Department of Waste Management and Material Flow

Rostock University

ACTUAL SITUATION AND APPROACH FOR MUNICIPAL SOLID WASTE TREATMENT IN THE ARAB REGION

DISSERTATION

Submitted in the fulfillment of the requirements of

The Academic Board of Rostock University

Faculty of Agriculture and Environmental Sciences

For the Degree of DOCTOR of Engineering (Dr. Eng.)

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2015

urn:nbn:de:gbv:28-diss2016-0072-7

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Date of submission: 08.11.2015

Date of defence: 31.03.2016

SUMMARY

Recently, some Arab countries have introduced the ISWM concept. Collection and sorting, composting, incineration of medical wastes and sanitary landfills are starting to be implemented, while recycling, reuse and resource recovery are still at the initial stages. In many countries 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 most of the Arab region 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 inability of the existing waste management systems to cope with the growing waste generation rates has led to significant health and environmental problems in most Arab countries

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

This PhD was conducted in two phases, the first phase was the evaluation of the current situation of SWM practices in the Arab region and the assessment of the compost produced from mixed MSW in the region; the second phase was the examination of the feasibility of mechanical biological treatment (MBT) technology as a solution for the conditions in the region to overcome some of its MSW management problems. In this study, the characteristics of several samples of mixed MSW composts were evaluated on the basis of chemical, physical and biological aspects and compared with German standards (BioAbfV).

This thesis also focused on MBT technology in the form of biodrying processes that produces refuse derived fuel (RDF) from mixed MSW. Laboratory analysis for RDF samples was carried out, to evaluate the RDF quality and compared with criteria and limits set by some European countries. The biological drying process of solid waste by aerated windrow composting/stabilization 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/stabilization was investigated as part of a pilot scale experiment carried out in Tunisia.

In conclusion, the results showed that compost from some operating facilities was of a poor quality and was not recommended to be used as soil fertilizers, due to the risk from heavy metals and organic pollutants combined with the physical risks from sharps and glass, and the aesthetic problem of plastic scraps that remain highly visible even after composting. The absence of local standards, monitoring systems and the legal barriers prevents the control of the selling and application of MSW compost to agricultural/horticultural land.

Over all, the results conclude that an efficient waste treatment could be achieved with a fairly basic and low-cost MBT concept. This is by utilizing the biological drying process to produce a substitute fuel for industrial processes and reduce 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, 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 involved parties (politicians, private sector, consultant companies and public sector). 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.

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List of Abbreviations

AfDB: African Development Bank

AT4: Respiration activity test

Cd: Cadmium.

CLO: Compost Like Output.

Cr: Chrome.

Cu: Copper.

DM: Dry Matter.

EC: Electric Conductivity.

EU: European Union.

Hg: Mercury.

HHW: Household Hazardous Wastes

ISWM: Integrated Solid Waste Management.

MBT: Mechanical Biological Treatment

MRF: Materials Recovery Facilities.

MSW: Municipal Solid Waste.

MSWFF: Biodried MSW Fine Fraction.

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.

UAE: United Arab Emirates.

UNEP: United Nations Environment Program

USEPA: United States Environment Protection Agency

W/C: Water Content.

W2W: Waste to Water

WtE: Waste to Energy

Zn: Zinc.

Zn: Zinc.

1. INTRODUCTION AND PROBLEM STATEMENT

In the last two decades, municipal waste management (MWM) has become a major concern and is presently one of the main subjects under discussion. This is probably due to the considerable increase of municipal solid waste (MSW) production in both total and per capita values. The amount of solid waste produced increases with economic growth and it demands efficient management solutions (McCarthy, 1994). Solid waste is an environmental problem in both developed and developing countries. Solid waste management (SWM) systems in developing countries 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 (Collivignarelli et al., 2004). The provision of adequate SWM services is critical because of the potential impact on public health and on the environment. Population growth in urban centers, lack of planning, lack of proper disposal, limited collection service, use of inappropriate technology and inadequate financing are considered the main problems facing SWM (Diaz et al., 1999).

Composting is a means of biologically degrading organic materials while stabilizing a residual organic fraction, which can be widely used in agriculture and horticulture (Garcìa et al., 1995). It also decreases the volume and weight of the raw material (Golueke, 1977; Schnitzer & Kahn, 1987). However, the quality of compost depends on the presence or absence of inorganic and organic pollutants, which could enter the food chain through plant uptake (Lazzari et al., 2000). MSW is the waste most commonly used for composting. It is an extremely heterogeneous material in particle size and chemical composition (Flyhammar, 1997). It may, moreover, contain high concentrations of heavy metals such as lead (Pb), copper (Cu), cadmium (Cd), and zinc (Zn) (Flyhammar, 1998).

The effective management system of solid waste involves the application of various treatment methods, technologies and practices. All applied technologies and systems must ensure the protection of the public health and the environment. There are a wide variety of alternative waste management options and strategies available for dealing with mixed MSW to limit the residual amount left for disposal in landfill sites. With proper MSW management and the right control of its polluting effects on the environment, MSW 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 stabilized product of MSW before landfill disposal have drawn increasing attention worldwide (Adani et al., 2002).

The aim of this thesis was to examine the MSW treatment practices in the Arab region in order to suggest possible treatment alternatives, 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 and practices in the Arab region and identify the factors that influence waste management in the region.
- Assess the possible SWM systems and some of the technologies that could be suitable for the local situation and conditions.
- Examine a possible technology that can produce good quality RDF and be a part of the region’s SWM solution.
- Investigate the potential for RDF production and the quantity of RDF that would be produced by using the biological drying/stabilization process.
- Identify the possible RDF composition that would be produced from mixed MSW in the Arab region.
- Recommend practices that will improve and yield benefits in municipal SWM process in the region.

2. TRENDS AND DEVELOPMENT OF SOLID WASTE MANAGEMENT

In the last two decades, MSW has become a major concern and it is presently one of the main subjects under discussion. This is probably due to the considerable increase of MSW production in both total and per capita values. The amount of solid waste produced increases with economical growth and the demand for efficient management solution (McCarthy, 1994). Solid waste is an environmental problem in both developed and developing countries. In recent years, most developing countries have started to improve their municipal solid waste management practices. The increasing amount of waste generated by rapid urbanization in these countries is usually not properly managed. SWM systems in developing countries 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 (Collivignarelli et al., 2004).

2.1 THE CONCEPT OF MUNICIPAL SOLID WASTE MANAGEMENT

Solid waste consists of both solid and liquid waste but not wastewater. Solid waste is the term usually used to describe non-liquid waste material arising from domestic, trade, commercial, agricultural and industrial activities, and from public services (Sasikumar, 2009). United States Environment Protection Agency (USEPA) defines it as 'any useless, unwanted or discarded material with insufficient liquid content to be free flowing' (Brown, 1991).

Municipal solid waste (MSW) includes all solid wastes generated in the community and it is broadly comprised of non-hazardous domestic, household hazardous wastes (for instance insecticides, pesticides, batteries, left over paints etc.), and commercial and industrial refuse including household organic waste, hospital and institutional garbage, street sweepings, yard trimmings and construction wastes (Zerboc, 2003).

Article 2(b) of the European Union Landfill Directive (EU Landfill Directive, 1999) broadened the definition further by defining MSW as waste arising from households as well as other wastes, which because of their nature and composition are similar to waste from households (EEA, 2003). It should be recognized that MSW is a management concept; its organized handling is usually a public issue, although many of the elements in the management system may be privately owned and operated. Municipal waste is the waste that is generated by citizens and civil work and similar waste from small businesses and industry (Christensen, 2011).

MSW management refers to the collection, transfer, treatment, recycling or resource recovery and disposal of solid waste in urban areas (Sasikumar, 2009). Today, nearly half of the world's growing population lives in urban areas, placing large 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 minimizing 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 MSW management is the supervision of MSW from the source of generation through collection, recovery and treatment to disposal (Sasikumar, 2009). According to Uriarte (2008), MSW management should focus on all administrative, financial, legal, planning, and processing of functions that lead to finding solutions to all problems of solid wastes (Tchobanoglous et al., 1993).

2.2 INTEGRATED SOLID WASTE MANAGEMENT (ISWM)

ISWM can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals in a way that favors the best interests of public health and takes into considerations environmental concerns (Tchobanoglous et al., 1993). 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 (McDougall et al., 2001). ISWM 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 (McGraw Hill).

There is no universally applicable solid waste management 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).

ISWM lacks a clear and widely accepted definition. A hierarchy is sometimes used to define ISWM (Figure 2.1). 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 (Bagchi, 2004; Daskalopoulos et al., 1998, Medina, 2002, Zerboc, 2003).

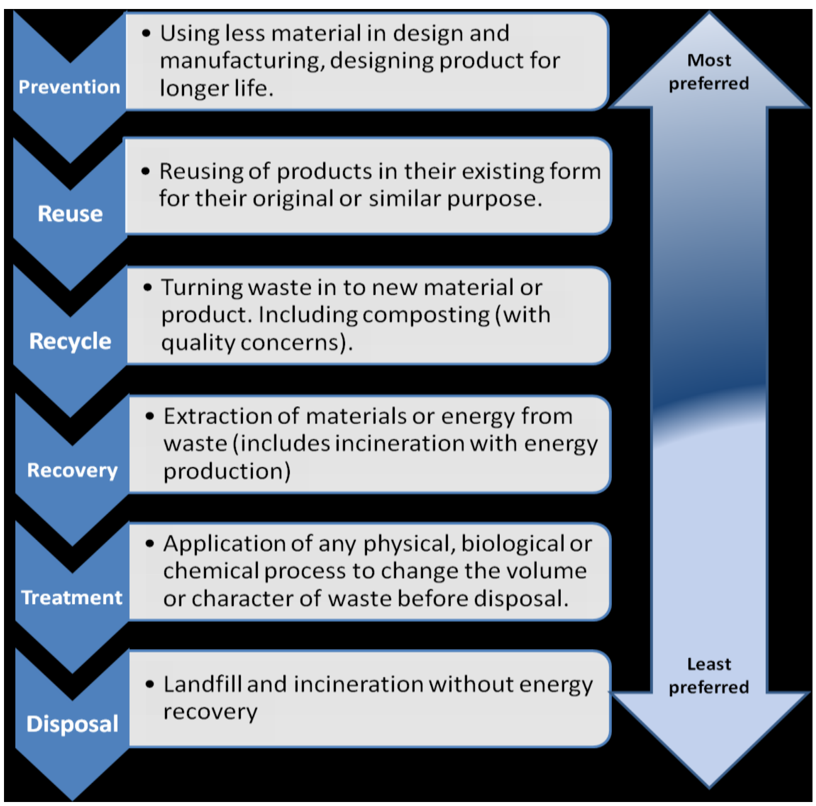

Figure 2.1. A hierarchy of integrated solid waste management (UNEP, 2005).

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.

2.3 TECHNOLOGICAL CONCEPTS OF MUNICIPAL SOLID WASTE TREATMENT

Nowadays, one of the priorities for municipalities is the collecting, recycling, treating and disposal of increasing quantities of MSW. 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 solid waste involves the application of various treatment methods, technologies and practices. All applied technologies and systems must ensure the protection of the public health and the environment. There are a wide variety of alternative waste management options and strategies available for dealing with mixed MSW 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, MSW 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 (Rechberger, 2011; Rotter, 2011).

2.4 WASTE-TO-ENERGY TECHNOLOGIES

Two basic techniques can be applied for the treatment of municipal waste. One is the mechanical treatment of municipal waste, which is combined with biological and thermal processes; the other is thermal treatment (the main concept of each method is described in Table 2.1).

The goals of these processes are:

- To break down the organic substances biologically or thermally to stabilize the waste before landfilling
- To obtain recyclable material

- To minimize the mass sent to landfill

Table 2.1. Processes of municipal waste before landfilling (Bundesumweltamt, 2014)

Concept	Preparation (MBT/MPS)	Thermal treatment
Target	Production of defined material flows for recovery or an environmentally friendly landfilling	Reduce of waste quantities for landfill, inert, sanitation and utilization of the energy content
Process	Mechanical aerobic biological treatment Mechanical anaerobic-aerobic biological treatment Mechanical biological stabilization (Drying) Mechanical physical stabilization (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)

2.4.1 Thermal treatment

Regarding the thermal treatment method, incineration is mainly used for the reduction of the quantities of the disposal for the inert, the sanitation and the utilization of energy. The creation of energy is not the main goal of the incineration. Nevertheless, it is a proven technology in industrialized 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 could be applied to the treatment of MSW. It is an effective MSW treatment option that contributes to waste stabilization 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 labor required for operations.

Relevant information and data about thermal treatment are listed in Table 2.2.

Table 2.2. Summary of the thermal treatment of waste (Bundesumweltamt, 2014)

Generated material flows and results	Slag, ash, flue gas, Metals depending on the pre-sorting (approx. 2-5%), electric power (approx. 20%), thermal energy (about 60%), residues and impurities (about 30%), dust, leachate and exhausted air.
Capacity	Plant capacities approx. 100,000 to 500,000 t /a (Calorific value 6,000-10,000 KJ/kg)
Advantages	No preparation necessary. Maximum volume reduction and reduction of pollutant and response potential. Production of energy for electricity and thermal power.
Disadvantages	High investment and high knowledge in the operation. High requirements on exhausted air treatment. Location next to a heat consumption. 20-30% residual materials, depending on the technology and the composition of the waste to disposal.
Investment cost	Approx. 350-600 €/t depending on the technology and plant size. Approx. 30-40% boiler and steam generator. Approx. 40-50% emissions treatment. Additional costs are: development, bunker, construction, generator, planning, approvals and financing etc.
Operating costs	Repair/maintenance (Construction app. 1%, machines and electrical engineering approx. 3-4% of the investment costs/a). Resources (fuel oil) and filter. Personnel costs and disposal for residual materials.
Total costs	60-100 € / t depending on the energy sale prices and disposal costs of waste.

2.4.2 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 in 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 utilized 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 utilization 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, 2007; Bilitewski, 2000; 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

Relevant information and data for the mechanical biological treatment are listed in Table 2.3.

Table 2.3. General overview of the mechanical-biological waste treatment/stabilization (Umweltbundesamt, 2014)

Application area	Treatment capacity 20,000 to 300,000 t/a.
Advantages	Reduction of reaction potential of the disposal waste and minimization of the mass for landfill. Minimization of the gas emissions leachate formation, pests and odor nuisances at landfills. Allows for energy recovery (biological processes). Generation of RDF. Simple and small capital intensive installations, depending on the treatment and its target.
Disadvantages	Only a preparation process to create specific material flows. Inert substances (20-30 %) depending on the treatment have to be disposed. Depending on the treatment, the RDF (30-50 %) is going to thermal utilization.
Energy demand	Energy requirement (depending on the treatment and its target) approx. 20-60 kWh/t (approx. 10-30 kWh/t only for the mechanical preparation).
Investment costs	Capital costs are about 12 million EUR for 50,000 t/a and 40 million EUR 300,000 for t/a.
Operating costs	Personnel and energy consumption (depending on local conditions). Repair and maintenance (component: 1%, machinery and electronics; 3-6% and mobile equipment; 8-15% of investment).
Total costs	Approx. 20-50 € depending on the process, environmental laws of the country, disposal costs of waste materials, sell price of alternative fuels, energy and personnel costs.

With the support of the 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 is very flexible and can adapt to the change of the composition of the waste very easily, which makes it productive. The core of the mechanical biological waste treatment is the treatment of the biodegradable fractions with the biological stage.

2.5 EU Landfill Directive to divert waste from landfills

Waste management in modern societies is passing through several development stages. However, the transition of waste management from pure disposal management over a more or less controlled waste management, towards a resource efficient material flow management, offers great challenges for all stakeholders involved in the process.

The European Union adopted the Landfill Directive aimed at preventing combustible waste from being landfilled. Landfilling MSW was to be reduced to 75% of the value of year 1995 by 2006 and to 50% by 2009. The third phase to be implemented by 2016 sets out a reduction down to 35% (Ulrich, 2014).

The European Commission describes the aims of the Landfill Directive as follows: "The objective of the Directive is to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing strict technical requirements for waste and landfills" (EC, 2014). European waste management builds on the principles of a waste hierarchy: preventing waste by reusing products, recycling and recovering, including energy through incineration, and finally disposal. Waste policy in the EU has evolved from dealing mostly with specific streams of waste to a more integrated approach to waste management and to resource management as a whole, with a focus on producer responsibility. The implementation of the European requirements is challenging not only for the Accession Countries but also for European Member States. Waste is therefore seen as a production resource and a source of energy. However, depending on regional and local conditions, these different waste management activities may have differing environmental impacts. Although the impacts of waste treatment on the environment have been considerably reduced, there is still potential for further improvement, first by full implementation of existing regulations, and then through the extension of existing waste policies to encourage sustainable consumption and production practices including more efficient resource use (EEA, 2010; Hansen et al., 2002).

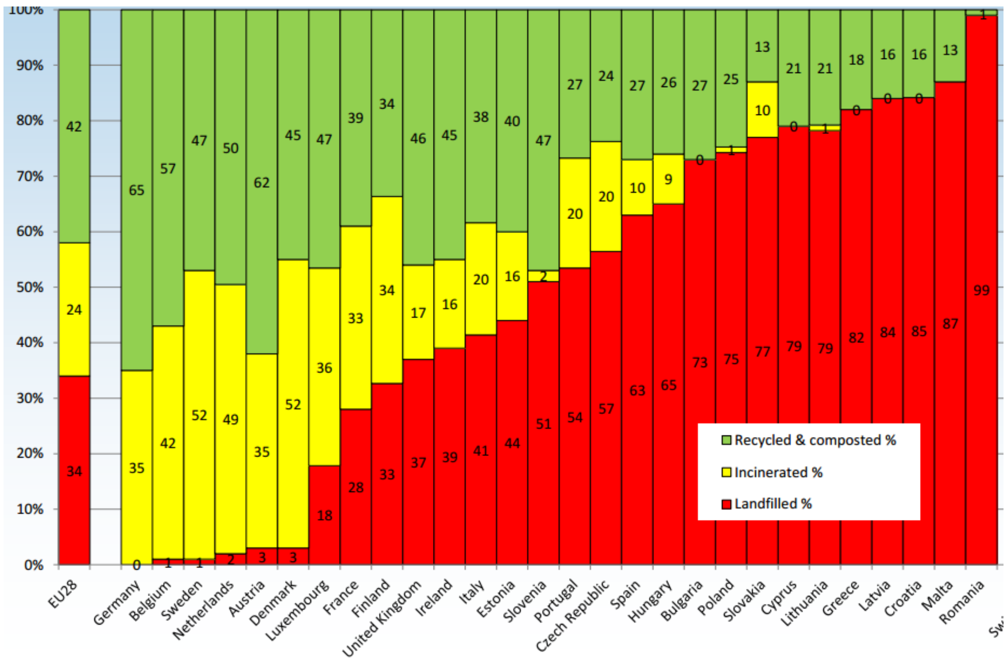

Figure 2.2. Municipal waste treatment in 2012 EU 28 (EUROSTAT, 2012)

As Figure 2.2 shows, taking into account the fact that not all municipal waste is suitable for recycling, waste that can be separated easily at source should be recycled. The remaining residual waste should be transformed into energy in clean and save WtE plants, instead of being buried in landfills. Countries that have most successfully reduced dependence on landfill (1% and below) have the highest recycling rates in Europe, and have achieved this in combination with WtE, proving that recycling and energy from waste, which cannot be recycled properly, go parallel in order to divert waste from landfills (CEWEP, 2012).

2.6 Development and Further Targets of the Solid waste management in Germany

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, the recycling of waste was given precedence over waste disposal (EEA, 2009; Fischer, 2013).

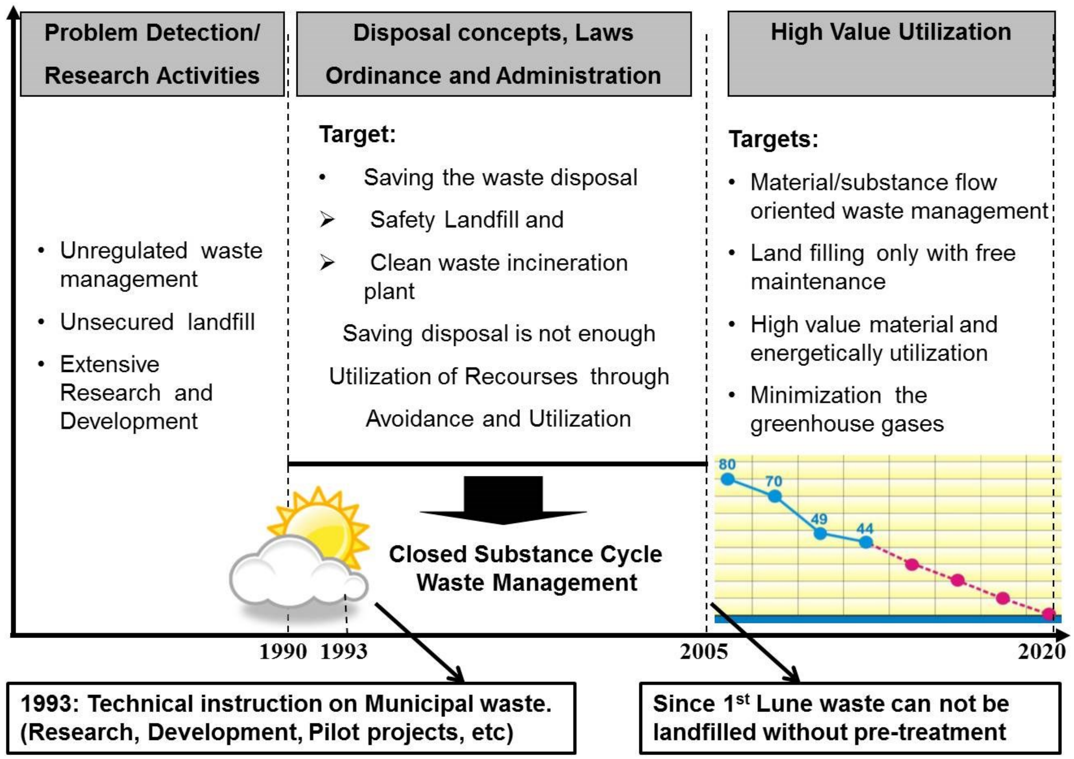

Figure 2.3. Development and further targets of the solid waste management in Germany

As illustrated in Figure 2.3, Germany has had landfill restrictions for municipal waste since 1993, for residual municipal wastes that cannot be recovered from both separately collected waste materials and unsorted municipal waste, and the part of municipal wastes that can be recovered. The restrictions are to ensure that the wastes being landfilled do not pose a danger to soil, groundwater, air or the climate. Residual municipal wastes 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).

2.7 THE RECYCLING OF MSW IN GERMANY

The development of recycling of MSW in Germany related to total recycling is shown in Figure 2.4. This is divided by recycling material, such as metal, glass, plastic, paper and cardboard and organic recycling, such as compost and other biological treatment.

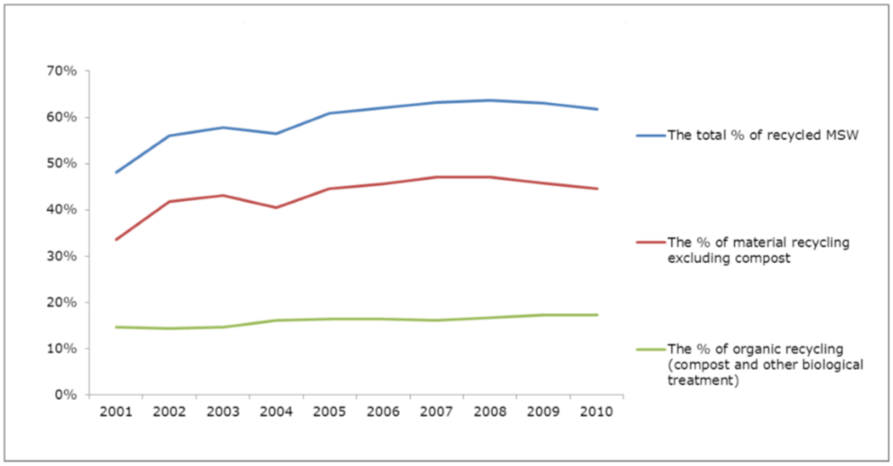

Figure 2.4. Recycling of MSW in Germany (Eurostat, 2012)

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 recycling increased during the period from 34% in 2001 to 45% in 2010. In the period from 2001 to 2010, organic recycling increased very little, from 15% to 17%. The increase has taken place during the last three years in particular (BMU, 2006; EEA, 2009; Fischer, 2013).

Germany aims to achieve almost complete high quality recovery of municipal waste by 2020. This will eliminate the need for landfill, which has adverse effects on the climate. Resource and climate protection will be incorporated into waste management to a greater extent at European and international levels over the next few years, for example by minimizing methane and CO2 emissions or substituting fossil fuels. Options for reducing the organic content in waste are either incineration or MBT. It has to be ensured that both treatment methods cause as little pressure to the environment as possible. The use of MBT as an alternative to incineration has been strongly encouraged and developed with different results. In order to reduce the waste quantities that require pre-treatment before landfilling, separate collection systems and sufficient recovery capacities for packaging paper and biowaste must be established (Weissenbach, 2007).

3. Review of Municipal Solid Waste Management in Arab Region

SWM is one of the many issues facing developing countries. The provision of adequate waste management services is critical because of the potential impact on public health and on the environment. Population growth in urban centers, lack of planning, lack of proper disposal, limited collection services, use of inappropriate technology and inadequate financing are considered the main problems facing SWM (Diaz et al., 1999).

3.1 Overview of the Arab region and the environment sector

The countries of the Arab region contain about 6% of the world's population. The total population of the region has increased from around 100 million in 1950 to around 380 million in 2000. During this period the population of the region increased 3.7 times, more than any other major world region. The region spans an area of about 11.1 million Km^2 (Figure 3.1 shows a map of the region). Pollution-related health problems, particularly in urban and industrial areas, represent a challenge. The causes include: open municipal waste dumps, the use of leaded gasoline in an aging and poorly maintained vehicle fleet, the inefficient use of fossil fuels for power generation, and particulate and sulfur oxide emissions from industry. Finally, weak environmental institutions and legal frameworks prevent countries from adequately addressing these environmental challenges (Hussein, 2008).

Figure 3.1. Location and countries of the Arab world (EIA, 2015)

With regards to industrial development, the current trends in the region fall within two categories: that of oil-rich countries such as the Gulf Cooperation Council (GCC) countries, and that of the less affluent Arab nations that rely heavily on the service and agricultural sectors as the backbone of their economy (Asfari, 2002; Al-Yousfi, 2002).

The Arab region is highly dependent on its non-renewable resources. Generally, across the region the waste resource sector is inadequately structured and regulated. Most Arab countries have not yet established proper waste legislation and long term strategies. Waste management in the region is also characterized by:

- Centralization of authority at the national level
- Absence of effective cost recovery mechanisms
- Deficit in trained personnel
- Service inequality between rural and urban areas
- Lack of reliable databases

3.2 CURRENT SITUATION OF WASTE MANAGEMENT IN THE ARAB REGION

Currently SWM is one of the major challenges facing any developing nation globally. The growing population, followed by rapid urbanization, produces a large amount of solid wastes; while on the other hand, the infrastructure in these countries are not equipped to deal with the problem. In the developed countries, municipal governments have generally assumed responsibility for the collection, transfer and disposal of the waste and this constitutes a basic and expected governmental function (Zerboc 2003). However, the municipal governments of developing nations lack the ability to provide even this basic function (Medina 2002).

Recently, some Arab countries have introduced the ISWM concept. Collection and sorting, composting, incineration of medical wastes and sanitary landfills are starting to be implemented, while recycling, reuse and resource recovery are still at the initial stages (Nassour et al., 2011).
In many countries 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 most of the Arab region 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 inability of the existing waste management systems to cope with the growing waste generation rates has led to significant health and environmental problems in most Arab countries (Abaza et al., 2011; Nassour et al., 2011).

3.3 LEGISLATION AND BASIC PRINCIPLES

With the rising environmental awareness in the Arab region, environmental protection and waste management have been given high priority on the political agenda. Most Arab countries have made efforts to organize SWM with the implementation of several laws and regulations. In some cases, foreign rules and regulation were enacted without any customization to suit the characteristics of the country. Some countries in the region have also agreed to and signed the Basel convention but are struggling to fulfill their commitments under this agreement. A lack of legislation and weak implementation are considered two of the main challenges facing waste management in the region (Al-Humoud, 2005; Nassour et al., 2011).

The fees for managing waste are generally collected via trade taxes or as part of properties and building taxes, but in some countries the relevant ministries and local authorities are responsible for financing the industry. The fees collected are 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 characterized by the absence of financial incentives and effective cost recovery mechanisms. There is an attempt toward increasing charges for waste management services. In Jordan, as one of the developing countries, a successful scheme has been introduced that is projected to recover 80% of the costs associated with managing waste via electricity bills (Nassour et al., 2008).

3.4 FRAMEWORK AND RESPONSIBILITY

The concept of ISWM and utilizing waste as a resource has been spreading in the Arab region. However, as Table 3.1 shows, the solid waste sector in many Arab countries can be characterized as a disorganized sector with sporadic service coverage. Waste management in the region is one of the major responsibilities of local government, with no significant participation by the private sector. Subcontractors are commonly brought in to handle specific activities such as collection and transportation (El-Sherbiny et al., 2011; Nassour et al., 2011).

Table 3.1. MSW stakeholders and their role in MSWM in some Arab countries (Al-Yousfi, 2005; Al-Humoud, 2005).

Country	Policy and Planning	Implementation and Operation	
		Authority	Responsibility
Egypt	Central Government	Ministry of State for Environmental Affairs, Ministry of Local Development and Ministry of Finance	Handle implementation issues.
		Governorates	Responsible for all SWM activities directly/contracting private sector companies.
		Municipalities	Responsible for implementation of the system, monitoring, inspection and training.
		NGOs	Provide MSW treatment, recycling, community development and public awareness.
Lebanon	Ministry of Environment, Ministry of Interior and Municipalities, Council for Development and Reconstruction.	Council for Development and Reconstruction (CDR)	MSW management in Beirut, Mount Lebanon and Tripoli
		Ministry of Environment (MoE) and Ministry of Interior and Municipalities (MoIM)	MSW management in Beirut, Mount Lebanon and Tripoli but to a lesser.
		The municipalities.	MSW management in the rest of Lebanon
Jordan	The Ministry of Municipal and Rural Affairs	The Ministry of Municipal and Rural Affairs	Provision of funds through which municipalities finance waste management capital expenditures.
		The Ministry of the Environment	Regulating activities that may have an impact on the environment, including waste management.
		Municipalities.	Waste management operations.
Morocco	Minister of Energy, Mines, Water, and Environment	Municipalities.	MSW management.
		Ministry of the Interior / General Directorate of Local Authorities /Water and Sanitation Directorate	Technical and financial support.
Syria	Ministry of Local Administration	Governorates and Municipalities	SWM activities
		Ministry of Environment	Monitoring and enforcement
Tunisia	Ministry of the Environment and Sustainable Development.	The National Agency for Waste Management.	Control and supervision of sanitary landfill operated by private entities.
		The Ministry of Interior and Local Development.	Control and financing of municipalities.
		Municipalities.	Local waste management policy, waste collection and transport to collection centers or landfills.

Country	Policy and Planning	Implementation and Operation	
		Authority	Responsibility
Yemen	Ministry of Local Administration.	Local Authorities	Providing SWM services and the planning of local taxes and fees.
		The City Cleaning and Improvement Funds	Independent public sector entities, headed by governors, and responsible for financing SWM services in their respective communities.
Kuwait	Ministry of Municipal Affairs and Kuwait Environment Public Authority.	Kuwait Municipality.	The collection process of waste, its transport and disposal.
Bahrain	The Ministry of Municipality Affairs and Agriculture	Contracting private sector companies.	SWM activities

In some countries, local private companies are involved in the collection and transport of solid waste and some various recycling activities.

Some countries define organizational frameworks, but they are poorly implemented and disrupted by the centralization of authorities at a national level. In addition, a lack of action by government institutions, 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 the region. Many Arab countries lack a national strategy for SWM while regulations to govern the sector do not exist. In Arab countries, the political commitment to waste management is limited (El-Sherbiny et al., 2011; Nassour et al., 2011).

3.5 SOLID WASTE GENERATION

The growth in population causes tremendous increases in the concentration of population in the urban centers due to migration and immigration of people from rural areas and near by countries in search of a better livelihood (Zerboc, 2003). Recently, solid waste generation in Arab countries has been growing due to population and economic growth, accelerated rates of urbanization, rapid industrialization, rising standards of living, changing consumption patterns and the lack of public awareness (El-Sherbiny et al., 2011).

The impact of a rapidly growing urban population is reflected in the growth in waste generation. Several studies have shown that growing urban populations leads to huge increases in waste generation (Medina, 2002; Schubeler, 1996; Zerboc, 2003; Zurbrugg, 2003). This is particularly true of developing countries where the rate of waste generation far exceeds the infrastructural provision. The pressure of the growing population on urban infrastructure in many cities overburdens the provision of urban services. Urban municipal governments are under intense pressure to meet the demand for basic services such as water, sanitation and SWM (Medina 2002). Globally, MSW generation has continued to increase in line with the growth of other socio-economic parameters such as population, personal income and consumption patterns (Achankeng, 2003; Sakurai, 1990).

In the last two decades, per capita waste generation in developed economies has increased nearly threefold. According to African Development Bank (AfDB) waste generation in developing nations is growing rapidly and may double in aggregate volume within this decade; this is driven largely by growth in population and improvements in living standards. If current trends persist, a fivefold increase in global MSW generation is probable by the year 2025 (AfDB, 2002).

Table 3.2. The estimated average rates and quantities of MSW generated in some Arab countries (Nassour et al., 2011).

Country	Population 2010 (x1000)	Average rate of generation of MSW (kg/per capita/day)	Estimated gross quantity of MSW (ton/year) millions
Egypt	84474	1.20	37
Jordan	6472	0.90	2.13
Kuwait	3051	1.40	1.6
Lebanon	4255	0.60	0.93
Libya	6546	0.95	2.27
Qatar	1508	1.30	0.72
Saudi Arabia	26246	1.40	13.41
Syria	22505	0.50	4.11
Tunisia	10374	0.60	2.27
UAE	4707	1.20	2.1

As Table 3.2 shows, across the region the per capita waste generation ranges between 0.5 kg and 1.5 kg per day. Although the rate of waste generation is growing across the whole region, the rate differs from country to country, due to factors such as social conditions and wealth (Abou-Elseoud, 2008). It is predicted that the amount of MSW generated in Arab countries in 2020 will exceed 200 million tons per year (LAS, 2009).

3.6 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 wastes generated in developed countries are mainly inorganic in nature, whereas organic contents form a large portion of waste in developing countries (Hoornweg, 1999; Medina, 2002; Zerboc, 2003; Zurbrugg 2003). In a developing country the proportion of organic contents in waste is almost three times higher than that in developed countries (Medina, 2002; Zerboc, 2003). 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 (Hoornweg, 1999; Medina, 2002; Zerboc, 2003; Zurbrugg, 2003). The nature and composition of waste is highly dependent on the income and lifestyle of the population. Being highly organic and humid in nature, SWM in developing countries presents both opportunities and constraints that are entirely different than those faced by developed countries (Hoornweg, 1999; Zurbrugg, 2003). Figure 3.2 shows the physical composition of MSW in some countries in the Arab region.

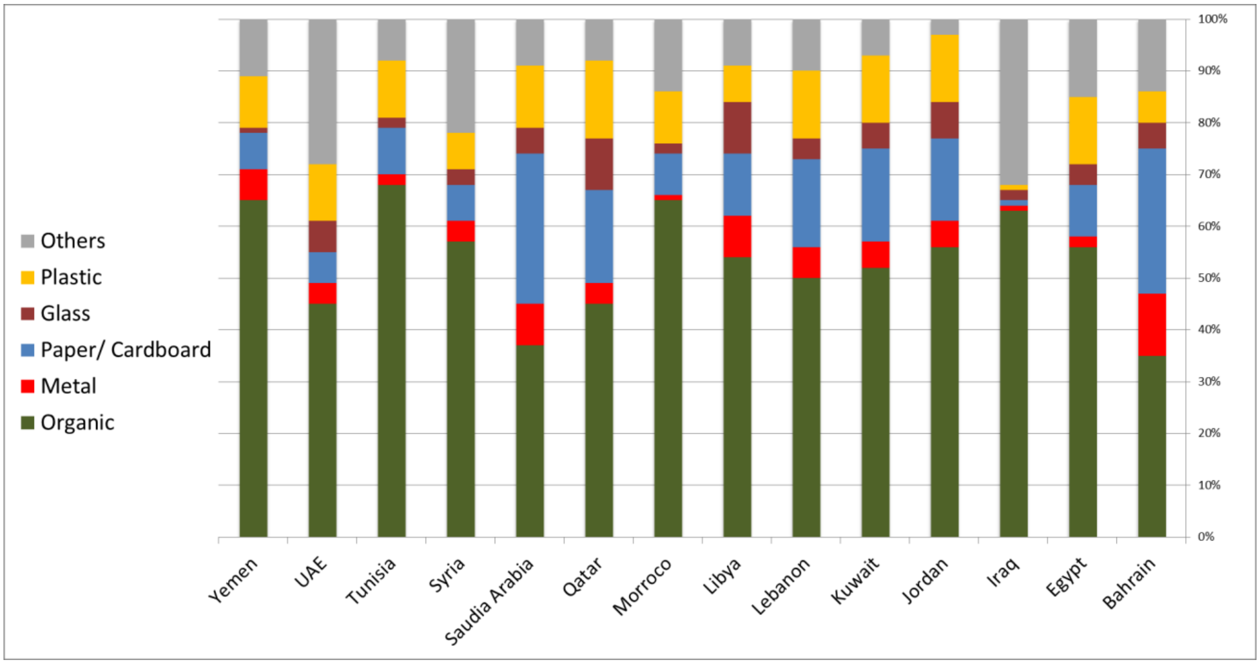

Figure 3.2. The physical composition of municipal solid waste in some countries in the Arab region (GCC, 2004; SWEEP-NET, 2010; Abou-Elseoud, 2008; Al-Yousfi, 2005; Al-Humoud, 2005).

Across the Arab region, 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, increasing the amount of municipal waste generated. The percentage of decomposable material in MSW is very high and varies from 30 to 70%; it consists mainly of fruits, vegetables and food scraps, while the proportion of wood is very low. Municipal waste also contains hazardous substances such as drug residues, expired medicines, chemicals, paints, batteries and other materials.

3.7 MUNICIPAL SOLID WASTE MANAGEMENT AND TREATMENT

3.7.1 GENERAL MANAGEMENT ISSUES IN DEVELOPING COUNTRIES

SWM is one of the many issues facing developing countries. The provision of adequate waste management services is critical because of the potential impact on public health and on the environment. Population growth in urban centers, lack of planning, lack of proper disposal, limited collection service, use of inappropriate technology and inadequate financing are considered the main obstacles facing municipal SWM in the Arab region (Diaz, 2003)

3.7.1.1 Finances and infrastructure

In a developing country (Bartone, 2000; Schübeler 1996), the SWM service is only provided to about 50% of the urban population; actual collection only accounts for around 60 to 70% of the waste generated (Gerlagh et al., 1999). The insufficiency of services results in the deterioration of the urban environment in the form of water, air and land pollution; which not only poses risks to human health but to the environment as well (Medina, 2002). Another impact of the increasing population is the creation of a vicious cycle of pollution. Rises in the population are not met by equal increases in infrastructural facilities, which leads to increases of uncollected or poorly managed waste (Zerboc, 2003).

3.7.1.2 Collection and transportation facilities

Developing countries lack the facilities for proper handling, collection and transportation of the generated wastes. Inadequate planning and layout, due to rapid urbanization, causes urban areas in developing countries 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 in open dumping spaces near human settlements. Congestion of traffic makes transportation of waste more time consuming and, as a result, more expensive and less efficient (Zerboc, 2003). A lack of proper transportation vehicles is also one of the problems facing SWM in developing countries. Most of the vehicles used for transporting wastes are often outdated, improper and non-functional (Zerboc, 2003).

3.7.1.3 Waste disposal

The main disposal method for solid waste in most developing countries is that of open dumping, often the dumping sites are very near to areas of human habitation (Medina, 2002). Little care is given to the status of the water table, water pollution and emission of hazardous and toxic gases. The disposal of hazardous, biomedical, or slaughterhouse wastes is rarely controlled. Illegal disposal of wastes in water bodies is a common practice, which not only causes toxins to be dispersed in the environment (Hoornweg et al., 1999; Zurbrugg, 2003) but also often ends up coagulating the water bodies and destroying the whole ecosystem of the area.

3.7.2 Waste management in the Arab region

Waste management in Arab countries is characterized by a high percentage of uncollected waste, with most of the waste directed to open or controlled dumpsites. Sorting and composting facilities are operated with limited capacity. Countries of the Gulf Cooperation Council (GCC) have higher waste generation rates of 1.2-2.7 kg/capita/day; they are able to provide better waste management services with coverage extending to remote or low-density population areas (AFED, 2008).

3.7.2.1 Storage and collection

SWM practices in the Arab world include waste collection, transportation, transfer, sorting, treatment, and final disposal. These practices vary widely from country to country, and even within a country or region. However, 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 the Arab world. Vehicle to vehicle transfer, open lot, and formal state-of-the art transfer stations are also utilized in other regions (El-Sherbiny et al., 2011). Depending on the finances available either plastic or steel 120 liter to 1100 liter bins are used, with a current trend to supply plastic bins of between 240 liters and 1100 liters in collaboration with German and other European countries. German companies have established some plastic bin production facilities in the UAE. A number of separate collection pilot projects have been carried out in Lebanon, Jordan and Saudi Arabia (Nassour et al., 2011).

3.7.2.2 Recycling and recovery

A recycling, reuse, and recovery industry does not exist in most of the Arab region, where they are still at their initial stages, although they are gaining increased consideration. Waste sorting and recycling are driven by an active informal sector. Such recycling activities are mostly manual and labor intensive (El-Sherbiny et al., 2011). About 1-3% of the total generated waste is recovered as recyclable materials, such as PET, other plastics, metals and paper. These materials are sorted from the waste containers and disposal sites by scavengers, the sorted paper, metals and some plastic materials are marketed and recovered in local recycling facilities, while the PET are marketed internationally (Nassour et al., 2011).

Although waste recycling in the high-income Arab countries has increased, it remains limited. The UAE has only 1.4% recycling rate, but it aims to reach 20%. The only comprehensive form of recycling in the GCC countries has been in the case of paper, cardboards, metals and cans (Indy ACT, 2010).

Food scraps and organic matter are separated by the informal sector to be recovered and reused as animal feed, which may cause hygienic issues. Some countries have applied waste-to-energy technologies using incineration and anaerobic digestion on a trial scale. However, such practices have not yet been approved. Composting is also gaining increased interest due to the high organic content of MSW. Composting has been increasingly adopted in some countries as a strategic choice for processing the organic content of waste. Although the municipalities of the high-income Arab countries have tried composting a fraction of organic waste, a large number of plants were not operated successfully (Alhoumoud et al., 2004). The region has had poor experience of sorting recyclable materials from municipal waste and processing the separated organic matter.

The integration of the informal sector in recycling activities is considered necessary in the region, due to social and organizational reasons and the significant economic and social benefits that will be gained from it. The involvement of the informal sector in the separation and collection of the recyclable materials from commercial centers and industrial facilities will have a positive effect on the recycling management (Nassour et al., 2011).

3.7.2.3 MSW DISPOSAL

Still, recycling rates remain low with most waste ending up in dumpsites. Waste disposal along curbsides and in uncontrolled dumps is still practiced in many parts of the Arab region. 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. The situation of solid waste disposal in some Arab countries is shown in Table 3.3.
Nearly all of the high-income Arab countries dispose of their waste in landfills, which are more like dumps than modern landfills (Alhoumoud et al., 2004).

Table 3-3. The situation of solid waste disposal in some Arab countries (Nassour et al., 2011)

Country	Disposal situation
Egypt	Landfills are located in large cities, while small dumps service small cities and towns.
Jordan	There are about 26 landfills around the country, with four of them considered to be regional.
Tunisia	Nine standard landfills and the necessary transfer stations have been built and are operated by the government agency for waste. The small landfills were not built with leachate treatment plants. Therefore, the leachate is transported and treated in central treatment plants.
Kuwait	There are 17 old landfills that the government and the environmental authority are working on to find a long-term solution for the problem for landfill rehabilitation.
Lebanon	There is not enough space for landfilling, or any solutions that require a large area. Therefore the trend is towards incineration as an alternative treatment option. The main problem in the country is dealing with old landfills and landfill rehabilitation.
Libya	Main controlled dumpsites exist in the big cities; some of them are badly located (near surface water and near the residential areas). The small cities are dumping their waste in open area outside the cities

Dumpsites in the region generate high levels of methane gas due to the significant amount of organic waste in the waste stream. Mixed waste contains hazardous materials such as batteries and cathode ray tubes, which contaminate the groundwater with toxic heavy metals. Open burning and outdated incinerators, even when fitted with pollution control devices, still release greenhouse gases, heavy metals, particulates, cancer causing dioxins and hazardous ash. İncineration of solid waste has been undertaken in some countries, but has been found to be expensive and strongly opposed by the public (Andy ACT, 2010).

4. Assessment of Mixed Municipal Solid Waste Composting Produced in the Arab Region

Composting is an ancient agricultural practice for the reuse of organic wastes and nutrients for crop production. The production of compost from agricultural and industrial wastes, and municipal by-products is an important means of recovering organic matter and an essential method of disposal. It is applied to cropland to maintain and improve soil structure and plant nutrition. In the course of ongoing urbanization and changing living conditions, organic waste lost its link to the traditional reuse practices in rural agriculture. Instead, it became a health hazard for cities and an environmental problem due to the lack of appropriate management (Gigliotti et al., 1996).

Since the 1970s, composting has experienced increased attention in the field of solid waste management. However, due to technological and managerial mistakes, composting gained a questionable reputation. It was believed that large-scale, highly developed solid waste composting plants could solve the waste problem in urban areas. Most of these composting plants turned out to be failures with serious financial consequences (Dulac, 2001). Most of the plants were abandoned for a number of reasons such as:

- The technology applied was often too complicated and not adapted to local circumstances.
- The over mechanization and choice of technologies without due analysis of waste characteristics.
- Financial and marketing aspects were usually ignored resulting in high operational costs.
- Management and technical expertise was often not sufficiently available.
- The absence of supportive institutional environments such as the legal and policy framework or economic circumstances.
- Poor quality of process outputs due to the use of mixed municipal waste with lot of inerts.
- Low skill/managerial inputs reduced the operating efficiencies resulting in high cost of production.
- A poor quality of finished compost resulting in problems in marketability.

Composting is a means of biologically degrading organic materials while stabilizing a residual organic fraction, which can be widely used in agriculture and horticulture (Garcìa et al., 1995). It also decreases the volume and weight of the raw material (Golueke, 1977; Schnitzer & Kahn, 1987). Theoretically, all the organic matter could break down and escape as CO_2 and water, in which case finished compost would consist of nothing but the remaining ash. The fact that this does not happen, and that the remaining stable organic fraction is useful to soils and plants, are two of the reasons that composting has such value (Brinton, 1979; Rynck, 1992). This can help to reduce the impact of several environmental problems (Chefetz et al., 1996).

However, the quality of compost depends on the presence or absence of inorganic and organic pollutants, which could enter the food chain through plant uptake (Lazzari et al., 2000). Previously MSW was the waste most commonly used in composting. It is an extremely heterogeneous material in particle size and chemical composition (Flyhammar, 1997). It may, moreover, contain high concentrations of Pb, Cu, Cd and Zn (Flyhammar, 1998). Consequently, the subsequent application of MSW composts that are rich in heavy metals to agricultural soils may cause accumulation of heavy metals to toxic levels (King et al., 1990; Veeken & Hamelers, 2002). The presence of heavy metals in composts is the main cause of adverse effects on animal and human health, transmitted through the food chain from soil, groundwater and plants. Consequently, analyzing the contents of heavy metals in composts is very important for the routine monitoring and risk assessment and regulation of the environment (Senesi et al., 1999).

4.1 QUALITY OF COMPOST PRODUCED FROM MSW

Compost quality could be defined based on standard parameters aimed at assuring compost suitability for agricultural exploitation. Obstacles due to the presence of contaminants can be avoided by a right choice of the starting materials and composting processes. Due to the qualitative and quantitative level of humification reached during the process, major difficulties concern the compost maturity (Adani et al., 1997; Senesi & Brunetti, 1996).

Compost quality refers to the overall state of the compost with regard to physical, chemical and biological characteristics, which indicate the ultimate impact of the compost on the environment.

It lies at the core of the issue of composting and biological treatment in general, as it defines the marketing potential and the outlets of the product and in most cases, the feasibility of the treatment plant, but also the long-term acceptability of biological treatment as a valuable option in the waste hierarchy (Hogg et al., 2002; Lasaridi, 1998).

The criteria that are relevant to the evaluation of quality depend on what purpose the compost is used for, the relevant environmental protection policies and the market requirements (Gillett, 1992; Kehres, 1992). For example, composts intended as growing media should meet more stringent quality criteria compared to composts that will be used as landfill cover. The difference in the MSW service level will affect the criteria that set the quality limits of the compost as product. There is a wide variation among the limit values adopted by the member countries within the EU with the north being usually more stringent than the south, due to the varying levels of progress on source separation of the biodegradable fraction of MSW, but also the different needs in soil organic matter (Deportes et al., 1995; Hogg et al., 2002).

A number of characteristics determine compost quality, such as moisture, organic matter and carbon content, heavy metals, salinity, inert contaminants and state of maturity or stability (Lasaridi, 1998). Similar values are set for foreign matter (glass, plastics and stones) in most national specifications, usually defined as maximum allowed content on a dry weight basis and in reference to their particle size (Hogg et al., 2002). The degree of compost stability and its nitrogen content are particularly important for its agricultural use and are increasingly more often defined in compost specifications. Compost stability is defined as microbial activity measured through the respiration activity (AT4) or the self-heating potential (Hogg et al., 2002; Lasaridi & Stentiford, 1998). In 1999, the European Union Landfill Directive (The Council of the European Union, 1999) required member states to reduce the amount of biodegradable waste being dumped (Anton et al., 2005), in order to minimize environmental impacts and the loss of organic resources. This directive promoted the adoption of measures to increase and improve sorting at the origin, and recovery and recycling, including composting of organic and green MSW. Organic MSW is defined as household waste and other waste which, because of its nature or composition, is similar to household waste, capable of undergoing anaerobic or aerobic decomposition, excluding green MSW from gardens and parks, which includes tree cuttings, branches, grass and wood. The composting of organic MSW, as well as reducing the total amount of landfill waste, yields a product that can be used in agriculture and destroys many of the pathogens and odor compounds (Jakobsen, 1995).

The aim of this thesis was to identify and analyze some compost produced from MSW in the Arab region, in order to derive their quality profile and examine their compliance with the international standards.

4.2 Mixed MSW Management

The typical problem in the MSW management of developing countries can be identified as: inadequate service coverage and operational inefficiencies of services, limited utilization of recycling activities, inadequate landfill capacity and inadequate management of hazardous and healthcare waste (Visvanathan et al., 2004). Different countries have adopted different strategies for reaching their goals, by applying advanced environmental technologies by extending recycling and reuse. Sustainable waste management will have to consider all possible options for the reduction of the negative impact of consumption (Ludwig et al., 2003).

Besides landfill and incineration, composting of MSW is considered as a waste management tool, as composting can effectively reduce the waste volume and beneficial utilization of compost can eventually turn waste material into a resource. Benefits of the soil application of compost have been attributed to improvement of physical properties; that is, increased water infiltration, water-holding capacity, aeration and permeability, reduction of disease incidence, weed control or improvement of soil fertility (Barker, 1997; Gallardo-Lara & Nogales, 1987; Mkhabela & Warman, 2005; Parr & Hornick, 1992; Rosen et al., 1993). The growth of MSW composting facilities will depend on the development of good operating facilities and the economics of waste management. Uniform standards are needed for compost products that will not hinder distribution and marketing. The standards should be based on sound scientific basis and related to public health and protection of the environment (Epstein, 1997).

4.2.1 MIXED MSW DEFINITION

Mixed MSW was defined in the 1991 Conn. Pub. Acts 293, §1 as consisting of "mixtures of solid wastes which have not been separated at the source of generation or processed into discrete, homogenous waste streams such as glass, paper, plastic, aluminum or tire waste streams" (DRS, 1992). It also refers to heterogeneous and commingled solid waste, which may include readily biodegradable organic wastes, as well as other organic wastes that are not readily biodegradable and may also contain inorganic and non-compostable wastes (DEM, 1997).

4.2.2 CHARACTERISTICS OF MIXED MSW

Mixed MSW is highly heterogeneous. It is characterized by mixed organic and inorganic waste, mixed combustibles and inert mixed dry and wet wastes, organic fractions at different stages of decomposition, and a high level of moisture as waste is mainly picked up from open community storage containers. In the main, domestic waste can be found mixed with hospital and other hazardous waste, construction and demolition debris, and drain silt. All of this leads to the presence of sand, silt, glass and metal fines (Asit Nema, 2009). Batteries, consumer electronics, ceramics, light bulbs, house dust and paint chips, lead foils, used motor oils, plastics, and some glass and inks can all introduce metal contaminants into the solid waste stream (Richard, 1992).

4.2.3 COLLECTION OF MIXED MSW

The collection time and costs of mixed MSW per ton are often less than those for separated material. Mixed MSW is deposited in large metal or plastic bins equipped with hinged lids. These bins are designed for easy transport to the processing facilities (Goldstein et al., 1990; Hoornweg et al., 1991). Mixed MSWis collected by vehicles and transported to a central processing facility, which employs a high degree of mechanization, including separation equipment such as shredders, trommels, magnets, and air classifiers, to recover the recyclables. Mixed waste collection requires no extra effort by the generator and results in no incremental collection costs; it is, however, accompanied by high processing and operating costs, and risks regarding technology and market economics due to uncertain capital and operations costs and potentially low recovery efficiency and material purity (Tchobanglous & Kreith, 2002).

Vehicles with enclosed trailers are used for collecting mixed MSW; these vehicles are equipped with rotary drums or with a compactor. The use of these trucks will result in sufficient size reduction of the waste, making it possible to increase the capacity of each container. The mixing is desirable when the collection is followed by incineration. However, it is undesirable if the recovery of recyclables is the next process step. For example, paper that is contaminated by food waste, glass, sand and inert mater is unusable for recycling. Compaction can make separation more difficult, however, and can greatly complicate the procedures and equipment that will be used to compost. The primary disadvantage of mixed MSW collection is that the separation must be performed as soon as possible once the material arrives at the facility (Bilitewski et al., 1994; Goldstein et al., 1990; Hoornweg et al., 1991; Williams, 1998).

4.2.4 PROCESSING AND RECYCLING OF MIXED MSW

The theoretically recyclable components in MSW include paper and board, plastics, glass, metal and putrescible materials. However, in some cases it is not possible to recycle some of the waste due to contamination. Certainly, the materials are contaminated with non-compostable contaminants, which includes visible materials such as plastic and glass, and chemical contaminants, such as Household Hazardous Wastes (HHW). Both physical contaminants, such as street sweepings that can contain a variety of contaminants such as motor oil and asbestos, and chemical contaminants can have a negative impact on the marketability of the finished product, and their removal forms a large part of the expense of modern MSW composting facilities (Richard, 1992; Williams, 1998).

Mixed MSW would require the separation of the components of waste to remove the inert material such as glass, ferrous and non-ferrous metals (Williams, 1998). One of the problems of collecting all recyclable items and waste together is the contamination of paper from broken glass. This type of contamination leads to a reduction in the value of the paper (Richard, 1992).
Having been mixed with waste in the container, or having been compacted and crushed in the collection vehicle, lowers the quality of the sorted recyclables. Contamination by soiling or wetting also limits the marketing of recyclables. It has been observed that the collection of recyclables from mixed MSW results in only a partial recovery of waste paper, plastic and glass (Bilitewski et al., 1994; Gallenkemper & Doedens, 1988).

4.2.5 Composting of mixed MSW

Mixed MSW is extremely heterogeneous in size, moisture and nutrient content. The organic fraction can contain varying degrees of non-compostable and possibly hazardous waste. Both physical and chemical materials found in the feedstock can have a negative impact on the marketability of the finished product. The sorting of mixed MSW requires more labor and machinery for manufacturing a marketable compost product from this material. Therefore, a range of physical processing technologies, in addition to the biological process management common to other types of composting, is needed (Richard, 1992). One important factor is the market acceptance of the final MSW compost product. The use of this compost in horticultural crops has some special concerns, which mainly relate to the presence of heavy metal compounds and foreign and undegradable particles, such as glass and rubber, or chemical fibers and toxic organic compounds (Rosen et al., 1993). The organic waste used for large scale composting facilities can be variable, and may also contain contaminants due to incorrect sorting. Therefore, end product quality may be difficult to guarantee for the end users (Williams, 1998). The development of mixed MSW composting has not received much endorsement for the last decade (Spencer & Goldstein, 2006).

4.3 Study materials

Solid waste treatment facilities with compost production, shown in Figure 4.1, do existed in the Arab region, but many of them no longer operate and some even closed before they started to operate. Their failure was due to their 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 and training of personnel for the operational procedures.

Figure 4.1. MSW treatment facilities with compost production no longer operate in the Arab region.

Samples of MSW composts were collected from some cities in different countries of the region. Recyclable materials such as plastic, glass, paper, metal, textiles, etc. are not sorted from the waste stream by separate collection, and the household waste in some cases is collected mixed with other types of waste, which increases the amount of municipal waste generated. Municipal waste also contains hazardous substances such as drug residues, expired medicines, chemicals, paints, batteries and other materials.

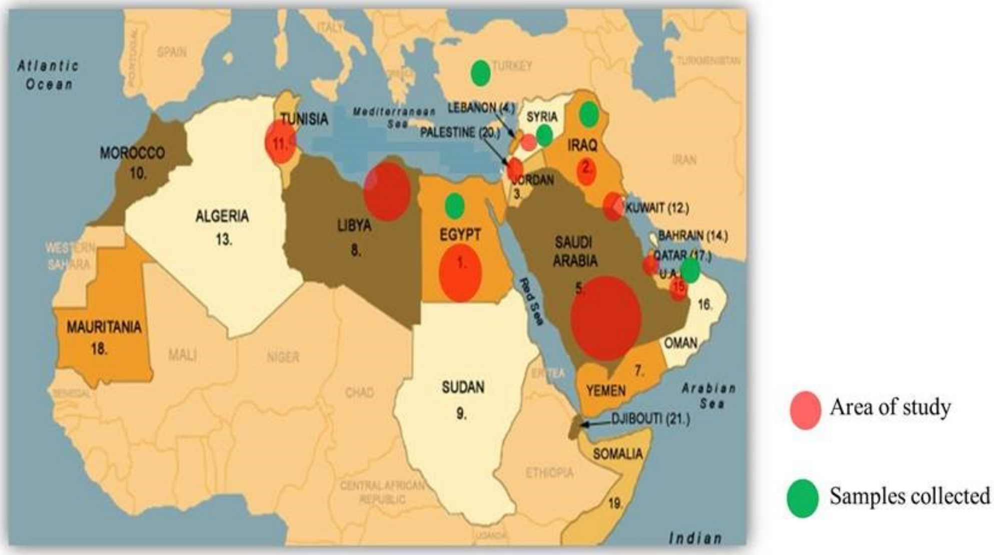

Figure 4.2. The study area and sampling locations.

4.4 METHODS OF ANALYSIS

Samples were collected from different cities in different countries in the region (Egypt, Syria, Iraq, Turkey and UAE) (see Figure 4.2). The main samples were MSW compost and the raw material to produce the compost, which was mixed municipal solid waste. Sampling was undertaken according to the same procedure from the composting plant, by the following steps:

- Dig samples from several depths and from the sides and top.
- Collect about 10–15 subsamples throughout the compost pile.
- Mix the subsamples together thoroughly into one sample.
- Coning and quartering to reach a final sample size of about 5 liters should reduce the sample.

4.5 RESULTS AND DISCUSSION

Compost shall be well decomposed and stable with regard to oxygen consumption and carbon dioxide generation. It shall be derived from agricultural, food and yard trimmings, source-separated or mixed MSW. The product shall contain no substances toxic to plants, possess no objectionable odors and shall not resemble the raw material it derived from. MSW is an extremely heterogeneous material, of which up to 60% is biodegradable material. There are however, major concerns about the quality of compost produced from MSW. However, it is not only the physical contamination that poses a problem for potential users of MSW composts: compost can also contain chemical and biological contaminants. The range and median values of chemical properties of the MSW composts are presented in Table 4.1.

Table 4.1. Summary of several parameters of the compost samples analysis taken during the study

Parameter	Range	Median	German standard (BioAbfV)
PH	7.12 – 8.12	7.68	-
EC ms/cm	6.47- 11.59	8.945	-
W/C %	7.4 – 33	18.5	55 %
Organic matter %	17.5 – 62.7	37.35	15-40 %
AT4 mgO_2/g.dm	0.2 - 82.1	21.3	See Table 4.2

The pH is a measure of active acidity in the feedstock or compost and most finished composts will have pH values in the range of 6 to 8: these ranges can be substantially different depending on the kinds of feedstock used. A lower pH is preferred for certain plants, while a neutral pH is suitable for most applications. The pH is not a measure of the total acidity or alkalinity and cannot be used to predict the compost effect on soil pH. The values of the pH were in the range from 7.12 to 8.12 with an overall median value of 7.68. The pH value of the compost is important, since applying compost to the soil can alter the soil pH, which in turn can affect the availability of nutrients to the plant (CIWMB, 2007; USCC, 2001).

Electric conductivity is a measure of the combined amount of salts in the compost: the greater the electrical conductance, the greater the concentration of soluble salts in the compost. Generally, compost soluble salt levels typically range from 1 to 10 ms/cm. Electric conductivity of the compost samples varied from 6.47 to 11.59 dS/m with a median value of 8.94. Soluble salts can be harmful to plants by reducing water absorption and producing conditions that are toxic to the plants. Ideal soluble salt levels will depend on the end use of the compost. Therefore, some compost uses can have higher soluble salts content, such as 12 ms/cm (Brinton, 2000). However, greater management is required depending on the soil to which it is added, the amount and frequency of adding the compost to the soil, the plant's tolerance to high salt concentrations, and the amounts and frequency of irrigation water or rainfall.

4.5.1 MOISTURE CONTENT

The moisture content of compost affects its bulk density and, therefore, may affect transportation cost. Moisture content can also affect product handling. The ideal moisture content for composting will depend on the water holding capacity of the materials being composted. In general, high organic matter materials have higher water holding capacity and a higher ideal moisture content. Compost that is too dry can be dusty and irritating to work with while compost that is excessively wet can be heavy and difficult to uniformly apply. According to the German standards for compost (BioAbfV), the desirable moisture content of the finished compost is around 50% or more.

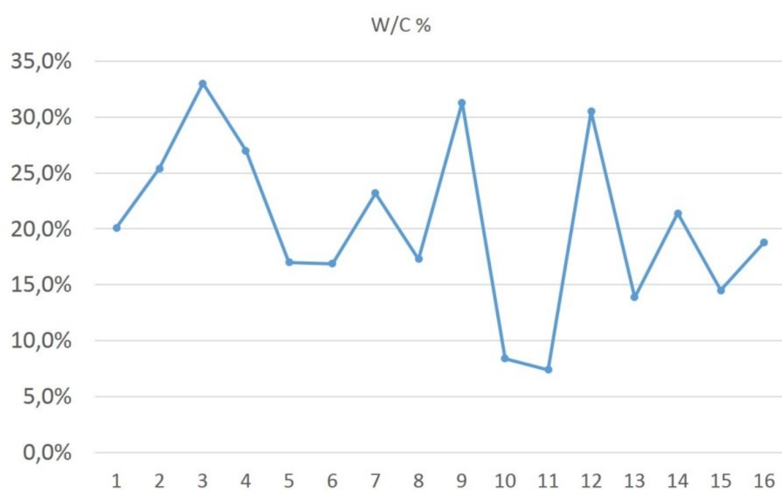

Figure 4.4. Water content of compost samples analyzed during the study.

As Figure 4.3 shows, the moisture content in the compost samples varied from 7.4 to 33%; such composts with very low water content may not have been fully stabilized or may have been stored for long periods leading to moisture loss. Since the water content of all samples was less than 35%, they were considered as dry compost. The main disadvantage of dry compost is that it produces significant amounts of dust.

4.5.2 ORGANIC MATTER

There is no ideal organic matter level for finished compost. Organic matter in the samples varied from 17.5% to 62.7% and about 20% of the compost samples had organic matter content higher than the value set by the German standard (BioAbfV), which should be between 15-45%. Dry compost that is high in organic matter content is difficult to incorporate into the soil because it tends to stay on the surface of the soil.

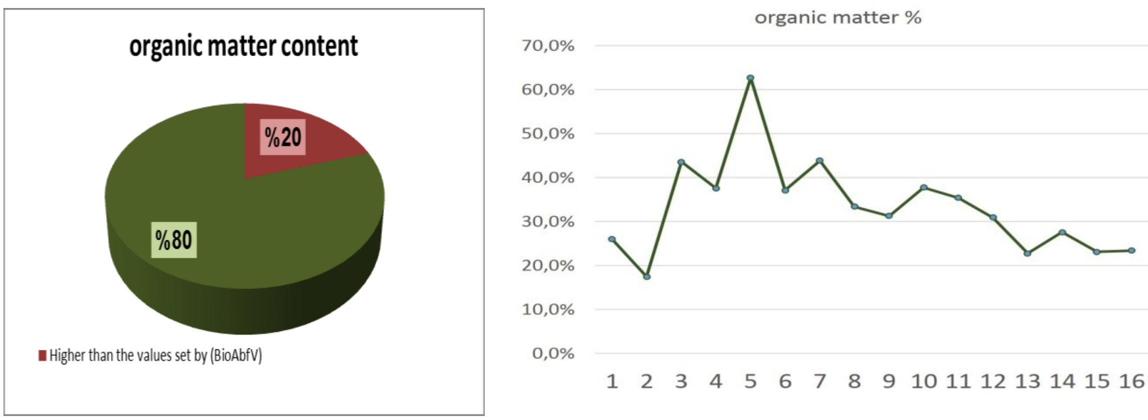

Figure 4.3. The results of the organic matter content in the analyzed compost samples.

4.5.3 RESPIRATION ACTIVITIES

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

Table 4.2. Classification of the compost samples analyzed for AT4 test (Kehres, 1998)

Rotting class	AT4 (mg O2/g DM)	Classification of the samples tested	Product description
I	>40	19%	Compost raw materials
II	40-28	19%	Fresh compost
III	28-16	6%	Fresh compost
IV	16-6	44%	Finished compost
V	<6	12%	Finished compost

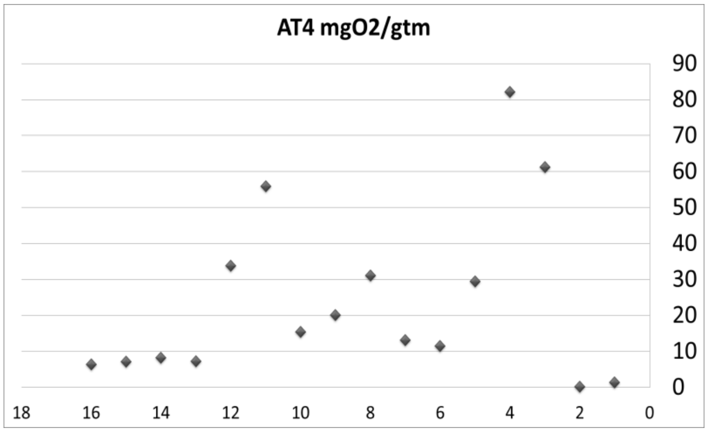

Figure 4.4. The results of the AT4 test for all compost samples included in the study

The stability of any given compost is important in determining the potential impact of the material on nitrogen availability in 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 soil. As shown in Table 4.1, compost respiration in the samples varied from 0.2 mgO_2/g.dm to 82.1 mgO_2/g.dm. Accordingly, only 56% of the compost samples appeared to be stable and considered as finished product of class IV and V (see Figure 4.6).

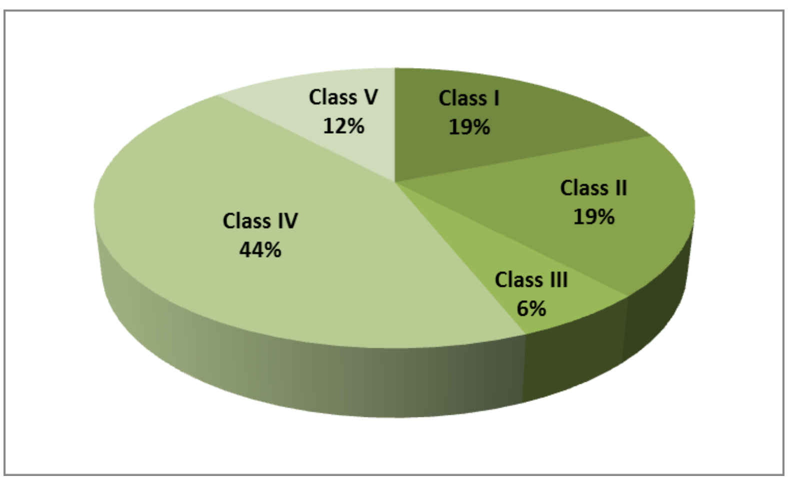

Figure 4.5. Distribution of compost samples according to their rotting degree/class

4.5.4 HEAVY METALS

Heavy metals are trace elements whose concentrations are regulated due to the potential for toxicity to humans, animals and plants. Many of these elements are actually needed by plants for normal growth. There are many sources of heavy metals within household waste, many of which can pass through mechanical screens designed to remove non-biodegradable matter such at batteries (Richard, 1992). The potential for contamination of MSW is worsened by the absence of recycling facilities for hazardous wastes (Slack et al., 2007). In addition, other materials such as paints, electronics, ceramics, plastics and inks can all contribute to the heavy metal load of MSW (Sharma et al., 1997). The results of the heavy metals concentration in the samples are shown in Table 4.3.

Table 4.3. Heavy metal concentrations of mixed MSW-derived compost compared with German standards

Parameter	**Range**	**German standard (BioAbfV)**	
		A	B
Pb mg/kg	7.35 – 319	**150**	**100**
Cd mg/kg	<0.1 – 1.66	**1.5**	**1.0**
Cr mg/kg	25.9 - 73	**100**	**70**
Cu mg/kg	30.4 – 182	**100**	**70**
Ni mg/kg	20.9 - 155	**50**	**35**
Hg mg/kg	0.04 – 0.8	**1.0**	**0.7**
Zn mg/kg	102 – 1550	**400**	**300**

High levels of heavy metals in compost represent an obvious concern when it is 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 the microbial degradation. Figure 4.7 shows the concentration of each element of heavy metals in the compost samples.

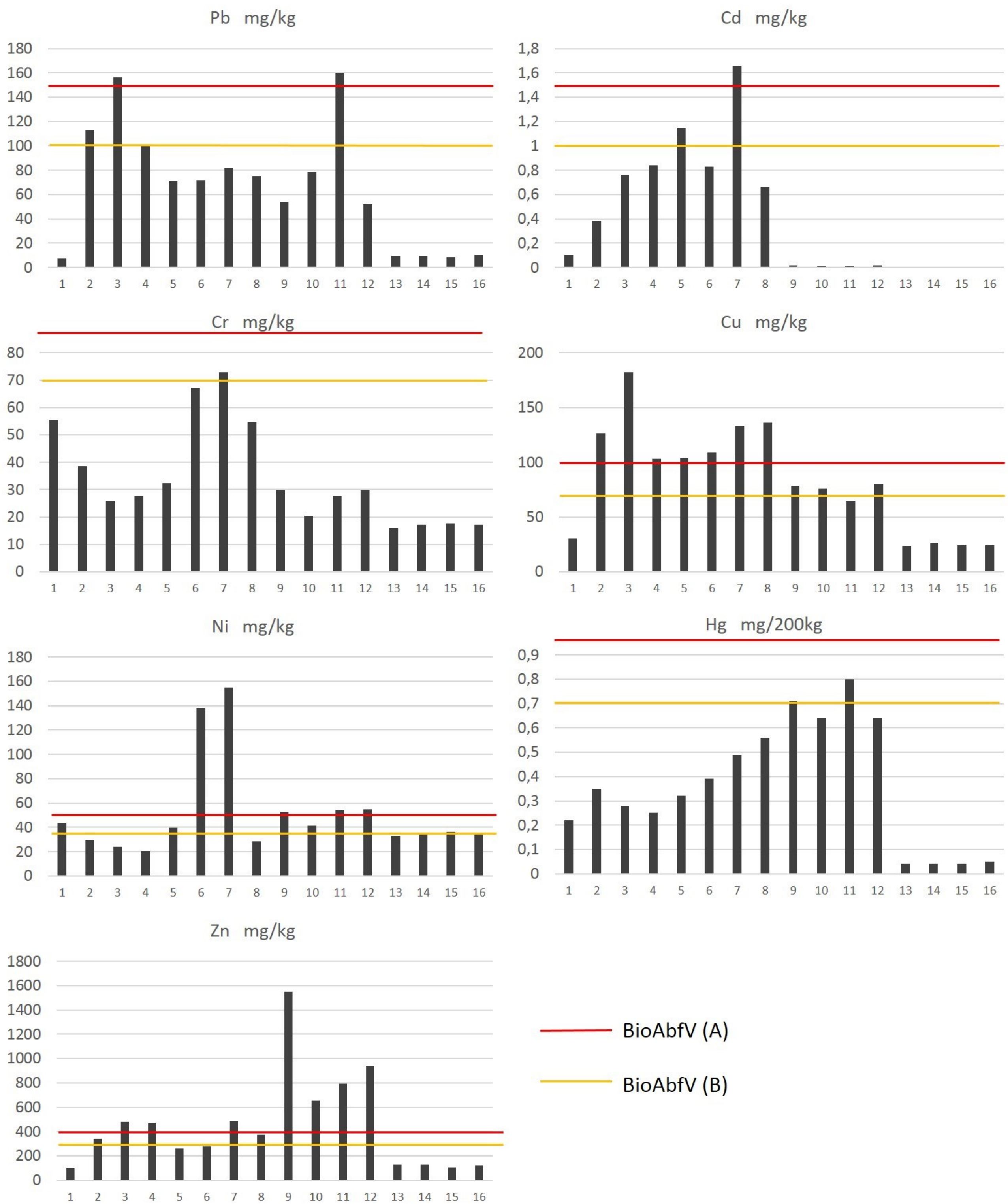

Figure 4.6. The concentration of each heavy metal element in the analyzed compost samples for this study.

The levels at which heavy metals are found can vary from negligible background levels in 'clean' composts, such as source-separated food waste, to potentially toxic levels in some mixed waste based composts (Richard, 1992).

High-quality compost should be low in trace elements and soluble salts, and should be free of inert contaminants such as stones, plastic, glass and metal. The heavy metal concentration of the compost sample analyzed for this study was compared with the German standards (BioAbfV). Figure 4.8 shows the results that 56% of the samples had three or more elements of the heavy metals higher than the proposed limit and that 12% had two elements more than the proposed limit, while only 32% had one element more than the proposed limit. Only one of the 16 tested samples fulfilled the BioAbfV requirements and was considered as stable compost of class (A), due to concentrations of Ni higher than the limit set by BioAbfV.

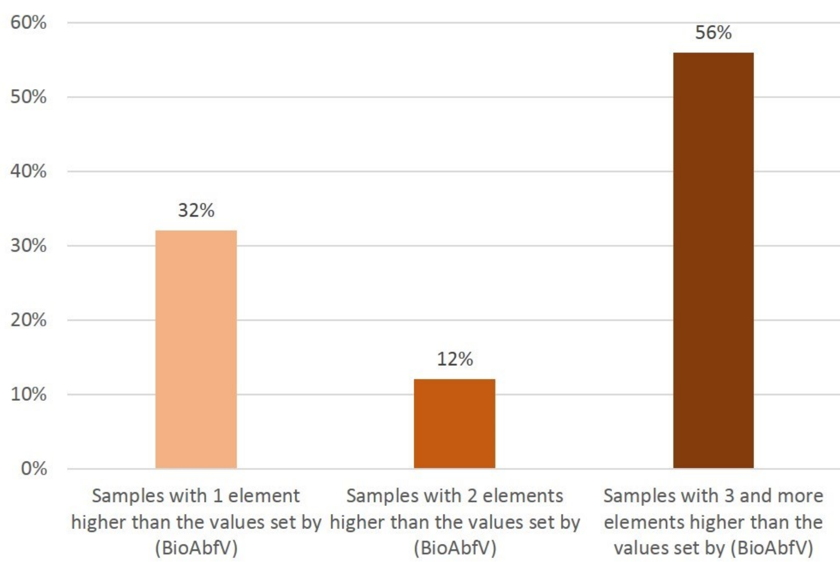

Figure 4.7. Results of heavy metals concentrations in the compost samples compared with the German standard (BioAbfV)

Generally, most compost samples tested in this study were of a poor quality and were not recommended for use as soil fertilizers. This was due to the risk from heavy metals and organic pollutants, alongside the physical risks from sharps, glass and the aesthetical problem of plastic scraps that remain highly visible even after composting. It is clear that the production of compost from mixed MSW is widely used in many countries in the Arab region and it needs sustainable methods for its disposal. Almost all composts derived from MSW tested in this study remained wastes rather than compost, even after successful processing to stabilize the organic matter. The absence of local standards, monitoring systems and legal barriers prevents the control of the application of MSW compost to agricultural/horticultural land. There is, however, a risk that the application of MSW compost will increase the heavy metals content of agricultural soils.

5. Biodrying for MBT of Mixed MSW and Potential for RDF Production

Considering the poor compost quality produced from mixed MSW, and the unfeasibility of a segregated collection in most developing countries and the Arab Region, other practical alternatives for the management of mixed MSW should be evaluated and considered for the region. Moreover, combustion and biological processes yielding thermal power, refuse derived fuel (RDF), compost, and stabilized product of MSW before landfill disposal have drawn increasing attention worldwide (Adani et al., 2002).

A good alternative for the region is the waste to energy (WtE) concept where mixed MSW is converted to RDF. This alternative mainly contributes to the reduction of the moisture content of the waste, which increases the calorific value of the resulting product and decreases the production of leachate of landfilled material if no further stabilization of organic material is applied. It also includes the possibility of converting the waste into energy, recovery of recyclable material and the reduction of pollutants emitted into the environment.

Due to a high proportion of food waste (>50%), MSW in many developing countries has a high water content, which lowers the recovery of material and increases the operation cost of combustion (Bezama et al., 2007; Hazra & 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-stabilization processes result in the degradation of easily degradable organic matter; biodrying processes dry the waste while increasing its heating value by reducing its water content (Bezama et al., 2007; Rada et al., 2007; Sugni et al., 2005; Zhang et al., 2008).

This chapter aims to provide some possible options of technologies referred to as mechanical biological treatment (MBT). The MBT technologies are pre-treatment technologies, which contribute to the diversion of MSW from landfill when operated as part of a wider integrated approach involving additional treatment stages.

5.1 MECHANICAL BIOLOGICAL TREATMENT (MBT)

An MBT system is a waste processing facility that combines a waste sorting facility with biological treatment methods (anaerobic digestion and/or composting). MBT plants are designed to process mixed household waste as well as commercial and industrial waste. Therefore, MBT is neither a single technology nor a complete solution, since it combines a wide range of techniques and processing operations (mechanical and biological) that are affected by the market needs of the end products. Thus, MBT systems vary greatly in their complexity and functionality.

MBT is a generic term for the integration of a number of waste management processes such as materials recovery facilities (MRF), RDF production, mechanical separation, sorting and composting. MBT are used for treating waste with the aim of improving waste management through the production of stabilized material for landfilling or, preferably, of added-value products such as solid recovered fuel (SRF) or compost (Juniper, 2005). MBT includes the separation of useful waste components for industrial reuse, such as metals and plastics, as well as RDF.

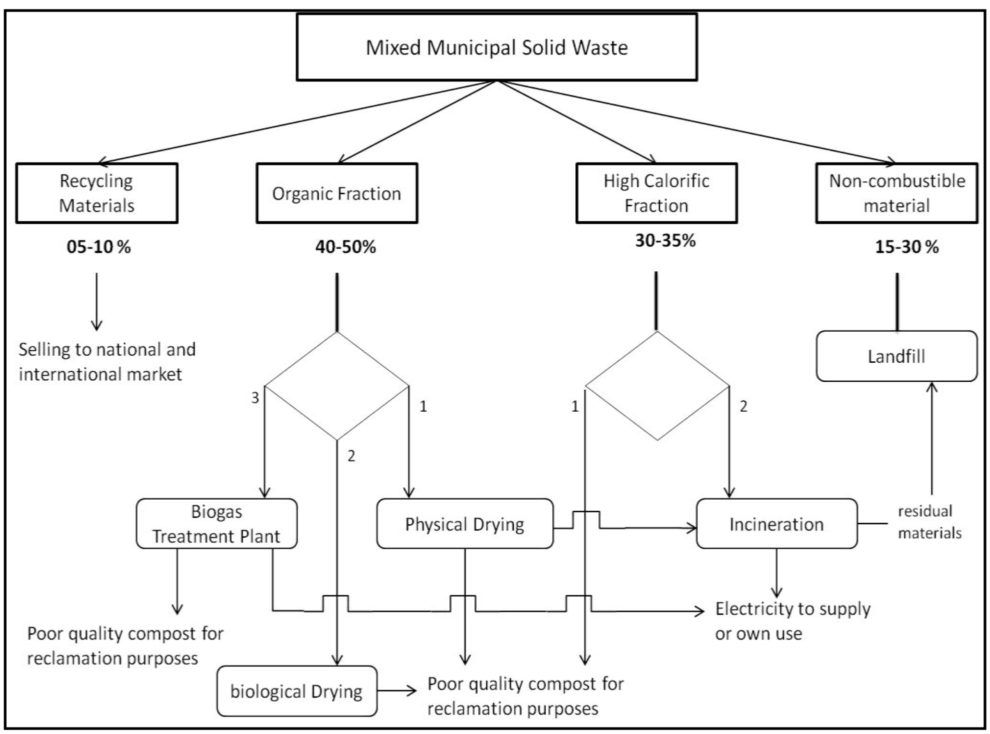

Figure 5.1. The possibilities of the treatment and recovery of the individual fractions of household waste and commercial waste in the Arab region.

Figure 5.1 illustrates the possibilities of the treatment and recovery of the individual fractions of household waste and commercial waste in the Arab Region. The challenge for such a proposed solution is to ensure the thermal utilization of the produced fuels. The ecological and economic assessment represents the utilization of alternative fuels in the cement industry. In most countries of the region there are already existing cement plants, which could use the RDF from municipal waste.

5.1.1 MECHANICAL SORTING COMPONENT

Mixed MSW is separated into various fractions, each of which is treated and, if possible, recycled in a way that is customized to its properties. Most MBT plants divide their input into a fine fraction for biological treatment and a coarse high-calorific fraction that undergoes extended mechanical or/and biological treatment, see Figure 5.2.

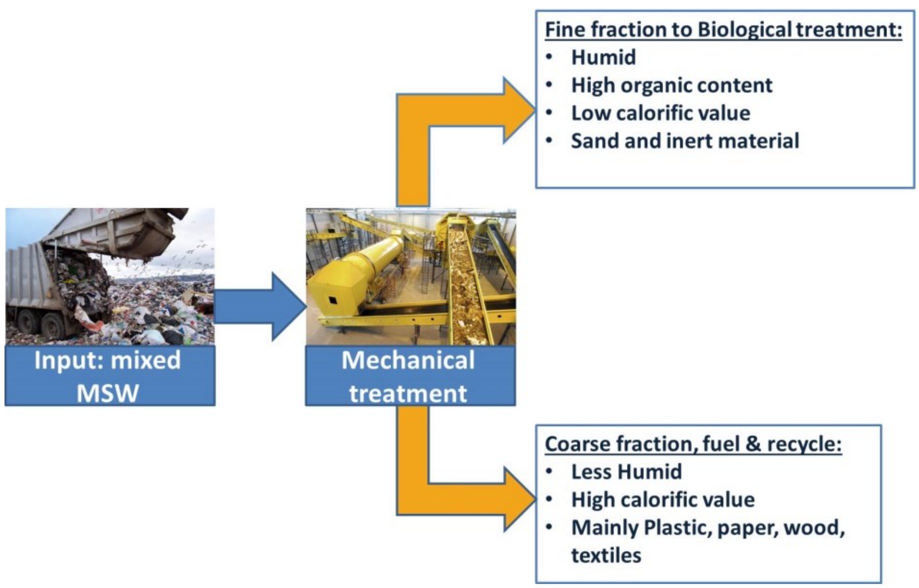

Figure 5.2. The separation of different fractions of waste by the mechanical sorting step.

5.1.2 BIOLOGICAL PROCESSING COMPARTMENT

The biological process includes the biological treatment of the biodegradable organic materials that has been sorted; it refers to the following methods:

- Anaerobic digestion
- Bio-stabilization/Aerobic treatment (composting)
- Biodrying/Aerobic treatment

The aerobic option is the most commonly used as it is easier to manage. In the field of aerobic processes, a distinction must be made between bio-stabilization and biodrying, see Table 5.1. Both processes adopt aeration into the mass of waste, but with different targets.

Table 5.1.Comparison between the two methods of the aerobic biological process.

Method	**Bio-stabilization**	**Biodrying**
Processes	Aeration	Aeration
Time	Long-time process	Short-time process
Actions	Highest conversion of organic carbon	Evaporation of the highest part of the humidity in the waste. Lowest conversion of organic carbon
Product	Stabilized solid end product (compost)	Produces a refuse-derived fuel.

Biodrying technology, aiming at removing water by microbial activities, is regarded as a good solution to reduce the water content of wet organic wastes (Choi et al., 2001). Besides the high water removal rate, it is expected to constrain organics degradation, preserving energy for subsequent utilization (Adani et al., 2002).

The reduction of moisture reduces the weight of the material and facilitates the sorting of different fractions from the waste stream for further recycling or/and recovery. Additional benefits include the reduced potential for odors and leachate since the resulting material is well aerated and partially stabilized.

Finally, the resulting material with its lower moisture content is more suitable for energy production. A comparison of the main aspects for both processes, to produce compost/stabilized material and RDF, is shown in Table 5.2. The biodrying process of MSW, which produces the RDF, takes place before the stabilization process of the dried screened fine organic fraction. Therefore, the time needed for the biodrying process is less than the time required for stabilized organic fine material. The aim of the biodrying is to dry the waste using the heat produced by the microbial activities where no water is added during the process. Therefore, the effect of the weather conditions will be on the degree of drying, as the waste would be dried in both winter and summer, with different percentages. Whereas, during the stabilization process, the weather conditions would have a negative impact on the process and affect the optimum environment for the bacterial activities

Table 5.2. Comparison of the main aspects for both process, to produce compost/stabilized material and RDF

Aspects	Stabilization	RDF
Time needed	8-12 weeks	2-4 weeks
Output	Low quality compost	High energy content
Land needed	Large area	Less area
Selling of the output	Needs marketing	High potential
Weather conditions	Negative impact	Positive impact

RDF becomes one of the interesting alternatives to solving MSW problems. Its benefits are not only to improve environmental quality, but also to reduce local economical loss. However, due to the high moisture content, low calorific value and high ash content of raw MSW, it needs to segregate the raw MSW and produce RDF. The advantage of RDF over raw MSW is that RDF has a higher calorific value and more consistency in quality.

5.2 BIODRYING OF MIXED MSW- PILOT PROJECT IN BEJA CITY, TUNISIA

The biodrying process of MSW is a pre-treatment process before the biostabilization of the screened fine fraction of the MSW. Within a pilot project supported with grant funds allocated by the German Government/Federal Ministry for Economic Cooperation and Development (BMZ) in the frame of the German Financial Cooperation via KfW Development Bank, the transfer of a low cost mechanical biological pretreatment technique of MSW, particular to the conditions in Tunisia, was to examined. Biodrying of mixed MSW took place during the processes of this pilot. Based on the results obtained from this pilot project test, a review of the biodrying process is presented below, as well as the potential of RDF production from mixed MSW in Tunisia.

5.2.1 SCOPE OF THE PROJECT

The project was planned to include trials during both the summer and the winter seasons to determine the impact of both climates on the waste composition and the decomposing conditions.

The objectives of the pilot project were to prove that the Pre Mechanical Biological (PMB) treatment is a feasible solution for the conditions in Tunisia.

The specific objectives of the biodrying treatment to be tested were to:

- Minimize:
    - The emissions of odors, landfill gas and leachate
    - The remaining waste to be landfilled (quantity and emission)
    - System costs
- Optimize the biological decomposition
- Determine the potential to produce secondary fuels (RDF)
- Identification of the optimal method for mechanical and biological processing steps under the conditions in Tunisia
- Determine the need for adaptation of the system of MBT to Tunisian conditions

Rostock University has a part in this pilot project; a PhD student was required to be present at Beja during both the winter and the summer trials, with experience in mechanical biological treatment, and in particular the assessment of the composting process regarding optimum conditions for efficient biodegradation.

Tasks included:

1. Preparation of the trial windrows.
2. Receiving of the waste.
3. Taking representative samples at waste characterization and from trial windrows.
4. Preparation of the samples (drying, sorting, shredding) and analysis, which are done in Beja.
5. Transport samples to Rostock University in Germany for further analysis.
6. Process monitoring of the trial windrows.
7. The design of relevant MBT options for Tunisian waste: process flow diagram, plant layout for different scale facilities.

5.2.2 Installation of the Demonstration plant

The demonstration plant was established at an existing small, windrow-composting facility in Béja (see Figure 5.4), which is located in the northwestern part of Tunisia in the Medjerda Valley. The plant is shown in Figure 5.3.

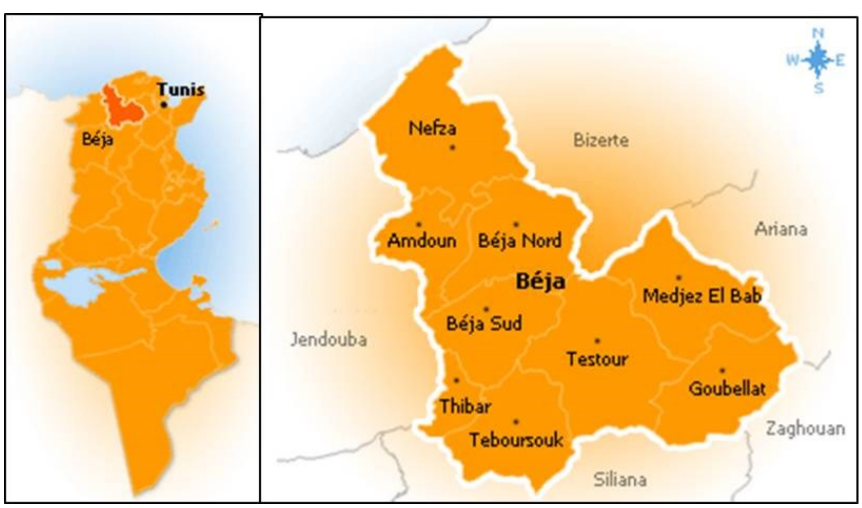

Figure 5.3. A map showing the location of Beja city in Tunisia (FIPA-TUNISIA, 2013).

The following equipment was provided and installed in the existing treatment facility:

- An aeration system for two windrows (40 m length).
- Semipermeable windrow cover sheets were used to protect the windrows from sun and rain (in the winter) and to reduce the odor.
- A windrow turner to enable mixing of the waste and turning of the composting windrows on a weekly basis.
- The existing machines in the site (shredder, screen, tractor) were tested and repaired where needed.
- Equipment for the lab to enable accurate monitoring of the trials.

Figure 5.4. Compost plant for the demonstration trials

Tasks of the process:

- Waste delivery: it was planned that the facility should receive about 100t for each trial/windrow.
- Shredding of the total received waste with the existing compost-shredder at the site was not possible. Therefore, the windrow turner was used to at least open the waste bags and mix the waste.
- Formation of windrows 5 m wide and 2 m high along the whole length of the aeration pipes (about 40 m).
- To maintain optimum composting/biodrying conditions the piles were turned and mixed once a week using a composting turner. As the aim was to dry the waste, no water was added at this stage of the process before screening the waste after three weeks.
- After three weeks the process should be finished and the waste should be dried. The waste was screened at 80 mm with the drum screen.
- Determination of the split between > 80 and < 80 mm on the site using buckets. Afterword the total RDF was weighed with the weighbridge in the close dumping site in order to estimate and calculate the mass balance.

5.2.3 BIODRYING CONCEPT

In biodrying, the main drying mechanism is convective evaporation, which uses heat from the aerobic biodegradation of waste components and is facilitated by the mechanically supplied airflow. The moisture content of the waste is reduced through two main steps: water evaporates from the surface of 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 as leachate. The appropriate control of aeration operational parameters (e.g., air-flow rate and direction) and temperatures 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, thus the capacity for water removal is limited by the amount of biodegraded organics. The air supply is controlled automatically and the temperature probe sensor manages the control mechanism.

Temperature is the key parameter for water evaporation and organics degradation during biodrying. The aeration of waste is critical for biodrying; it provides a mass and energy flow media, enabling water content removal, heat-transfer redistribution, removing excessive heat, adjusting the windrow temperature and insure O_2 delivery for aerobic decomposition. Air blowers are set to maintain average compost temperatures of around 40 ˚C to 70 ˚C and waste is turned weekly by the compost turning 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 is afterwards screened in order to separate the oversize fraction characterized by high net heating value from the smaller fraction ("biodried MSW fine fraction", (MSWFF) that is characterized by low heating values (Tambone et al., 2011; Velis et al., 2010).

5.2.4 MATERIAL AND METHODS

5.2.4.1 INPUT MATERIAL (MSW)

The summer trials were spread over nearly four months and during this period three trials were carried out. The winter trial was spread over three months with two trials. The schedule of the summer and winter trials is listed in Table 5.3 below.

For each test, the waste was subjected to a biodrying phase (self-draining of waste) for a three week period to enabled an effective screening of waste for separation of recyclable materials and high calorific value components of fine organic fraction. The sampling was carried out during the different steps of the process as follows:

- Sampling for the characterization of received waste at the site
- Sampling during screening (at 80 mm) the dried waste after 3 weeks (output)
- Sampling during the weekly turning of waste for monitoring biological reactions

Table 5.3. The schedule of the summer and winter trials during the the pilot project period.

Trials	Quantity of waste (t)	Number of windrows	Beginning of trial	End of trial
1	110	2	25/06/2014	15/07/2014
2	96	1	04/08/2014	28/08/2014
3	98	1	03/09/2014	23/09/2014
4	145	2	27/10/2014	19/11/2014
5	60	1	02/12/2014	17/12/2014

5.2.4.2 CHARACTERISTICS OF THE MSW

After delivery of fresh waste, about 100 ton for each windrow, sub-samples were taken from different waste trucks before the shredding and turning of waste to achieve a representative samples for waste characterization. A drum screen with 40 mm screen was used to screen the waste to small fraction < 40 mm and large fraction > 40 mm to record the size distribution of waste fraction, see Figure 5.6.

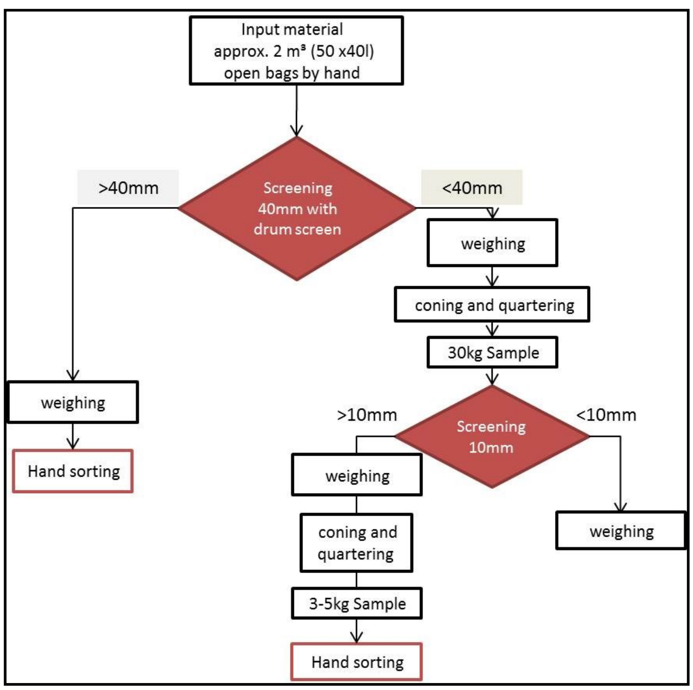

Figure 5.5. The sampling procedure of input material for waste characterization (the manual of the pilot project).

The characterization method followed that described in the manual of the pilot project. A drum screen machine with a screen of 40 mm was used for the first screening. The entire waste sample was screened. Waste bigger 40 mm was then placed on a table and sorted. The sorting team consisted of five sorters with a team leader. Before the first screening step at 40 mm, plastic bags were opened to make contents available for screening/sorting. In addition large particles (e.g., large cardboards, plastic film etc.), which may disturb the screening process and could reduce the quality of the screening, should be separated by hand and specified according to the defined sorting fractions. The sorting fractions were then weighed.

From the waste, which was fed to the first screening step of 40 mm, about 10% was separated for taking a sample for lab analysis. The screen overflow > 40 mm was then sorted by hand in the sorting fractions, defined in Table 5.5. The sorting fractions were then weighed.

The complete fine fraction <40 mm was weighed and then a proportionate quantity of at least 40 l was taken for further investigation. The procedure to obtain this sample of 40 l was performed as follows: the material <40 mm was piled on an even surface into a cone. This cone was once turned into a new cone to further homogenize the material. The homogenized 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. Only this portion of fines <40 mm had to be screened by 10 mm and the screening at 10 mm was done by a hand screen.

The particle size 10 - 40 mm was only sorted for the following sorting fractions:

- Organics
- Paper/cardboard
- Plastics
- Metals
- Inert (incl. glass)

The fines < 10 mm were not sorted but just weighed and samples were taken for lab analysis.

Table 5.4. Sorting fractions of waste samples (the manual of the pilot project).

Nr.	Sorting fractions	Examples	Comments
1	**Organic "garden"**	Grass clippings, leaves, weeds, tree and shrub cuttings,	
2	**Organic "kitchen"**	Food waste, spoiled food, coffee and tea filters, kitchen waste etc.	
3	**Organics 10 - 40 mm**	from sorting fines < 40 mm	
4	**Wood**	painted and treated wood, wood covered with plastics, untreated wood	
5	**Plastic film**	Plastic bags, freezer bags, cling wrap, covering and packaging films	Excluding PVC (if possible)
6	**Plastics 3D**	Plastic buckets, bottles, containers, toys etc.	Additional sorting of PET, PP, PE (if possible)
7	**Plastics 10 - 40 mm**	from sorting fines < 40 mm	
8	**Composite materials**	Drink cartons for milk, juice, wine, coffee vacuum packaging, instant soups	
9	**Fe-metals**	Magnetic drink and food cans, other magnetic metals	
10	**Non Fe-metals**	Non-magnetic drink and food cans, other non-magnetic metals such as aluminium	
11	**Metals 10 - 40 mm**	from sorting fines < 40 mm	
12	**Glass**	Bottles, jars for jam, fruit and vegetables, drinking glasses, windows	
13	**Inert**	Porcellain, clay pottery, tiles, ceramics, stones, brick, concrete	
14	**Inert 10 - 40 mm**	including glass (from sorting fines < 40 mm)	
15	**Paper**	Newspapers, magazines, catalogues, writing paper, envelopes, advertising, tissue paper	In case of additional screening: in grain size < 80 mm together
16	**Cardboard**	Carton, boxes	
17	**Paper / cardb. 10 - 40 mm**	from sorting fines < 40 mm	
18	**Textiles, shoes, bags**	Clothes, covers, curtains, Leather and plastic shoes, handbags, backpacks	Excluding PVC (if possible)
19	**Nappies**	Nappies, sanitary pads, bandages	In case of additional screening: only in grain size 80-150 mm and >150 mm
20	**Batteries**	Batteries, rechargeable batteries	
21	**Electronical goods**	Electrical and electronical goods,	
22	**Miscellaneous combustible**	Rubber, hazardous material, undefined materials	
23	**Miscellaneous non-combustible**		
24	**Miscell. 10 - 40 mm**	from sorting fines < 40 mm	
B	**Fines < 10 mm**	Screened material (not further specified)	

5.2.5 SAMPLING AND ANALYTICAL METHODS FOR INPUT MATERIAL

During biodrying, the samples of fresh wastes were collected from each windrow for fresh input waste and during each turning of the windrows. Four buckets of 80l 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 5.13. The main parameters are: the dry matter content, ash content, chlorine content, heavy metals and calorific value.

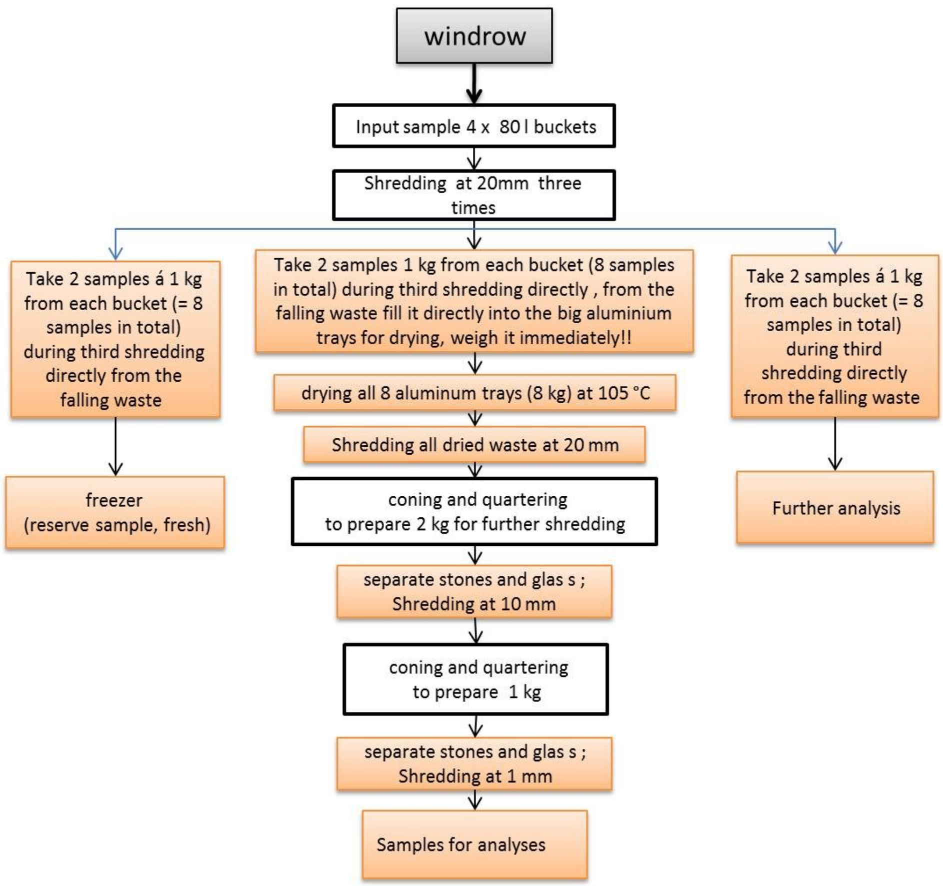

Figure 5.6. Sampling and analytical methods for input material (the manual of the pilot project).

5.2.6 SAMPLING AND ANALYSIS FOR THE COARSE FRACTION (>80 MM)

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

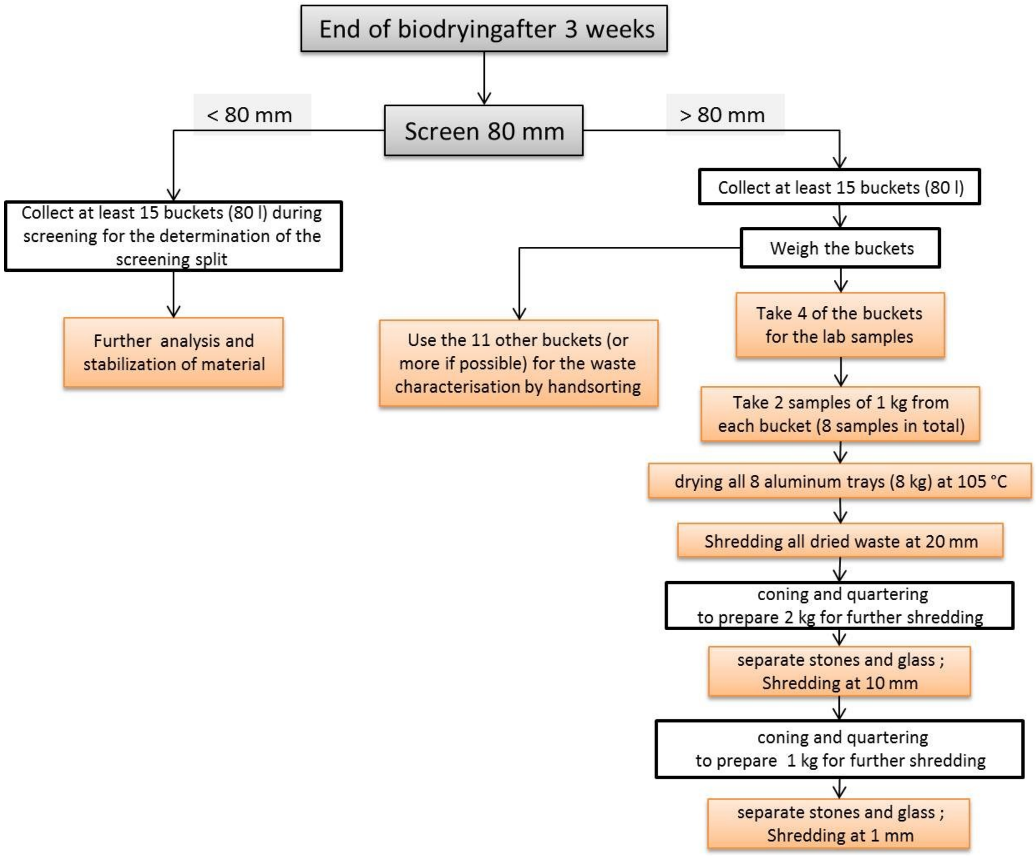

Figure 5.7. Sampling and analysis for the coarse fraction (>80 mm) (the manual of the pilot project).

A total of five RDF samples were sorted manually, three samples during the summer trial (from June 2014 to September 2014) and two samples during the winter trial (from September 2014 to December 2014).

Sampling for coarse fraction characterization and analysis was done by collecting at least 15 buckets of 80l during screening parallel to the sampling of <80 mm for the determination of the screening split. As shown in Figure 5.7, 11 buckets were used for the waste characterization by hand sorting, the various components of the RDF were weighed and the results are presented as percentages on weight/weight basis. The other four buckets were used for the lab samples, which went through various samples preparation processes such as shredding and drying.

RDF is one of the products of recycling combustible waste fractions from MSW to be used as fuel for stream or electricity production. To produce RDF, the heat value and chemical constituents, especially heavy metals and chloride, are normally taken into account to assure the RDF quality in order to avoid the environmental problems that may result from incineration (Rotter et al., 2001).

5.2.7 EXPERIMENTAL MONITORING

The biodrying process of the formed windrows was monitored by an automatic temperature control system that continuously measured the temperature of the windrows. A forced aeration system was installed to ensure that sufficient air was blown into the waste, which is necessary to provide optimum conditions for composting. The aeration system (illustrated in Figure 5.11) was set to maintain average compost temperatures around 40 ˚C to 70 ˚C. Waste was turned weekly by the compost turning 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.

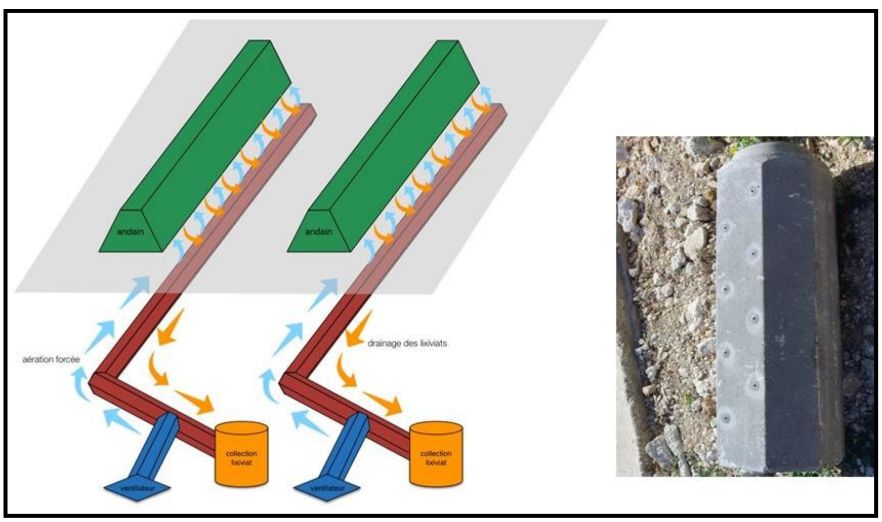

Figure 5.8. Ventilation system installed at the pilot site (unpublished interim report of the project).

In addition to the evaporation of water, the forced aerations helped to establish optimum composting conditions and to reduce the production of odorous substances. To further reduce the emission of odors into the environment, the windrows were covered with a membrane. The other purpose of the membrane was to protect the composting windrows against sun and rain.

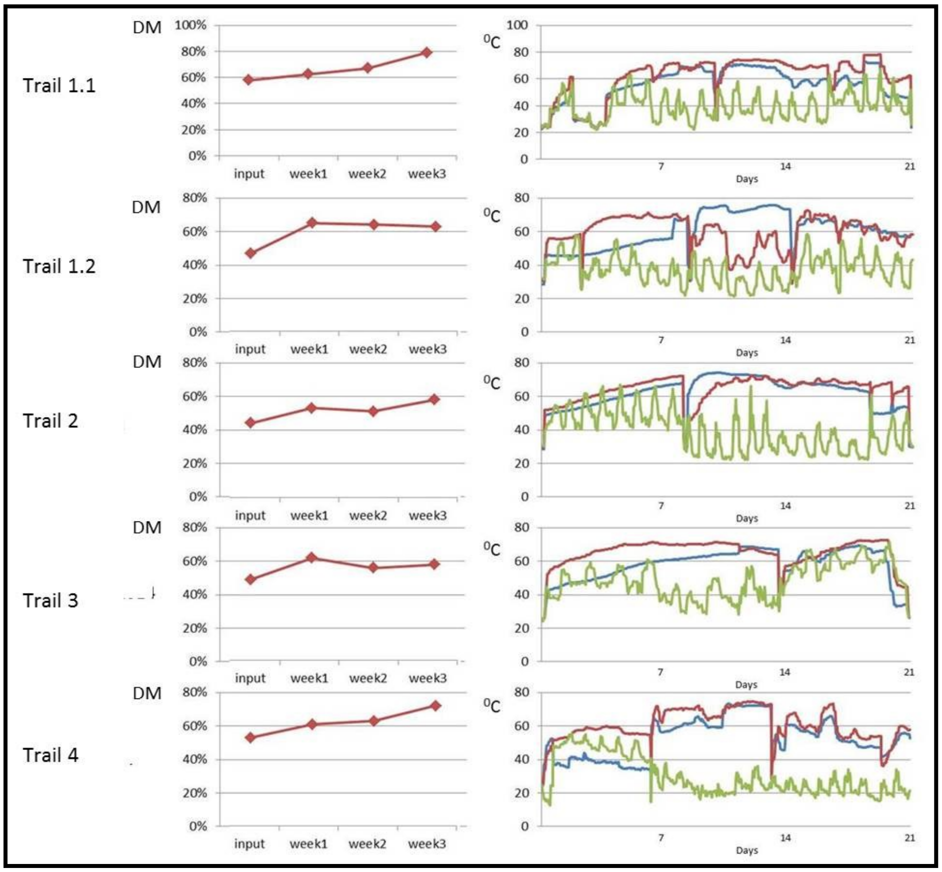

Figure 5.9. Monitoring of temperature and water evaporation during the biodrying process

As shown in Figure 5.12, the temperature of the windrows during the biodrying process was maintained at 40-70 ˚C for most of the duration of the biodrying process. After three weeks of composting, the waste was fairly dry with a moisture content of between 20 and 45%; the dry matter of the final product increased from the initial 44-53% to 53-72%.

5.2.8 Results and Discussion

5.2.8.1 Characteristics of the MSW

The results for each sample and the overall results of the waste characterization and screening during the project are described in Table 5.5.

The waste of the studied area had the typical waste characteristics of most developing countries, such as high moisture contents and large organic fractions both of which contribute to the production of leachat and landfill gasses with the presence of the odor problem.

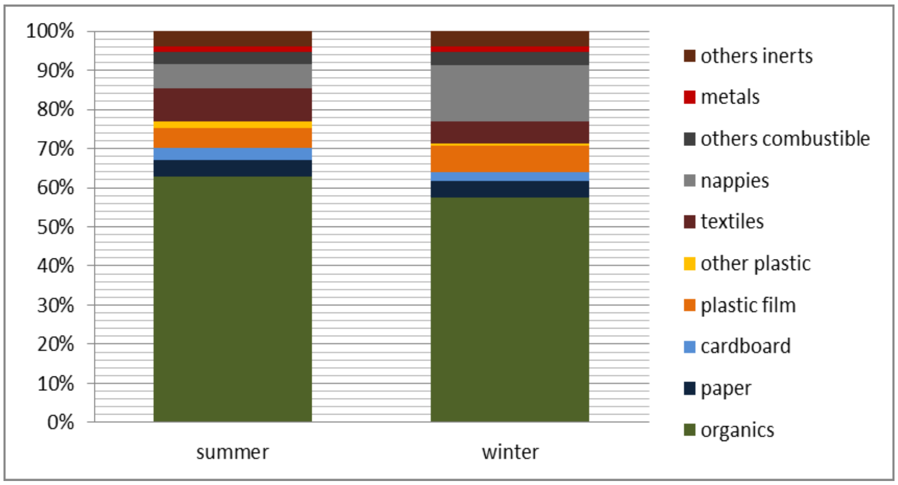

Figure 5.10. Composition of household waste from Beja, average of each season's analysis

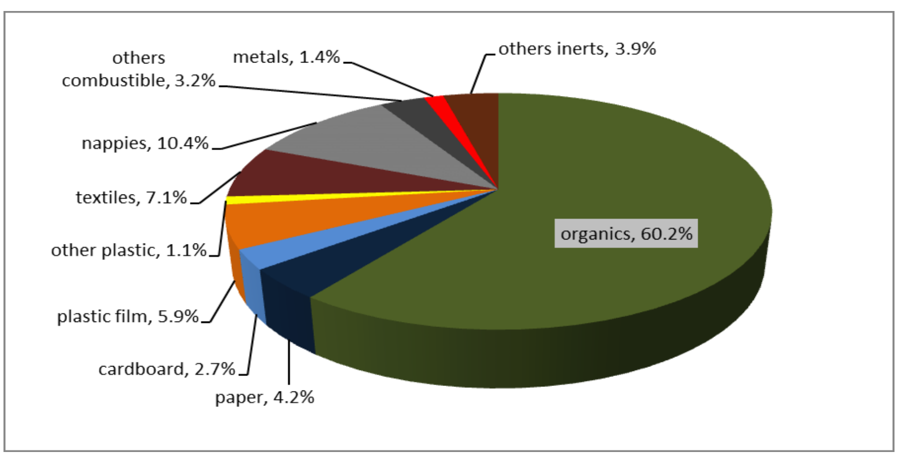

Figure 5.11. Composition of household waste from Beja, average of total analysis during both seasons (summer and winter)

Table 5.5.Overall results of the waste characterization and screening during the project.

Sample area	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Area under investigation	
Date of collection	17/07/2014		28/05/2014		24/09/2014		19/11/2014		16/12/2014		Total result	
Particle size	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
> 80 mm	82.3	51.2%	168.1	58.5%	227.5	56.0%	43.6	74.4%	77.4	82.9%	598.8	**86.7%**
10 - 80 mm	24.8	15.4%	23.7	8.2%	23.7	5.8%	15.0	25.6%	16.0	17.1%	103.2	**18.4%**
< 10 mm	53.8	33.4%	95.6	33.3%	154.7	38.1%	0.0	0.0%	0.0	0.0%	304.2	**34.9%**
Total sample weight	160.9	100.0%	287.4	100.0%	405.9	100.0%	58.6	100.0%	93.4	100.0%	1,006.2	**140.0%**
Sorting fractions	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Organic "garden"	3.0	2.5%	5.6	1.9%	34.3	8.5%	0.8	1.4%	2.1	2.2%	45.7	**4.6%**
Organic "kitchen"	7.6	6.4%	22.5	7.8%	5.3	1.3%	3.5	5.9%	11.4	12.2%	50.2	**6.4%**
Organics 10 - 80 mm	17.2	14.6%	16.6	5.8%	1.5	0.4%	8.0	13.6%	9.1	9.7%	52.3	**9.6%**
Wood	1.4	1.2%	0.5	0.2%	2.5	0.6%	0.6	0.9%	0.4	0.4%	5.4	**0.9%**
Plastic film	7.6	6.5%	45.4	15.8%	43.2	10.6%	7.6	12.9%	19.1	20.4%	122.8	**13.5%**
Plastics 3D	2.3	2.0%	12.0	4.2%	5.3	1.3%	2.8	4.8%	2.6	2.7%	24.9	**3.4%**
Plastics 10 - 80 mm	1.7	1.5%	5.8	2.0%	4.6	1.1%	0.7	1.2%	1.8	1.9%	14.6	**1.8%**
Composite materials	3.4	2.9%	5.9	2.1%	14.5	3.6%	2.5	4.2%	3.2	3.4%	29.4	**3.7%**
Fe-metals	7.3	6.2%	4.7	1.6%	19.4	4.8%	2.2	3.7%	2.6	2.7%	36.0	**4.9%**
Non Fe-metals	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Metals 10 - 80 mm	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.2	0.3%	0.8	0.8%	1.0	**0.1%**
Glass	0.2	0.2%	0.6	0.2%	1.1	0.3%	0.1	0.2%	0.4	0.4%	2.5	**0.3%**
Inert	3.0	2.5%	2.7	0.9%	2.7	0.7%	0.6	1.0%	0.5	0.6%	9.6	**1.6%**
Inert 10 - 80 mm	0.0	0.0%	0.0	0.0%	17.5	4.3%	3.6	6.2%	2.3	2.5%	23.5	**2.7%**
Paper	4.1	3.5%	8.5	2.9%	10.9	2.7%	5.0	8.5%	7.3	7.8%	35.7	**4.7%**
Cardboard	6.7	5.6%	6.0	2.1%	18.5	4.5%	0.0	0.0%	9.5	10.1%	40.6	**4.1%**
Paper / cardb. 10 - 80 mm	0.0	0.0%	0.0	0.0%	0.0	0.0%	2.5	4.3%	2.1	2.2%	4.6	**0.9%**
Textiles, shoes, bags	23.2	19.7%	32.3	11.2%	43.5	10.7%	11.9	20.3%	10.1	10.8%	120.9	**17.9%**
Nappies	9.2	7.8%	17.8	6.2%	17.2	4.2%	5.2	8.8%	8.2	8.7%	57.4	**7.8%**
Batteries	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Soft PVC	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Electronical goods	0.0	0.0%	0.2	0.1%	0.3	0.1%	0.0	0.0%	0.2	0.2%	0.7	**0.1%**
Miscell. comb.	3.2	2.7%	3.1	1.1%	7.3	1.8%	0.7	1.2%	0.1	0.1%	14.4	**2.1%**
Miscell. non-comb.	0.3	0.3%	0.5	0.2%	1.7	0.4%	0.3	0.5%	0.0	0.0%	2.9	**0.4%**
Miscell. 10 - 80 mm	5.9	5.0%	1.3	0.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	7.2	**1.8%**
< 10 mm	10.6	9.0%	95.6	33.3%	154.7	38.1%	0.0	0.0%	0.0	0.0%	260.9	**26.8%**
Control	117.7	100.0%	287.4	100.0%	405.9	100.0%	58.6	100.0%	93.4	100.0%	962.9	120.0%

All these materials have a high calorific value and can be utilized to produce RDF, which can, for example, be used in cement factories. There were little metals (1.4%) and glass in the waste. The average results of the waste characterization of each and both seasons are summarized in Figures 5.7 and 5.8.

5.2.8.2 SIZE DISTRIBUTION OF FRESH WASTE

The screening of the received waste at the site showed that most of waste fraction was of size >40 mm. According to the size distribution of solid waste, as shown in Figure 5.9, approximately 63.3% of the total solid waste screened could be recovered as the large fraction, whereas 28.2% and 8.5% had sizes of 10-40 mm and 40 mm respectively.

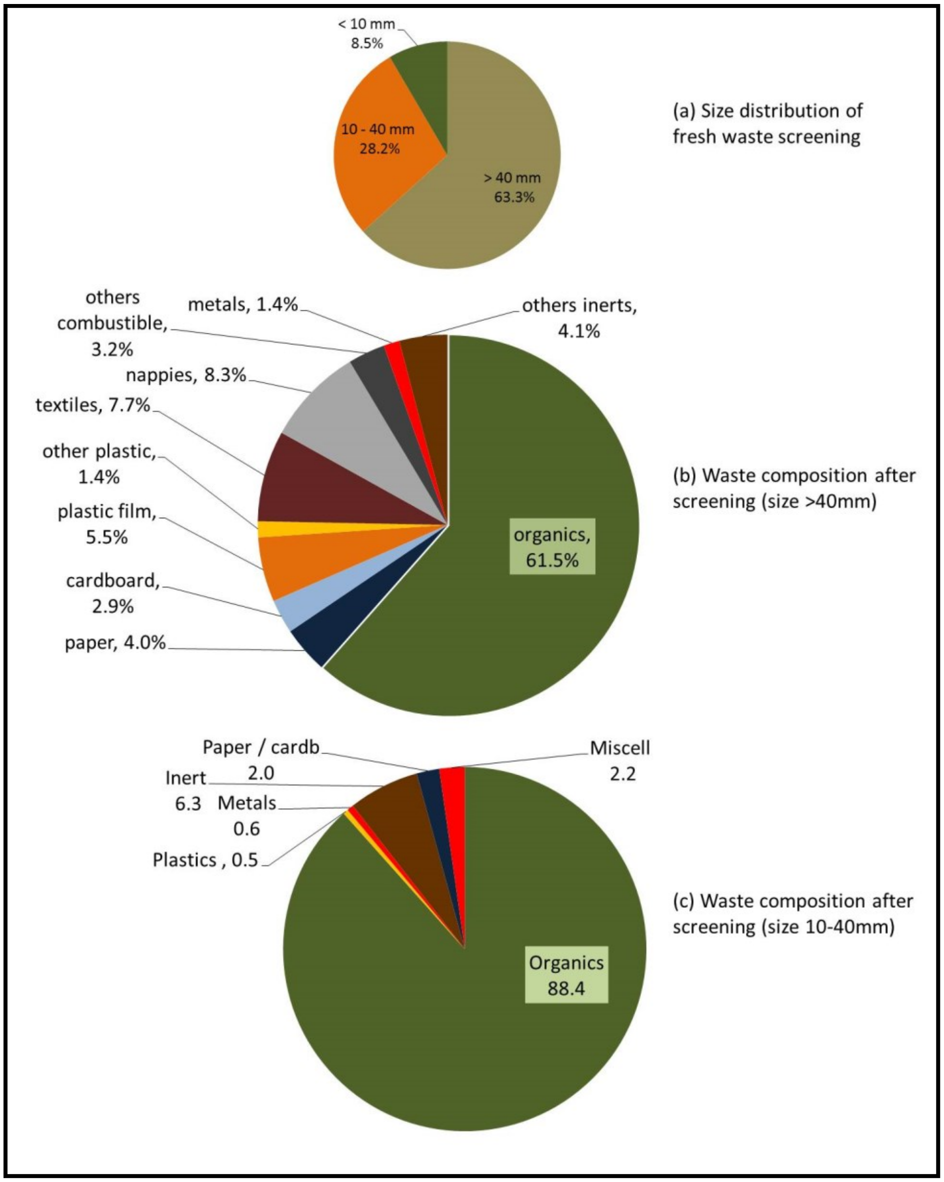

Figure 5.12. Size distribution and composition of fresh waste

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 52% of the total organic materials were included in the waste fraction of 10-40 mm. In the case of the waste of size 10-40 mm, approximately 88.4% of the waste was organics. The small fractions were 0.5% plastics and 2% paper and cardboard (5-10). For the large fraction >40 mm, the waste included 46% organics and 38.8% combustible material, which can be recovered from waste as RDF.

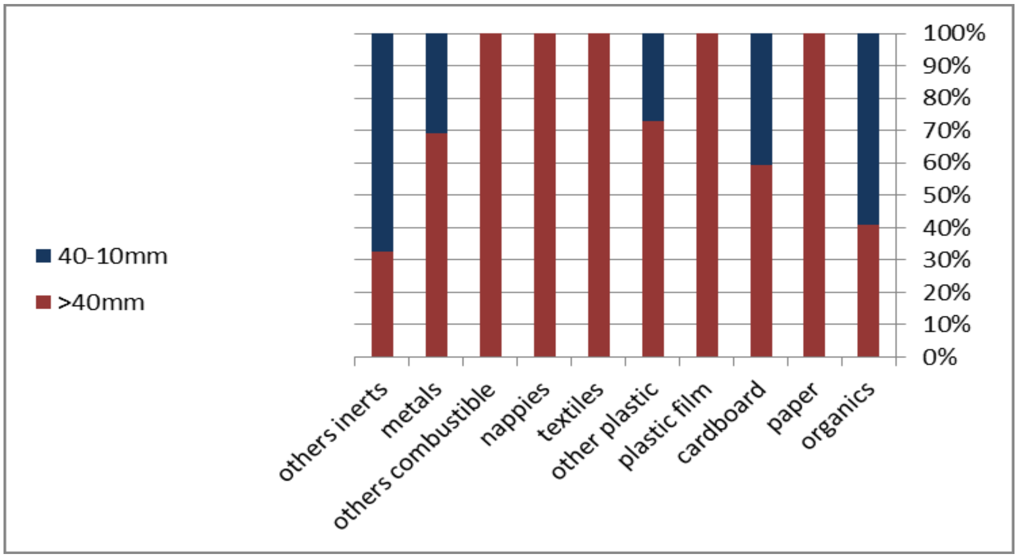

Figure 5.13. Size distribution of each waste component of the received waste at the site (Input).

5.2.8.3 THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF MSW

The unsorted waste was sampled and dried for dry matter analysis. The initial dry matter (DM) obtained from the input material raw waste was in the same range for all windrows formed during both session 44-53% (see Table 5.4).

The average DM during the summer was about 47%, while the average DM during winter was 51%. Figure 5.5 illustrates the results of the DM for the input material for 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.

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

Table 5.6. Dry matter results of the raw waste during the biodrying process before screening.

Trial	Dry matter (%)			
	Input	Week 1	Week 2	Week 3
Summer trial				
Trial 1	47%	65%	64%	63%
Trial 2	44%	53%	51%	58%
Trial 3	51%	62%	56%	53%
Winter trial				
Trial 4.1	53%	61%	63%	72%
Trial 4.2	47%	60%	56%	66%
Trial 5	53%	52%	N.A.	N.A.

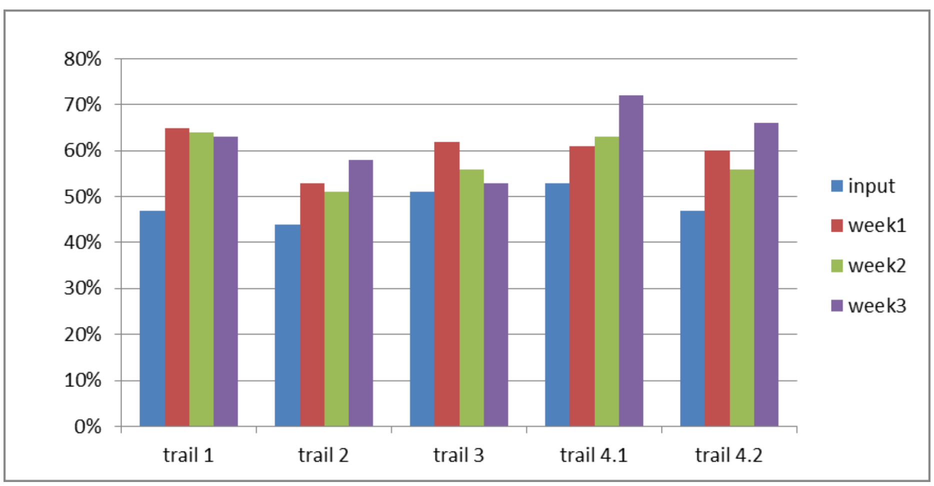

Figure 5.14. Dry matter results of the raw waste during the biodrying process before screening

5.2.8.4 SCREENING AT 80 MM AND MASS BALANCE

After three weeks of composting and drying, the waste can be screened efficiently into a coarse fraction with high calorific values, which can be used as a basis for the production of substitute fuel, e.g., in cement kilns or combustion facilities. The results of screening splits and mass balance of all trials during summer and winter seasons are illustrated in Table 5.6 and Figure 5.15.

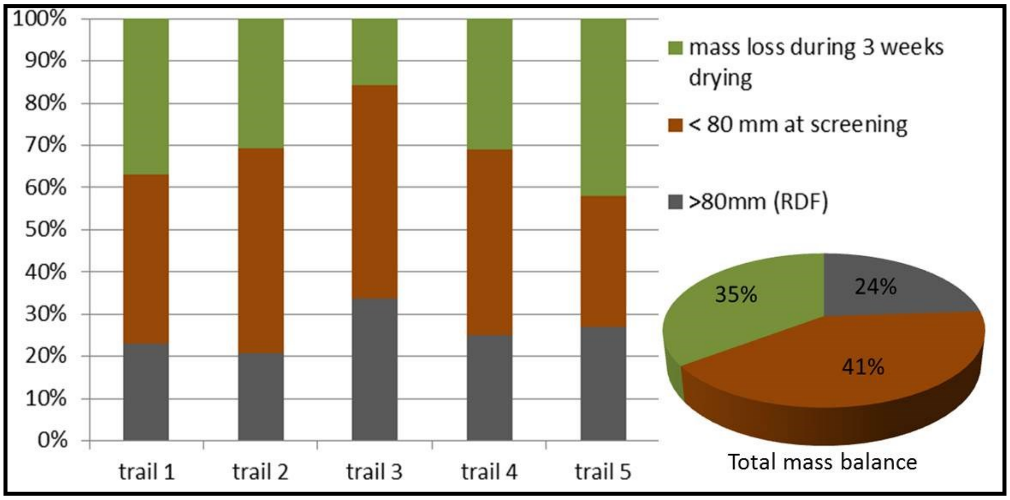

Figure 5.15. The percentage of output fractions after screening at 80 mm for the total and each trial during the pilot project period

As shown in Table 5.4, the initial dry matter content for the waste of trial three was (51%) higher than the DM percentage of the previous two trials, but then the results of the screening splits and the DM content during the drying process showed that the values of trial three differed from the values of the others trials and was not in the same range. As shown in Table 5.4, the DM content increased after the first week to reach 61% but it decreased for the rest of the biodrying process, reaching 56% after two weeks and 53% at the end of the process after three weeks of biodrying, with an overall increase of 2% in the DM. It was also observed during the site work that the waste of trial three was considerably wet after the end of the biodrying process, which will have affected the quality of the separated RDF, whereby more fine material will be separated with the coarse fraction and less fine fraction will be obtained after screening the temperature probe reading of trial three (shown in Figure 5.12). A different curve shape is observed from the other trial due to a breakdown in the system where no data were recorded for almost a week (from

10/09/15 till 17/09/15), seven days after the beginning of the drying process (03/09/15). All of the above indicated that there was something unusual with the drying process of trial three; therefore, the values of trial three were excluded from the calculations of the mass balance.

Table 5.7. Results of screening splits and the fresh and dry weight of each fraction after screening of all trials during summer and winter season

Trial	The split of fractions (%)	Fresh material		Dry matter content (%)	Dry material	
		Mass (t)	% of total mass		Mass (t)	% of total mass
Summer trial						
Trial 1						
Input	N.A.	110	100%	47%	52.2	47%
>80 mm (RDF)	37%	25.6	23%	75%	19.2	17%
< 80 mm at screening	63%	43.6	40%	70%	30.5	28%
Mass loss during 3 weeks drying	N.A.	40.8	37%	N.A.	2.5	2%
Trial 2						
Input	N.A.	96.0	100%	44%	42.0	44%
>80 mm (RDF)	30%	20.0	21%	/69%	13.7	14%
< 80 mm at screening	70%	46.7	49%	60%	27.9	29%
Mass loss during 3 weeks drying	N.A.	29.3	31%	N.A.	0.3	0.3%
Trial 3						
Input		98.0	100%	51%	50.0	51%
>80 mm (RDF)	40%	33.0	34%	50%	16.5	17%
< 80 mm at screening	60%	49.5	51%	60%	29.7	30%
Mass loss during 3 weeks drying	N.A.	15.5	16%	N.A.	3.8	4%
Winter trial						
Trial 4						
Input	N.A.	145.0	100%	50%	72.5	50%
>80 mm (RDF)	36%	36.1	25%	69%	17.3	12%
< 80 mm at screening	64%	64.0	44%	72%	1.7	22%
Mass loss during 3 weeks drying	N.A.	44.9	31%	N.A.	13.9	10%
Trial 5						
Input		60.0	100%	53%	31.8	53%
>80 mm (RDF)	46%	15.9	27%	58%	9.2	15%
< 80 mm at screening	54%	18.7	31%	62%	11.6	19%
Mass loss during 3 weeks drying	N.A.	25.4	42%	N.A.	11.0	18%

On average, for trials one, two, four and five, biodrying removed 27% of water, and 8% of solid waste mass was lost from the input material weight. In total, the weight of MSW decreased by 33% during the summer and 37% during the winter; the RDF utilization was still not considered in these figures of mass reduction.

Table 5.8. Mass balance after the biodrying process during the pilot test.

Trial	Input material %		Output of biodrying 3 weeks %					Mass loss %	
	Dry matter	Water content	RDF		<80 mm		Water	Dry matter	Water
			Fresh	Dry	Fresh	Dry			
Summer	46	54	22	16	45	29	22	1	32
Winter	51	49	26	14	37	21	28	16	21
Average	49	52	24	15	41	25	25	8	27

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 utilization from the dried waste, the mass of waste to be landfilled was reduced by approx. 59%. Furthermore, by dumping the dried waste in the landfill, leachate would not be produced if the landfill was carefully covered and protected from rainfall.

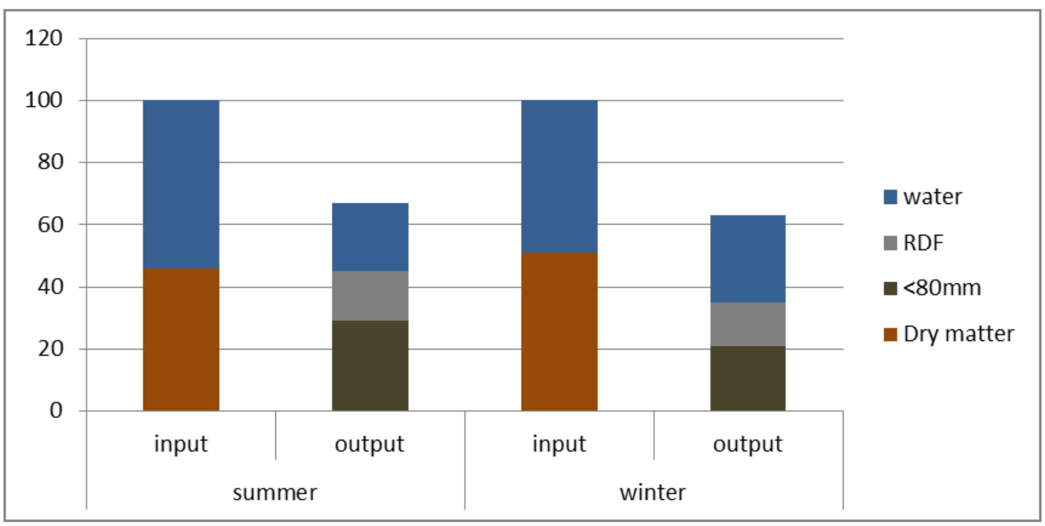

Figure 5.16. The mass balance after the biodrying process for the summer and winter trials.

5.2.8.5 CHARACTERIZATION OF THE COARSE FRACTION

An 80 mm drum screen was used to separate the coarse fraction > 80 mm from the fines fraction < 80 mm: approx. 24% of the waste input material was found to be >80 mm. Material samples were taken from this both for lab analysis and waste characterization (by means of hand sorting). Sorting analysis of coarse fraction, after the end of the biodrying process, was conducted for each trial during both seasons. The results of RDF percentage composition of each trial are presented in Table 5.8.

Table 5.9. Characterization analysis of output material >80 mm (RDF) during the period of the pilot project.

Sample area	trail 1		trail 2		trail 3		trail 4		trail 5		Area under investigation	
Date of collection	17/07/2014		28/05/2014		24/09/2014		19/11/2014		16/12/2014		**Total result**	
Particle size	**> 80 mm**		**> 80 mm**		**> 80 mm**		**> 80 mm**		**> 80 mm**		**> 80 mm**	
Sorting fractions	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Organic "garden"	3.0	3.6%	5.6	3.3%	34.3	15.1%	0.8	1.8%	2.1	2.6%	43.7	**5.3%**
Organic "kitchen"	7.6	9.2%	22.5	13.4%	5.3	2.3%	3.5	7.9%	11.4	14.7%	38.8	**9.5%**
Wood	1.4	1.7%	0.5	0.3%	2.5	1.1%	0.6	1.3%	0.4	0.5%	5.0	**1.0%**
Plastic film	7.6	9.2%	45.4	27.0%	43.2	19.0%	7.6	17.3%	19.1	24.6%	103.8	**19.4%**
Plastics 3D	2.3	2.8%	12.0	7.1%	5.3	2.3%	2.8	6.4%	2.6	3.3%	22.3	**4.4%**
Composite materials	3.4	4.1%	5.9	3.5%	14.5	6.4%	2.5	5.6%	3.2	4.1%	26.2	**4.7%**
Fe-metals	7.3	8.8%	4.7	2.8%	19.4	8.5%	2.2	5.0%	2.6	3.3%	33.5	**5.7%**
Non Fe-metals	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Glass	0.2	0.3%	0.6	0.4%	1.1	0.5%	0.1	0.3%	0.4	0.5%	2.0	**0.4%**
Inert	3.0	3.6%	2.7	1.6%	2.7	1.2%	0.6	1.4%	0.5	0.7%	9.0	**1.7%**
Paper	4.1	5.0%	8.5	5.0%	10.9	4.8%	5.0	11.5%	7.3	9.4%	28.4	**7.1%**
Cardboard	6.7	8.1%	6.0	3.6%	18.5	8.1%	0.0	0.0%	9.5	12.2%	31.1	**6.4%**
Textiles, shoes, bags	23.2	28.1%	32.3	19.2%	43.5	19.1%	11.9	27.3%	10.1	13.0%	110.8	**21.3%**
Nappies	9.2	11.1%	17.8	10.6%	17.2	7.6%	5.2	11.8%	8.2	10.5%	49.3	**10.3%**
Batteries	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Soft PVC	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	**0.0%**
Electronical goods	0.0	0.1%	0.2	0.1%	0.3	0.1%	0.0	0.0%	0.2	0.2%	0.5	**0.1%**
Miscell. comb.	3.2	3.9%	3.1	1.8%	7.3	3.2%	0.7	1.6%	0.1	0.2%	14.3	**2.1%**
Miscell. non-comb.	0.3	0.4%	0.5	0.3%	1.7	0.8%	0.3	0.7%	0.0	0.0%	2.9	**0.4%**

The average characteristics of coarse fraction for the summer and winter seasons are illustrated in Figure 5.17. On average for both seasons (see Figure 5.18) the major components of RDF were textiles (21.2%), plastics films (19.7%), nappies (10.5%) and cardboard (6.4%) Other combustible materials present included paper (15.4%), other plastics (4.5%) and organics (14.5%).

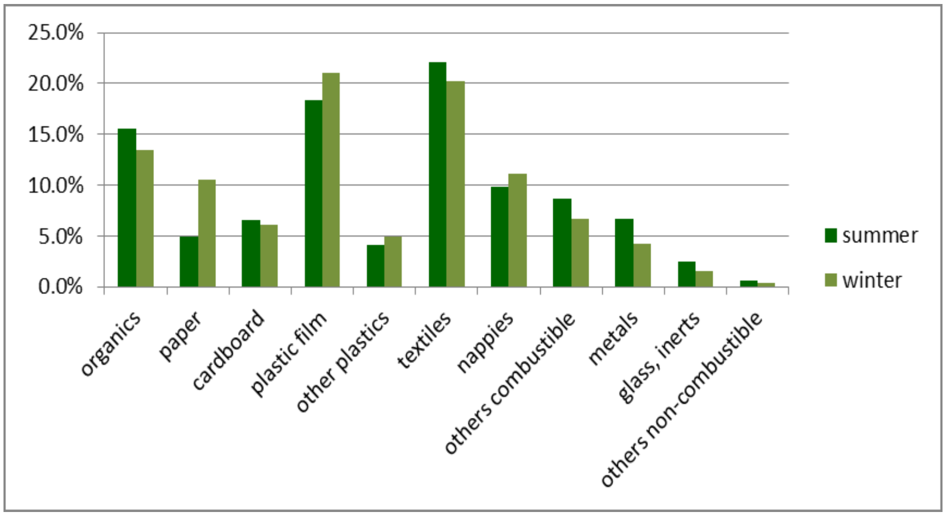

Figure 5.17. The average characteristics of coarse fraction for the summer and the winter season during the pilot project

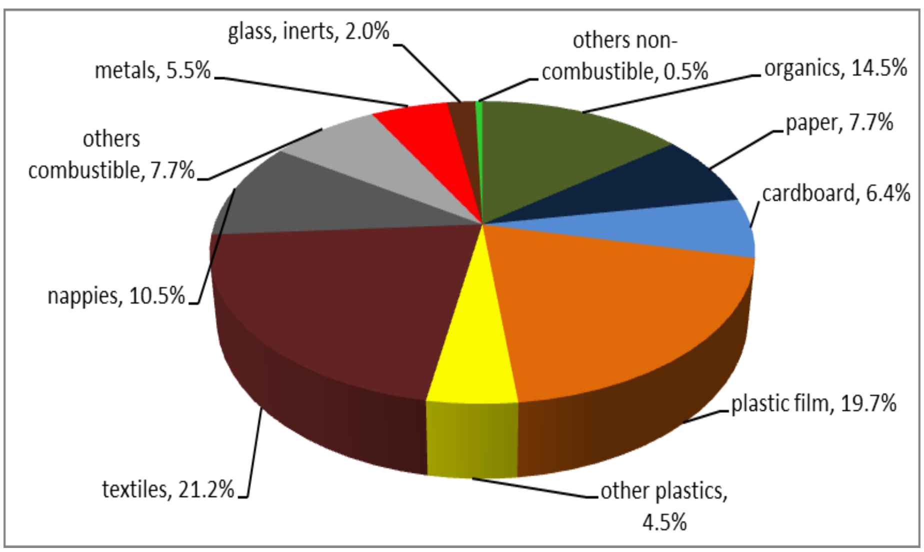

Figure 5.18. Average total composition of coarse fraction characteristics.

The proportion of plastics, textiles, nappies and paper/cardboard were increased compared to the fresh waste composition, as shown in Figure 5.19. There was still some organics in the coarse fraction, but this could be further reduced by optimization measures. Impurities in the RDF comprised of non-combustible materials, namely metals (5.5%) and glass and inert materials (2%).

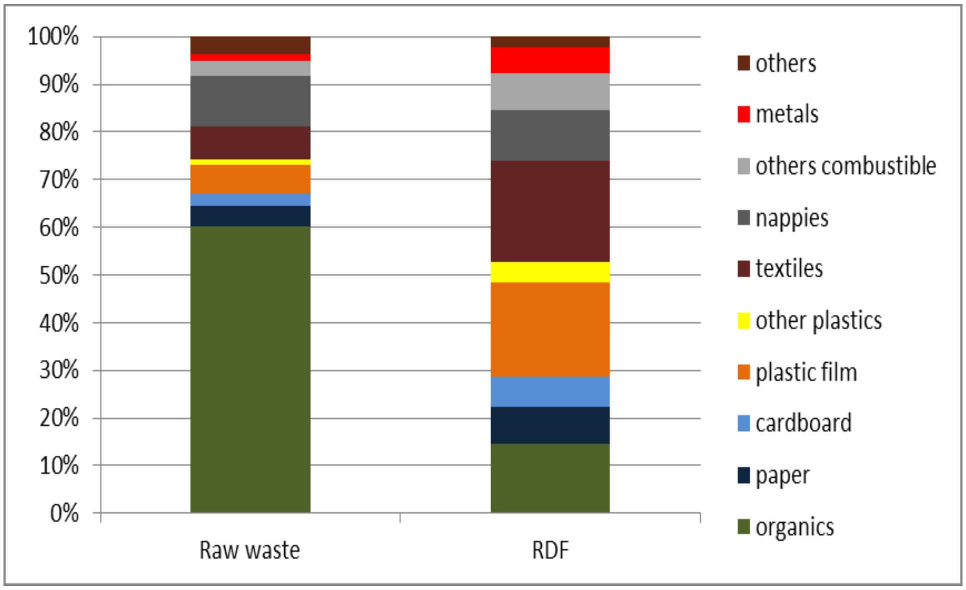

Figure 5.19. The average characteristics of fresh waste (input) and the coarse fraction >80 mm after the end of the biodrying process (three weeks).

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 requirement during combustion (Caputo & Pelagagge, 2002).

5.2.8.6 CHEMICAL PROPERTIES OF THE RDF

Table 5.9 presents the results of the basic chemical features of RDF. In addition to the heating value, other important fuel properties, such as the moisture content/dry matter, the chlorine content and the ash content were measured. DM showed great variability ranging from 50% to 75%: Figure 5.20 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.

Table 5.10. The basic chemical features of RDF produced in the study area.

Parameter		Summer trial			Winter trial	Total
		1	2	3	4	
DM_{Input} (%)		47	44	51	47	47.67
UHV_{Input} (MJ/Kg) dry sample		16.04	16.79	17.94	15.56	16.24
UHV_{Input} (MJ/Kg) wet sample		7.54	7.39	9.69	7.31	7.76
LHV_{Input} (MJ/Kg)		6.21	5.99	8.54	5.99	6.45
$DM_{output/RDF}$ (%)		75	69	50	67	65.83
$UHV_{output/RDF}$ (MJ/Kg) dry sample		18.87	20.61	19.96	18.87	19.34
$UHV_{output/RDF}$ (MJ/Kg) wet sample		14.15	14.22	9.98	12.64	12.71
$LHV_{output/RDF}$ (MJ/Kg)		13.53	13.45	8.73	11.82	11.86
$Ash_{output/RDF}$ (%)		31.9	17.6	20.3	23.8	23.53
$Chlorine_{output/RDF}$ (%)		0.84	0.66	1.30	0.94	0.94
Heavy $metals_{output/RDF}$ (mg/Kg)	Cd	0.76	0.45	4.18	0.62	1.21
	Cr	89	74.7	96	142	114.28
	Ni	71.1	34.9	45.6	70.2	60.37
	Hg	0.45	0.34	0.27	0.55	0.45
	Zn	262	141	140	229	205
	As	3.5	2.3	4.5	3	3.22

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 52%, as consequence of the waste moisture reduction. The calorific value of unprocessed MSW ranged between 5.99-6.21 MJ/Kg. The calorific value of the RDF produced from the pilot project ranged from 11.82- 13.53 MJ/kg, which made it appropriate as a fuel (see Figure 5.21). The ash content of the RDF produced in Beja appeared to have a high range between 20-31%.

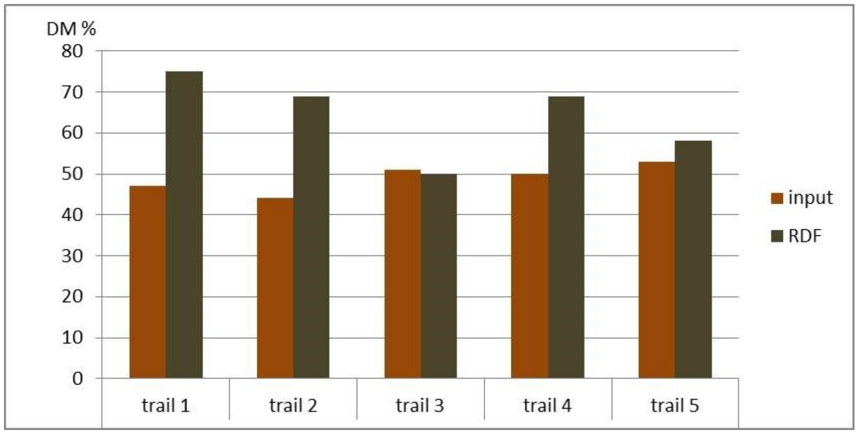

Figure 5.20. The dry matter of the input waste and the produced RDF after biodrying in the pilot project.

Chlorine was also a limiting factor for RDF quality, not only for ecological reasons, but also for technical ones. Chlorine content ranged from 0.66-1.30% w/w. chlorine concentrations, which related to the content of plastics in the RDF; this required more attention because it is considered a source of acidic pollutants and an important reactive element in the formation of dioxins (Watanabe et al., 2004).

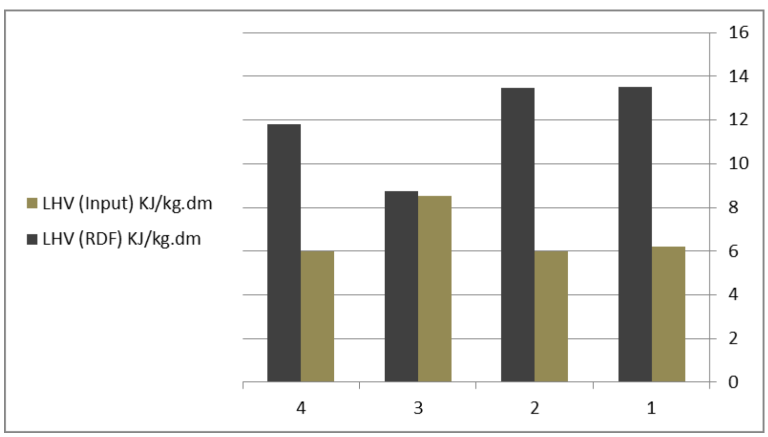

Figure 5.21. Low heating value (LHV) of the input material (raw waste) the RDF produced for each trial.

As Table 5.9 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 fine particles in the RDF produced, which may have high heavy metals.

The advantage of RDF over raw MSW is that RDF can be considered as 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 needed to segregate the raw MSW and produce RDF.

The important characteristics for RDF as a fuel are the calorific value, water content, ash content and chlorine content. The values of these parameters will vary according to raw waste characteristics and the processes applied to produce the RDF. The composition of the RDF produced in Beja is compared with the typical composition for RDF from MSW originating in different places (see Table 5.10 and Figure 5.22). The characteristics and results of the produced RDF in Beja were obtained from unprocessed RDF, which means that samples were taken from the screened material at 80 mm, just after the end of the biodrying process.

Table 5.11. Typical composition for RDF according to MSW origin.

<table>
<tr><th>Waste fraction</th><th>Flemish region</th><th>Italy</th><th>UK</th><th>Beja[(a)]</th></tr>
<tr><td>Plastic (%)</td><td>9</td><td>23</td><td>11</td><td>24.2</td></tr>
<tr><td>Paper/cardboard (%)</td><td>64</td><td>44</td><td>84</td><td>14.1</td></tr>
<tr><td>Wood (%)</td><td rowspan="3">25</td><td>4.5</td><td rowspan="4">5</td><td></td></tr>
<tr><td>Textile (%)</td><td>12</td><td>21.2</td></tr>
<tr><td>Others (%)</td><td>14</td><td>32.5 [(b)]</td></tr>
<tr><td>Undesirable material (%) (glass, stone, metal)</td><td>2</td><td>2.5</td><td>8 [(c)]</td></tr>
</table>

Source: Gendebien et al., 2003, PAGE)

(a) Unprocessed RDF, screened material at 80 mm without further shredding or screening

(b) Includes organic degradable waste

(c) Nappies includes others noncombustible material

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 set by some European countries.

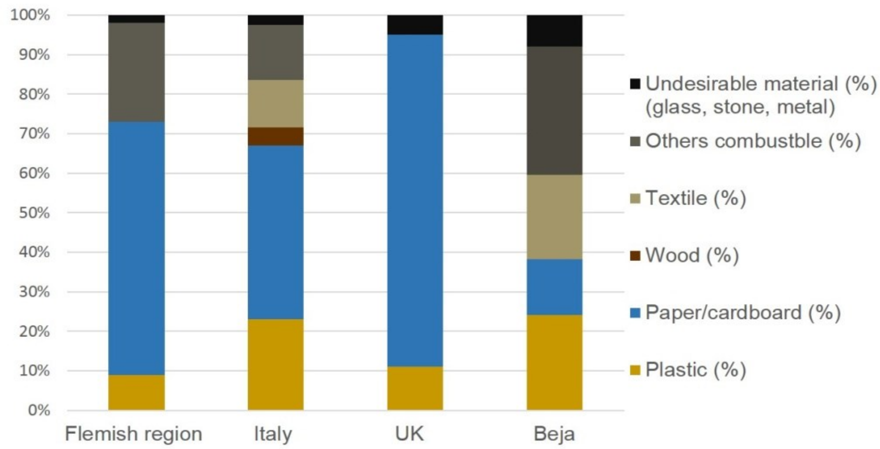

Figure 5.22. Composition of the RDF produced in Beja compared with the composition set by European countries

The quality of RDF required that it should have a high calorific value and have low concentration of toxic chemicals, especially for heavy metals and chlorine. Due to the different point of view of RDF producers, potential RDF customers and the respective authorities, suggested RDF quality varies from one group to another (Rotter et al., 2004).

Table 5.12. Chemical properties of the produced RDF in Beja compared with quality criteria set by European countries.

Parameter	Finland	Italy	UK	Beja
Calorific value (MJ/Kg)	13-16	15	18.7	12.87-20.61
Moisture content %	25-35	25 max	7 to 28	25-34
Ash content %	5 to 10	20	12	17.6-31.9
Chlorine %	<1.5*	0.9	0.3-1.2	0.66-1.3

Source : Gendebien et al, 2003)

*standard class III RDF

Although many European countries and organizations have already set specifications and quality criteria for the chemical characteristics of RDF, limited work exists on actual measurements of 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 5.11 and 5.12, the results of the RDF produced in Beja are compared with the available data on the chemical characteristics of RDF reported from European countries.

Table 5.13. Heavy metals content of the produced RDF in Beja compared with quality criteria set by European countries.

Parameter	EURITS[a]	Italy	Finland	Beja
Cd (mg/kg)	N/A	10	5	0.44-0.76
Cr (mg/kg)	200	100	N/A	74-142
Ni (mg/kg)	200	40	N/A	34-71
Hg (mg/kg)	2	N/A	0.5	0.27-0.55
Zn (mg/kg)	500	500	N/A	140-262
As (mg/kg)	10	9	N/A	2.3-4.5

Source: Gendebien et al., 2003)

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

It becomes clear from the results that the RDF produced in Beja was of high calorific value, low moisture and acceptable chlorine content compared to the RDFs produced in other countries. Concerning heavy metal content, it is interesting to note that, although the Beja RDF showed different ranges of heavy metal concentrations in the samples, as shown in Figures 5.23 and 5.24, in most cases they were lower than the reported ranges from the other countries.

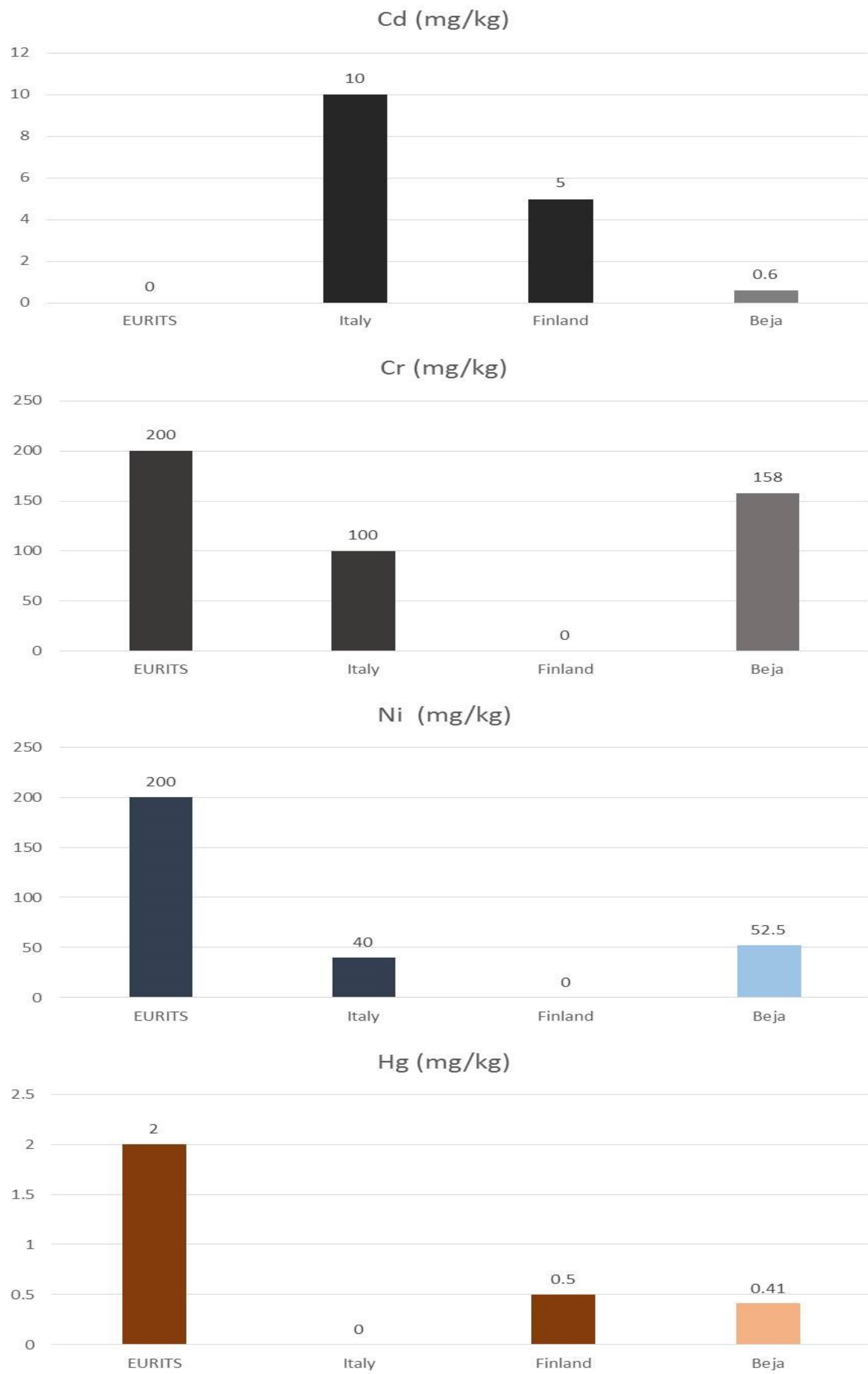

Figure 5.23. Heavy metals concentrations (Cd, Cr, Ni & Hg) of RDF produced in Beja compared with criteria and values set by European countries

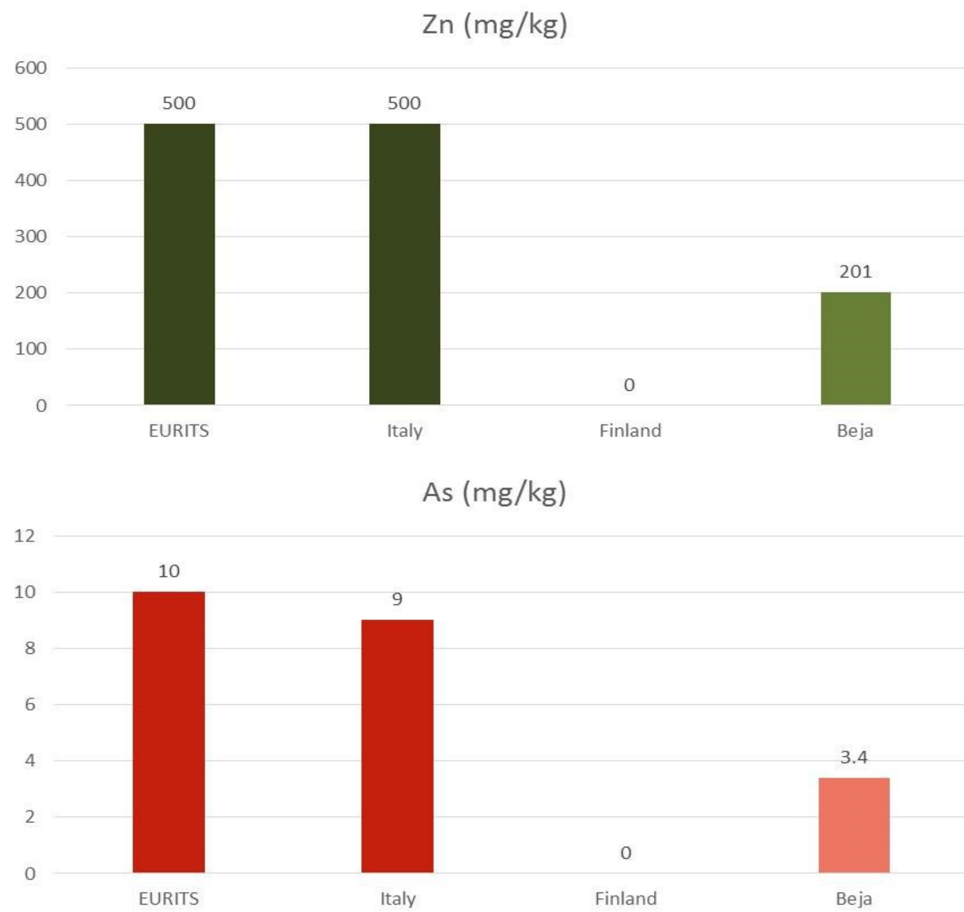

Figure 5.24. Heavy metals concentrations (Zn & As) of RDF produced in Beja compared with criteria and values set by European countries

5.2.8.7 Fine fraction characteristics after the biodrying process

After the end of the biological drying process the screened fine fraction (<80 mm) was further composted. Some parameters of the fine fraction are presented in Table 5.13.

Based on the results of stabilization, there was a reduction in the respiration activities compared with the input material. Comparing the results obtained with the classification of the rotting degree of compost (Table 4.2), the produced fine fraction after three weeks of biodrying is considered as fresh compost of class III.

Table 5.14. Characteristics of the fine fraction (<80 mm) after three weeks of the biodrying process

Parameter	Samples of fine fraction <80 mm after the biodrying process					
	Summer trial				Winter trial	
	1.1	1.2	2	3	4	5
Dry matter %	70	61	60	58	76	62
AT4 (mg O2/g DM)	19.43	19.43	20.41	24	24.05	22.85

In addition to which, as a result of the mass reduction during the biodrying process, the waste was partially stabilized and had low moisture content, consequently this would reduce the formation of greenhouse gases. Furthermore, in order to reduce leachate production when dumping this fraction in a landfill, protection measures must be considered to prevent any water getting through to the dumped waste. The more stabilized the waste the less landfill gas and leachate will be produced in the landfill. The stabilization can be measured with the biological test parameter 'respiration activity' AT4. One of the objectives of the pilot project, which was not discussed in this thesis, was to examine the possibility of producing stabilized fine fraction (<80 mm). Therefore, the fine fraction <80 mm went through further stabilization/composting processes. To establish effective stabilization of the material and further mass reduction, optimum moisture content of 40 – 50% in the composting pile has to be maintained. As the material had lower moisture content of 30 - 40% after the screening, water had to be added. After adding water the material was mixed again and further composted. During this process water is also lost and has to be added if needed.

5.2.8.8 Stabilized material produced/ Compost like output (CLO)

After further composting of the fines fraction, approx. 15% of mass reduction was achieved. The material after composting mainly consisted of stabilized organic material similar to the organic material of compost, but it was mixed with impurities such as plastics and glass particles.

Samples of the produced compost in Beja were collected and examined for the heavy metals concentrations and compared with the results obtained earlier in Chapter 4 for compost samples collected from different facilities operating in the region. The results are shown in Table 5.15.

The compost produced in Beja was in the same range of the compost produced in other operating facilities in the region with the exception of Cr and Hg: the concentration of these two elements were higher than the range of the compost produced in the region. Furthermore, of the three compost samples collected from Beja, one of them did not fulfill the limits set by the German standards due to the high value of the Hg (see Figures 5.25 and 5.26), while the other two could be considered with the same quality of other compost produced in the region regarding heavy metals.

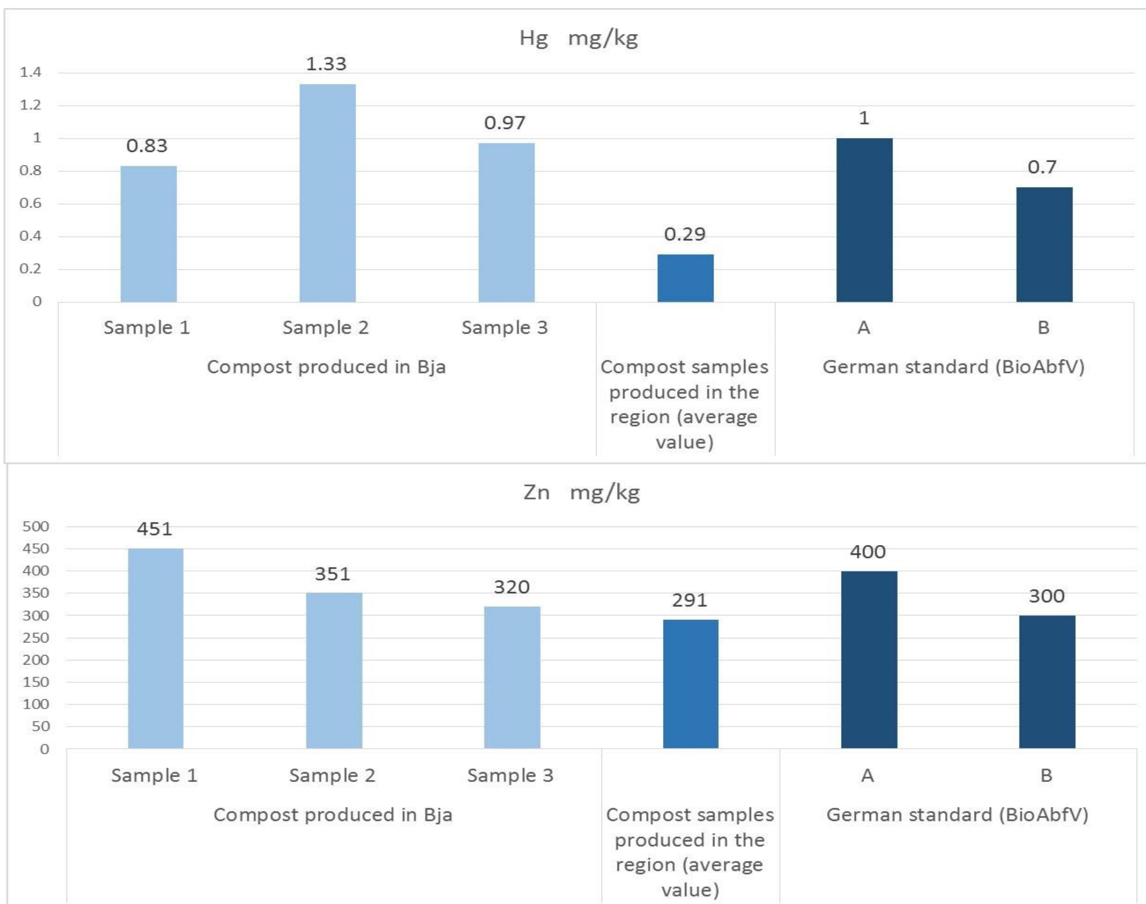

Figure 5.25. Heavy metals concentrations (Hg & Zn) of stabilized material produced in Beja and in other composting facilities in the region compared with the German standard

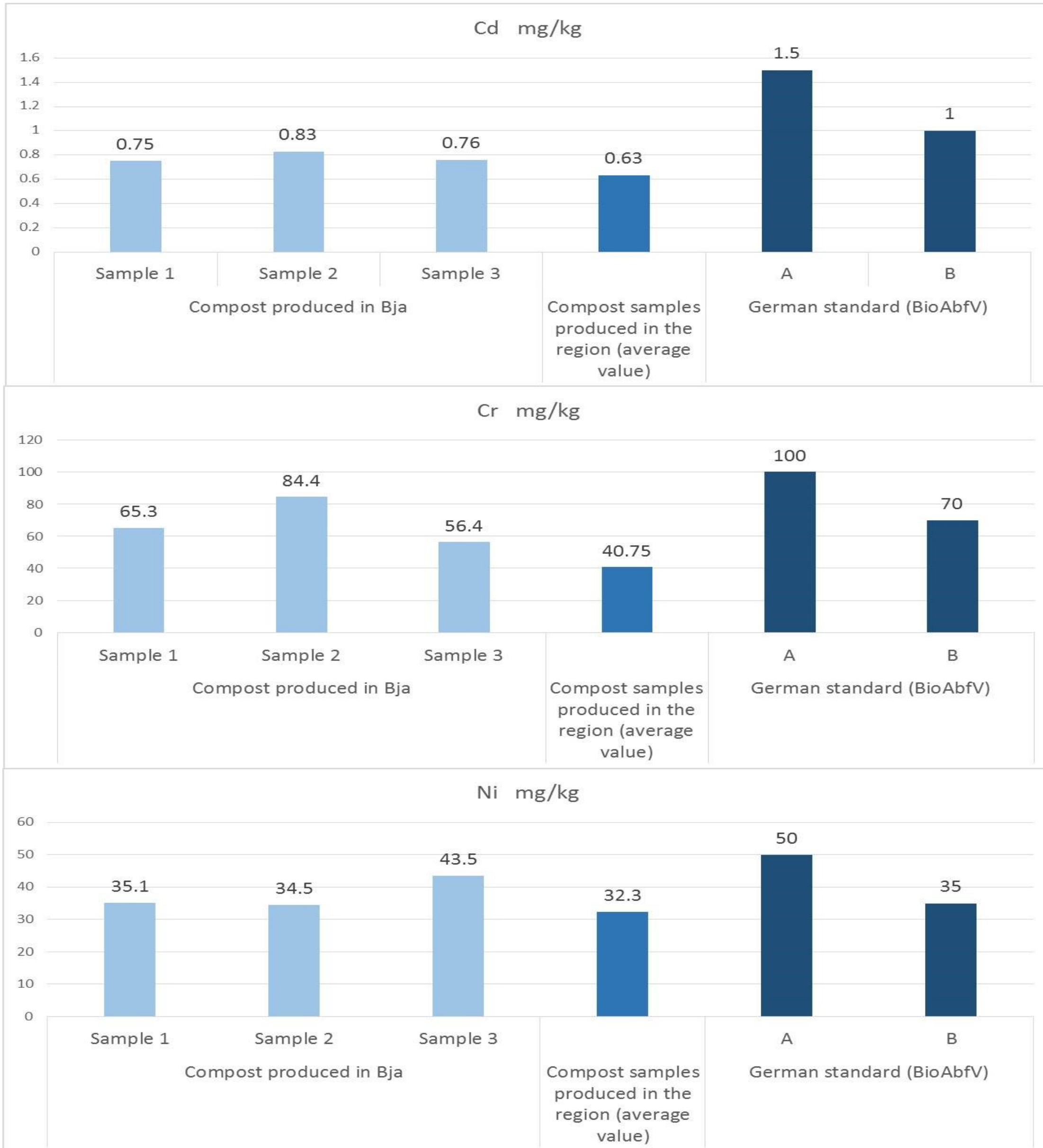

Figure 5.26. Heavy metals concentrations (Cd, Cr & Ni) of stabilized material produced in Beja and in other composting facilities in the region compared with the German standard

The biodrying process allowed drying of the waste within three weeks. This enabled an efficient screening of the waste to separate the recyclables and high calorific components from the organic fines fraction. The organic fines fraction was then further composted/stabilized to further reduce the waste volume, as designed for the pilot project (the stabilization process was not included in this thesis).

The results showed that an efficient waste treatment can be achieved with a fairly basic and low-cost MBT concept utilizing the biological drying process to produce a substitute fuel for industrial processes and reduce the landfill volume required and air emissions from the landfill, in particular greenhouse gases.

6. Possible Waste Treatment Alternatives Design for Mixed MSW and Economical Feasibility in the Arab Region

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. MBT for waste drying and sorting, and Mechanical Biological Stabilization (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 refuse derived fuel (RDF).

6.1 Mechanical Biological treatment (MBT)

MBT can be classified in four process concepts: material stream separation, mechanical biological stabilization (with a biological drying process), mechanical-physical stabilization (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 is spread 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 et al., 2011).

6.2 Mechanical Biological Stabilization (MBS) with biological drying,

The aim of Mechanical Biological Stabilization (MBS) is to stabilize 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 & Hoffmann, 2008; Thiel et al., 2011). There are different variants of treatment processes existing in an MBT facility, which are divided into mechanical and biological steps.

6.2.1 Mechanical treatment

The mechanical processes are usually the first step of an MBT facility, of which different fractions would be separated out of mixed MSW. It has the following functions:

- Separation of bulky waste, to protect the machines, and homogenization of the waste for the biological treatment (e.g., shredding).
- Separation of high calorific fractions for use as RDF by sieving (150-200 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.

6.2.2 Biological treatment

The biological treatment (aerobic treatment) is achieved by aerated windrows operated under a roof or directly in the open air, which are turned from time to time. The windrows should be covered to protect the waste from getting wet and to prevent odor and insect problems. Process control (e.g., moisture management) is difficult, or at least not very accurate, but it is possible to achieve a huge improvement of the landfilled waste at low investment costs. Experienced personnel are needed to run the windrows properly.

6.3 Proposed strategies for MSW treatment with MBT facilities

Two strategies have been considered for 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 further stabilized before landfilling.

The assumptions made for the following strategies are based on the available results obtained during the summer trial from the pilot project in Beja. The main objectives of the chosen options are:

- Recovering recyclable material
- Diverting material from landfill
- Relevant factors include recovery efficiency, costs and time needed for treatment.

6.3.1 Strategy One: Biological drying of mixed MSW with RDF production and recyclables recovery.

The concept of this strategy is proposed for facilities with a capacity of Option 1., 50000 Mg/a and Option 2., 100,000 Mg/a. The waste will 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)(see Figure 6.2).

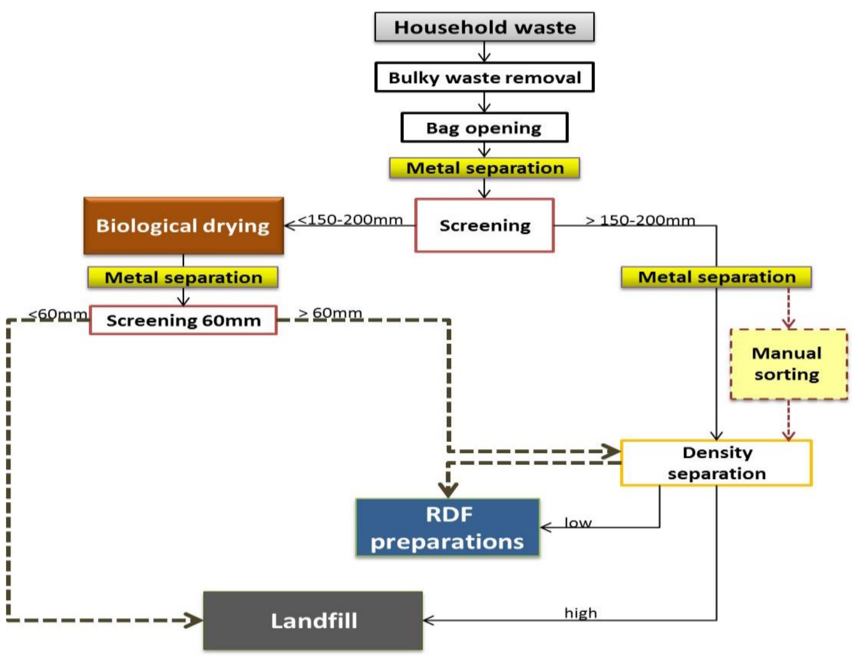

Figure 6.1. Strategy one: biological drying, RDF production and recyclable material recovery.

Based on the results obtained for the pilot project in Beja, the mass of input waste will be reduced by approx. 60%. This means that only 40% of the input material will be sent to the landfill and 60% will be diverted from landfill. The mass balance is illustrated in Figure 6-3.

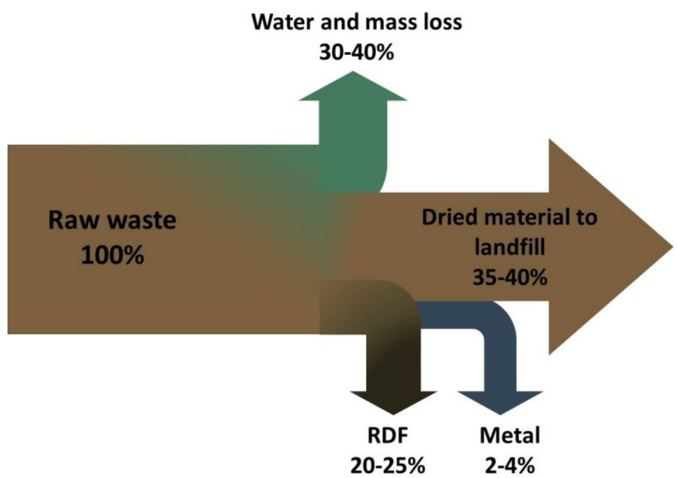

Figure 6.2. Mass balance of strategy one.

6.3.2 Strategy Two: Biological drying of mixed MSW with RDF and metal recovery and stabilization of organic material before landfilling.

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/stabilization for further mass reduction. The composting period is about 6-8 weeks (see Figure 6.4). Two options will be studied for this strategy:

Option 3. Biodrying with RDF, recyclables recovery and stabilized material for landfilling.

Option 4. Biodrying with RDF, recyclables recovery, compost-like output (CLO) and inert material for landfilling.

Based on the stabilization results obtained from the pilot project in Beja, the mass of the stabilized portion will be reduced by approx. 87%. This means that only 13% of the waste input will be sent to the landfill, while the rest is recovered as RDF fuel, recyclable material (metals) and compost like product with moisture content loss as a result of the biodrying and stabilization process. The mass balance is illustrated in Figure 6.5.

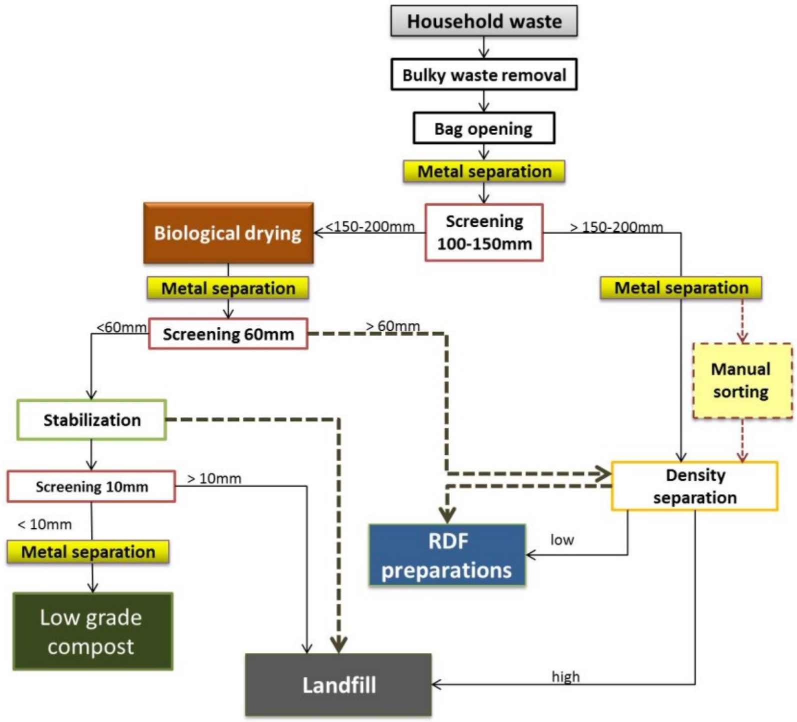

Figure 6.3. Strategy two: biological drying, RDF and stabilized material production and recyclable material recovery.

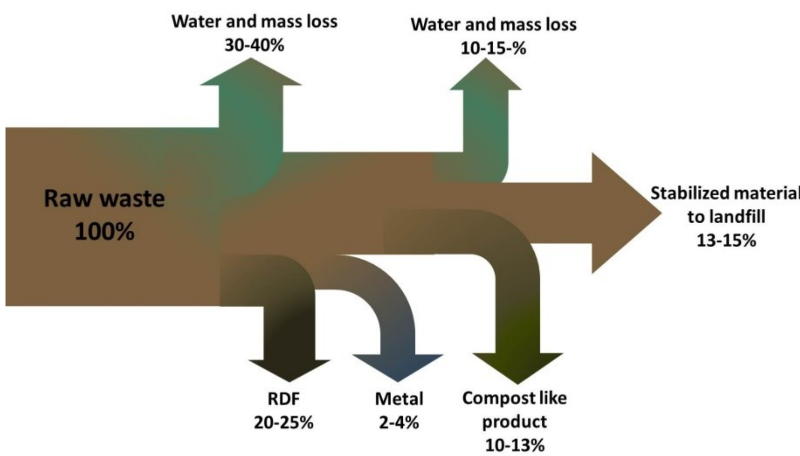

Figure 6.4. Mass balance of strategy three.

The coarse fraction produced in strategies two and three 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 utilization process. MBT 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 will 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.

6.4 ECONOMIC FEASIBILITY ANALYSIS

The financial sustainability of solid waste management systems is one of the greatest challenges in low- and middle-income countries. Fees to cover solid waste management costs do not always exist and, where they do, the authorities in charge often cannot raise them effectively; this means that total SWM costs (capital as well as operating costs) are rarely covered. Fees can be used not only to cover costs, but also to create incentives for waste reduction, recycling or particular treatment and disposal options.

In a sustainable SWM system, not only technical factors but also economic aspects need to be considered. For each planning scenario of SWM, the calculation of costs and benefits must be taken into account. The key issue for any type of SWM is to ensure whether the charge system is affordable, viable or sustainable for the community receiving the services. Cost and benefit of the SWM system should be balanced to ensure proper operation of the facilities (Chang & Pires, 2015). Based on the availability of the RDF and its composition, it is useful to estimate the costs related to its production and management.

6.4.1 COST ESTIMATION AND ECONOMICS

The cost of each plant includes two main components: total capital investment and operation and maintenance costs. Total capital investment includes the costs of the main machineries and equipment, their installation, engineering, construction and supervision, and the cost of capital or interest payment. Meanwhile, operation and maintenance costs are generally divided into maintenance, operating labor, supervision, plant overheads, laboratory expenses, raw materials/consumables, utilities and transportation. Revenue is generated, mainly from the sale of the produced RDF, recycled materials, as well as from MSW gate fee.

6.4.1.1 CAPITAL COST

An estimation of the capital cost (shown in Table 6,1) was made from the calculation prepared for the four treatment options, shown in annex (1).

Table 6.1. Estimation of the capital investment for the proposed treatment options

Option	Capacity	Quantity (Mg/a)	Capital investment (Million Euro)
1	RDF production and recyclables recovery.	50000	8
2	RDF production and recyclables recovery.	100000	12
3	RDF, recyclables recovery and stabilized material for landfilling.	100000	14
4	RDF, recyclables recovery, compost-like output (CLO) and inert material for landfilling.	100000	14

Investment cost and operational and maintenance costs are required to be calculated for sustainable operation and maintenance of the proposed waste management system and also to meet expected service standards and the full technical lifetimes of the investment under the existing conditions.

6.4.1.2 OPERATION AND MAINTENANCE COSTS

In order to calculate these costs, assumption were made according to the situation in the region; it was assumed that the plant will work for 4000 hours per year to treat the required quantity of waste, which means that the plant will operate two, eight hour shifts per day. The other estimated parameters for the calculation of the operation and maintenance costs for the proposed options are given in Table 6.2.

Table 6.2. Estimated parameters for the calculation of the operation and maintenance costs for the proposed options

Annual cost		
Net equity percentage	30	%
Useful economic life	15	years
Interest (inflation adjusted)	5	%p.a.
Insurance, Revisions	2	%p.a.

Expenses		
Removal costs for residues and transportation	10	EUR / Mg
Maintenance costs	10	% of capital cost
Electricity costs*	110	EUR / MWh
Electricity consumption**	0.032	MWh/t
Personnel costs (1 man) *(STEG, 2015) **(Karagiannidis, 2012)	6880	€/a

To calculate the cost and revenue for each option, the mass balance must be known for each of them. The output from each option is summarized in Table 6.3. The detailed mass balance during the processes of the proposed options can be found in annex 2.

Table 6.3. Output of each proposed treatment option

Option	1	2	3	4	
Input					
Quantity of waste	**50,000**	**100,000**	**100,000**	**100,000**	Mg/a
Water content	**50**				%
Output					
Metal	**731**	**1,463**	**1,463**	**1,463**	Mg/a
Recyclables	**2,000**	**4,000**	**4,000**	**4,000**	Mg/a
RDF	**10,350**	**20,700**	**20,700**	**20,700**	Mg/a
Compost	**0**	**0**	**0**	**21,212**	Mg/a
Material for landfill	Dried material		Stabilized material	Inert material	Mg/a
	19,794	**39,588**	**34,240**	**3,938**	

Variations in operating costs are less dependent on the technical solutions applied than the capital costs, but may be strongly influenced by the local conditions (Vaitkus & Stankiewicz, 2013). For rough evaluation purposes, the assumed operating and maintenance costs for the proposed treatment option are listed in Table 6.4.

Table 6.4. Details of the operation and maintenance cost estimation

Option	**1**	**2**	**3**	**4**	
Waste quantity	**50**	**100**	**100**	**100**	**Mg/a**
Operation and Maintenance Costs:					
Net debt service	**859,517**	**1,289,275**	**1,504,154**	**1,504,154**	EUR/a
Maintenance	**800,000**	**1,200,000**	**1,400,000**	**1,400,000**	EUR/a
Removal of residues	**197,938**	**395,875**	**342,400**	**39,375**	EUR/Mg
Electricity consumption	**174,400**	**348,800**	**348,800**	**348,800**	EUR/a
Number of necessary persons	**30**	**40**	**50**	**50**	person
Effective personnel costs	**206,400**	**275,200**	**344,000**	**344,000**	EUR/a
Total O&M cost	**2,238,255**	**3,509,150**	**3,939,354**	**3,636,329**	EUR/a

6.4.1.3 GATE FEES AND RDF PRICE

Gate fees are the fee charged at a solid waste facility and it is generally used to recover the costs of operating the facility. High gate fees can result in the diversion of waste to informal dumpsites. Therefore, the gate fees should be set as reasonable amount, which can be affordable and provide subsidies to sustainable plant operation (Chang & Pires, 2015). There are no available data on the amount of gate fees and RDF price for the region. Thus, the gate fees and RDF selling price have been studied in the analysis of the proposed options to investigate the effect of change in these parameters upon investment return and to estimate the best reasonable price suitable for the region. The annual cost, expenses and the price of recovered material and gate fees are estimated and listed in Table 6.5.

Table 6.5. Assumption of different parameters for revenue calculation

Revenue		
Gate fee	10,20,30,40	€ / Mg
Sale of RDF	15,20,25,30	€ / Mg
Sale of recyclables	50	€ / Mg
Sale of compost like output	10	€ / Mg

Considering the mass balance of each option, the capital costs and the operation and maintenance the revenue (pre-tax profit) for each case was calculated for the different values of gate fees and RDF price as shown in Tables 6.6, 6.7, 6.8 and 6.9.

Table 6.6. Capital costs, operation and maintenance and the revenue for option 1 for the different values of gate fees and RDF price

Gate fees	10				20				30				40				Unit
RDF price	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	30	
Annual costs:																	
Net debt service	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	859,517	EUR / a
Personnel costs	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	206,400	EUR / a
Maintenance costs (abs)	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	EUR / a
Electricity consumption costs	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	174,400	EUR / a
Removal of residues	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	197,938	EUR / a
Sum costs	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**2,238,254**	**EUR / a**
Revenues:																	
Waste acception	500,000	500,000	500,000	500,000	1,000,000	1,000,000	1,000,000	1,000,000	1,500,000	1,500,000	1,500,000	1,500,000	2,000,000	2,000,000	2,000,000	2,000,000	EUR / a
Sale of recyclable material	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	136,563	EUR / a
Sale of RDF	155,250	207,000	258,750	310,500	155,250	207,000	258,750	310,500	155,250	207,000	258,750	310,500	155,250	207,000	258,750	310,500	EUR / a
Sale of compost like product	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EUR / a
Sum earnings	**791,813**	**843,563**	**895,313**	**947,063**	**1,291,813**	**1,343,563**	**1,395,313**	**1,447,063**	**1,791,813**	**1,843,563**	**1,895,313**	**1,947,063**	**2,291,813**	**2,343,563**	**2,395,313**	**2,447,063**	**EUR / a**
Pre-tax profit	**-1,446**	**-1,395**	**-1,343**	**-1,291**	**-946**	**-895**	**-843**	**-791**	**-446**	**-395**	**-343**	**-291**	**54**	**105**	**157**	**209**	**EUR / a**

Table 6.7. Capital costs, operation and maintenance and the revenue for option 2 for the different values of gate fees and RDF price

Gate fees	10				20				30				40				**Unit**
RDF price	15	20	25	30	15	20	25	30	15	20	25	30	15	20	25	30	
Annual costs																	
Net debt service	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	1,289,275	EUR / a
Personnel costs	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	275,200	EUR / a
Maintenance costs (abs)	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	EUR / a
Electricity consumption costs	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	EUR / a
Removal of residues	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	395,875	EUR / a
Sum costs	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**3,509,150**	**EUR / a**
Revenues																	
Waste acception	1,000,000	1,000,000	1,000,000	1,000,000	2,000,000	2,000,000	2,000,000	2,000,000	3,000,000	3,000,000	3,000,000	3,000,000	4,000,000	4,000,000	4,000,000	4,000,000	EUR / a
Sale of recyclable material	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	EUR / a
Sale of RDF	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	EUR / a
Sale of compost like product	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EUR / a
Sum earnings	**1,583,625**	**1,687,125**	**1,790,625**	**1,894,125**	**2,583,625**	**2,687,125**	**2,790,625**	**2,894,125**	**3,583,625**	**3,687,125**	**3,790,625**	**3,894,125**	**4,583,625**	**4,687,125**	**4,790,625**	**4,894,125**	**EUR / a**
Pre-tax profit	**-1,926**	**-1,822**	**-1,719**	**-1,615**	**-926**	**-822**	**-719**	**-615**	**74**	**178**	**281**	**385**	**1,074**	**1,178**	**1,281**	**1,385**	**EUR / a**

Table 6.8. Capital costs, operation and maintenance and the revenue for option 3 for the different values of gate fees and RDF price

Gate fees	**10**				**20**				**30**				**40**				**Unit**
RDF price	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	30	
Annual costs																	
Net debt service	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	EUR / a
Personnel costs	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	EUR / a
Maintenance costs (abs)	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	EUR / a
Electricity consumption costs	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	EUR / a
Removal of residues	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	342,400	EUR / a
Sum costs	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**3,939,354**	**EUR / a**
Revenues																	
Waste acception	1,000,000	1,000,000	1,000,000	1,000,000	2,000,000	2,000,000	2,000,000	2,000,000	3,000,000	3,000,000	3,000,000	3,000,000	4,000,000	4,000,000	4,000,000	4,000,000	EUR / a
Sale of recyclable material	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	EUR / a
Sale of RDF	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	EUR / a
Sale of compost like product	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EUR / a
Sum earnings	**1,583,625**	**1,687,125**	**1,790,625**	**1,894,125**	**2,583,625**	**2,687,125**	**2,790,625**	**2,894,125**	**3,583,625**	**3,687,125**	**3,790,625**	**3,894,125**	**4,583,625**	**4,687,125**	**4,790,625**	**4,894,125**	**EUR / a**
Pre-tax profit	**-2,356**	**-2,252**	**-2,149**	**-2,045**	**-1,356**	**-1,252**	**-1,149**	**-1,045**	**-356**	**-252**	**-149**	**-45**	**644**	**748**	**851**	**955**	**EUR / a**

Table 6.9. Capital costs, operation and maintenance and the revenue for option 4 for the different values of gate fees and RDF price

Gate fees	**10**				**20**				**30**				**40**				**Unit**
RDF price	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	**30**	**15**	**20**	**25**	30	
Annual costs																	
Net debt service	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	1,504,154	EUR / a
Personnel costs	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	344,000	EUR / a
Maintenance costs (abs)	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	EUR / a
Electricity consumption costs	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	348,800	EUR / a
Removal of residues	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	39,375	EUR / a
Sum costs	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**3,636,329**	**EUR / a**
Revenues																	
Waste acception	1,000,000	1,000,000	1,000,000	1,000,000	2,000,000	2,000,000	2,000,000	2,000,000	3,000,000	3,000,000	3,000,000	3,000,000	4,000,000	4,000,000	4,000,000	4,000,000	EUR / a
Sale of recyclable material	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	273,125	EUR / a
Sale of RDF	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	310,500	414,000	517,500	621,000	EUR / a
Sale of compost like product	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	212,118	EUR / a
Sum earnings	**1,795,743**	**1,899,243**	**2,002,743**	**2,106,243**	**2,795,743**	**2,899,243**	**3,002,743**	**3,106,243**	**3,795,743**	**3,899,243**	**4,002,743**	**4,106,243**	**4,795,743**	**4,899,243**	**5,002,743**	**5,106,243**	**EUR / a**
Pre-tax profit	**-1,841**	**-1,737**	**-1,634**	**-1,530**	**-841**	**-737**	**-634**	**-530**	**159**	**263**	**366**	**470**	**1,159**	**1,263**	**1,366**	**1,470**	**EUR / a**

The results showed that a return of investment will be gained for most of the options, where the gate fees is 30€/t (see Figure 6.5). It is preferable for the gate fees to be as low as possible to avoid waste being dumped somewhere other than the treatment facility or the landfill, and also to insure that the facility receives the designed quantity of waste to work full load capacity. The RDF selling price was also assumed to be 30€/t as the preferable amount to gain revenue.

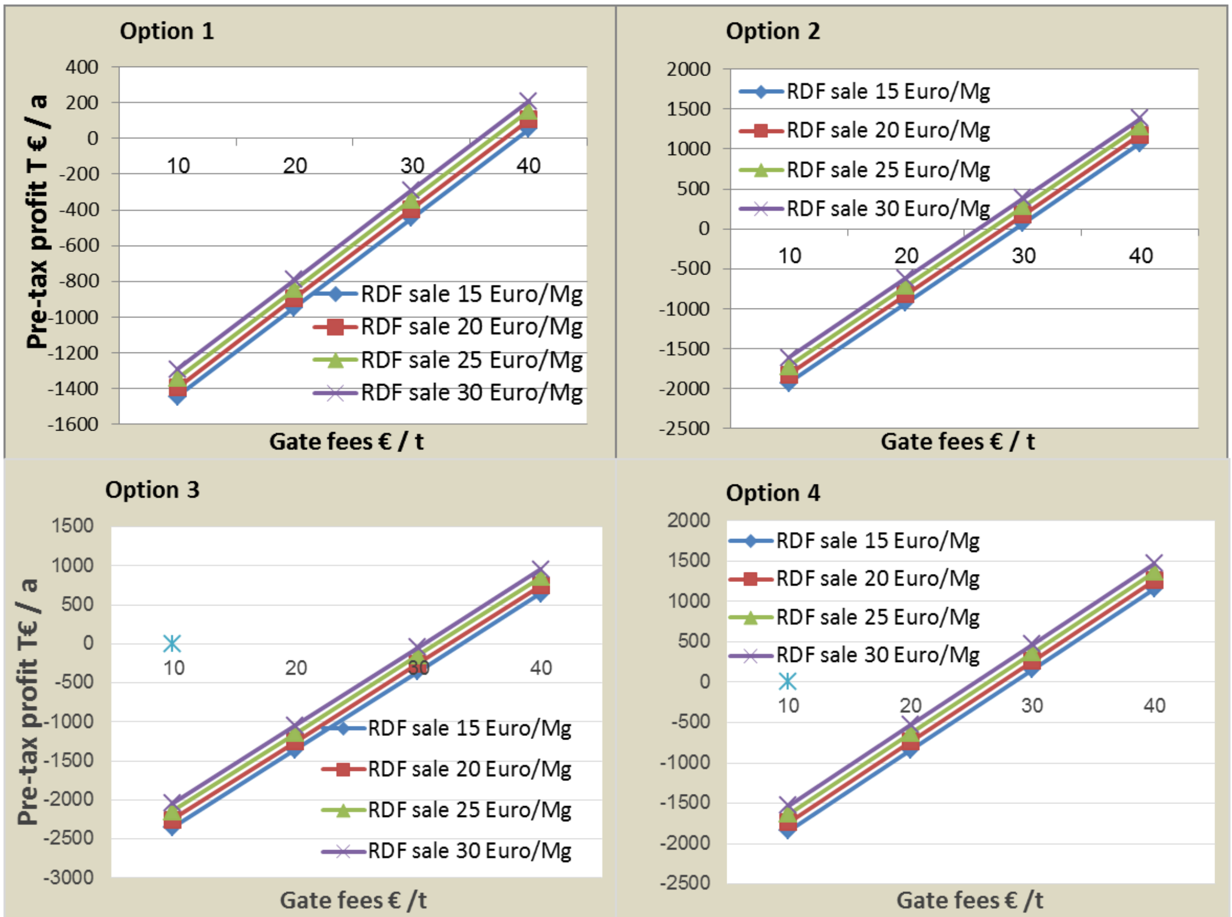

Figure 6.5. The effect of change in gate fees and RDF price upon investment return for all suggested options

6.4.2 Cost analysis with capital investment cost

Cost analysis was performed for the different options and the assumptions were made for the different parameters involved in the cost calculation to suit the regional situation (see Table 6.10).

Table 6.10. Total capital investment, operation and maintenance cost and revenues for the four suggested alternatives

Option	1	2	3	4	
Parameter:					
Capital investment	**8**	**12**	**14**	**14**	MioEUR
Net equity	**30**	**30**	**30**	**30**	%
Useful economic life	**15**	**15**	**15**	**15**	years
Interest (inflation adjusted)	**5**	**5**	**5**	**5**	% p.a.
Costs:					
Capital investment	**859,517**	**1,289,275**	**1,504,154**	**1,504,154**	EUR/a
Effective personnel costs	**206,400**	**275,200**	**344,000**	**344,000**	EUR/a
Maintenance	**800,000**	**1,200,000**	**1,400,000**	**1,400,000**	EUR/a
Removal of residues	**197,938**	**395,875**	**342,400**	**39,375**	EUR/a
Electricity consumption	**174,400**	**348,800**	**348,800**	**348,800**	EUR/a
Earnings:					
Gate fees	30				EUR/Mg
RDF sale	30				EUR/Mg
Sale of recyclables	50				EUR/Mg
Sale of compost like output	10				EUR/Mg

Moreover, capital investment cost price (net debt service) and quantity of waste treated were studied in the analysis of the proposed options as a case study. Figure 6.6 shows the effect of change on these parameters upon investment return. From the cost analysis, it was clear that larger sized plant and machinery are required. Therefore, high capital investment is needed to set up an RDF plant.

		waste quantity	37,500	50,000	62,500	75,000	100,000	125,000	150,000	t
Pre-tax profit T€/a	Option 1.	50000 t/a (*drying and RDF production)*	-685	-291	102	496				T€/a
	Option 2.	100000 t/a (*drying and RDF production)*				-402	385	1,172	1,960	T€/a
	Option 3.	100000 t/a (*stabilized material to landfill)*				-846	-45	756	1,556	T€/a
	Option 4.	100000 t/a (*sell of compost like output)*				-460	470	1,399	2,329	T€/a

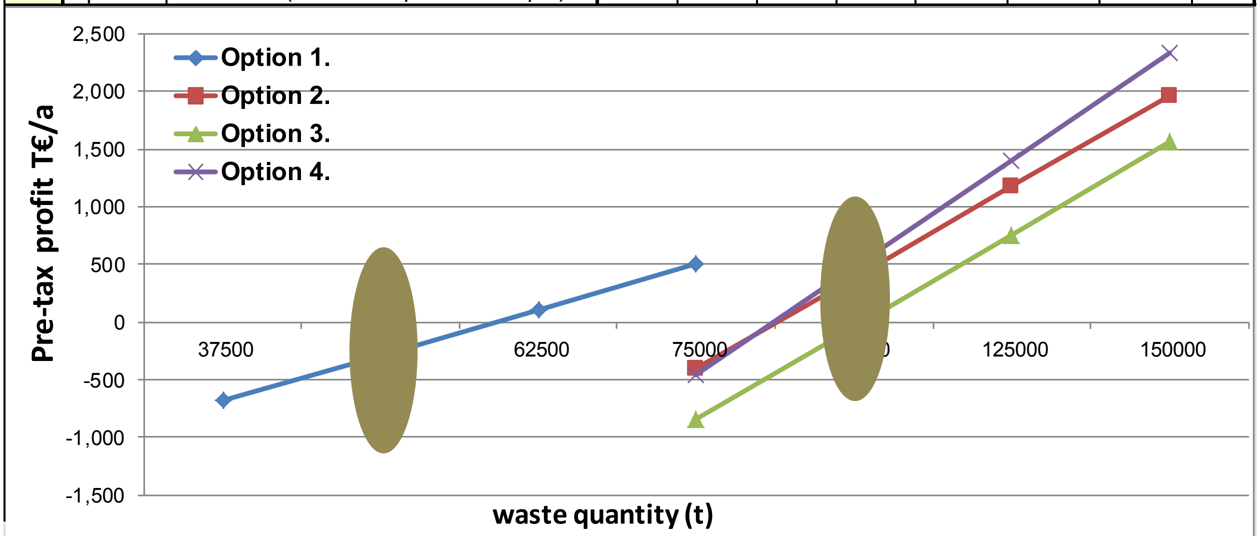

Figure 6.6. Revenue from the four suggested alternatives considering the capital cost is covered by the private sector

As shown in Table 6.11, the high figure of the investment costs makes it hard to gain enough revenue through the sale of RDF and recycling material produced. For treatment costs of more than 36€/t per ton there was no profit. Therefore, the cost of treatment per ton should be equal or less than 36 €/t.

By far the largest cost item in the operation of such plants is the repayment of the capital investment, which results in capital charges of 13-17 € per ton of MSW processed.

Table 6.11. Cost analysis summary for all options

Treatment option	1	2	3	4
Operation cost of total cost (%)	62%	63%	62%	59%
Investment cost of total cost (%)	38%	37%	38%	41%
Operation cost per ton (€/t)	28	22	24	21
Investment cost per ton (€/t)	17	13	15	15
Total cost (€/t)	45	35	39	36

The operating costs including the capital investment cost for such facilities for treating mixed MSW and RDF production vary in the range of 35-45 €/t. The biggest share of operational costs is attributed to maintenance of the process equipment. The second biggest operational costs category is salaries, followed by the residual removal costs. However, return on investment is not guaranteed to treat the designated waste quantity for all cases

6.4.3 COST ANALYSIS WITHOUT CAPITAL INVESTMENT COST

It is clear from the section above that the most challenging parameter appears to be the capital costs, which can reach up to 40% of the total costs; to overcome this obstacle, the involvement of the local municipalities and governments is recommended so they can take responsibility for providing the initial capital costs, where the public sector has better opportunities to gain grants and loans for such projects, see Table 6.12. Therefore, as a result, the rate of return will increase and better economic performance can be achieved and sustained for all alternatives, which will cover the operational and maintenance costs to ensure sustained operation of the facilities, as shown in Figure 6.7.

Table 6.12. Total capital investment, operation and maintenance cost and revenues for the four suggested alternatives

Option	**1**	**2**	**3**	**4**	
Parameter :					
Capital investment	-	-	-	-	MioEUR
Net equity	-	-	-	-	%
Useful economic life	-	-	-	-	years
Interest (inflation adjusted)	-	-	-	-	% p.a.
Costs:					
Effective personnel costs	**206,400**	**275,200**	**344,000**	**344,000**	EUR/a
Maintenance	**800,000**	**1,200,000**	**1,400,000**	**1,400,000**	EUR/a
Removal of residues	**10**	**10**	**10**	**10**	EUR/Mg
Electricity consumption	**174,400**	**348,800**	**348,800**	**348,800**	EUR/a
Earnings:					
Waste acceptance fee	**20**				EUR/Mg
RDF sale	**25**				EUR/Mg
Sale of recyclables	**50**				EUR/Mg
Sale of compost like output	10				EUR/Mg

The results in the case of excluding the capital investment cost from the operation costs showed that provision would be accomplished with more flexibility regarding the treated amount of waste. Whereas, a profit can still be gained for most of the options, even when the facility treats less than the required quantity of waste with a reduction in the values of gate fees and the selling price of the RDF assumed in the previous section.

	waste quantity		37,500	50,000	62,500	75,000	100,000	125,000	150,000	t
Pre-tax profit T€/a	Option 1.	50000 t/a (*drying and RDF production)*	-239	17	272	528				T€/a
	Option 2.	100000 t/a (*drying and RDF production)*				59	571	1,082	1,594	T€/a
	Option 3.	100000 t/a (*stabilized material to landfill)*				-169	355	880	1,405	T€/a
	Option 4.	100000 t/a (*sell of compost like output)*				217	871	1,524	2,178	T€/a

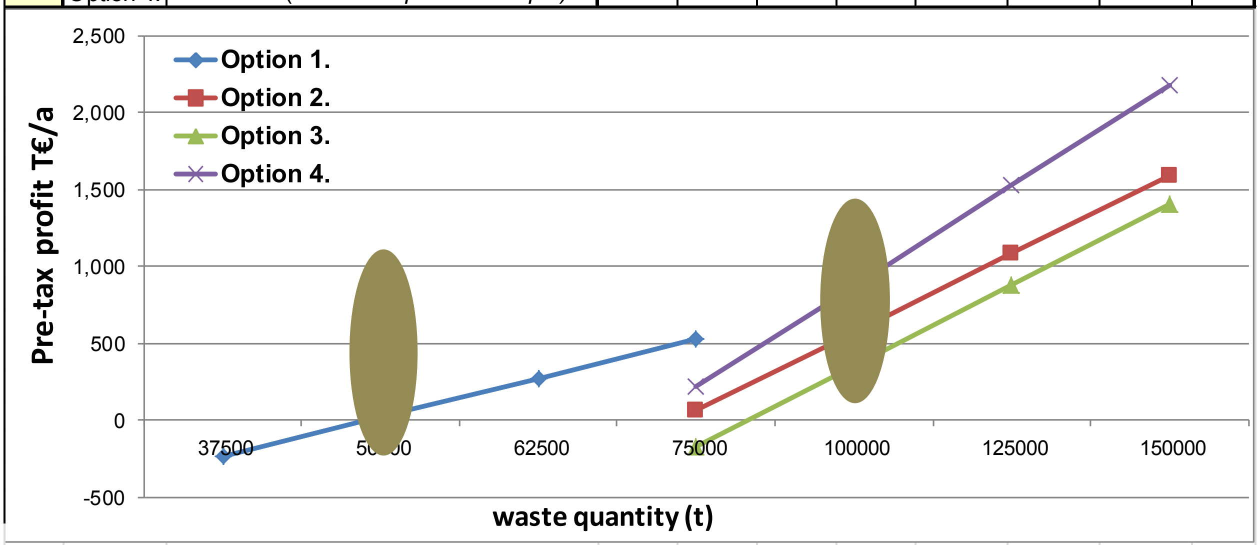

Figure 6.7. Revenue from the four suggested alternatives considering the capital cost is covered by the public sector.

The suggested alternatives should not be considered as the ultimate solution to the problem of solid waste in the region. Instead it would be a starting point to solve the MSW problem in the region, improve the existing situation of solid waste management and to move forward toward a more developed sustainable MSW management system. Furthermore, it is important to point out that other benefits could be achieved in terms of improved quality of life, reduced health damage, as well as environmental benefits associated with reduced pollution and preserved landfill.

6.5 FURTHER DEVELOPING FOR SUSTAINABLE SOLID MANAGEMENT SYSTEM SWM SYSTEM

The aim of these strategies, discussed previously, is to reduce the damage to the environment and recover material from the waste stream.

MSW management represents one of the ongoing problems of modern society. National, regional and municipal governments must face this problem. Furthermore, all of the previously adopted technologies for MSW treatment and the low cost disposal practices are no longer acceptable from different aspects.

With the implementing of alternatives suitable for the region, other steps should be taken to improve the technologies chosen, to improve the quality of the output from the waste after treatment and establish a sustainable market for the output material.

6.5.1 SEPARATE COLLECTION OF MSW

There are other alternative solutions that could be established, such as introducing separate collection of organic wastes and recyclable material to divert them from landfills and to accomplish maximum by-products utilization. Activities for the introducing and encouraging of separate collection systems may require some time, about 5-10 years, to be accepted and implemented, but it is a step that must be taken. Separate collection is considered fundamental for resources oriented waste management.

A wet/dry separation program (see Figure 6.8) could be implemented as a first step to introducing the separation of different fractions of waste at the source. Where the waste is separated into two fractions, dry waste can be of value on the recycling market, such as plastic, cans, glass, paper, cardboard; wet waste is all food and gardening waste such as fruit and vegetable peels, meat, paper towels and personal sanitary products. Such a program, would improve the quality of the products of the treatment facilities and reduce the investment and running costs of the facilities, where some items and steps of the treatment process will not be needed afterwards.

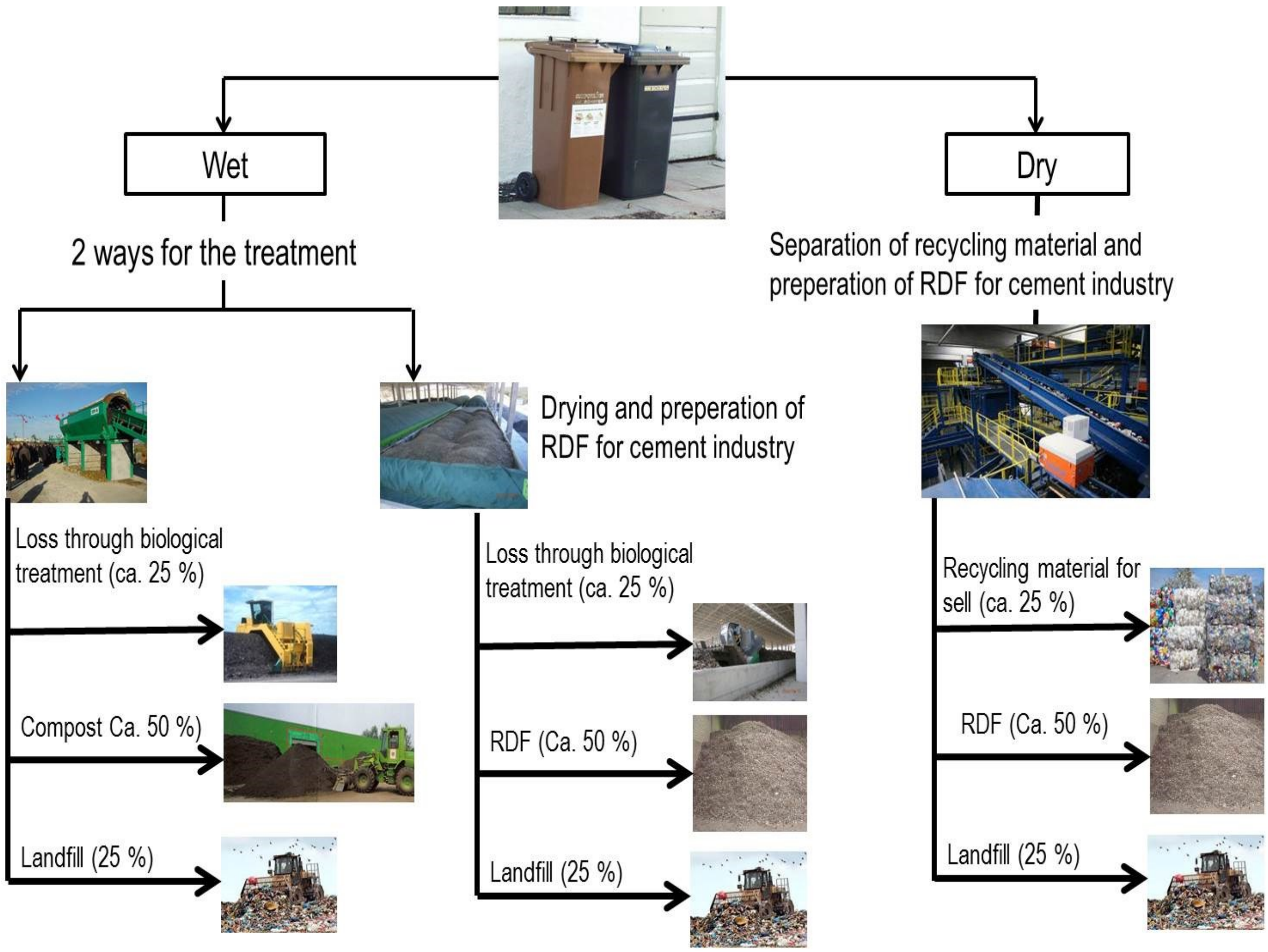

Figure 6.8. Wet and dry separation program and flow of material(Nassour, 2011)

6.5.2 Cooperation between municipalities, private sector and international companies

The success of SWM is based on the organization between different involved parties (politics, private sector, consultant companies and public sector) (See Figure 6.9), cooperation between municipalities and the recycling market and cement industry should be arranged; in addition to collaboration with developed countries for technology transfer.

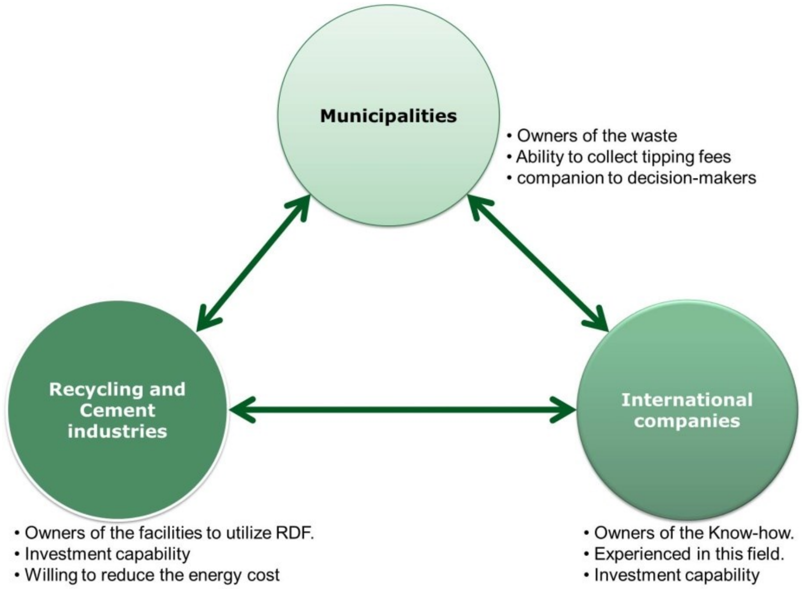

Figure 6.9. Cooperation between municipalities, private sector and international companies (Nassour, 2011)

Overall, every possible solution will still need a landfill for inert or stabilized material. The selection of the appropriate solution for MSW must be based on many factors, such as the availability of land for disposal, markets for recyclable material and the need for energy production, taking into account economic and social aspects, with particular attention to environmental issues.

6.5.3 WASTE TO WATER TECHNOLOGY (W2W)

The W2W technologies can be implemented to solve the problems of waste disposal and water shortage by desalinating sea and brackish waters. Some arid regions of the world, especially in the Arab region, have a lack of drinking water and a high accumulation of waste, where the cost of energy source to operate the desalination plant is considerably high.

The W2W is an advanced technology: its fundamental principle technology is simple and straightforward, as illustrated in Figure 6.10. The waste is used to produce an alternative energy, which can be fed directly into desalination plants to generate valuable drinking and service water

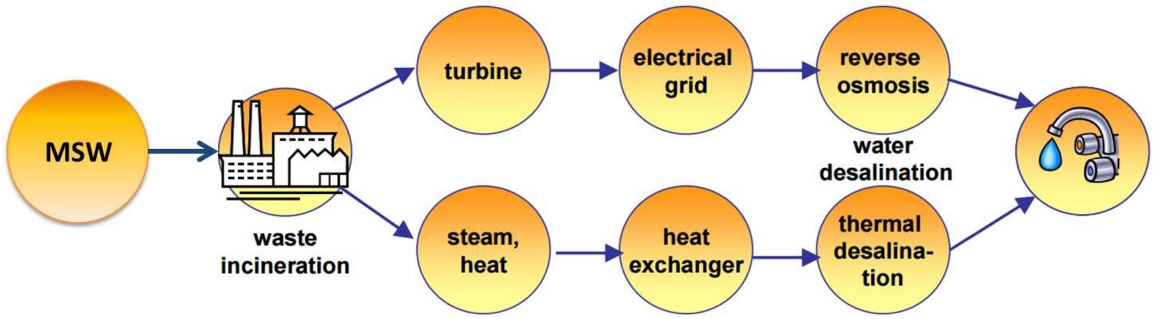

Figure 6.10. Principle of Waste-2-Water technology (BMUB, 2009).

There are various combustion processes that use waste to produce heat and steam. The heat can be used to run water desalination plants, which require an enormous amount of energy. Such plants are, for example, urgently needed in the countries of the Middle East and North Africa to address the water shortage there (BMUB, 2009). The efficiency of these plants delivers clear ecological and economic advantages; it ensures that waste is disposed of in an environmentally sound way while simultaneously resolving the water shortage in these regions.

The understanding of W2W allows great benefits. There are great opportunities to directly associate resource and energy streams and to develop a sustainable complete approach to support the solving of waste and water issues in an ecologically and economically sensible way. The concept of W2W is technically feasible and is capable of replacing fossil oil; it is also contributes to the fulfillment of EU legislations for waste disposal and clean energy production.

7. CONCLUSIONS

In recent years some Arab countries have introduced the integrated solid waste management concept. Collection and sorting, composting, incineration of medical wastes 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 2-5% of materials are recovered as recyclable materials: these materials are sorted by the informal sector.

Landfill and open dumps are still the common disposal method in the region; about 95% of generated MSW is directed to landfill for disposal without any treatment. However, landfilling of waste without treatment is considered a bad choice for many countries in the region, due to the lack of space available and the nature of the waste to be disposed. Moreover, the high organic material in MSW 50% to 70%, high water content of about 60%, and 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 odor problems in the surrounding area. Waste management in Arab countries is characterized by a high percentage of uncollected waste, with most of the waste directed to open or controlled dumpsites. Sorting and composting facilities are being operated with limited capacity. Most of them are not operating anymore and some of them even closed before they started to operate. Their failure was due to their mismanagement because of the inappropriate technology chosen for the local conditions, resulting in high operating costs and frequent mechanical breakdowns through poor maintenance, lack of understanding of the composting process and training of personnel for the operational procedures.

Compost from some operating facilities was of a poor quality and was not recommended to be used as soil fertilizers, due to the risk from heavy metals and organic pollutants combined with the physical risks from sharps and glass, and the aesthetic problem of plastic scraps that remain highly visible even after composting. The absence of local standards, monitoring systems and the legal barriers prevents the control of the selling and application of MSW compost to agricultural/horticultural land.

A test project conducted in Beja proved that an efficient waste treatment can be achieved with a fairly basic and low-cost MBT concept utilization, using the biological drying process to produce a substitute fuel for industrial processes, reduce the landfill volume required and air emissions from the landfill, in particular greenhouse gases.

The biodrying process allowed drying of the waste within three weeks. This enabled an efficient screening of the waste to separate the recyclables and high calorific components from the organic fines fraction. The RDF produced in Beja is of high calorific value, low moisture and acceptable chlorine content compared to the RDFs produced in other countries. Concerning heavy metals content, it is interesting to note that although the Beja RDF shows a different range of heavy metals, in most cases they are lower than the reported ranges from European countries. In addition to the mass reduction during the biodrying process, the waste was partially stabilized and had low moisture content, consequently this would reduce the formation of greenhouse. The more stabilized the waste, the less landfill gas and leachate would be produced in the landfill. The compost produced in Beja was in the same range of the compost produced in other operating facilities in the region with the exception of two elements, which were higher than the range of the compost produced in the region.

The common issues for practicing waste management are choosing the suitable treatment method of waste and the optimization of disposal logistics (e.g., introduction of separate waste collection, cost reduction). 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 stabilized before landfilling.

The main objectives of the chosen alternatives are:

- Recover recycling material
- Minimum material for landfill
- Relevant factors: recovery efficiency, costs, time needed for treatment.

The cost of each plant was included into two main components: total capital investment and operation and maintenance cost. Revenues come mainly from the sale of produced RDF and recycled materials, as well as from MSW gate fees. Cost analysis has been performed for different facilities and the assumptions were made for the different parameters involved in the cost calculation to suit the region situation. The high percentage of the investment cost makes it hard to gain enough revenue from the sale of RDF and recycling material produced. From the cost analysis, it was clear that larger sized plant and machinery are required. Therefore, high capital investment is needed to set up an RDF plant. However, return on investment is not guaranteed to treat the designed waste quantity for all cases. The most influential parameter appeared to be the capital cost: to overcome this obstacle, the involvement of the local municipalities and governments is recommended to take responsibility for providing the initial capital cost.

The suggested options should not be considered as the ultimate solution to the problem of solid waste in the region. With the implementing of alternatives suitable for the region, 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.

Overall, a good alternative for the region is the WtE concept, where mixed MSW is converted to RDF. This alternative mainly contributes into 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 stabilization of organic material is applied. RDF 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 needed 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 high calorific value and low concentrations of toxic chemicals, especially for 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 is by utilizing the biological drying process to produce a substitute fuel for industrial processes and reduce 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, 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 involved parties (politicians, private sector, consultant companies and public sector). 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.

8. RECOMMENDATION

An ISWM approach should be adopted in solving the waste management problem. It is important that resources for running the waste management program are properly employed. Financial resources, the legal institutional framework and human resources are the fundamental components on which the waste management can be run.

The current centralized approach to waste management planning needs to be reviewed. The institutional and organizational aspects of the planning process should appoint responsibilities to prepare and implement 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 running 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 know-how, appropriate training courses could be arranged at local and international levels, by training arrangements through exchange programs with other international institutions.

Public education is also recommended to ensure the acceptance and understanding of the SWM system, by educating people on the socio-economic and environmental impacts of improper waste handling and informing them on the values of the waste, if properly handled.

Introducing separate collection programs in the region to improve the waste treatment aspect and provide more possibilities for other treatment options to be considered for the region.

In the meantime, producing compost for agricultural uses should be disregarded for the region at present and reconsidered as an option in the future, after improving the collection services by implementing the separate collection where the organic waste would be collected separately.

Governments have to promote the ISWM hierarchy and set up national policy regarding the minimization of waste to landfill. Local standards must be set for compost, RDF and landfill material in order to carry a quality control program.

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 implemented solid waste management system.

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THESIN

1. The solid waste sector in many Arab countries can be characterized as a disorganized sector with sporadic service coverage. Waste management in the region is one of the major responsibilities of local government, with no significant participation by the private sector. Subcontractors are commonly brought in to handle specific activities such as collection and transportation. Most Arab countries have made efforts to organize SWM with the implementation of several laws and regulations. In some cases, foreign rules and regulation were enacted without any customization to suit the characteristics of the country.

2. Some countries define organizational frameworks, but they are poorly implemented and disrupted by the centralization of authorities at a national level. In addition, a lack of action by government institutions, 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 the region.

3. Waste sorting and recycling are driven by an active informal sector. About 1-3% of the total generated waste is recovered as recyclable materials, such as PET, other plastics, metals and paper. These materials are sorted from the waste containers and disposal sites by scavengers, the sorted paper, metals and some plastic materials are marketed and recovered in local recycling facilities, while the PET are marketed internationally.

4. Composting is also gaining increased interest due to the high organic content of MSW. it has been increasingly adopted in some countries as a strategic choice for processing the organic content of waste. Although the municipalities of the high-income Arab countries have tried composting a fraction of organic waste, a large number of plants were not operated successfully. The region has had poor experience of sorting recyclable materials from municipal waste and processing the separated organic matter.

5. Waste disposal along in uncontrolled dumps is still practiced in many parts of the Arab region. 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.

6. The Arab region needs a sustainable, flexible and resource oriented waste treatment system. Mechanical biological/physical treatment is considered the most suitable solution. Incineration is unpayable for the most cities in the region. The Gulf region has the possibility for finance options. Further problems are the lower calorific value <7000KJ/Kg, use of waste heat and the needed know-how for the operation.

7. Solid waste treatment facilities with compost production do existed in the region, but many of them no longer operate and some even closed before they started to operate. Their failure was due to their 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 and training of personnel for the operational procedures.

8. Samples of MSW composts were collected from some cities in different countries of the region. Generally, most compost samples tested in this study were of a poor quality and were not recommended for use as soil fertilizers. This was due to the risk from heavy metals and organic pollutants, alongside the physical risks from sharps, glass and the aesthetical problem of plastic scraps that remain highly visible even after composting. Therefore, compost of MSW cannot be considered as appropriate solution for big cities in the region. The production RDF to be used in cement industry and power stations could be practical and feasible solution for the local conditions of the region.

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

10. Temperature of the windrows during the biodrying was maintained at 40-70 ˚C for most of the duration of the process. After three weeks the waste was fairly dry with a moisture content of between 20 and 45%.

11. 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 utilization from the dried waste, the mass of waste to be landfilled was reduced by approx. 59%. Furthermore, by dumping the dried waste in the landfill, leachate would not be produced if the landfill was carefully covered and protected from rainfall.

12. The biodrying process allowed an increase of the waste calorific value (LHV) of about 52%, as consequence of the waste moisture reduction. The calorific value of unprocessed MSW ranged between 5.99-6.21 MJ/Kg. The calorific value of the RDF produced from the pilot project ranged from 11.82- 13.53 MJ/kg, which made it appropriate as a fuel. The ash content of the RDF produced in Beja appeared to have a high range between 20-31%.

13. The characteristics and results of the produced RDF in Beja were obtained from unprocessed RDF just after the end of the biodrying process. It was compared with the typical composition for RDF from MSW originating in different places. the quality of the RDF produced did not differ from the RDF quality set by some European countries.

14. The RDF produced in Beja was of high calorific value, low moisture and acceptable chlorine content compared to the RDFs produced in other countries. Concerning heavy metal content, it is interesting to note that, although the Beja RDF showed different ranges of heavy metal concentrations in the samples, in most cases they were lower than the reported ranges from the other countries.

15. After further composting of the fines fraction, approx. 15% of mass reduction was achieved. The material after composting mainly consisted of stabilized organic material similar to the organic material of compost, but it was mixed with impurities such as plastics and glass particles.

16. The compost produced in Beja was in the same range of the compost produced in other operating facilities in the region with the exception of Cr and Hg: the concentration of these two elements were higher than the range of the compost produced in the region.

Furthermore, of the three compost samples collected from Beja, one of them did not fulfill the limits set by the German standards due to the high value of the Hg, while the other two could be considered with the same quality of other compost produced in the region regarding heavy metals.

17. Two strategies have been considered for 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 further stabilized before landfilling.

18. A return of investment will be gained for most of the options, where the gate fees is 30€/t. It is preferable for the gate fees to be as low as possible to avoid waste being dumped somewhere other than the treatment facility or the landfill. The RDF selling price was also assumed to be 30€/t as the preferable amount to gain revenue.

19. The high figure of the investment costs makes it hard to gain enough revenue through the sale of RDF and recycling material produced. For treatment costs of more than 36€/t per ton there was no profit. By far the largest cost item in the operation of such plants is the repayment of the capital investment, which results in capital charges of 13-17 € per ton of MSW processed.

20. The most challenging parameter appears to be the capital costs, which can reach up to 40% of the total costs; to overcome this obstacle, the involvement of the local municipalities and governments is recommended so they can take responsibility for providing the initial capital costs, where the public sector has better opportunities to gain grants and loans for such projects

21. Excluding the capital investment cost from the operation costs showed that provision would be accomplished with more flexibility regarding the treated amount of waste. Whereas, a profit can still be gained for most of the options, even when the facility treats less than the required quantity of waste with a reduction in the values of gate fees and the selling price of the RDF assumed in the previous section.

Appendix I.

Option 1. Biological drying with RDF production 50000 t/y

component	unit/dimension	unit price	quantity	investment cost C_i
	to be specified	[Euro/unit]	no. of units	[Euro/unit]
mechanical treatment				
manual sorting (conveyor)	-	75,000	2	150,000
magnetic separator	-	75,000	3	225,000
crushing / shredding (household waste)	-	500,000	1	500,000
sieving	-	625,000	2	1,250,000
waste drying				
blower and cover system	tons	30	8	240
compost turner	-	500,000	4	2,000,000
RDF treatment system (refuse derived fuel)				
crushing / shredding	-	500,000	1	500,000
near infrared sorting	-	190	1	190
ballistic separation	-	125,000	1	125,000
infrastructure				
security fence	m	60	5,000	300,000
signage placed along the fence	m	25	5,000	125,000
truck scale and associated computer system	-	125,000	1	125,000
gatehouse	-	25,000	1	25,000
waste reception hall	m²	190	8,000	1,520,000
treatment hall	m²	190	15,000	2,850,000
rain water storage tank	m³	75	1,000	75,000
fire protection equipment	-	125,000	1	125,000
office building	-	125,000	1	125,000
maintenance building	-	125,000	1	125,000
vehicles & further equipment				
front end loader	-	125,000	4	500,000
dozer	-	125,000	4	500,000
fork lifter	-	85,000	2	170,000
water spray truck	-	75,000	1	75,000
container	-	6,500	8	52,000
total				11,442,430

Option 2. Biological drying with RDF production 100000 t/y

component	unit/dimension	unit price	quantity	investment cost C_i
		Euro/unit	no. of units	[Euro/unit]
mechanical treatment				
manual sorting (conveyor)	-	75,000	2	150,000
magnetic separator	-	75,000	3	225,000
crushing / shredding (household waste)	-	500,000	1	500,000
sieving	-	625,000	2	1,250,000
waste drying				
blower and cover system	tons	30	6	180
compost turner	-	500,000	2	1,000,000
RDF treatment system (refuse derived fuel)				
crushing / shredding	-	500,000	1	500,000
near infrared sorting	-	190	1	190
ballistic separation	-	125,000	1	125,000
infrastructure				
security fence	m	60	3,000	180,000
signage placed along the fence	m	25	3,000	75,000
truck scale and associated computer system	-	125,000	1	125,000
gatehouse	-	25,000	1	25,000
waste reception hall	m²	190	5,000	950,000
treatment hall	m²	190	10,000	1,900,000
rain water storage tank	m³	75	1,000	75,000
fire protection equipment	-	125,000	1	125,000
office building	-	125,000	1	125,000
maintenance building	-	125,000	1	125,000
vehicles & further equipment				
front end loader	-	125,000	2	250,000
dozer	-	125,000	2	250,000
fork lifter	-	85,000	2	170,000
water spray truck	-	75,000	1	75,000
container	-	6,500	6	39,000
total				8,239,370

Options 3and 4. Biological drying with RDF and stabilized material production

component	unit/dimension	unit price	quantity	investment cost C_i
	to be specified	[Euro/unit]	no. of units	[Euro/unit]
mechanical treatment				
manual sorting (conveyor)	-	75,000	2	150,000
magnetic separator	-	75,000	4	300,000
air separator	-	115,000	1	115,000
crushing / shredding (household waste)	-	500,000	2	1,000,000
sieving	-	625,000	3	1,875,000
waste drying				
blower and cover system	tons	30	6	180
compost turner	-	500,000	4	2,000,000
biological treatment				
rotting system (container, box, tunnel, etc.)	m^3	125	6	750
blower	tons	1,900	4	7,600
RDF treatment system (refuse derived fuel)				
crushing / shredding	-	500,000	1	500,000
near infrared sorting	-	190	1	190
ballistic separation	-	125,000	1	125,000
infrastructure				
security fence	m	60	5,000	300,000
signage placed along the fence	m	25	5,000	125,000
truck scale and associated computer system	-	125,000	1	125,000
gatehouse	-	25,000	1	25,000
waste reception hall	m^2	190	8,000	1,520,000
treatment hall	m^2	190	15,000	2,850,000
rain water storage tank	m^3	75	1,000	75,000
fire protection equipment	-	125,000	1	125,000
office building	-	125,000	1	125,000
maintenance building	-	125,000	1	125,000
vehicles & further equipment				
front end loader	-	125,000	6	750,000
dozer	-	125,000	4	500,000
fork lifter	-	85,000	2	170,000
water spray truck	-	75,000	2	150,000
container	-	6,500	10	65,000
total				13,103,720

Appendix II.

Option 1. Mass balance through the treatment process

					Annual plant operation time		
					4,000	h/a full load	
quantity of waste	$m_{Domestic\ waste}$ =	**50,000**	t/a	$m_{Domestic\ waste}$ =	**12.5**	Mg / h	
water content of input	w_1 =	**0.50**	kg/kg				
Composition of household waste	im Anlieferungszustand:						
water content of input	50.0%	**25,000**	Mg/a				
material for RDF production	**34.6%**	**17,300**	Mg/a				
Organic	**60.0%**	**30,000**	Mg/a				
stones	**1.9%**	**950**	Mg/a				
Metal fractions (ferrous and nonferrous) - Total	**1.5%**	**750**	Mg/a				
Inert materials	**2.0%**	**1,000**	Mg/a				
total	100.0%	50000	Mg/a				
process: shredding -->	no change in the material composition						
process: ferrous and non-Fe-separation -->	**50%**	metal separation		**375**	Mg/a =	**0.094**	Mg /h
hand sorting	**4%**	of total waste		**2,000**	Mg/a =	**0.500**	Mg /h
Composition of household waste after metal separation							
water content of input	50.00%	25,000	Mg/a	6.25	Mg /h		
material for RDF production	32.13%	15,300	Mg/a	3.825	Mg /h		
Organic	62.99%	30,000	Mg/a	7.5	Mg /h		
stones	1.99%	950	Mg/a	0.2375	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.79%	375	Mg/a	0.09375	Mg /h		
Inert materials	2.10%	1,000	Mg/a	0.25	Mg /h		
total	100.00%	47,625	Mg/a	11.9	Mg/a		
process: biological drying 2-3 weeks -->							
Composition of household waste after biological drying							
water content	35.00%	11,375	Mg/a =	2.844	Mg /h		
RDF production	38.00%	10,350	Mg/a =	2.588	Mg /h		
Organic	54.85%	17,825	Mg/a =	4.456	Mg /h		
stones	2.92%	950	Mg/a =	0.238	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.15%	375	Mg/a =	0.094	Mg /h		
Inert materials	3.08%	1,000	Mg/a =	0.250	Mg /h		
total after biological drying	100.00%	**30,500**	Mg/a =	7.6	Mg /h		
process: screening 80mm -->	to separate the RDF from the dried waste						
process: RDF separation separation -->	**38%**	RDF		**10,350**	Mg/a =	**2.588**	Mg /h
position of household waste after screening and RDF separation							
water content	40.00%	**8,060**	Mg/a =	2.015	Mg /h		
Organic for compost production	88.46%	**17,825**	Mg/a =	4.456	Mg /h		
stones	4.71%	**950**	Mg/a =	0.238	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.86%	**375**	Mg/a =	0.094	Mg /h		
Inert materials	4.96%	**1,000**	Mg/a =	0.250	Mg /h		
total after screening	100.00%	**20,150**	Mg/a =	5.038	Mg /h		
process: ferrous and non-Fe-separation -->	**95%**	metal separation		**356**	Mg/a =	**0.089**	Mg /h
Composition of household waste after biodrying and metal separation							
stones	4.80%	**950**	Mg/a =	0.238	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.09%	**19**	Mg/a =	0.005	Mg /h		
dried materials	95.11%	**18,825**	Mg/a =	4.706	Mg /h		
total material for landfil	100.00%	**19,794**	Mg/a =	4.948	Mg /h		

Option 2. Mass balance through the treatment process

					Annual plant operation time		
					4,000	h/a full load	
quantity of waste	$m_{Domestic\ waste}$ =	100,000	t/a	$m_{Domestic\ waste}$ =	25	Mg / h	
water content of input	w_1 =	0.50	kg/kg				
Composition of household waste	im Anlieferungszustand:						
water content of input	50.0%	50,000	Mg/a				
material for RDF production	34.6%	34,600	Mg/a				
Organic	60.0%	60,000	Mg/a				
stones	1.9%	1,900	Mg/a				
Metal fractions (ferrous and nonferrous) - Total	1.5%	1,500	Mg/a				
Inert materials	2.0%	2,000	Mg/a				
total	100.0%	100000	Mg/a				
process: shredding -->	no change in the material composition						
process: ferrous and non-Fe-separation -->	50%	metal separation		750	Mg/a =	0.188	Mg /h
hand sorting	4%	of total waste		4,000	Mg/a =	1.000	Mg /h
Composition of household waste after metal separation							
water content of input	50.00%	50,000	Mg/a	12.5	Mg /h		
material for RDF production	32.13%	30,600	Mg/a	7.65	Mg /h		
Organic	62.99%	60,000	Mg/a	15	Mg /h		
stones	1.99%	1,900	Mg/a	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.79%	750	Mg/a	0.1875	Mg /h		
Inert materials	2.10%	2,000	Mg/a	0.5	Mg /h		
total	100.00%	95,250	Mg/a	23.8	Mg/a		
process: biological drying 2-3 weeks -->							
Composition of household waste after biological drying							
water content	35.00%	22,750	Mg/a =	5.688	Mg /h		
RDF production	38.00%	20,700	Mg/a =	5.175	Mg /h		
Organic	54.85%	35,650	Mg/a =	8.913	Mg /h		
stones	2.92%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.15%	750	Mg/a =	0.188	Mg /h		
Inert materials	3.08%	2,000	Mg/a =	0.500	Mg /h		
total after biological drying	100.00%	61,000	Mg/a =	15.3	Mg /h		
process: screening 80mm -->	to separate the RDF from the dried waste						
process: RDF separation separation -->	38%	RDF		20,700	Mg/a =	5.175	Mg /h
position of household waste after screening and RDF separation							
water content	40.00%	16,120	Mg/a =	4.030	Mg /h		
Organic for compost production	88.46%	35,650	Mg/a =	8.913	Mg /h		
stones	4.71%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.86%	750	Mg/a =	0.188	Mg /h		
Inert materials	4.96%	2,000	Mg/a =	0.500	Mg /h		
total after screening	100.00%	40,300	Mg/a =	10.075	Mg /h		
process: ferrous and non-Fe-separation -->	95%	metal separation		713	Mg/a =	0.178	Mg /h
Composition of household waste after biodrying and metal separation							
stones	4.80%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.09%	38	Mg/a =	0.009	Mg /h		
dried materials	95.11%	37,650	Mg/a =	9.413	Mg /h		
total material for landfil	100.00%	39,588	Mg/a =	9.897	Mg /h		

Option 3. Mass balance through the treatment process

					Annual plant operation time		
					4,000	h/a full load	
quantity of waste	$m_{Domestic\ waste}$ =	100,000	t/a	$m_{Domestic\ waste}$ =	25	Mg / h	
water content of input	w_1 =	0.50	kg/kg				
Composition of household waste	im Anlieferungszustand:						
water content of input	50.0%	50,000	Mg/a				
material for RDF production	34.6%	34,600	Mg/a				
Organic	60.0%	60,000	Mg/a				
stones	1.9%	1,900	Mg/a				
Metal fractions (ferrous and nonferrous) - Total	1.5%	1,500	Mg/a				
Inert materials	2.0%	2,000	Mg/a				
total	100.0%	100000	Mg/a				
process: shredding -->	no change in the material composition						
process: ferrous and non-Fe-separation -->	50%	metal separation		750	Mg/a =	0.188	Mg /h
hand sorting	4%	of total waste		4,000	Mg/a =	1.000	Mg /h
Composition of household waste after metal separation							
water content of input	50.00%	50,000	Mg/a	12.5	Mg /h		
material for RDF production	32.13%	30,600	Mg/a	7.65	Mg /h		
Organic	62.99%	60,000	Mg/a	15	Mg /h		
stones	1.99%	1,900	Mg/a	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.79%	750	Mg/a	0.1875	Mg /h		
Inert materials	2.10%	2,000	Mg/a	0.5	Mg /h		
total	100.00%	95,250	Mg/a	23.8	Mg/a		
process: biological drying 2-3 weeks -->							
Composition of household waste after biological drying							
water content	35.00%	22,750	Mg/a =	5.688	Mg /h		
RDF production	38.00%	20,700	Mg/a =	5.175	Mg /h		
Organic	54.85%	35,650	Mg/a =	8.913	Mg /h		
stones	2.92%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.15%	750	Mg/a =	0.188	Mg /h		
Inert materials	3.08%	2,000	Mg/a =	0.500	Mg /h		
total after biological drying	100.00%	61,000	Mg/a =	15.3	Mg /h		
process: screening 80mm -->	to separate the RDF from the dried waste						
process: RDF separation separation -->	38%	RDF		20,700	Mg/a =	5.175	Mg /h
position of household waste after screening and RDF separation							
water content	40.00%	16,120	Mg/a =	4.030	Mg /h		
Organic for compost production	88.46%	35,650	Mg/a =	8.913	Mg /h		
stones	4.71%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.86%	750	Mg/a =	0.188	Mg /h		
Inert materials	4.96%	2,000	Mg/a =	0.500	Mg /h		
total after screening	100.00%	40,300	Mg/a =	10.075	Mg /h		
process: composting 6-8 weeks -->							
Composition of household waste after composting							
water content	40.00%	16,120	Mg/a =	4.030	Mg /h		
Organic for compost production	86.70%	30,303	Mg/a =	7.576	Mg /h		
stones	5.44%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	2.15%	750	Mg/a =	0.188	Mg /h		
Inert materials	5.72%	2,000	Mg/a =	0.500	Mg /h		
total after composting	100.00%	34,953	Mg/a =	8.738	Mg /h		
process: ferrous and non-Fe-separation -->	95%	metal separation		713	Mg/a =	0.178	Mg /h
Composition of household waste afterstabilization and metal separation							
stones	5.55%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.11%	38	Mg/a =	0.009	Mg /h		
Inert materials	94.34%	32,303	Mg/a =	8.076	Mg /h		
total material for landfil	100.00%	34,240	Mg/a =	8.560	Mg /h		

Option 2. Mass balance through the treatment process

					Annual plant operation time		
					4,000	h/a full load	
quantity of waste	$m_{Domestic\ waste}$ =	100,000	t/a	$m_{Domestic\ waste}$ =	25	Mg / h	
water content of input	w_1 =	0.50	kg/kg				
Composition of household waste	im Anlieferungszustand:						
water content of input	50.0%	50,000	Mg/a				
material for RDF production	34.6%	34,600	Mg/a				
Organic	60.0%	60,000	Mg/a				
stones	1.9%	1,900	Mg/a				
Metal fractions (ferrous and nonferrous) - Total	1.5%	1,500	Mg/a				
Inert materials	2.0%	2,000	Mg/a				
total	100.0%	100000	Mg/a				
process: shredding -->	no change in the material composition						
process: ferrous and non-Fe-separation -->	50%	metal separation		750	Mg/a =	0.188	Mg /h
hand sorting	4%	of total waste		4,000	Mg/a =	1.000	Mg /h
Composition of household waste after metal separation							
water content of input	50.00%	50,000	Mg/a	12.5	Mg /h		
material for RDF production	32.13%	30,600	Mg/a	7.65	Mg /h		
Organic	62.99%	60,000	Mg/a	15	Mg /h		
stones	1.99%	1,900	Mg/a	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.79%	750	Mg/a	0.1875	Mg /h		
Inert materials	2.10%	2,000	Mg/a	0.5	Mg /h		
total	100.00%	95,250	Mg/a	23.8	Mg/a		
process: biological drying 2-3 weeks -->							
Composition of household waste after biological drying							
water content	35.00%	22,750	Mg/a =	5.688	Mg /h		
RDF production	38.00%	20,700	Mg/a =	5.175	Mg /h		
Organic	54.85%	35,650	Mg/a =	8.913	Mg /h		
stones	2.92%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.15%	750	Mg/a =	0.188	Mg /h		
Inert materials	3.08%	2,000	Mg/a =	0.500	Mg /h		
total after biological drying	100.00%	61,000	Mg/a =	15.3	Mg /h		
process: screening 80mm -->	to separate the RDF from the dried waste						
process: RDF separation separation -->	38%	RDF		20,700	Mg/a =	5.175	Mg /h
position of household waste after screening and RDF separation							
water content	40.00%	16,120	Mg/a =	4.030	Mg /h		
Organic for compost production	88.46%	35,650	Mg/a =	8.913	Mg /h		
stones	4.71%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	1.86%	750	Mg/a =	0.188	Mg /h		
Inert materials	4.96%	2,000	Mg/a =	0.500	Mg /h		
total after screening	100.00%	40,300	Mg/a =	10.075	Mg /h		
process: composting 6-8 weeks -->							
Composition of household waste after composting							
water content	40.00%	16,120	Mg/a =	4.030	Mg /h		
Organic for compost production	86.70%	30,303	Mg/a =	7.576	Mg /h		
stones	5.44%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	2.15%	750	Mg/a =	0.188	Mg /h		
Inert materials	5.72%	2,000	Mg/a =	0.500	Mg /h		
total after composting	100.00%	34,953	Mg/a =	8.738	Mg /h		
process: screening 10mm --> compost <10mm	70%	of organics		21,212	Mg/a =	5.303	Mg /h
process: ferrous and non-Fe-separation -->	95%	metal separation		713	Mg/a =	0.178	Mg /h
Composition of household waste afterstabilization and metal separation							
stones	48.25%	1,900	Mg/a =	0.475	Mg /h		
Metal fractions (ferrous and nonferrous) - Total	0.95%	38	Mg/a =	0.009	Mg /h		
Inert materials	50.79%	2,000	Mg/a =	0.500	Mg /h		
total material for landfil	100.00%	3,938	Mg/a =	0.984	Mg /h		