic and low-cost MBT concept. This would be by utilising the biological drying process to produce a substitute fuel for industrial processes and reducing the landfill areas required, as well as reducing the air emissions from the landfill, in particular greenhouse gases. High capital investment is needed to set-up an RDF plant. However, the return on investment is not guaranteed to treat the designated waste quantity for all cases. Therefore, the success of SWM is based on the partnership and cooperation between different parties involved, including politicians, local private sector, public sector and international consultant companies. The selection of an appropriate solution for MSW must be based on many factors, such as the availability of land for disposal, the market for recyclable material and the need for energy production, and taking into account the economic and social aspects, with particular attention to environmental issues.

A new integrated solid waste management approach focusing on the overall solid waste management cycle (street-cleaning, collection, transfer and transport, treatment and disposal) and supplemented by legal, organisational and institutional recommendations must be adopted to solve the problem of waste management. It is important that resources for running the waste management programme are properly employed. Financial resources, the legal institutional framework and human resources are the basic components of successful waste management.

The current centralised approach to waste management planning needs to be reviewed. The institutional and organisational aspects of the planning process should designate responsibilities for the preparation and implementation of the plan. The following aspects should be taken into consideration to improve the SWM system:

- Set service standards
- Enabling of laws and regulations
- Monitoring and evaluation of the operational services
- Encourage private sector investment by ensuring fair competition between private sector service providers and between the public and private sectors.

To overcome the problem of lack of professional expertise, appropriate training courses could be arranged at local and international levels, with training arrangements through exchange programmes with other international institutions.

Public education is also recommended to ensure the acceptance and understanding of the SWM system and what is required of them. This will ensure the public are engaged in the process, and people are educated about the socio-economic and environmental impacts of improper waste handling and informed about the values of the waste, if properly handled .

Initiation of a collection service that supports waste separation at source to improve the waste treatment aspect and provide more possibilities for other treatment options should be considered for Jordan. In the meantime, composting has been identified as one of the best waste management approaches and should be regarded as an option in the future to manage solid waste in Jordan, since comparably high amounts of organic waste are discarded by the community. This should be done after improving the collection services by implementing a separate collection whereby the organic waste would be collected separately. Through a composting process, it is possible to reduce the landfill waste. In particular, it will provide better, sound management as a result of reduced landfill gases as well as improvement of environmental conditions at the waste management site.

The proposed new ISWM approach will require a sufficient budget. Therefore, in order to improve the economic situation, municipalities should consider several ways to enhance their budgets. First, an immediate step would be to introduce, and strictly adhere to, levies on residents and commercial enterprises in receipt of waste collection and treatment services. The community should be made to pay for disposing of their waste and, at the same time, for the services the municipality provides. This will support the financial base of the waste management process. Moreover, the polluter-pays principle should be introduced with the development of an EPR system. Second, the implementation of a functioning waste separation system, focused on recycling and composting, will generate an income from the sale of such products. Simultaneously with a waste separation scheme is the need to introduce appropriate infrastructure to assist households. Residents could be required to buy their coloured waste bins from the municipalities or use the 'prepaid bag' system. Third, municipalities spend more than half of their MSWM budget on disposal of waste to landfill. Diversion of waste away from landfill will result in substantial savings. Finally, municipalities could research ways to reduce total expenditure for waste management, such as waste-to-energy production.

The Government has to promote the ISWM hierarchy and set up a national policy regarding the minimisation of waste to landfill. Local standards must be set for compost, RDF and landfill material in order to maintain a quality control programme. Cooperation between private and public sectors involved in the solid waste management system is required in order to guarantee the technical, financial and social sustainability of the solid waste management system implemented.

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1. The solid waste sector in Jordan can be characterised as a disorganised sector with sporadic service coverage. Waste management in the country is one of the major responsibilities of local government and the private sector is not a significant player in this field; there is no significant participation by the private sector. Subcontractors are commonly brought in to handle specific activities such as collection and transportation.
2. Recently, Jordan has realised that the way the country manages its solid waste does not satisfy the objectives of sustainable development. Therefore, the country has decided to move away from traditional SWM options to more integrated SWM approaches. To this end, Jordan's Government has made considerable progress in its ability to organise SWM through an improved legislative framework, stronger institutions and a number of publicly funded projects. In some cases, foreign rules and regulations were enacted without any customisation to suit the characteristics of the country .
3. Jordan defines organisational frameworks, but they are poorly implemented and disrupted by the centralisation of authorities at a national level. In addition, a lack of action by government institutions, the overlapping mandates and responsibilities and unclear lines of authority, a lack of investment by the private sector and the absence of public participation in decision making have all hampered the development of proper SWM practices in Jordan.
4. The fees collected for managing waste are generally charged on the electricity bill. The cost recovery is very low, covering only 60% of the costs in Greater Amman Municipality and no more than 30% in the other municipalities. In some cases, the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterised by the absence of financial incentives and effective cost recovery mechanisms. Now, there is an attempt towards increasing charges for waste management services by introducing the "polluter-pays" principle.
5. Municipalities are responsible on a day-to-day basis for municipal cleaning, waste collection and disposal of the mixed household waste generated. The existing MSW collection system has been developed based on limited data. It is considered to be adequate in urban centres, but services tend to be poor or non-existent in small towns and rural areas.
6. Under the Deputy City Manager, the Directorate of Environmental Affairs in each municipality oversees waste collection and manages the transport of waste from the collection areas (districts) to the landfill. The waste disposal is managed by the landfill site and treatment department. Each of the aforementioned districts are responsible for their waste collection and for transport to the transfer station (if any) or the landfill.

The districts all have a SWM organisation under which drivers, waste collectors and street sweepers are coordinated.

7. Waste sorting and recycling are undertaken by the informal sector, so much of the recycling is done inside landfills and some from the waste containers. About 2–5% of the total generated waste is recovered as recyclable materials, such as PET, other plastics, metals and paper. Sorting of the different types of solid waste at generation source is not yet practised in Jordan, so a considerable amount of recyclable materials are sent to final disposable sites. The processes have not yet reached a sustainable level, but some recycling initiatives and pilot project undertaken by NGOs have proved to be very successful, as the public was very positive, but once the projects of the NGOs were terminated, so was the recycling.
8. Composting, due to the high organic content of MSW, has received particular interest recently in relation to the recycling and conversion of organic solid waste into a stable product that can be used as a soil conditioner or fertiliser.
9. Waste disposal in uncontrolled dumps is still practised in many parts of Jordan. The most commonly used method of disposal is in controlled dumpsites. Disposal in sanitary landfills is increasingly being adopted, particularly where there is a strong sense of environmental awareness.
10. Jordan needs a sustainable, flexible and resource-oriented waste treatment system to promote waste minimisation, recycling and resource recovery in order to reduce the solid waste directed to landfills. Composting and mechanical biological/physical treatment options are considered the most suitable solution. Incineration is uneconomic for most cities in Jordan. Further problems are the lower calorific value <7000KJ/Kg, use of waste heat and the requisite knowledge for the operation.
11. Work is underway in Jordan on the establishment of seven plants to produce compost from different types of organic waste. Jordan currently has no experience of sorting recyclable materials from municipal waste and processing the separated organic matter. Therefore, many obstacles are expected to be encountered in the operation of the upcoming composting facilities, such as mismanagement because of the inappropriate technology chosen for the local conditions (resulting in high operating costs and frequent mechanical breakdowns through poor maintenance), a lack of understanding of the composting process, or limited availability of trained and skilled manpower needed for effective operating procedures.
12. A research study was performed using the ArcGIS Network Analyst tool in order to improve the efficiency of waste collection and transportation in the cities of Irbid, Karak and Mafraq, Jordan. A Geographic Information System (GIS) has been created based on data collection involving GPS tracking (collection route/bin position). Both key performance and key operational costs indicators of the actual state (Scenario S0) were evaluated, and by modifying particular parameters, other scenarios were generated and analysed to identify optimal routes.

13. The results showed that the three scenarios guarantee savings compared to S0 in terms of the total cost of waste collection of 15, 13 and 23% for S1, S2 and S3, respectively in the city of Irbid; 6, 3 and 8% for S1, S2 and S3, respectively in the city of Karak; and 11, 6 and 13% for S1, S2 and S3, respectively in the city of Mafraq. Thus, a direct impact on vehicle operating times can be expected with savings of 30%, without mentioning the additional benefits related to CO_2 emissions, hours of work, vehicle wear/maintenance and so forth.

14. A study was conducted to explore the physical and chemical properties of compost made from different segregated bio-waste raw materials. Four experimental windrow piles, constructed from different types of organic waste (fruit, vegetable and garden waste), were initiated and then temporally monitored. Plant residues and sawdust were used as bulking agents to provide the required C/N ratio needed for efficient decomposition. The compost produced was monitored in terms of moisture content, bulk density, pH, EC, total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and compost respiration.

15. The experimental process showed overall decreasing profiles versus composting time for moisture, organic carbon, carbon/nitrogen content (C/N) and pile volume, as well as overall increasing profiles for electrical conductivity, total nitrogen, total phosphorus, total potassium and bulk density. These provided qualitative indications that the process had progressed. The quality of the final product was examined and assessed against the quality specifications set out in the German End of Waste Criteria for bio-waste that has been subjected to composting. It was found that heavy metal concentrations (Cr, Cu, Ni, Cd, Pb, Zn and Hg) were within the set limits and much lower than German standards. Furthermore, compost respiration in the samples varied from 3.9 to 7.7 mgO_2/g dm. This indicated that all the compost samples were stable and can be rated as class IV and V final products.

16. A test project conducted in Amman proved that RDF from MSW could be a strategic component of an integrated waste management system in order to achieve the recycling and reduction targets for combustible materials going to landfill.

17. From several factors, high content of organic matter, the required investment and operation cost, easily adapted know-how, etc. biodrying is the more suitable technology for production of RDF from mixed collected MSW in Jordan.

18. The prepared materials were well-blended and aligned in two long windrow piles by a front-end loader and periodically turned on a daily basis. After three weeks, the waste was fairly dry with a moisture content of between 25 and 35%.

19. At the end of the biodrying process, the mass of waste was reduced on average by approx. 35% when the dried waste was directed to landfill without the recovery of material. In the case of RDF utilisation from the dried waste, the mass of waste to be landfilled was reduced by approx. 69%. Furthermore, by dumping the dried waste in

the landfill, leachate would not be produced if the landfill was carefully covered and protected from rainfall.

20. The RDF produced was of high calorific value, with low moisture and acceptable chlorine content (0.56–1.20% w/w) compared to the RDF produced in other countries. The quality of the RDF produced did not differ from the RDF quality set by some European countries. Concerning heavy metal content, it is interesting to note that all the RDF samples showed different ranges of heavy metal concentrations. However, in all cases, they were lower than the reported ranges from the other countries considered.
21. The biodrying process allowed an increase of about 58% in the waste calorific value (LHV) as a consequence of the waste moisture reduction. The calorific value of unprocessed MSW ranged from 6.21 to 6.45 MJ/Kg. The calorific value of the RDF produced from the pilot project ranged from 14.83 to 15.58 MJ/kg, which made it suitable as a fuel. The ash content of the RDF produced appeared to have a low range between 16% and 19%.
22. The findings showed that adding 15% RDF which equals 4.92 tons/h to the fuel used at cement kilns will save 3.24 ton/h Petcoke, 486 USD/h from Petcoke costs, 2.27 tons/ h of CO_2 being emitted into the atmosphere, 34 USD/h from the decrease in CO_2 emissions alone, and 389 USD/h as the net saving.
23. Overall results revealed that the use of RDF as an alternative fuel in cement production will be an economically viable and environmentally sound option that has the potential to result in less solid waste, reduced fuel costs, reduced landfill volume required and reduced air emissions from the landfill, in particular greenhouse gases and an environmentally sustainable future.
24. Two strategies have been considered for an RDF production facility. The first is based on the recovery of RDF and recyclables after the biodrying of raw waste, while in the second strategy the raw waste is processed into RDF, recyclable material are recovered, and the fine fraction is then to be subjected to further stabilisation before landfilling.
25. A technical model was proposed for mixed MSW treatment. It recommends establishment of recycling centres (transfer station, sorting and composting plant) at the municipal level across the country. For the estimation, the mass balance of the generated waste fractions, average waste content of wet/food waste in household waste of 60% and the rates of separate collected of organic waste generation of 10, 20, 30 and 40 % for urban ratio of >85, 70-85, 50-70 and <50 %, respectively, were used. MBT plant efficiency was assumed up to 85%.
26. In this model, it was considered that simple waste-picking activities are normally undertaken by informal private sector workers for recovery of recyclable materials mainly paper, glass, metals and plastics (around 7%). Further, 30% of the remaining mixed solid wastes would be deposited in the landfill without any treatment.

27. With a view to making calculations in terms of the required capacity and numbers of treatment facilities (MBT and composting plants), the amount of waste generated in each municipality was estimated based on the population of each municipality and the average waste generation of 0.9 and 0.6 kg/cap/d in urban and rural areas, respectively.

28. The number of required treatment plants was calculated for each municipality based on the population and amount of waste generated. At the outset phase, due to the lack of experience and expertise, as well as the absence of qualified staff, installation of the proposed treatment plants of a low capacity was considered. To this end, the projected capacity of the MBT and composting plants were assumed to be 5,000 and 50,000 ton/year, respectively.

29. As a result, through the implementation of this strategy, the amount of waste to be landfilled would not exceed 30%, which reduces the environmental effects in the case of the dumping of waste from pre-treatment as the current situation, in addition to the economic aspect in terms of cost reduction dealing with waste within landfill boundaries.

30. For the city of Amman, in particular, a technical treatment model including installation of an incineration plant was proposed. Four scenarios have been proposed to implement this model. It was assumed that the source-separated collection efficiency for food waste would be achieved by 15%, while the efficiency for recyclables, which are more complex to separate, was expected to reach 20%.

31. Scenario 1 represents the MSW mixed collection system which represents the current situation in Amman city. Both Scenario 2 and 3 represent a short-term MSWM plan system. Scenario 2 represents the MSWM under source-separated collection, and the separation efficiency for wet/food waste and recyclables is 15 and 20%, respectively, while the initial amount of waste to be incinerated is 45% and the remaining 20% would be landfilled. Scenario 3 suggests the same calculations for the separation efficiency for wet/food waste and recyclables (15 and 20%) while the amount of waste to be converted to the incineration plant increases to reach 65% and accordingly the amount of waste to be landfilled amounts to 15%. Scenario 4 represents a long-term plan based on scenario 3, where food waste is expected to be biologically treated instead of separately landfilled. The amount to be burned and disposed of represents 55% and 10%, respectively.

32. The proposed technical models above must consider the lack of required resources to enhance the environmental performance of waste disposal as one of the main challenges. Moreover, the absence of qualified and well-trained staff is another major challenge that hinders proper management of the proposed facility.

Appendix I: Optimisation of waste collection (Chapter 5)

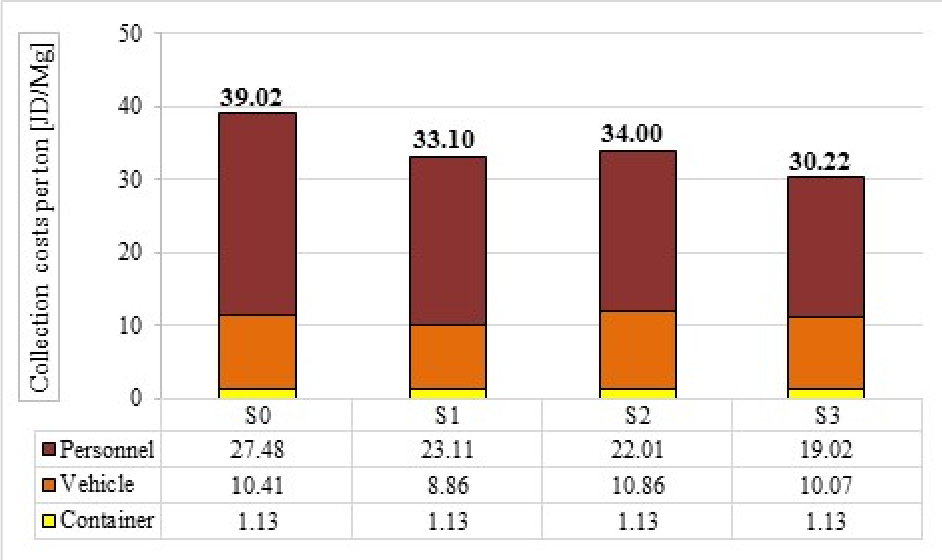
Costs benefits analysis for different scenarios for solid waste collections & transportation in the study areas

JD/a		Irbid				Karak			
		Initial situation	Scenario 1	Scenario 2	Scenario 3	Initial situation	Scenario 1	Scenario 2	Scenario 3
3-Axle	**Container**	21,352 JD/a	21,352 JD/a	21,352 JD/a	21,352 JD/a	9,608 JD/a	9,608 JD/a	9,608 JD/a	9,608 JD/a
	Vehicle	178,788 JD/a	184,363 JD/a	239,280 JD/a	241,741 JD/a	62,582 JD/a	75,179 JD/a	77,562 JD/a	88,728 JD/a
	Personnel	360,185 JD/a	371,417 JD/a	330,953 JD/a	335,911 JD/a	140,186 JD/a	147,354 JD/a	136,007 JD/a	141,930 JD/a
	Total	560,324 JD/a	577,131 JD/a	591,584 JD/a	599,003 JD/a	212,375 JD/a	232,142 JD/a	223,177 JD/a	240,266 JD/a
2.Axle	**Container**	127,339 JD/a	127,339 JD/a	127,339 JD/a	127,339 JD/a	13,097 JD/a	13,097 JD/a	13,097 JD/a	13,097 JD/a
	Vehicle	1,048,064 JD/a	964,849 JD/a	1,218,449 JD/a	1,142,956 JD/a	156,352 JD/a	148,807 JD/a	161,891 JD/a	159,701 JD/a
	Personnel	2,562,953 JD/a	2,359,460 JD/a	2,171,960 JD/a	1,987,347 JD/a	232,389 JD/a	193,527 JD/a	213,898 JD/a	185,558 JD/a
	Total	3,738,356 JD/a	3,451,648 JD/a	3,517,747 JD/a	3,257,641 JD/a	401,838 JD/a	355,431 JD/a	388,886 JD/a	358,356 JD/a
Small vehicle	**Container**	30,841 JD/a	30,841 JD/a	30,841 JD/a	30,841 JD/a	12,698 JD/a	12,698 JD/a	12,698 JD/a	12,698 JD/a
	Vehicle	421,931 JD/a	253,458 JD/a	263,114 JD/a	209,708 JD/a	79,617 JD/a	79,091 JD/a	85,806 JD/a	84,987 JD/a
	Personnel	1,429,187 JD/a	930,154 JD/a	983,093 JD/a	690,290 JD/a	272,402 JD/a	236,776 JD/a	241,255 JD/a	209,522 JD/a
	Total	1,881,959 JD/a	1,214,453 JD/a	1,277,047 JD/a	930,840 JD/a	364,718 JD/a	328,565 JD/a	339,759 JD/a	307,207 JD/a
Total	**Container**	179,531 JD/a	179,531 JD/a	179,531 JD/a	179,531 JD/a	35,403 JD/a	35,403 JD/a	35,403 JD/a	35,403 JD/a
	Vehicle	1,648,783 JD/a	1,402,670 JD/a	1,720,842 JD/a	1,594,405 JD/a	298,551 JD/a	303,077 JD/a	325,258 JD/a	333,416 JD/a
	Personnel	4,352,325 JD/a	3,661,030 JD/a	3,486,005 JD/a	3,013,548 JD/a	644,977 JD/a	577,658 JD/a	591,161 JD/a	537,010 JD/a
	Total	6,180,640 JD/a	5,243,232 JD/a	5,386,379 JD/a	4,787,484 JD/a	978,931 JD/a	916,138 JD/a	951,822 JD/a	905,829 JD/a
	Amount of waste	**158,400**				**23,040**			

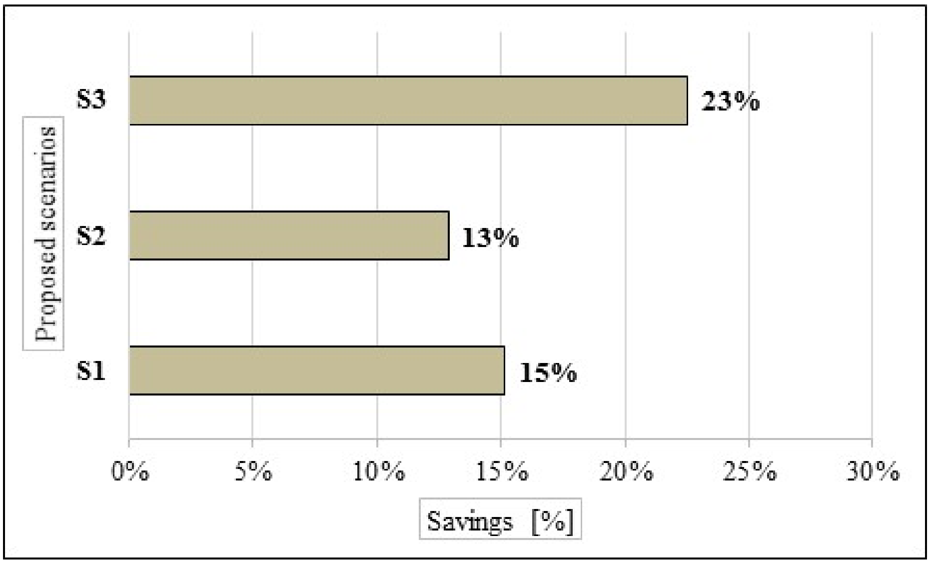
total costs JD/ton		Irbid				Karak			
		Initial situation	Scenario 1	Scenario 2	Scenario 3	Initial situation	Scenario 1	Scenario 2	Scenario 3
Total	Container	1.13 JD/ton	1.13 JD/ton	1.13 JD/ton	1.13 JD/ton	1.54 JD/ton	1.54 JD/ton	1.54 JD/ton	1.54 JD/ton
	Vehicle	10.41 JD/ton	8.86 JD/ton	10.86 JD/ton	10.07 JD/ton	12.96 JD/ton	13.15 JD/ton	14.12 JD/ton	14.47 JD/ton
	Personnel	27.48 JD/ton	23.11 JD/ton	22.01 JD/ton	19.02 JD/ton	27.99 JD/ton	25.07 JD/ton	25.66 JD/ton	23.31 JD/ton
	Total	39.02 JD/ton	33.10 JD/ton	34.00 JD/ton	30.22 JD/ton	42.49 JD/ton	39.76 JD/ton	41.31 JD/ton	39.32 JD/ton

vehicle costs JD/ton		Irbid				Karak			
		Initial situation	Scenario 1	Scenario 2	Scenario 3	Initial situation	Scenario 1	Scenario 2	Scenario 3
3-Axle	Container	0.13 JD/ton	0.13 JD/ton	0.13 JD/ton	0.13 JD/ton	0.42 JD/ton	0.42 JD/ton	0.42 JD/ton	0.42 JD/ton
	Vehicle	1.13 JD/ton	1.16 JD/ton	1.51 JD/ton	1.53 JD/ton	2.72 JD/ton	3.26 JD/ton	3.37 JD/ton	3.85 JD/ton
	Personnel	2.27 JD/ton	2.34 JD/ton	2.09 JD/ton	2.12 JD/ton	6.08 JD/ton	6.40 JD/ton	5.90 JD/ton	6.16 JD/ton
	Total	3.54 JD/ton	3.64 JD/ton	3.73 JD/ton	3.78 JD/ton	9.22 JD/ton	10.08 JD/ton	9.69 JD/ton	10.43 JD/ton
2.Axle	Container	0.80 JD/ton	0.80 JD/ton	0.80 JD/ton	0.80 JD/ton	0.57 JD/ton	0.57 JD/ton	0.57 JD/ton	0.57 JD/ton
	Vehicle	6.62 JD/ton	6.09 JD/ton	7.69 JD/ton	7.22 JD/ton	6.79 JD/ton	6.46 JD/ton	7.03 JD/ton	6.93 JD/ton
	Personnel	16.18 JD/ton	14.90 JD/ton	13.71 JD/ton	12.55 JD/ton	10.09 JD/ton	8.40 JD/ton	9.28 JD/ton	8.05 JD/ton
	Total	23.60 JD/ton	21.79 JD/ton	22.21 JD/ton	20.57 JD/ton	17.44 JD/ton	15.43 JD/ton	16.88 JD/ton	15.55 JD/ton
Small vehicle*	Container	0.19 JD/ton	0.19 JD/ton	0.19 JD/ton	0.19 JD/ton	0.55 JD/ton	0.55 JD/ton	0.55 JD/ton	0.55 JD/ton
	Vehicle	2.66 JD/ton	1.60 JD/ton	1.66 JD/ton	1.32 JD/ton	3.46 JD/ton	3.43 JD/ton	3.72 JD/ton	3.69 JD/ton
	Personnel	9.02 JD/ton	5.87 JD/ton	6.21 JD/ton	4.36 JD/ton	11.82 JD/ton	10.28 JD/ton	10.47 JD/ton	9.09 JD/ton
	Total	11.88 JD/ton	7.67 JD/ton	8.06 JD/ton	5.88 JD/ton	15.83 JD/ton	14.26 JD/ton	14.75 JD/ton	13.33 JD/ton

vehicle costs JD/ton	Irbid				Karak			
	Initial situation	Scenario 1	Scenario 2	Scenario 3	Initial situation	Scenario 1	Scenario 2	Scenario 3
3-Axle	22.11	22.77	23.34	23.63	28.81	31.49	30.27	32.59
2-Axle	32.33	29.85	30.42	28.17	42.54	37.63	41.17	37.94
Small vehicle*	108.01	69.70	73.29	53.42	58.63	52.82	54.62	49.38
Total	**39.02**	**33.10**	**34.00**	**30.22**	**42.49**	**39.76**	**41.31**	**39.32**

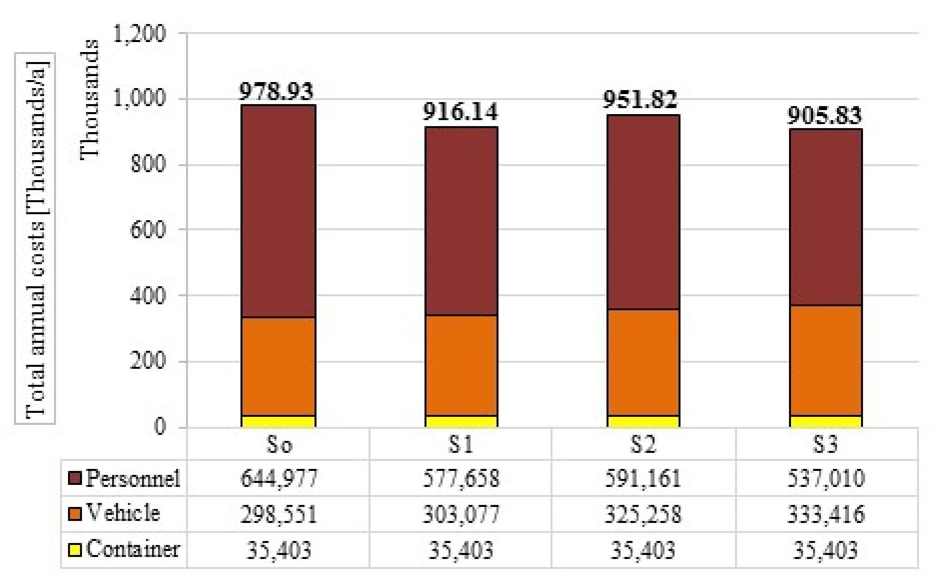


(a)

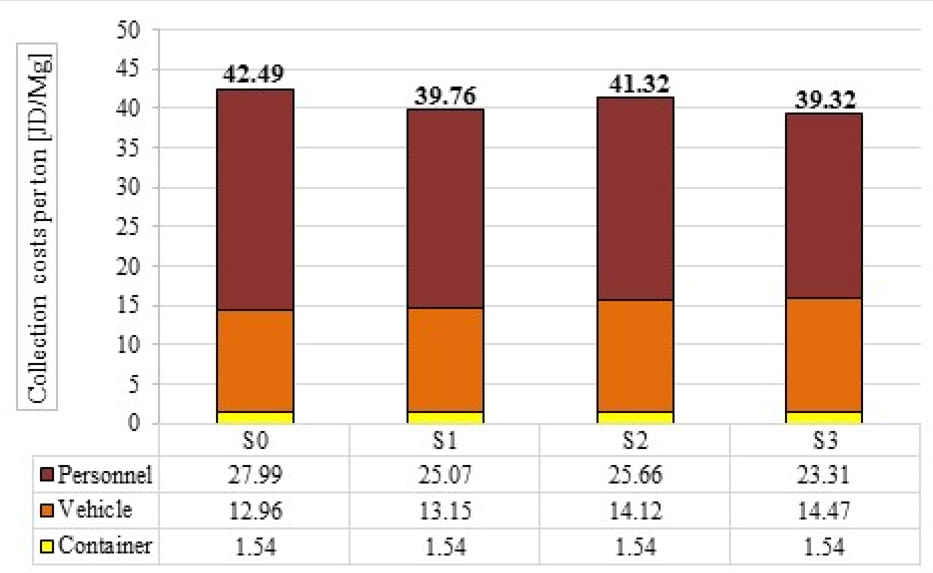


(b)

(a) The collection costs projections [JD/ton] and (b) Savings [%] for the proposed scenarios & compared with the initial situation in the city of Irbid

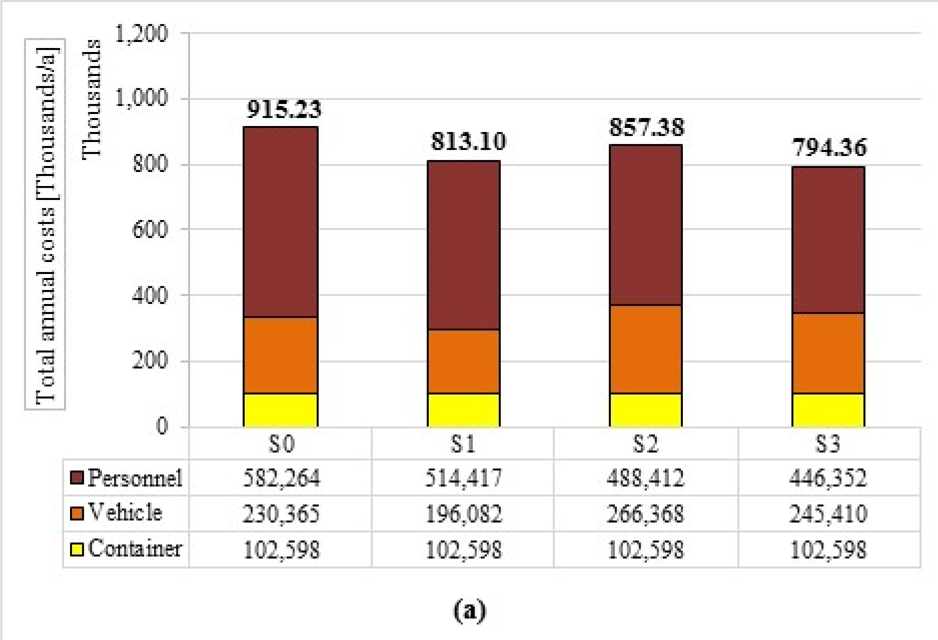


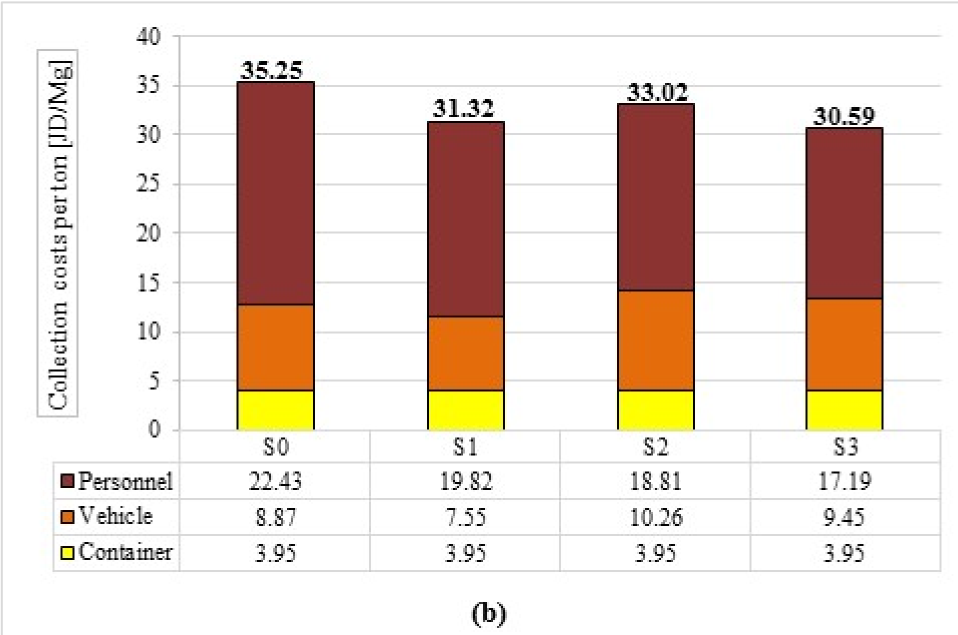
(a)



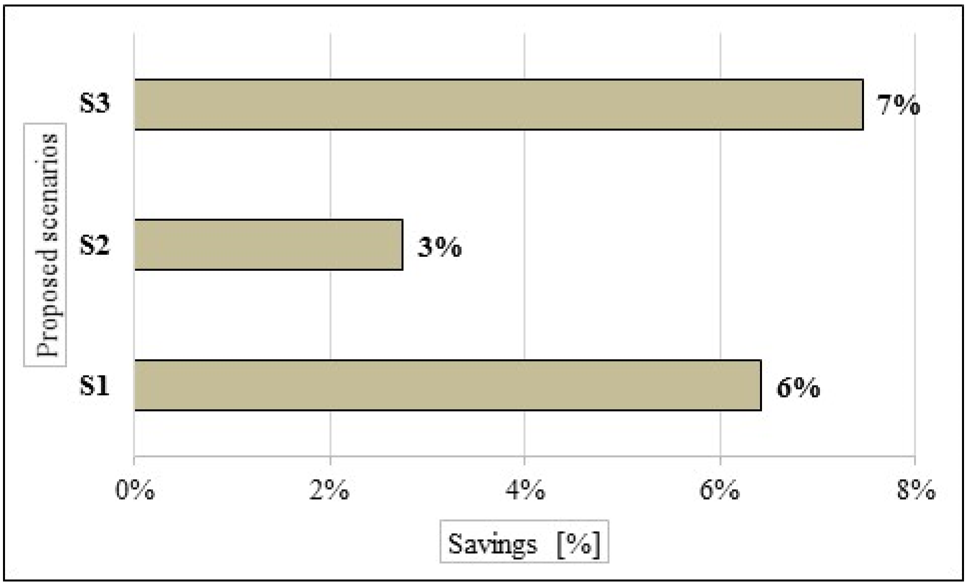
(b)

(a) The annual collection costs projections [JD/a] and (b) The collection costs projections [JD/ton] for the proposed scenarios & compared with the initial situation in the city of Karak

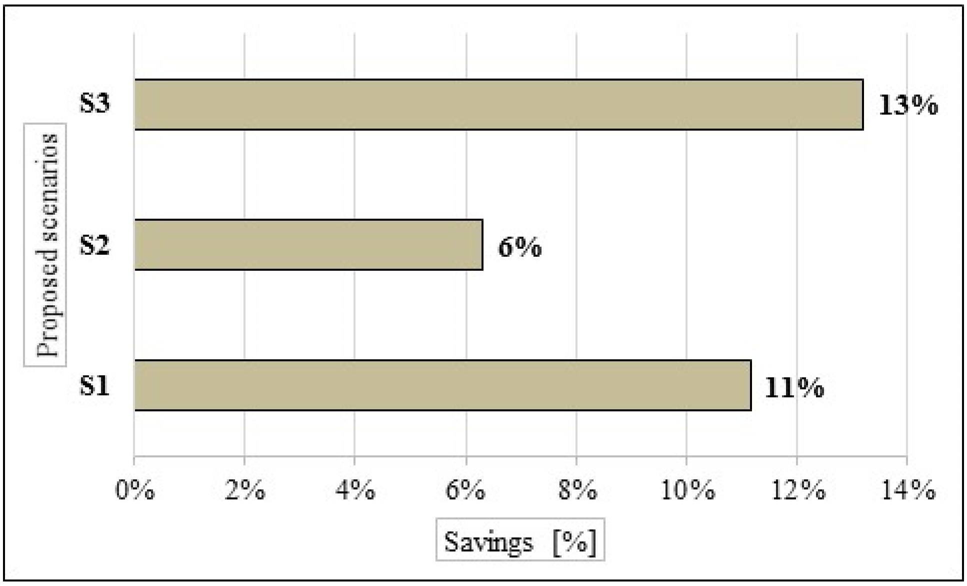




(a) The annual collection costs projections [JD/a] and (b) The collection costs projections [JD/ton] for the proposed scenarios & compared with the initial situation in the city of Mafraq



Savings [%] for the proposed scenarios & compared with the initial situation in the city of Karak



Savings [%] for the proposed scenarios & compared with the initial situation in the city of Mafraq

Appendix II: Assessment of separated organic waste composting (Chapter 6)

Average measured temperatures during composting runs

Week	Ambient Temp.	Pile 1 (P1) Temp.	Pile 2 (P2) Temp.	Pile (P3) Temp.	Pile (P4) Temp.
0	14	18	17.6	17	16.5
1	15.43	52.74	47.36	49.97	47.79
2	11.29	63.64	65.57	62.81	62.44
3	14.57	60.36	65.20	61.17	58.59
4	17.00	56.83	60.74	57.70	54.23
5	12.43	52.46	58.23	53.83	48.39
6	14.57	47.01	57.20	51.71	45.69
7	14.71	43.61	55.60	48.27	42.43
8	12.71	41.54	50.86	45.43	38.96
9	13.71	39.70	49.77	43.26	35.17
10	13.57	36.46	41.94	37.64	32.43
11	14.00	31.30	27.87	26.91	25.46
12	14.57	18.39	18.27	17.04	16.87

Average measured O_2 & Co_2 concentrations during composting runs

Week	P1		P2		P3		P4	
	O_2 %	CO_2 %	O_2 %	CO_2%	O_2%	CO_2%	O_2%	CO_2%
0	6	3	5	3	5	3	6	3
1	1	18	2	19	0	20	1	18
2	0	17	0	18	1	19	2	17
3	1	16	1	17	2	18	3	16
4	2	14	2	16	4	17	5	14
5	4	13	3	15	6	16	6	13
6	5	12	4	14	8	13	8	10
7	7	11	7	12	9	11	10	8
8	11	9	8	11	10	9	11	7
9	11	6	10	9	12	7	12	5
10	13	5	13	7	13	4	13	4
11	14	4	14	6	14	3	15	3
12	16	4	14	5	14	3	15	2

Average moisture content during composting runs

Week	P1	P2	P3	P4
0	28	26	25	23
1	59	58	53	49
2	49	46	50	48
3	53	53	54	52
4	47	41	49	50
5	51	50	39	53
6	48	43	49	51
7	43	50	42	53
8	51	48	53	50
9	47	43	47	48
10	40	39	44	44
11	36	37	40	39
12	33	34	37	38

Average nutrients content wt/wt (%) during composting runs

	N		P		K	
	start	end	start	end	start	end
P1	1.06	1.87	1.12	1.65	1.29	1.69
P2	1.09	2.1	1.27	1.85	1.37	1.77
P3	1.11	2.33	1.44	2.09	1.41	1.85
P4	1.15	2.61	1.48	2.21	1.47	1.98

Average EC values during composting runs

Week	P1	P2	P3	P4
0	2.43	2.45	3.01	3.36
2	2.54	2.45	3.16	3.38
4	2.57	2.42	3.21	3.42
6	2.51	2.46	3.18	3.57
8	2.58	2.54	3.21	3.72
10	2.62	2.65	3.32	3.89
12	2.76	2.8	3.54	4.09

Average measured reduction in C/N ratios during composting runs

Pile No.	C/N ratio values over 12 weeks							Reduction in C/N ratio (%)
	0	2	4	6	8	10	12	
P1	24	21.6	18.9	16.9	15.7	15	14.2	41
P2	25.1	22.8	20.8	18.9	17.2	16	15.3	39
P3	27	23.1	20	19.4	18	17	16.7	38
P4	29	25.6	22	20.5	19.4	18.7	18.4	36

Pile volume, water added and bulk density during composting runs

Pile No.	Initial Volume	Final Volume	Volume Reduction %	Water Added	m^3 water / m^3 fresh waste	Initial Bulk Density Kg/m^3	Final Bulk Density Kg/m^3	Bulk Density Reduction %
P1	36	25.3	29.7	21.4	0.59	521	603	-15.74
P2	38	28.4	25.3	22.1	0.58	472	542	-14.83
P3	36	27.7	23.1	21.4	0.59	371	424	-14.29
P4	40	31.1	22.3	24.6	0.62	295	340	-15.25

AT4 test Results for all compost samples included in the study

Sample No.	AT4 mgO_2/gDM
1	5.30
2	4.20
3	6.50
4	7.50
5	5.40
6	4.10
7	6.70
8	7.70
9	5.60
10	3.90
11	6.60
12	7.50

Heavy metal concentrations of compost

Heavy metals	Unit	Heavy metals values			
		P1	P2	P3	P4
Pb	mg/kg_{TS}	38.30	19.30	53.65	12.22
Cd	mg/kg_{TS}	0.39	0.28	0.32	0.19
Cr	mg/kg_{TS}	17.0	16.0	16.0	12.0
Cu	mg/kg_{TS}	57.0	42.0	42.0	21.0
Ni	mg/kg_{TS}	14.0	13.0	13.0	11.0
Zn	mg/kg_{TS}	268.0	167.0	166.0	152.0
Hg	mg/kg_{TS}	< 0,05	< 0,05	< 0,05	< 0,05

Appendix III: Investigating the potential of RDF production from mixed MSW (Chapter 7)

Raw municipal solid waste sample collected from Amman city (Input raw materials)

Raw materials area	District	District code	Name of City	Amount of waste collected in 2017/ ton	% of the total waste collected
Greater Amman Municipality (GAM)	Al-Jami'ah	D1	Abu Nuṣair	18301	21%
			Al-Jubayhah	54350	
			Shafa Badran	15407	
			Ṣuwaylih	38663	
			Tila' al-'Ali- Khilda - Umm as-Summaq	84539	
		Total		211260	
	Qaṣabah 'Amman	D2	Al-'Abdalli	52415	28%
			Al-Madinah	28395	
			Al-Yarmuk	52032	
			Badr	52703	
			Ras Ala'in	43264	
			Zahrān	43161	
		Total		271970	
	Al-Quwaysimah	D3	Al-Quwaysimah - Abu 'Alanda - Al-Juwaydah	69785	15%
			Khraibat as-Suq- Jawa - Al-Yadudah	48778	
			Umm Quṣayr- Al-Muqabalin	34290	
		Total		152853	
	Marka	D4	Al-Nasr	54481	22%
			Basman	79286	
			Marka	42001	
			Tariq	43587	
		Total		219355	
	Wadi as-Sir	D5	Marj al-Hamam	29434	12%
			Wadi Essier	88200	
			Badr Jadeda	3937	
		Total		121571	
	Saḥab	D6	Uhod	10888	1%
		Total		10888	
Total				9,878,970	100%

Composition of municipal waste from Amman city, average of total analysis during both trials (input raw municipal materials)

Trial 1 (Screening at 100 mm)	
Sorting fractions	**%**
Organics	**54.1**
Hygienic products	**8.1**
Plastic film	**5.5**
Paper	**6.2**
Cardboard	**4.6**
Textiles, shoes, bags	**5.0**
Plastics 3D	**3.1**
Composite materials	**2.6**
Non Fe-metals	**2.1**
Glass	**2.1**
Combustible materials	**2.0**
Inert	**1.4**
Fe-metals	**1.4**
Wood	**1.2**
Batteries	**0.4**
Electronical goods	**0.4**
Sum	**100**

Trial 2 (Screening at 150 mm)	
Sorting fractions	**%**
Organics	**56.0**
Hygienic products	**9.7**
Plastic film	**5.6**
Paper	**6.0**
Cardboard	**4.1**
Textiles, shoes, bags	**4.3**
Plastics 3D	**2.7**
Composite materials	**2.3**
Combustible materials	**2.3**
Glass	**1.8**
Non Fe-metals	**1.5**
Fe-metals	**1.0**
Wood	**1.1**
Inert	**1.0**
Batteries	**0.5**
Electronical goods	**0.0**
Sum	**100**

Average main input waste composition	
Sorting fractions	**Average %**
Organics	**55**
Hygiene products	**9**
Paper	**6**
Plastic film	**6**
Cardboard	**4**
Textiles	**5**
Plastics 3D	**3**
Composite materials	**3**
Combustible materials	**2**
Glass	**2**
Non Fe-metals	**2**
Fe-metals	**1**
Inert	**1**
Wood	**1**
Batteries	**1**
Electronic goods	**0**
Sum	**100**

Size distribution and composition of fresh waste

Fractions < 100 mm fractions	
Sorting fractions	**%**
Organics	55.2
fines < 10 mm	9.7
Hygienic products	9.1
Plastic film	4.9
Paper	4.4
Cardboard	3.7
Plastics 3D	3.3
Glass	1.9
Fe-metals	1.2
Batteries	1.3
Combustible materials	1.2
Textiles	1.1
Inert	1.0
Non Fe-metals	0.9
Composite materials	0.5
Wood	0.4
Electronical goods	0.4
Sum	**100**

Fractions > 150 mm fractions	
Sorting fractions	**%**
Plastic film	18.6
Paper	18.4
Textiles	16.1
Organics	8.1
Cardboard	12.7
Combustible materiales	7.2
Plastics 3D	3.6
Hygienic products	2.7
Electronical goods	2.6
Glass	2.6
Composite materials	2.0
Fe-metals	1.6
Wood	1.6
Inert	1.5
Non Fe-metals	0.8
Batteries	0.0
Sum	**100**

Fractions > 100 mm fractions	
Sorting fractions	**%**
Plastic film	20.4
Paper	18.3
Textiles	14.5
Cardboard	12.3
Organics	8.4
Combustible materials	4.5
Plastics 3D	3.8
Hygienic products	3.2
Glass	2.9
Composite materials	2.8
Electronical goods	2.1
Fe-metals	1.9
Wood	1.9
Inert	1.9
Non Fe-metals	1.0
Batteries	0.0
Sum	**100**

Fractions < 150 mm fractions	
Sorting fractions	**%**
Organics	52.5
fines < 10 mm	10.4
Hygienic products	10.3
Plastic film	5.3
Paper	4.9
Cardboard	3.1
Plastics 3D	3.0
Glass	2.2
Fe-metals	1.3
Combustible materiales	1.2
Batteries	1.1
Inert	1.1
Non Fe-metals	1.1
Electronical goods	1.0
Composite materials	0.6
Textiles	0.6
Wood	0.5
Sum	**100**

Size distribution of each waste component of the received waste (Input)

Materials Compositions	Fraction Size			
	>100mm	10-100mm	>150mm	10-150mm
Organics	8.4	55.2	8.1	52.5
Paper	18.3	4.4	18.4	4.9
Cardboard	12.3	3.7	12.7	3.1
Plastic film	20.4	4.9	18.6	5.3
Plastic 3D	3.8	3.3	3.6	3.0
Textiles	14.5	1.1	16.1	0.6
Hygiene products	3.2	9.1	2.7	10.3
Others combustible	4.5	1.2	2	1.2
Metals	2.9	2.1	2.4	2.4
Others inerts	11.7	15	15.4	17.3
Total	**100**	**100**	**100**	**100**

The average characteristics of fresh waste (input) and the coarse fraction >80 mm after the end of the biodrying process (three weeks).

Materials Compositions	Raw waste %	RDF %
Organics	57	12
Plastic film	6	19
Hygiene products	8	11
Paper	5	7
Cardboard	4	6
Textiles	5	20
Organic "garden"	0	0
Plastics 3D	3	4
Composite materials	3	5
Other combustible	1	8
Metals	3	3
Others	5	5
Sum %	**100**	**100**

The average characteristics of coarse fraction for both trails

Materials Compositions	Trial 1 (Screening at 100 mm)	Trial 2 (Screening at 150 mm)
Organics	11%	13%
Paper	6%	9%
Cardboard	6%	7%
Plastic film	20%	19%
Plastic 3D	5%	5%
Textiles	20%	21%
Hygiene products	12%	10%
Others combustible	8%	7%
Metals	3%	3%
Glass, inerts	4%	3%
Other non-combustible	2%	1%
Sum	**100%**	**100%**

Heavy metal concentrations of RDF samples

Heavy metals	Unit	Heavy metals values							
		S1	S2	S3	S4	S5	S6	S7	S8
As	mg/kgTS	0.87	0.98	1.2	1.4	0.83	0.64	0.6	0.82
Pb	mg/kgTS	59.00	110.00	87.00	120.00	51.00	100.00	300.00	58.00
Cd	mg/kgTS	3.00	1.60	2.10	2.50	2.60	1.90	2.20	3.00
Cr	mg/kgTS	44.00	78.00	87.00	62.00	36.00	45.00	50.00	60.00
Ni	mg/kgTS	18.00	120.00	150.00	39.00	18.00	57.00	39.00	22.00
Zn	mg/kgTS	130.00	260.00	280.00	220.00	150.00	230.00	220.00	160.00
Hg	mg/kgTS	< 0,03	< 0,03	< 0,03	< 0,03	< 0,03	< 0,03	< 0,03	< 0,03
Cl	% of TS	0.70%	0.95%	0.73%	1.20%	0.56%	0.71%	0.60%	0.76%

S: Sample

Appendix V (Chapter 8): *Capacities and number of the proposed facilities of the new SWM Strategy for the Northern Region*

Governorate	District	Population	Urban %	Rural %	Waste amount (ton/day)	Recycling (Informal)	Recycling Centre at a transfer station				Landfilling	
							Composting		MBT			
						Quantity (ton/ day)	Quantity (ton/ day)	No. of plants	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	%
Irbid Governorate	Irbid Qasabah District	534,420	83	17	**454**	32	54	3	257	2	149	33
	Bani Obeid District	133,126			**113**	8	14	1	64	0	37	33
	Wastiyyah District	34,208			**29**	2	3	1	16	0	10	33
	Taybeh District	41,444			**35**	2	4	0	20	0	12	33
	Mazar Shamali District	62,840			**53**	4	6	0	30	0	18	33
	Koura District	129,548			**110**	8	13	1	62	0	36	33
	Bani Knenanah District	108,698			**92**	6	11	1	52	0	30	33
	Ramtha District	155,288			**132**	9	16	1	75	0	43	33
	Aghwar Shamaliyah District	121,231			**103**	7	12	1	58	0	34	33
Total		**1,320,803**	**83**	**17**	**1,121**	**78**	**135**	**9**	**636**	**4**	**368**	**33**
Mafraq Governorate	Mafraq Qasabah District	145,287	39	61	**104**	7	25	1	50	0	29	28
	Badiah Shamaliyah District	82,436			**59**	4	14	1	29	0	17	28
	Badiyah Shamaliyah Gharbiyah District	107,084			**77**	5	18	1	37	0	21	28
	Ruwaished District	14,008			**10**	1	2	0	5	0	3	28
Total		**348,815**	**39**	**61**	**250**	**18**	**60**	**4**	**121**	**1**	**70**	**28**
Ajloun Governorate	Ajloun Qasabah District	131,674	76	24	**109**	8	13	1	62	0	36	33
	Kofranjahh District	38,959			**32**	2	4	0	18	0	11	33
Total		**170,632**	**76**	**24**	**141**	**10**	**17**	**1**	**80**	**1**	**46**	**33**
Jerash Governorate	Jerash Qasabah District	222,670.00	63	37	**176**	12	32	2	132	1	59	34
Total		**222,670**	**63**	**37**	**176**	**12**	**32**	**2**	**132**	**1**	**59**	**34**

Appendix V (Chapter 8): *Capacities and number of the proposed facilities of the new SWM Strategy for the Central Region*

Governorate	District	Population	Urban %	Rural %	Waste amount (ton/day)	Recycling (Informal)	Recycling Centre at a transfer station				Landfilling	
							Composting		MBT			
						Quantity (ton/ day)	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	%
Amman Governorate	Amman Qasabah District	817,351	94	6.0	**721**	50	67	4	422	3	244	34
	Marka District	715,738			**631**	44	59	3	370	2	214	34
	Quaismeh District	380,572			**336**	23	31	2	197	1	114	34
	Al-Jami'ah District	413,269			**365**	26	34	2	214	1	124	34
	Wadi Essier District	257,098			**227**	16	21	1	133	1	77	34
	Sahab District	84,375			**74**	5	7	0	44	0	25	34
	Jeezeh District	62,213			**55**	4	5	0	32	0	19	34
	Muwaqar District	44,406			**39**	3	4	0	23	0	13	34
	Naur District	97,965			**86**	6	8	0	51	0	29	34
Total		**2,872,988**	**94**	**6**	**2,534**	**177**	**236**	**12**	**1,485**	**9**	**859**	**34**
Madaba Governorate	Madaba District	144,706	71	29	**118**	8	22	1	61	0	35	30
	Theeban District	40,794			**33**	2	6	0	17	0	10	30
Total		**185,500**	**71**	**29**	**151**	**11**	**28**	**2**	**79**	**1**	**45**	**30**
Balqa Governorate	Balqa (Al Salt) Qasabah District	157,716	72	28	**129**	9	24	1	67	0	39	30
	Deir Alla District	66,720			**54**	4	10	1	28	0	16	30
	Shouna Janoobiyyeh District	55,627			**45**	3	8	0	24	0	14	30
	Ain Al Basha District	185,094			**151**	11	28	2	79	1	46	30
	Mahes & Fheis District	31,989			**26**	2	5	0	14	0	8	30
Total		**497,145**	**72**	**28**	**406**	**28**	**75**	**4**	**211**	**1**	**122**	**30**
Zarqa Governorate	Zarqa Qasabah District	650,772	95	5	**576**	40	54	3	337	2	195	34
	Ruseifah District	387,831			**343**	24	32	2	201	1	116	34
	Hashimya District	66,964			**59**	4	6	0	35	0	20	34
Total		**1,105,567**	**95**	**5**	**978**	**68**	**91**	**5**	**573**	**4**	**332**	**34**

Appendix V (Chapter 8): ***Capacities and number of the proposed facilities of the new SWM Strategy for the Southern Region***

Governorate	District	Population	Urban %	Rural %	Waste amount (ton/day)	Recycling (Informal)	Recycling Centre at a transfer station				Landfilling	
							Composting		MBT			
						Quantity (ton/ day)	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	No. of plants required	Quantity (ton/ day)	%
Aqaba Governorate	Aqaba District	134,554	86	14	**115**	8	11	1	68	0	39	34
	Qweirah District	27,134			**23**	2	2	0	14	0	8	34
Total		**161,688**	**86**	**14**	**139**	**10**	**13**	**1**	**81**	**1**	**47**	**34**
Ma'an Governorate	Ma'an Qasabah District	76,326	55	45	**58**	4	16	1	27	0	15	26
	Petra Qasabah District	35,671			**27**	2	8	0	12	0	7	26
	Shobak Qasabah District	16587			**13**	1	4	0	6	0	3	26
	Husseiniyeh District	12429			**10**	1	3	0	4	0	3	26
Total		**141,013**	**55**	**45**	**108**	**8**	**30**	**2**	**49**	**0**	**28**	**26**
Karak Governorate	Karak Qasabah District	91,891	35	65	**65**	5	24	1	25	0	15	23
	Mazar Janoobiyyeh District	81,042			**57**	4	21	1	22	0	13	23
	Qasr District	29,562			**21**	1	8	0	8	0	5	23
	Aghwar Janoobiyah District	45,974			**32**	2	12	1	13	0	7	23
	Ayy District	13,764			**10**	1	4	0	4	0	2	23
	Faqo'e District	17,261			**12**	1	5	0	5	0	3	23
	Qatraneh District	9,850			**7**	0	3	0	3	0	2	23
Total		**289,343**	**35**	**65**	**204**	**14**	**76**	**4**	**80**	**1**	**46**	**23**
Tafileh Governorate	Tafileh District	64,687	71	29	**53**	4	10	1	27	0	16	30
	Hasa District	12,463			**10**	1	2	0	5	0	3	30
	Bsaira District	26,693			**22**	2	4	0	11	0	7	30
Total		**103,843**	**71**	**29**	**84**	**6**	**16**	**1**	**44**	**0**	**25**	**30**

CURRICULUM VITAE

Eng. Safwat Hemidat
Faculty of Agriculture and Environmental sciences
Department of Waste and Resource Management
Justus-von-Liebig-Weg 6A
18059 Rostock
Germany
E-mail – **safwat.hemidat@uni-rostock.de**

OBJECTIVES — Environmental Engineer/ Solid Waste Management/ Waste to Energy/ Renewable energy/ Wastewater treatment/ Pollution control

PRESENT POSITION	PhD student
FAMILY NAME:	Hemidat
FIRST NAMES:	Safwat
DATE OF BIRTH:	15/06/1977
NATIONALITY:	Jordanian
CIVIL STATUS:	Married

1. EDUCATION:

Institution	School of Engineering, Department of Industrial Engineering, The University of Jordan, Jordan.
Date *from to*	2010-2013
Degree(s) or Diploma(s) obtained	Master of Science, Industrial Engineering
Institution	School of Engineering, Department of Mining Engineering, Al- Balqa Applied University, Jordan.
Date *from to*	1998-2003
Degree(s) or Diploma(s) obtained	Bachelor of Engineering, Mining Engineering.

2. LANGUAGE SKILLS, *mark 1 (worst) to 5 (best) for competence:*

Language	Speaking	Writing	Reading
Arabic	5	5	5
English	4	4	4

3. KEY QUALIFICATIONS:

As an Environmental Engineer, my experience started as a junior engineer for develop guidelines for environmental, health and safety management and other mining related procedures, after 6 years of work in Germany, my experience included planning and management of:

- Solid waste management assessment
- Waste characterization study
- Municipal solid waste treatment
- Alternative fuel production and preparation
- Alternative fuel utilization in the cement industry
- Solid waste material recovery
- MSW Bio-drying and Composting
- Knowledge of Landfill mining and rehabilitation
- Experience in developing countries mainly MENA region
- Optimization the routing network used for waste collection services by using GIS technics
- Assessment of Urban Services
- Solid waste management for energy conversion processes.
- Environmental Impact Assessment of solid waste energy conversion processes projects
- Feasibility Studies including cost-benefit analysis of energy conversion projects

During my research work, I had the chance to work with remarkable international experts of different backgrounds who had their clear finger prints on my knowledge and career development.

4. PROFESSIONAL EXPERIENCE RECORD:

Date	March, 2017 till present
Location	Universität Rostock, Germany.
Company	GIZ and University of Rostock, Germany.
Position	Research Assistant as well as PhD degree in Environmental Engineering (solid waste management, treatment and disposal).
Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	Contribution in Waste to Positive Energy (Wt(P)E) project in the Jordan. it Supported and funded by GIZ and with the participation of three German universities (University of Rostock, TU Hamburg and TU Dresden) and four Jordanian universities (Jordan University of Science and Technology, Mu'tah University, University of Jordan and German-Jordanian University). The project aimed to effectively involve the Jordanian academic institutions in the process of improving the waste management system in Jordan and other countries in the MENA region by addressing the main obstacles facing it, examine the best Waste to Energy (WtoE) treatment technologies and proposed sustainable solutions through a master's thesis for the students benefiting from the project.
Date	01. April. 2014- 01.March. 2017
Location	Universität Rostock, Germany.
Company	Universität Rostock / Dep. of Waste and Resource Management.
Position	PhD degree in Environmental Engineering (waste management, treatment and disposal).
Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	• The assessment of the current situation of solid waste management in Jordan and examine compost and RDF quality produced from mixed solid waste. • Studying and planning the most appropriate alternative as an economical technological solution for the solid waste problems in the Jordan. • Introducing an Integrated Solid Waste Management System in terms of solid waste collection, treatment and disposal. • Preparation of feasibility studies for different solid waste management projects in the Jordan. • Contribution in pilot project in the Jordan for examine and choosing the best Waste to Energy (WtoE) treatment technologies for solid waste management.
Date	01. August. 2017- 10. February. 2018
Location	Jordan
Company	GIZ and University of Rostock, Germany.
Position	**Local Expert**

Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	**"Investigation the potential of RDF utilization as alternative Fuel in Cement Industry in Jordan (Waste to Energy)"** The main objective of this project is to provide a complete waste management solution (treatment and disposal) during adapting the technical requirements to the local condition in order to convert as much waste into energy (RDF) as possible. Moreover, this research aims to provide scientific based knowledge regarding combustion mechanisms of alternative fuels (RDF) applied in cement production. This will be achieved by a combination of theoretical and experimental investigations on a laboratory coupled industrial experience. The specific objectives of this research are to: • Investigate the potential end users together with their expectation on RDF and quantify RDF market size in Jordan. • Find out the possible RDF composition which conforms to end users' requirements. • Select the appropriate technology which can produce required quality of RDF. • Identify the driving mechanisms of RDF utilization in cement production in Jordan. ***Activities Performed:*** 1. Waste characterization. 2. Sampling and analysis. 3. Process monitoring. 4. Environmental and economical assessment of RDF produced. 5. Design RDF substitution options accordingly.
Date	01. August. 2017- 06. February. 2018
Location	Jordan
Company	UNDP and University of Rostock, Germany.
Position	**Local Expert**
Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	**"Study and Assessment of Segregated Bio-waste Composting: The Case Study of Jordan"** This study aimed to monitor the composting process of the first small-scale segregated bio-waste composting scheme in Jordan to divert different types of organic wastes and to evaluate the final product quality, which can be recovered and used as compost. To this end, four experimental windrow piles, from different types of organic wastes (fruit, vegetable, and garden waste), were first initiated and temporally monitored. Plant residues and sawdust were used as bulking agents to ensure the required C/N ratio needed for efficient decomposition. The produced compost was monitored against moisture content, bulk density, pH, EC, total

	organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and compost respiration, indicating that the biological conditions were sufficiently developed. Four different types of compost were obtained by mixing fruit, vegetable and plant residues at different ratios to form: 1. P1: Fruit &Vegetables (100:0) 2. P2: Fruit &Vegetables and plant residues (75:25) 3. P3: Fruit &Vegetables and plant residues (50:50) 4. P4: Fruit &Vegetables and plant residues (25:75) During each run, the different organic raw materials (fruit, vegetable and plant residues) were blended with each other in certain ratios and gently mixed with bulking agents (tree clipping & sawdust) to ensure the required C/N ratio needed for efficient decomposition; then suitable conditions to support rapid aerobic composting (moisture and aeration) were supplied directly after mixing. ***Activities Performed:*** 1. Use of state-of-art technologies to produce high quality compost that complies with international standards, 2. Sampling and analysis. 3. Process monitoring. 4. Environmental assessment of compost produced.
Date	01. July. 2016- 25. October. 2016
Location	Jordan
Company	UNDP
Position	**Local Expert**
Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	**"Stakeholders Identification and Mapping"** The project aimed to assist UNDP with the identification of waste stakeholders including municipalities, and waste pickers. The strategy consisted of conducting workshops on integration options for waste pickers, consult with stakeholders to define best options and approaches for the formalization of the waste picking activities, and supporting in setting up of waste pickers organization and agreement with municipalities at the collection phase linked to the composting and waste bank project. ***Activities Performed:*** 1. Identify the waste operations stakeholders including municipalities, and waste pickers. 2. Conduct proper stakeholders mapping.

<table>
<tr><td></td><td>3. Conduct workshops on integration options of waste picking activities for the identified stakeholders (e.g.: waste pickers, NGOs, CBOs, Municipality, etc.) to determine best approaches for activities formalization and organization.
4. Supporting in setting up of waste pickers organization and agreement with municipalities at the collection phase linked to the composting and waste bank project in accordance to the outputs of the workshops conducted.
5. Through the outcomes of the stakeholders mapping and the outputs of the workshops, the best approaches taking into consideration all related aspects (legal, stakeholder’s recommendations, institutional, operational, capacity basis, etc.) were properly analyzed, formalized and presented in the form of possible scenarios with detailed description of each (describing also basic SWOT analysis). The recommendations were made taking into consideration the scope of works of the composting and waste bank project.
6. Develop best agreement approaches accordingly.</td></tr>
<tr><td>Date</td><td>20. June. 2016-01. January. 2017</td></tr>
<tr><td>Location</td><td>Jordan</td></tr>
<tr><td>Company</td><td>DEG, Germany and GAM, Jordan</td></tr>
<tr><td>Position</td><td>Local Expert</td></tr>
<tr><td>Description
✓ Similar project / Task
✓ Leadership experience
✓ Developing country
✓ Regional experience</td><td>“Monitoring of Composting Process Parameters – A Case Study in Jordan”
The study experiments with annual capacity of 300 m^3 were conducted on an established composting pilot plant which is located at Al-Ghabawi landfill site around 40 km east of Jordan’s capital.
On the basis of the elementary value of compost as a natural fertiliser in agriculture, different types of organic wastes, such as animal manures (poultry, cow, and horse) were used as the composting input material. Plant and vegetable residues and sawdust were used as bulking agents to ensure the required C/N ratio needed for efficient decomposition.
In this study, four experimental windrow piles were first initiated and temporally monitored. The composting process was monitored against temperature, moisture and oxygen content, indicating that the biological conditions were sufficiently developed. The monitored experimental process showed overall decreasing profiles versus composting time for moisture, organic carbon and carbon/nitrogen content (C/N), as well as overall increasing profiles for electrical conductivity and total nitrogen, which represented qualitative indications of progress in the process.
<u>Activities Performed:</u></td></tr>
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	1. Use of state-of-art technologies to produce high quality compost that complies with international standards, 2. Sampling and analysis. 3. Process monitoring. 4. Environmental assessment of compost produced. 5. Capacity building and training of Jordanian stakeholders on compost production and application of organic fertilizers.
Date	23. June. 2015-01. January. 2016
Location	Jordan
Company	GIZ
Position	Project Engineer
Description ✓ Similar project / Task ✓ Leadership experience ✓ Developing country ✓ Regional experience	**“Advice to Refugee Hosting Communities in Waste Management” – ADHOC 1– GIZ Project** In this pilot project, optimized scenarios were developed using the ArcGIS Network Analyst tool in order to improve the efficiency of waste collection and transportation in the cities of Irbid, Karak and Mafraq, Jordan. Geographic Information System (GIS) has been created based on data collection involving GPS tracking (collection route/bin position). Both key performance and key operational costs indicators of the actual state (Scenario S0) were evaluated, and by modifying particular parameters, other scenarios were generated and analyzed to identify optimal routes. ***Activities Performed:*** 1. Enhancement of maintenance, service and operation system of vehicle fleet. 2. Optimizing the routing system and the placement of waste containers. 3. Analyzing and optimizing the reporting and data system on the operation and maintenance of the vehicle fleet. 4. Assessment and analyze the current waste management key figures in the municipalities of Irbid, Mafraq and Karak. 5. Collect, evaluate and analyse all important key figures necessary for an optimized waste routing planning. 6. Tracking the overall relevant key operational cost indicators of waste collection and transportation in terms of vehicles and staff. 7. On base of the collected key data for waste collection operations, different scenarios were developed and cost analysis for each scenario were performed and compared to the current situation.

5. PUBLICATIONS

Published Papers

1. Hemidat, S.; Saidan, M.; Al-Zu'bi, S.; Irshidat, M.; Nassour, A. and Nelles, M. (2019). Potential Utilization of RDF as an Alternative Fuel for the Cement Industry in Jordan. Sustainability.Vol. 11 (20), Pp: 1–23, DOI: 10.3390/su11205819.
2. Hemidat, S.; Saidan, M.; Nassour, A. and Nelles, M. (2019). Comprehensive Assessment of Segregated Bio-waste Composting: The case of Syrian Refugees Hosting Communities in Northern Jordan. 13. Rostocker Bioenergieforums". Juni 2019 an der Universität Rostock. ISBN 978-3-86009-487-7. Vol. 87, Pp: 337-351.
3. Chaabane, W.; Selmi, M.; Hemidat, S.; Chaher, N.; Nassour, A. and Nelles, M. (2019). Monitoring of Composting Process Parameters from Bio-waste and Green Waste Generated in Tourism Destinations: A Case Study of Tunisia. 13. Rostocker Bioenergieforums". Juni 2019 an der Universität Rostock. ISBN 978-3-86009-487-7. Vol. 87, Pp: 325-335.
4. Hemidat, S.; Saidan, M.; Nassour, A. and Nelles, M. (2019). Study and Assessment of Segregated Bio-waste Composting. Deutsche Gesellschaft für Abfallwirtschaft e.V. (DGAW). DGAW-Wissenschaftskongress „Abfall- und Ressourcenwirtschaft". März 2019 an der OTH in Amberg/Weiden. ISBN 978-3-903187-48-1. Vol. 9, Pp: 171-176.
5. Nassour, A.; Hemidat, S. Chaabane, W and Nelles, M. (2018). Current developments in waste management in the Arab world. Müll und Abfall, Fachzeitschrift für Abfall- und Ressourcewirtschaft, ISBN 978-3-503-17664-9. Vol. 4, Pp: 160-166. [In German].
6. Hemidat, S.; Jaar, M.; Nassour, A. and Nelles, M. (2018). Monitoring of Composting Process Parameters – A Case Study in Jordan. Waste and Biomass Valorization.Vol. 9 (12), Pp: 2257–2274. Springer.
7. Hemidat, S.; Oelgemöller, D.; Nassour, A. and Nelles, M. (2017). Evaluation of Key Indicators of Waste Collection via GIS Techniques as a Planning and Control Tool for Route Optimization. Waste and Biomass Valorization. Vol. 8 (5), Pp: 1533-1554. Springer.
8. Nassour, A.; Hemidat, S.; Lemke, A.; Elnaas, A. and Nelles, M. (2017). Separation By Manual Sorting at Home: State of the Art in Germany. Source Separation and Recycling. The Handbook of Environmental Chemistry, ISBN 978-3-319-69071-1. Vol. 63, Pp: 67-87. Springer, Cham.
9. Nassour, A.; Elnass, A.; Hemidat, S. and Nelles, M. (2016). Approaches to Improve Waste Management in the Arab Region. Müll und Abfall, Fachzeitschrift für Abfall- und Ressourcewirtschaft, ISBN 978-3-503-15774-7. Vol. 4, Pp: 177-184. [In German].

STATEMENT:

I, the undersigned, certify that to the best of my knowledge, these data correctly describe me, my qualifications and my experience.

Safwat Hemidat Hemidat 01.11.2019