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# Scenario Assessment of Solid Waste Management for Izmir based on the Methodology of Material Flow Analysis


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## Preface

This report has been elaborated by Nur Onder during her internship at the FAR/Vienna University of Technology. The main goal of this practicum was to learn the methodology of material flow analysis, the software STAN, economic analysis and scenario analysis. Since the data base for Izmir was not fully developed yet, uncertainies of this report are significant. Thus, the numerical results are less important than the methodological approach, which can and should be applied for an in depth study based on solid data in Izmir and elsewhere.

**Abstract**

In Izmir, approximately 5100 tons of municipal solid waste (MSW) are generated per day. Between 1992 and 2013, more than 32 million tons of wastes have been disposed of in the Harmandali landfill. This practice poses a public health hazard due to landfill gases, odors and dust formation, and untreated leachates, which are discharged into the Gulf of Izmir, may reach surface and groundwater, and pollute soils, too.

The aim of this study is to assess the current solid waste management system of Izmir, and to compare various scenarios for integrated MSW management based on biological waste treatment and the methodology of material flow analysis. Aerobic as well as anaerobic treatment processes and combinations thereof are taken into account. The following research questions are investigated: What are the flows of wastes, products and emissions of key substances for the status quo and selected scenarios? What are the transfer coefficients for the goods and substances of the various processes investigated? What are the operational and investment costs of the scenarios? How do the scenarios perform in their total costs when compared to the status quo? The results are as follows:

Biological treatment could decrease the volume of MSW landfill in Izmir by 40%. The amount of organic constituents landfilled will be reduced by 95% and greenhouse gas emissions from landfilling and biological treatment will be reduced by 30%. Thus, the impact on human health and environment will decrease considerably. On the other hand, the costs of waste management will increase significantly: While Izmir municipality spends now 14 €/capita&year for solid waste management, the most economic scenario of biological treatment will cost an additional 21.- €/capita&year, increasing todays waste management costs by 150%. For effective waste management decision support, it is recommended to repeat this scenario analysis with a comprehensive and validated data set.

# 1 Introduction

Municipal solid waste problem is a major concern, especially for large cities in Turkey such as Izmir. The main solid waste disposal method in a number of cities in Turkey has been unsanitary landfilling or open dumping, including Izmir.

According to the Turkish Law of Metropolitan Municipalities municipalities are responsible for arranging solid waste management plans, and providing facilities of source collection, transportation and recovery of the municipal, industrial, and medical wastes (Official Gazette, 2004). However, the collection and transportation stages of solid waste management are well organized in Izmir, while disposal of the collected waste is in a worse situation. Municipalitiy of Izmir prefers landfilling as a disposal method due to their low cost and simplicity. It creates secondary pollutions such as water pollution by leachate, uncontrolled atmospheric emissions of landfill gases, bad odors and dust formation. Untreated leachates are discharged directly into the Gulf of Izmir and they can permeate underground water, also. Leachates contribute to the pollution of soil, underground water and surface water, furthermore, leachates may cause malodors and aerosols.

Anaerobic decomposition of MSW in landfills generates anthropogenic greenhouses gases which are about 40-60% methane and 40-50% carbon dioxide. This generation from landfill sites has drawn attention due to their significant contribution to global warming.

Landfill areas cause not only environmental problems but also threat public health. Biodegradation in landfill sites last over 100 years. Landfill sites are a heritage to our children from us. For this reason, next generations have to cope with the problems stemming from landfill sites.

Izmir is a large metropolitan city of Turkey in the western Anatolia. It is located in the Aegean Region of Turkey. Aegean Sea is to the west of the city and it has a big gulf called Gulf of Izmir. Izmir has an area of about 11,973 $km^2$ and the population of it is 4.050.028. It consists of 28 townships. 91% of the population lives in the province and districts centers, while 9% of population lives in the villages (Turkstat 2010).

According to the Prime Ministry Turkish Statistical Institute database 2010, the amount of municipal solid waste (MSW) per capita in Izmir was found as 1.28 kg/ca.d. Approximately 5130 tons/day of municipal solid waste is generated in Izmir. Harmandalı Solid Waste Landfill Area has been under service since 1992, which is operated by the Izmir Metropolitan Municipality. At this site, more than 32 million tons waste has been landfilled until now. Increasing population, rapid economic growth, the rise of living standards and immigration will accelerate the future solid waste generation rate in Izmir. According to the Prime Ministry Turkish Statistical Institute database 2013, it is expected that the total population of Izmir will be 4,405,279 in 2023. According to this data, approximately 20 million tons waste will be disposed of in the next decades. Today, the Harmandali landfill site is nearly completed its capacity. Disposal sites failed to catch up with the increasing volume of waste. It is difficult to find new landfill area. While Izmir municipality looks for a new area, they try to find some alternative solid waste management systems. Due to these disadvantages of landfilling, alternative uses of MSW such as composting, digestion, recycling must be implemented in Izmir.

Approximately 46% of the total MSW was organic waste, amounting to about 2360 tons/day. Paper comprised 12% of the MSW at 618 tons/day. The quantities of plastic, glass, metal, inert and other materials were 618, 206, 155 and 1184 tons per day, respectively.

MSW components of Izmir have been composed of energy-rich biodegradable residuals such as organic waste.

Uzundere and Menemen Composting Plants were active a short while ago, but they became inactive due to operational problems such as high cost and low quality of the compost produced. According to findings, it is expected that 9,2 million tones of organic waste will be generated in Izmir until 2023. Due to huge amount of organic waste, composting plants and anaerobic digestion plants should be constructed. In this way, volume of landfill site, cost of transportation fuels, production of toxic leachate, gas emissions will be decreased and the loss of valuable material will be prevented, as well. It is estimated that in the year 2012, approximately 200 million $m^3$ of methane has been emitted from the landfill site and in the year 2023, emissions will reach to 240 million $m^3$. Implemention of organic waste disposal methods prevent not also serious environmental problems but also conserve resources.

In order to solve these problems, the integrated municipal waste management system and an effective biological treatment method will be determined based on the methodology of material and substance flow analysis.

## 2 Aim of Study and Research Questions

The aim of this study is to compare various scenarios for integrated waste management based on biological waste treatment and the methodology of material flow analysis that was introduced by Baccini & Brunner (1991).

Integrated waste management has been defined as the integration of waste streams, collection and treatment methods, environmental benefit, economic optimisation and societal acceptability into a practical system for any region.

In the past 20 years, as the economy has achieved faster growth, ecological damage and environmental pollution have increased at a high rate.

An integrated solid waste management (ISWM) system which includes the reducing, reusing, recycling and disposal of waste material is considered to be an optimized waste management system where the environmentally and economically best solution is chosen for each case, without regard to the waste hierarchy.

As shown in Figure1, there were a lot of changes in the strategies of solid waste management in the advanced industrial countries during the period of 1960-2004. One revolutionary change was that the solid waste management begins with reduction-using less to begin with and reusing more- and recycling. In addition, incinerating and composting organic waste became dominant methods of solid waste treatment instead of disposal by landfills (Hui, Y. et al, 2006).

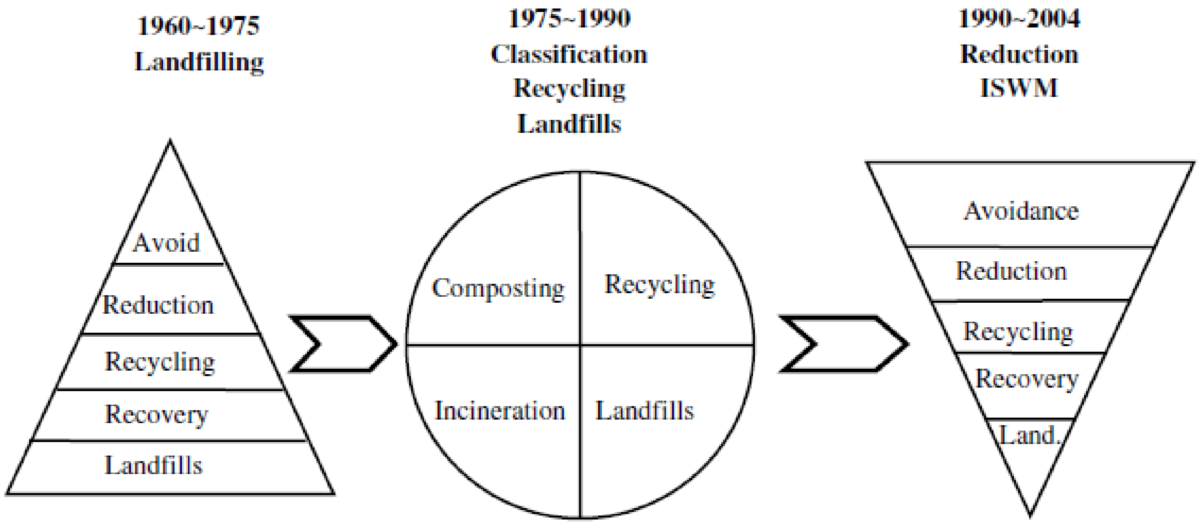



Figure 1. Solid waste management- revolutionary changes in the strategies in the advanced industrial countries during the period 1960-2004 (Hui, Y. et al, 2006).

EU has firm principles upon which its approach to waste management is based.

- prevention principle – waste production must be minimised and avoided where possible
- producer responsibility and polluter pays principle- those who produce the waste or contaminate the environment should pay the full costs of their actions
- precautionary principle- we should anticipate potential problems
- proximity principle- waste should be disposed of as closely as possible to where it is produced (Strange, K., 2002).

These principles are made more concrete in the 1996 EU general strategy on waste which sets out a preferred hierarchy of waste management operations

- prevention of waste
- recycling and reuse
- optimum final disposal and improved monitoring (Strange, K., 2002)

These countries are centered on a broadly accepted “hierarchy of waste management” (Figure 1) which gives a priority listing of the waste management options available. Several variations of the hierarchy are currently in circulation, but they are essentially similar.

The hierarchy has little scientific or technical basis. It has a little use when a combination of options is used in ISWM system. In ISWM system, the hierarchy can not predict, for example, whether composting combined with incineration would be preferable to recycling combined landfilling. The hierarchy can not provide an assessment of ISWM system and does not address costs. If prevention is the most economic way of reaching a particular waste management objective, then this method should be chosen. If the disposal option is more economic, the waste hierarchy should not be used to justify avoiding this choice. Neither is a “waste hierarchy” approach needed such as “prevention before recycling and disposal” (Brunner, P.H., et al., 2012).

Integrated waste management starts with collection and sorting, implies the use of a range of different treatment and disposal options such as recycling, composting and anaerobic digestion, incineration, landfill and alternative options such as pyrolysis, gasification, composting and anaerobic digestion and waste reduction, re-use.

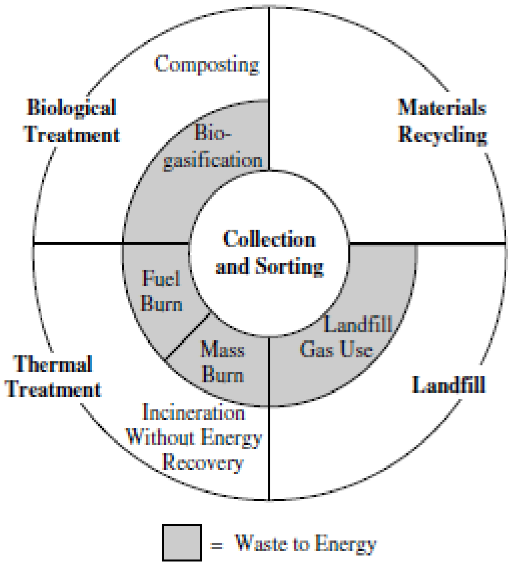



Figure 2. The Elements of Integrated Waste Management

However, integration also implies that no one option of treatment and disposal is better than another, but that the overall waste management system is the best environmentally and economically sustainable one for a particular region. Environmental sustainability means to reduce overall environmental impacts of waste management, including energy consumption, pollution of land, air and water. Economic sustainability means that the overall costs of the waste management system should operate at a cost level acceptable to all areas of the community, including householders, businesses, institutions and government (White et al 1995; Warmer Bulletin 49, 1996).

While designing integrated waste management system, the following goals have been adopted for integrated solid waste management:

- Protection of mankind and the environment.
- Conservation of resources such as materials, energy, land and biodiversity
- Aftercare-free waste treatment system (e.g., landfills)
- Find solution at the least cost

The municipal solid waste are composed of energy-rich biodegradable residuals, such kitchen waste which includes vegetables, fruits and cooked and processed food. In Izmir, 1.87 million tons of waste were generated in 2010 of which organic waste refuse accounted for 46%. Anaerobic digestion (AD) of KW is regarded as an attractive option due to its environmental and economical benefits. Firstly, the main solid waste management system was established and then three different biological treatment scenerios were investigated and compared with one another regarding to these goals. Construction waste and industrial waste materials were not considered.

*Objectives and Research Questions*

The goal of this study is to support the decision-maker on investment in waste management system in Izmir. It is important that the cost of waste treatment will be affordable according to its budget and it must reduce the direct impacts of environmental impact.

Currently, MSW is dumped directly on a landfill site. Direct landfilling pollutes to ground water and soil, releases emissions and greenhouse gases to atmosphere, causes many risks for public health, leads to loss of valuable material. Landfill site needs huge volume and land. Harmandali landfill site has an area of 900.000m$^2$. In this study, a cost analysis will illustrate current and scenarios costs and will help to decide biological treatment method.

In order to reach the goal of the study, the following major research questions have to be answered: How much of organic fraction of MSW is there in the MSW of Izmir? How much of wastes do go to biological treatment plant? What is the recycling ratio and disposal ratio? How much does it cost to treat organic wastes? The costs include the investment cost, operational costs and depreciation costs.

## 3 Methodology of Material and Substance Flow Analysis

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks and outputs of of a process (Brunner, P.H., 2004).

It has to be known that knowledge of the material flows into, out from and within all processes in the waste management system to reach effective waste management.

The main purpose of waste management is separation and transformation or accumulation of substances, either by logistics (separate collection) or by chemical and mechanical technologies (thermal, separation and size reduction). An appropriate waste management strategy for reaching the objectives is to establish “clean cycles” (treatment) and direct remaining materials to safe “final sinks”. The main elements of such a system are collection, treatment and final disposal (Brunner, P.H., et al., 2012). An MFA consists of several steps that are;

- System definition in Space (Izmir) and Time (year)
- Determine system boundry
- Determine waste generation rates (the ratio of mass per time- kg/day, tons/day, etc.) and waste composition, substance concentrations (g/kg)
- Data uncertainties and reconciliation of data
- Determine transfer coefficients
- Establish a mass balance of materials for each process; inputs, outputs, stocks
- Establish a mass balance of substances for each material
- Calculate cost of processes
- Evaluate results

# 4 Process Description

## 4.1 Theory and Technology of Composting

*Theory of composting and effecting parameters of composting process*

Composting is a microbial aerobic transformation and stabilization of heterogeneous organic matters in aerobic conditions and in solid state (Stentiford, E. et al, 2010). Aerobic microorganisms extract energy from the organic matter through a series of exothermic reactions that break the material down to simpler materials. The basic aerobic decay equation is;

[complex organics] + $O_2$(aerobic microorganisms)→ $CO_2$ + $H_2O$ + $NO_3^-$ + $SO_4^{-2}$ + [other less complex organics] + [heat]

MSW composting results in a volume reduction of up to 50 percent and consumes about 50 percent of the organic mass on a dry weight basis, by releasing mainly $CO_2$ and water (Diaz, L.F. et al, 2007).

*Temperature*

The water and aeration are the significant factor to be controlled during composting. The process is exothermic and energy is released. A part of this energy is used by microorganisms and the rest of energy is lost in the form of heat. This heat can produce a temperature increase in the mass. Temperature reaches and exceeds 70-90°C. Indeed, high temperatures inhibit microbial growth, causes slowing the biodegradation of organic matter. Temperature effects microbial metabolic rates and population structure. To have a maximum microbial diversity, the temperature must range between 25 and 45°C; to have the highest rate of biodegradation, the temperature must range between 45 and 55°C. Bacteria, actinomycetes and fungi are the main microbial biomass during composting process. If the temperature is below 20°C, microbial activity is low. When the temperature is above 55°C, the highest rate of pathogen inactivation can be obtained. In large composting masses, temperatures do not exceed about 80°C, which is also the temperature at which biological activity effectively stops (Palmisano, A.C. et al., 1996).

Composting progresses through a sequence of stages. The first stage of composting process is mesophilic phase in which temperatures rise from ambient temperature to 45°C. Within a few days, second phase of composting (thermophilic phase) starts and the temperature can easily reach and exceed 70°C. This phase is limited in terms of temperature and exposure time to obtain a balance between high stabilization rates and good sanitization, often to satisfy local legistation regarding sanitization conditions (Stentiford, E. et al., 2010). During the third phase, the amount of easily decomposable materials declines, maturation stage starts. The temperature drops from around 50°C to ambient.

*Moisture content*

Water is essential for all microbial activity. The moisture contents of MSW, organic waste and garden waste vary between 60-75%, 55-75% and 45- 65%, respectively. Average moisture content of MSW is 65-80% in Turkey (Melikoglu, M., 2012). All microbial activity ceases when the moisture content is less than 8-12% (Diaz, L.F. et al., 2007). At the end of the composting process, the finished compost should not have a moisture content greater than 35-45% to avoid storage, transport and handling problems and to prevent any further biological activity in the stabilized compost. Compost with a moisture content lower than 35-45% may increase the release of dust (Krogmann, U. et al., 2010). Optimal moisture content in the incoming waste varies and depends on the physical state and size of the particles. Normally, a 60% moisture content in the incoming waste should be satisfactory. It is estimated that moisture content of organic waste varies 60% in Izmir.

*Aeration, Particle Size, Oxygen Content*

Regardless of the feedstock or the selected technology, a minimum free space of 20-30% is recommended for a sufficient supply of oxygen to the waste (Krogmann, U. et al., 2010). Grinding and shredding reduce particle size and porosity but enhance degradation rate owing to increase surface area of total mass. There is a minimum size below which it is exceedingly difficult to maintain an adequate porosity in a composting mass. This size is the “minimum particle size” of the waste material. It is suggested that particle size of organic waste can be bigger than 2.5-5.0 cm.

Oxygen is a key element in the composting. The carbon dioxide content gradually increases and the oxygen level falls. The average $CO_2$ plus $O_2$ content inside the mass is about 20%. Oxygen concentration varies from 15 to 20% and carbon dioxide from 0.5 to 5%. When the oxygen level falls below this range, anaerobic microorganisms begin to exceed aerobic ones. Fermentation and anaerobic respiration processes take over. A lack of oxygen is common reason for composting failures (Palmasino, A.C., 1996). Therefore, it is important to supply oxygen to the mass of organic waste. In the windrow composting facilities, turning of windrows provides oxygen up-take.

*C/N and pH*

Biodegradable wastes generally contain enough macronutrients and micronutrients to sustain the composting process. The macronutrients for microbes are (C), nitrogen (N), phosphorous (P), and potassium (K). The micronutrients are cobalt (Co), magnese (Mn), magnesium (Mg), copper (Cu), and a number of other elements. Calcium (Ca) falls between the macro and the micronutrients.

The optimum C/N ratio for most types of wastes is about 25-30. Wastes with a lower or higher C/N can be composted, but too high C/N slows down the microbial degradation and too low C/N results in the release of nitrogen as ammonia. If a compost has a high C/N and decomposes rapidly in the soil, it can rob the soil of the nitrogen needed to support plant growth. If the compost has a too low C/N, the ammonia released can be phytotoxic to plant roots (Zucconi et al, 1981).

The optimum pH range is between 7 and 8. During composting the pH increases due to the degradation and volatilization of organic acids. If anaerobic conditions prevail during composting, pH decreases in biomass owing to organic acids produced as anaerobic intermediate products.

*Technological process factors of windrow composting*

Windrow composting can be constructed for Izmir. Because windrow composting is the simplest and the cheapest technology. Windrows are naturally ventilated as a result of diffusion and convection. They are aerated by forced or vacuum –induced aeration.

During composting, three particular features can serve as useful indicators for monitoring the performance of a compost process. They are: (1) temperature rise and fall; (2) biodegradation of organic material - destruction of volatile solids; (3) change in odor and appearance.

The degradation of organic matter during composting, measured as the percentage of the initial mass of volatile solids that is lost and the length of the composting period including curing. In a typical composting facility, food wastes are degraded more than 60%, biowaste (source separated food and yard waste) about 50% and lignocellulytic plant materials about 35-45% (Krogmann, 1994).

The optimum temperature during the high-rate decomposition period is about 40-55°C. Within this temperature interval, high rate of stabilization is obtained. At temperatures over 60°C, the diversity of the microorganisms is greatly reduced. At 70°C the total biological activity is 10-15% less than the one at 60°C, whereas, at 75-80°C, no significant biological activity is detected (Krogmann, U. et al., 2010). In order to obtain a high rate of sanitization, the temperature in the mass of windrow must range from 55-70°C (Stentiford, E. et al., 2010). The elevated temperatures destroy most of the pathogenic bacterium, eggs and cysts. Some of the more common pathogens and their survival at elevated temperatures are shown in Table 1. The product of thermophilic composting is essentially free of pathogens.

During curing, the optimum temperature is around 40°C. If the supply of easily decomposable material is depleted, the maturation phase begins. Temperature begins to decline, persists until ambient temperature is reached. Reduction of the concentration of volatile solids is a indicator of the stabilization of compost. Some of the early methods proposed for determining stability were the following: final drop in temperature (Golueke and McGauhey, 1953); degree of self-heating capacity (Niese, 1963); amount of decomposable and resistant organic matter in the material (Rolle and Orsanic, 1964); oxygen uptake (Schulze, 1964); growth of the fungus *Chaetomium gracilis* (Obrist, 1965); and the starch test (Lossin, 1970). In the United States, pathogen reduction regulations require temperatures above 55°C for 15 days and five turnings during this time in windrow facilities (US EPA, 1993). In Germany, pathogen reduction regulations require temperatures above 55°C for 14 days or above 65°C in open and above 60°C in in-vessel facilities for 7 days (German Federal Government, 1998). The main difficulty is to ensure that all particles are achieved to the desired temperature.

Table 1. Destruction of Some Common Pathogens and Parasites during Composting (Vesilind, P.A., 2010)

| | |
|---|---|
| Salmonella typhosa | No growth beyond 46ºC; death within 30 min at 55-60ºC and within 20 minutes at 60ºC; destroyed in a short time in compost environment |
| Salmonelia sp | Death within 1h at 55ºC and within 15-20 min at 60ºC |
| Escherichia coli | Death for most within 1h at 55ºC and within 15-20 min at 60ºC |
| Shigella sp. | Death in 1 h at 55ºC |
| Entamoeba histolytica cysts | Death within a few minutes at 45ºC |
| Trichinella spiralis larvae | Quickly killed at 55ºC |
| Brucella abortus or Br. Suis | Death within 3 min at 62ºC and within 1 h at 55ºC |
| Streptococcus pyogenes | Death within 10 min at 50ºC |
| Mycobacterium tuberculosis var. Hominis | Death within 15-20 min at 66ºC or after momentary heating at 67ºC |
| Corynebacterium diphtheriae | Death within 45 min at 55ºC |
| Ascaris lumbricoides eggs | Death in less than 1 h at 50ºC |

The attainment of a dark color or an earthy odor is not an indication, because these characteristics may be acquired long before stability is reached. Reaching a C/N lower than 20/1 also is not indicative. For example the C/N of raw manures may be lower than 20/1. Dryness should not be confused with stability either. It is true that if the moisture content is lower than 15-20%, microbial activity is minimal (Palmasino, A.C., 1996).

Aeration is one of the most important factors of composting process. Aeration is provided by turning of windrow with windrow turner. When the windrows are turned, both their porosity increases and homogenize compost, moisture -temperature gradients are balanced in the mass of windrow, also. If the windrow is turned constantly, the effect of turning on the oxygen uptake could be more efficient.

There is a relationship between turning frequency of composting and some physicochemical parameters that may serve as compost maturity indicators (CCQC, 2001). Turning frequency effects rate of decomposition as well as compost quality. Turning affects moisture content, dry matter, pH, total carbon, total nitrogen, C/N ratio and temperature of composting piles (Getahun, T. et al., 2012). As the turning frequency increases, carbon content of compost, nitrogen content of compost and C/N ratio decrease within the composting mass. It leads to lower plant growth. However, excessive aeration causes to decrease temperature and moisture content of material.

A higher turning frequency leads to a decrease in retention time and less investment cost and an increase in operating cost. For example, the retention time to produce a “stabilized compost” made from leaves, grass clippings and brush was reduced from 4-5 months to 2-3 months when the turning frequency was increased from once per month to seven times per month (Micheal et al., 1996).

High turning frequency requires labor-intensive management and causes high cost. After high rate degradation phase, generally turning is not made due to high cost. Turning frequency decreases from high-rate degradation to curing (Krogmann, U. et al., 2010). For frequently turned, naturally ventilated windrows of biowaste, retention times of 12-20 weeks are reported (Kern, 1991), while for windrows of yard waste 12-72 weeks are found. (Krogmann, U. et al., 2010). In order to prevent the lack of moisture which inhibites composting, moisture content of windrows should be adjusted to 50-60% by sprinkling water. It is recommended that the moisture content should not fall below 35-40%, but at the end of process, the moisture content should be 35-40% in the stabilized compost.

To sum up, biodegradation rate depends on temperature, retention time, turning frequency, transfer coefficients classified according to composting types.

On Table 2, amount of volatile solids losses and reaction rate constants are given with operation conditions of some composting facilities in Europe. According to these data, volatile solids losses range from 29%-66%, whereas Adani et al.(2000) obtained a value of 50% and Fricke and Muller (1999) values that ranged from 34% to 68%(Baptista,M., 2010). The low VS consumption values (29% and 32%) were an indication that process management in these plants was poor (Baptista,M., 2010). The avarage of the rest of the VS loss data on the table is 59.5. Thus, the volatile solid loss can be estimated as 60%.

First-order rate constants presented in the literature. For example, Mason (2006) and Mason (2008a) reported values in the ranges 0.0181-0.0749 $d^{-1}$ and 0.02-0.41$d^{-1}$ respectively (Baptista M., 2010).

On the other hand, using first order kinetic equation (1), the VS losses can be calculated for different retention times (Table 3-4). On the Table 2, first order rate constants range from 0.035 to 0.29. Between the these reaction rates, amounts of volatile solid losses were calculated using equation (2).

VS (consumed)= VS(initial) x (1- $e^{-kxt}$) (1)

VS (incoming waste) = 0.70

VS (the fast degrading volatile solids) =0.35

VS (the slow degrading volatile solids) =0.35

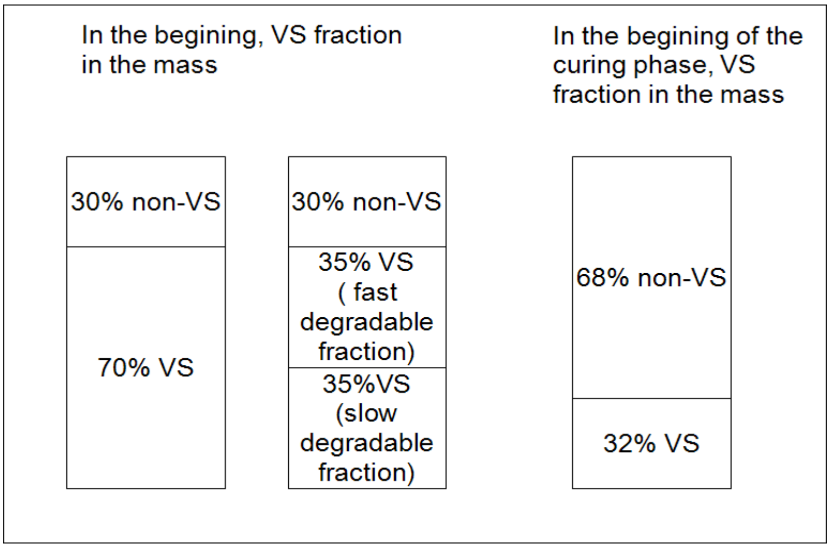
$k_f$ = fast reaction rate

$k_S$ = slow reaction rate

VS (consumed)= 0.70-(0,35 $e^{-kfxt}$ +0,35$e^{-ksxt}$) (2)

Table 2. Volatile Solids loses and Reaction Rates

| Material | System description | Study scale | Residence time (day) | VS loss (%) | k | k (fast+slow-calculated) | Source |
|---|---|---|---|---|---|---|---|
| Scottish MSW treated in a rotating drum for 6 h, then sieved at 50mm | Static pile with hybrid aeration system, one mixing over the 51 d; 10 tons test | Pilot | 51 | 61 | | 0,27+0.01 | Sesay et al.(1998) |
| Italian MSW treated mechanically; fraction <50mm | First 37 day- continually aerated windrow; turning every 2 days; then curing phase | Full | 37+79 | 57 | | 0,29+0.01 | Adani et al.(2000) |
| | First 37day- composting in a 150l adiabatic reactor with forced aeration; then 79 d in a non-ventilated heap, turned every 4-5 d; with water addition; 26 kg sample | Lab | 37+79 | 66 | | 0,27+0.01 | |
| French MSW | Windrow with positive forced aeration; 37.5 tons test | Pilot | 175 | 62 | | 0,25+0.01 | Lornage et al.(2007) |
| Portugal MSW | Positive aerated windrows; closed building; turning frequency :6.3 (d) | 150,000 ton/year | 63 | 29 | 0.05-0.084 | | Baptista, M. et al. (2010) |
| Portugal MSW | Negative aerated windrows; closed building; turning frequency :7(d) | 160,000 ton/year | 49 | 32 | 0.035-0.052 | | Baptista, M. et al. (2010) |
| Portugal MSW | Negative aerated windrows; closed building; turning frequency :7(d) | 50,000 ton/year | 59.5 | 52 | 0.064-0.114 | | Baptista, M. et al. (2010) |




It is estimated that the fraction of the "fast" degrading volatile solids is 35% and the fraction of the "slow" degrading volatile solids is 35% (Figure 3).

Figure 3. Fractions of volatile and non-volatile solids

Table 3. VS losses of different first order rate constants for different retention times.

| $k_f$ (fast) | $k_S$ (slow) | VS loss % 30days (turning) +45 days (nonturning) | VS loss % 40days (turning) +45 days (nonturning) | VS loss % 50days (turning) +45 days (nonturning) |
|---|---|---|---|---|
| 0.035 | 0.02 | 50 | 55 | 58.7 |
| 0.05 | 0.02 | 54 | 59 | 61.92 |
| 0.10 | 0.02 | 60 | 63 | 64.56 |
| 0.15 | 0.02 | 61.80 | 63.50 | 64.78 |
| 0.20 | 0.02 | 62.10 | 63.59 | 64.79 |
| 0.25 | 0.02 | 62.18 | 63.59 | 64.79 |
| 0.30 | 0.01 | 62.19 | 63.59 | 64.79 |

Table 4. VS losses of different first order rate constants for different retention times

| $k_f$ (fast) | $k_s$ (slow) | VS loss % 40 days (turning) +10 days (nonturning) | VS loss % 40 days (turning) +45 days (nonturning) | VS loss % 40 days (turning) +90 days (nonturning) |
|---|---|---|---|---|
| 0.035 | 0.02 | 32.71 | 55 | 55.58 |
| 0.05 | 0.02 | 36.61 | 59 | 59.47 |
| 0.10 | 0.02 | 40.7 | 63 | 63.57. |
| 0.15 | 0.02 | 41.25 | 63.50 | 64.12 |
| 0.20 | 0.02 | 41.33 | 63.59 | 64.20 |
| 0.25 | 0.02 | 41.34 | 63.59 | 64.21 |
| 0.30 | 0.01 | 41.34 | 63.59 | 64.21 |

On table 3/4, It is found that VS losses vary between 55% and 63.59% for 40 days high rate composting, then curing 45 days. The retention time of composting plant can be 85 days, because VS losses are above 60%.

On Table 5, for windrow composting, transfer coefficients of compost, transfer coefficients of losses are calculated and they are 66±7.6, 34± 7.6, respectively. For enclosed composting, transfer coefficients of compost, transfer coefficients of losses are calculated and they are 34±3, 66±6 respectively. For home composting, transfer coefficients of compost, transfer coefficients of losses are calculated and they are 43±5, 57± 7, respectively. For in-vessel composting, transfer coefficients of compost, transfer coefficients of losses are calculated and they are 39±8, 60±8, respectively. Moreover, transfer coefficient can be calculated using first order kinetic equation (3);

$M_t= M_0x\ (fo+f_1\ e^{-k1xt} +f_2e^{-k2xt+\text{.................}+}\ fne^{-knxt})$ (3)

$M_t$= mass remaning time t

$M_0$= initial mass =81.6 kg/ca.a

fn= fraction of mass with a reaction rate of kn

fo= non volatile fraction=0.30 (Figure 1)

f1 (fast) = the fast degrading volatile solids fraction=0.35 (Figure1)

f2 (fast) = the slow degrading volatile solids fraction=0.35 (Figure1)

$k_f$: 0.15 (Table3-4)

$k_s$: 0.02 (Mason(2006) and Mason (2008a))

Fast Degradation Phase ( First 40 days)

$M_{40}= 81.6x\ (0.3+0.35\ e^{-0.15x40} +0.35e^{-0.02x40})=81.6x0.46=37.54$ kg

$TK_{compost}$ =46% and $TK_{loss}$=%54

Curing (45 days)

$M_{40}=37.4x\ (0.72+0.28e^{-0.02x45})= 37.4x0.83=31.04$ kg

$TK_{compost}$ =38% and $TK_{loss}$=62%

*In this work, the transfer coefficient of composting is 62% for losses and is 38% for compost.*

Table 5. Classification of Transfer coefficient, moisture content, dry solid loss, processing time, frequency of mixing according to types of composting

| Types of wastes | TK total compost | TK residue (%) | TK compost (%) | TK losses (%) | Moisture content of compost (%) | Dry solid Loss (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Garden waste (Vienna 2013) | 60 | 15 | 45 | 40 | 35--40 | 35--40 | Windrow composting | 6-9 weeks | once a day | Lobau composting plant |
| Garden waste (Vienna 2002) | 44 | 13 | 31 | 56 | 35--40 | 35--40 | Windrow composting | 6-9 weeks | once a day | Bruuner, P.H., et al. |
| Garden waste | 74 | 11 | 63 | 26 | 30..5 | 30..5 | Windrow composting | | | Andersan, J.K., et al. |
| **Mean ± SD** | **59** | | | **41** | | | | | | |
| | | | | | | | | | | |
| Mixed waste ( Damascus city-2003) | 64 | 38 | 26 | 36 | | | Windrow composting | NA | | Brunner, P.H., et al. |
| Mixed waste | 59 | 43 | 16 | 41 | | | In-vessel + Windrow comp. | NA | | Razvi and Gildersieve, 1992 |
| OFMSW | 77 | 0 | 77 | 23 | | | Tunnel+windrow composting | 3 weeks | | M. Pognani et. Atl., 2012 |
| **Mean ± SD** | **66±7.6** | | | **34±7.6** | | | | | | |
| | | | | | | | | | | |
| **Calculation (first order kinetics)** | **38** | | | **62** | | | | | | |
| **Food wastes** | **40** | | | **60** | | | | | | U. Krogmann, 1994 |
| **Biowaste** | **50** | | | **50** | | | | | | U. Krogmann, 1994 |
| | | | | | | | | | | |
| Organic waste + Garden waste | 15 | 15 | | 70 | NA | | Enclosed composting | 8 weeks | NA | Istanbul composting plant |
| Organic waste | 37 | | | 63 | | | Enclosed composting | NA | | Boldrin, A., Christensen, T.H. |
| Mean ± SD | 33.5±3.5 | | | 66.5±6.5 | | | | | | |

To Table 5.

| Types of wastes | TK total compost | TK residue (%) | TK compost (%) | TK losses (%) | Moisture content of compost (%) | Dry solid Loss (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mixed waste (Dhaka city- 2002) | 19 | 54 | | 27 | | | Home composting | | | Brunner, P.H., et al. |
| 40%Garden+60% Food waste | 47 | | | 53 | 72 | 56 | Home composting | 6 months | | Imperial College London |
| 20%Garden+80% Food waste | 37 | | | 63 | 77 | 63 | Home composting | 6 months | | Imperial College London |
| 40%Garden+58% Food waste+2% Paper | 45 | | | 55 | 71 | 60 | Home composting | 6 months | | Imperial College London |
| 40%Garden+56% Food waste+4% Paper | 42 | | | 58 | 72 | 66 | Home composting | 6 months | | Imperial College London |
| 20%Garden+78% Food waste+2% Paper | 38 | | | 62 | 75 | 62 | Home composting | 6 months | | Imperial College London |
| 40%Garden+58% Food waste+2% Paper | 53 | | | 47 | 70 | 53 | Home composting | 6 months | | Imperial College London |
| 100%Garden | 58 | | | 42 | 68 | 40 | Home composting | 13 months | | Imperial College London |
| 40%Garden+60% Food waste | 45 | | | 55 | 72 | 31 | Home composting | 13 months | | Imperial College London |
| 20%Garden+80% Food waste | 39 | | | 61 | 74 | 58 | Home composting | 13 months | | Imperial College London |
| 40%Garden+58% Food waste+2% Paper | 43 | | | 57 | 72 | 58 | Home composting | 13 months | | Imperial College London |
| 40%Garden+56% Food waste+4% Paper | 39 | | | 61 | 72 | 63 | Home composting | 13 months | | Imperial College London |
| 40%Garden+60% Food waste | 33 | | | 67 | 73 | 66 | Home composting | 13 months | | Imperial College London |
| 40%Garden+60% Food waste | 43 | | | 57 | 71 | 58 | Home composting | 13 months | | Imperial College London |
| Organic waste | 45 | | | 55 | 75 | NA | Home composting | 1 year | every week | Andersan, J.K., et al., 2011 |
| Organic waste | 35 | | | 65 | 73 | NA | Home composting | 1 year | every week | Andersan, J.K., et al., 2011 |
| Organic waste | 36 | | | 64 | 69 | NA | Home composting | 1 year | every 6th week | Andersan, J.K., et al., 2011 |
| Organic waste | 27 | | | 73 | 71 | NA | Home composting | 1 year | every 6th week | Andersan, J.K., et al., 2011 |
| Organic waste | 44 | | | 56 | 67 | NA | Home composting | 1 year | No | Andersan, J.K., et al., 2011 |
| Organic waste | 35 | | | 65 | 71 | NA | Home composting | 1 year | No | Andersan, J.K., et al., 2011 |
| Mean ± SD | 42.85±5.28 | | | 57.15±6.69 | 71.84±9.8 | 56.46± | | | | |

To Table 5.

| Types of wastes | TK total compost | TK residue (%) | TK compost (%) | TK losses (%) | Moisture content of compost (%) | Dry solid Loss (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Organic waste | 32 | 2 | | 66 | | | In-vessel composting | | NA | Boldrin, A., Christensen, T.H. |
| Agricultural wastes | | | | | | | | | | |
| AGW-T01 | 49 | | | 51 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| AGW-T02 | 47 | | | 53 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| AGW-T03 | 46 | | | 54 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| AGW-U01 | 36 | | | 64 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| AGW-U02 | 38 | | | 62 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| AGW-U03 | 34 | | | 66 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| Household wastes | | | | | | | | | | |
| HHW-T01 | 39 | | | 61 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| HHW-T02 | 41 | | | 59 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| HHW-T03 | 50 | | | 50 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| HHW-U01 | 34 | | | 66 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| HHW-U02 | 35 | | | 65 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| HHW-U03 | 36 | | | 64 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| Municipal wastes | | | | | | | | | | |
| MSW-T01 | 47 | | | 53 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| MSW-T02 | 42 | | | 58 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| MSW-T03 | 57 | | | 43 | | | In-vessel composting | | turning | Adekunle, I.M.,2010 |
| MSW-U01 | 38 | | | 62 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| MSW-U02 | 39 | | | 61 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| MSW-U03 | 35 | | | 65 | | | In-vessel composting | | non-turning | Adekunle, I.M.,2010 |
| Food waste | 19 | | | 81 | 23 | 48 | Horizontal bioreactor | 90 days | every two weeks | Zhang H. et al., 2010 |
| Mean ± SD | 39.7±7.90 | | | 60.2±7.92 | | | | | | |

SD,standard deviation; T-series, composts prepared with turning schedule; U-series, composts prepared without turning schedule

## 4.2 Theory and Technology of Anaerobic Digestion

*Theory of anaerobic digestion and effecting parameters of anaerobic digestion process*

Anaerobic digestion of municipal solid waste is a controlled process of microbial decompostion where, under anaerobic conditions, a consortium of microorganisms convert organic matter into methane, carbon dioxide, inorganic nutrients, and humus (Palmisano, A.C.,1996) (Figure 4). The anaerobic decomposition of organics can be described as (Worrell, A.W., 2010);

[Complex organics] + heat $\rightarrow CO_2 + CH_4 + H_2S + + NH^+_4$

The overall anaerobic biological process involves several general pathways for decomposition of organic complexes and compounds to methane and carbon dioxide. These pathways are depolymerization, fermantation, acetogenesis and methanogenesis.

*Depolymerization*

Microorganisms hydrolyze polymeric (macromolecular) solid substrates into smaller and dissolved molecules. This step is referred to as hydrolysis, also. Hydrolysis reactions are fulfilled by extracellular enzymes called *hydrolases which are esterases, glycosidases, peptidases, lipases,* lyases*, etc.* The products of depolymerization are soluble smaller molecules, hereby, this step is also known as solubilization.

Different groups of fermentative bacteria are capable of excreting the extracellular enzymes that are needed for the hydrolysis of complex polymeric compounds in the waste into oligomers and monomers that can be taken up by the microorganisms. The proteleolytic bacteria produce proteases that catalyze the hidrolysis of proteins into aminoacids. The cellulytic and xylanolytic bacteria produce cellulases and/or xylanases that degrade cellulose and xylan (both are carbohydrates) to glucose and xylose, respectively. The lipolytic bacteria produce lipases that degrade lipids (fat and oils) to glycerol and long-chain fatty acids (Angelaki, I. et al., 2010).

*Fermentation*

During fermentation, sugars and amino acids are converted to volatile fatty acids (VFA), alcohols, hydrogen and $CO_2$, but long-chain fatty acids from the hydrolysis of lipids are not converted. When the reactor is operating under stable conditions, most substrate is converted to acetate and hydrogen directly. However, when the reactor is overloaded, either excessive production of acetate and hydrogen, or pH extremes occur.

*Acetogenesis*

Acetogenesis is a linkage between the degredation into water-soluble compounds and methane formation. Volatile fatty acids (VFAs) and alcohol are oxidized to acetate and $H_2$. This conversion can only take place at a low concentration of hydrogen ($H_2$), which is produced during acetogenesis as a by-product. Hydrogen consuming methanogens which convert $H_2$ and $CO_2$ to $CH_4$ keep the concentration of $H_2$ low. While acetogens produce $H_2$, methanogens consume $H_2$. Thus, at the standard conditions, the balance is set up in the biomass.

*Methanogenesis*

Methane is generated primarily by two pathways: Hydrogenotrophic methanogenesis, which converts $H_2$ and $CO_2$ into $CH_4$, and aceticlastic methanogenesis, which converts acetate into $CH_4$ and $CO_2$. While hydrogenotrophic methanogenesis typically accounts for 60-

70% of $CH_4$, aceticlastic methanogenesis typically generates 60-70% of $CH_4$. These organisms are strict anaerobs and have very slow growth rates (Angelidaki, I. et al., 2010).

The main products of anaerobic digestion are biogas and digestate. The biogas from organic compounds usually consist of 55-65% $CH_4$ and 35-45% $CO_2$. The biogas contains also ammonia, $H_2S$ and numerous volatile organic compounds, which constitute only less than 1% of the biogas (Angelidaki, I. et.al., 2010).Biogas yield for some types of waste are given in Table 6.

The energy content of biogas is significant and it can be used directly for producing electricity and heat or can be converted to a fuel oil.

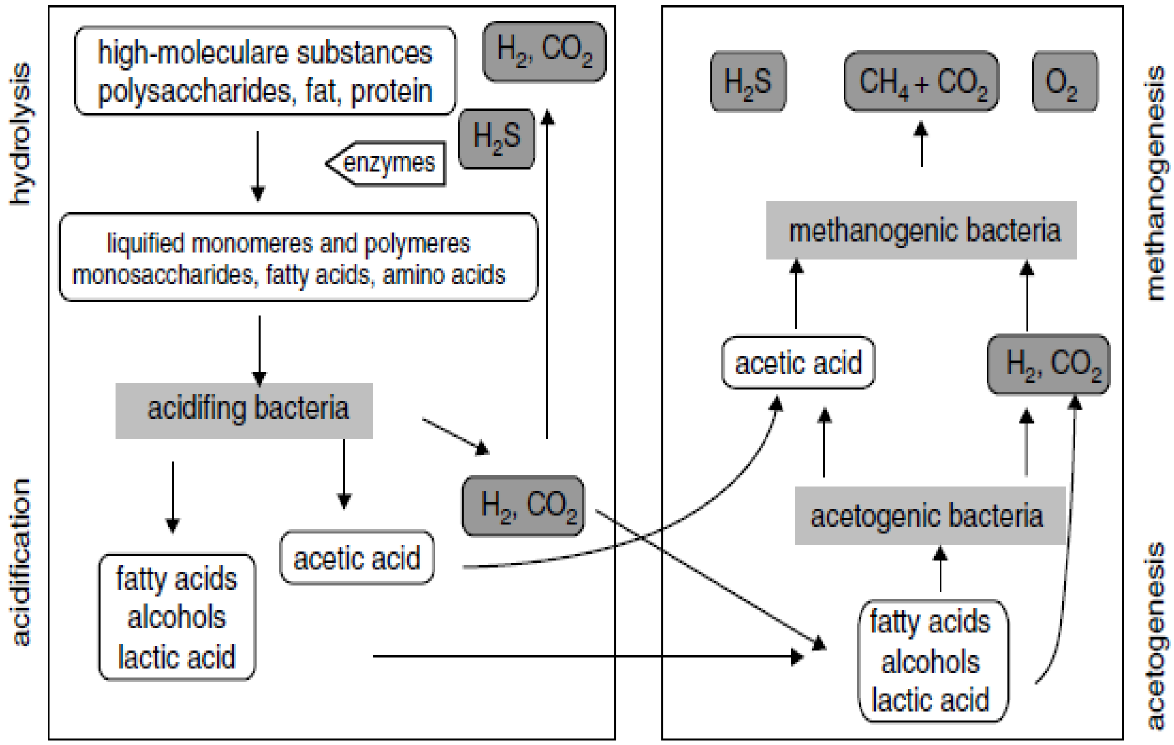



Figure 4. Degradation steps of anaerobic digestion (Pesta, G., 2007)

Table 6. Biogas yield recorded from anaerobic digestion of the solid organic waste (Khalid, A., et al., 2011).

| **Substrate** | **Methane yield (l/kg VS)** |
|---|---|
| Municipal solid waste | 360 |
| Fruit and vegetable wastes | 420 |
| Municipal solid waste | 530 |
| Fruit and vegetable waste and abattoir wastewater | 850 |
| Swine manure | 337 |
| Municipal solid waste | 200 |
| Food waste leachate | 294 |
| Rice straw | 350 |
| Maize silage and straw | 312 |
| Jatropha oil mill waste | 422 |
| Palm oil mill waste | 610 |
| Household waste | 350 |
| Lignin-rich organic waste | 200 |
| Swine manure and winery wastewater | 348 |
| Food waste | 396 |

The overall performance of the anaerobic digestion process depends on several process factors which are temperature, nutrient balance, pH, retention time.

*Temperature*

Temperature has a strong influence on both biodegradation rate and biogas production. The change of rate constans regarding the temperature is given on Table 7. Viscosity decreases and diffusivity increases with increasing temperature. It effects gas-liquid equilibrium, also. Gases are less soluble at higher temperature, therefore as the temperature is increased, the more gas is transferred to the gas phase. While within temperature ranges from 40-60 °C, termophilic bacteria prevail in the digester, mesophilic bacteria prevail within the 25-40°C temperatures. It has been observed that higher temperatures in the thermophilic range reduce the required retention time.

Table 7. Rate Constants, k, for Gas Production in Anaerobic Digesters (Worrell, W.A., et al., 2010)

| | Rate constant ( $day^{-1}$) | |
|---|---|---|
| Temperature, °C | Initial | Final |
| 35 | 0.055 | 0.003 |
| 40 | 0.084 | 0.043 |
| 45 | 0.052 | 0.007 |
| 50 | 0.117 | 0.030 |
| 55 | 0.623 | 0.042 |
| 60 | 0.990 | 0.040 |

Source: Pfeffer, J.T. 1974. “Temperature Effects on Anaerobic Fermentation of Domestic Refuse” Biotechnology and Bioengineering 16: 771-787. Copyright © 1974, John Wiley and Sons.

*Nutrient Balance*

Substrate composition is a major factor affecting the methane yield and methane production rates. Table 6 shows the specific biogas yields and qualities of carbohydrates, lipids and proteins. Due to the composition of the biodegradable organic compounds such as lipids and proteins, a higher percentage of methane is produced, compared to oxidized compounds like sugars.

Microorganisms utilize carbon during anaerobic digestion 20 to 30 times faster than nitrogen. This predicts an optimal ratio from C to N of 20-30:1 within the substrate. For an effective biogas process a ratio of at least 35-40 is required (Pesta, G., 2007).

*pH*

One of the most important environmental requirements is the proper pH. Easily degradable substrate tend to acidify rapidly and the pH lowers noticeably. Methane bacterium are inhibited when the pH falls below 6.2.

The pH in an anaerobic digester initially will decrease with the production of volatile acids. However, as methane-forming bacteria consumes the volatile acids and alkalinity is produced, the pH of the digester increases and then stabilizes.

*Retention Time*

The required retention time for completion of the AD reactions varies with differing technologies process temperature. and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days (Pesta, G., 2007).

*Technological process factors of anaerobic digestion*

There are the great diversity of reactor designs because of large variability of waste composition and operational parameters (retention time, solids content, mixing, recirculation, inoculation, number of stages, temperature). The discussion and evaluation of reactor designs will greatly vary depending on whether one takes a biological, technical, economical, or environmental viewpoint.

The commercial options for anaerobic digestion can be classified according to the solids content in the reactor. When the digestion process contains 10-15% solids, it is considered wet and the biomass in the digester looks like a liquid. But, when the digestion process contains 20-40% solids, it is considered dry and the biomass in the digester looks like a thick slurry. These systems can be one stage, two stages or batch facilities. A two-stage digesters separete digestion process into two steps. In the first step, hydrolysis, acidification and liquefaction take place, acetate, hydrogen and carbon dioxide are transformed into methane in the second step. In two or multi-stage systems, the reactions take place sequentially in the at least two reactors.

The digestion systems can be classified according to the temperature at which the process is conducted. During mesophilic digestion, the temperature in the digestion keeps around 35°C and during thermophilic digestion, the temperature in the digestion keeps above 50°C. Advantages and disadvantages of various anaerobic digestion systems have been summarized on Table 8.

Table 8. Advantages and Disadvantages of Various Anaerobic Digestion Systems. (Vandevivere P., et al., 2010).

| | Criteria | Advantages | Disadvantages |
|---|---|---|---|
| Single-Stage Wet Systems | Technical | Derived from well developed waste-water treatment technology<br>Simplified material handling and mixing | Short-circuiting<br>Sink and float phases<br>Abrasion with sand<br>Complicated pre-treatment |
| | Biological | Dilution of inhibitors with fresh water | Sensetive to shock as inhibitors spread immediately in reactor<br>VS lost with removal of insert fraction in pre-treatment |
| | Economic and Environmental | Less expensive material handling equipment | High consumption of water and heat<br>Larger tanks required |
| Single-Stage Dry Systems | Technical | No moving parts inside reactor<br>Robust (insert material and plastics need not be removed)<br>No short-circuiting | Not appropriate for wet (TS<5%) waste streams |
| | Biological | Less VS loss in pre-treatment<br>Larger OLR ( high biomass)<br>Limited dispersion of transient peak concentrations of inhibitors | Low dilution of inhitors with fresh water<br>Less contact between microorganisms and substrate (without inoculation loop) |
| Two- Stage Systems | Technical | Operational flexibility | Complex design and material handling |
| | Biological | Higher loading rate<br>Can tolerate fluctuations in loading rate and feed composition | Can be difficult to achieve true separation of hydrolysis from methanogenesis |
| | Economic and Environmental | Higher throughput, smaller footprint | Larger capital investment |
| Batch Systems | Technical | Simplified material handling<br>Reduced pre-sorting and treatment | Compaction prevents percolation and leachate recycling |
| | Biological | Separation of hydrolysis and methanogenesis<br>Higher rate and extent of digestion than landfill bioreactors | Variable gas production in single-reactor systems |
| | Economic and Environmental | Low cost<br>Appropriate for landfills | Less complete degradation of organics (leach bed systems |

*Single-stage wet system*

The single-stage wet system had been inspired from technology in use for anaerobic stabilization of biosolids (Figure 5). Both fresh and recycled process water are added to attain 10-15%TS. A pulper with three vertical auger mixers is used to shred, homogenize and dilute wastes in sequential batches. The obtained slurry is then digested in large complete mix reactors where the solids are kept in suspension by vertical impellers (Vandevivere P., et al., 2010). Single-stage digesters are simple to design, build and operate. The methane yield in one full-scale plant varied between 170 and 320 Nm3 CH4/kg VS fed (40 and 75 % VS reduction) during the summer and winter months, respectively, as a result of the higher proportion of garden waste during summer months (Saint-Joly et al., 1999).

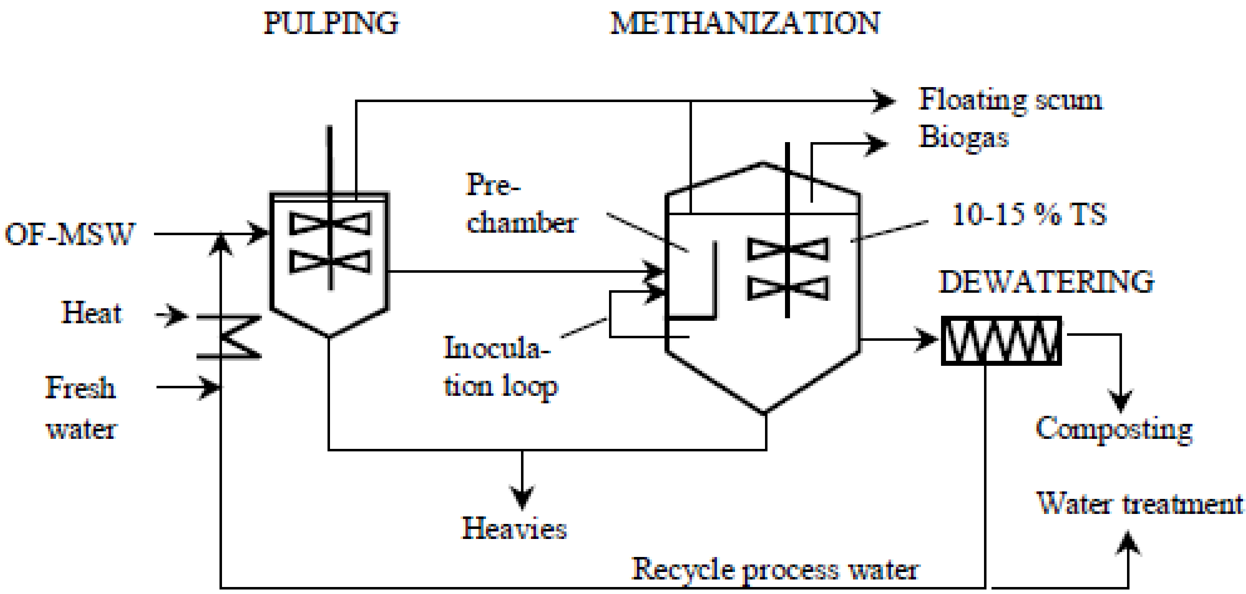



Figure 5. Typical design of a single-stage “wet“system (Vandevivere P., et al., 2010).

*Single- stage “dry“ systems*

In dry systems, the fermentation mass within the reactor is kept at a solids content in the range 20-40% TS, so that only very dry substrates (> 50% TS) need be diluted with process water (Oleszkiewicz and Poggi-Varoldo, 1997). The only pre-treatment is necessary to remove the coarse impurities which are larger than ca. 40mm before feeding the wastes into the reactor. Due to high viscosity, the biomass moves via plug flow inside the reactor. This makes technical simplicity as no mechanical devices need to be installed within the reactor for mixing. To guarantee adequate inoculation and mixing and to prevent local overloading and acidification, there have been three designs: Dranco, Kompogas, Valorga (Figure 6).

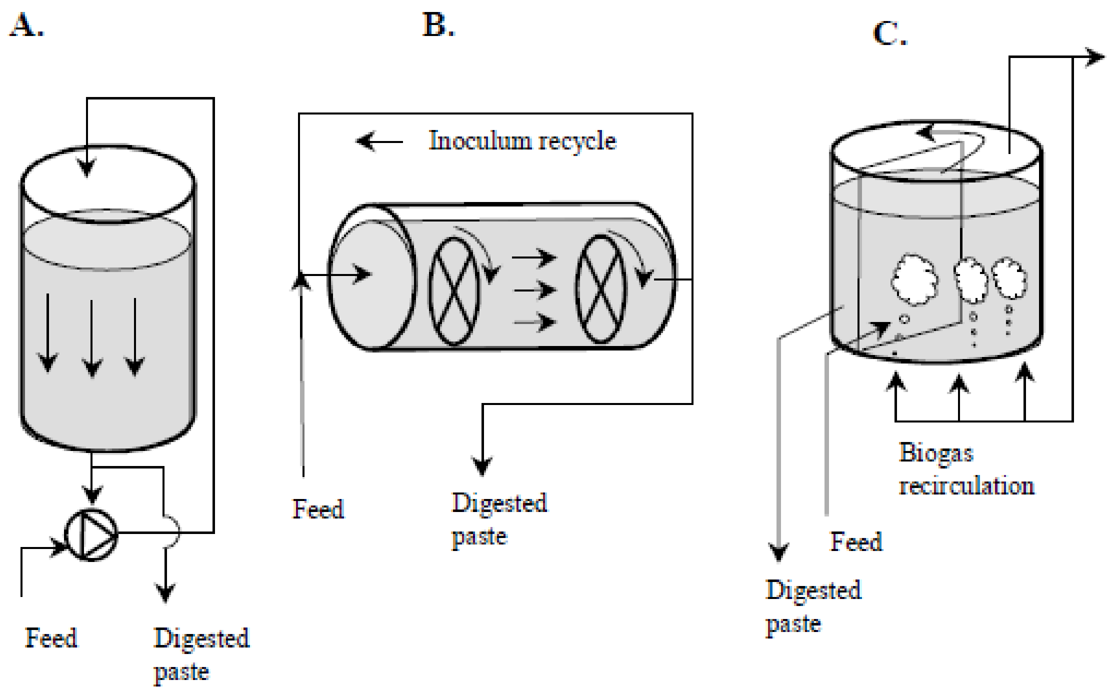



Figure 6. Different digester designs used in dry systems (A illustrates the Dranco design, BRV designs, and C the Valorga design) (Vandevivere P., et al., 2000).

In the Dranco process, the mixing occurs via recirculation of the wastes at the bottom end. The total content of total solids ranges from 20 to 50%. The Kompogas process works similarly, except that plug flow takes place horizontally. The horizontal plug flow is aided by slowly-rotating impellers inside the reactors, which also serve for homogenization, degassing, and resuspending heavier particles. The total content of total solids is around 23%.

The Valorga system is quite different in that the horizontal plug flow is circular in a cylindrical reactor and mixing occurs via biogas injection at high pressure at the bottom of the reactor every 15 minutes through a network of injectors (Fruteau de Laclos et al., 1997). This elegant pneumatic mixing mode seems to work very satisfactorily since the digested wastes leaving the reactor need not be recirculated to dilute the incoming wastes (Vandevivere P., et al., 2000).

*Two stage systems*

Typically, two stages are used where the first one harbors the liquefaction-acidification reactions, with a rate limited by the hydrolysis of cellulose, and the second one harbours the acetogenesis and methanogenesis, with a rate limited by the slow microbial growth rate (Liu and Ghosh, 1997; Palmowski and Müller, 1999). The main advantage of two-stage systems is not only higher reaction rate, but also a greater biological reliability for wastes (Table3). These systems provides adequate buffering and mixing of incoming wastes and controlled feeding rate.

There are two types of two stage systems; with and without a biomass retention scheme in the second stage (Figure 7 and Figure 8).

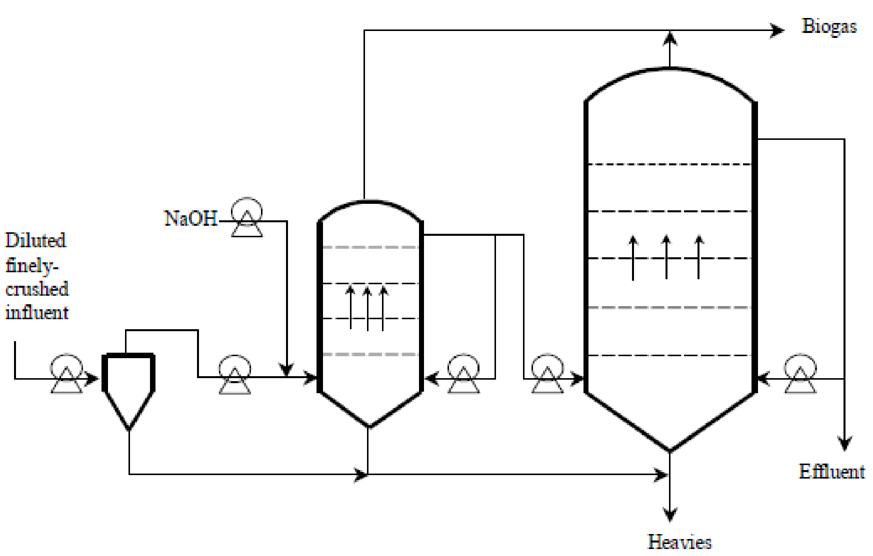



Figure 7. The Schwarting-Uhde process, a two-stage “wet wet“ plug-flow system applicable to source-sorted biowastes, finely-choped (ca. 1mm) and diluted and diluted to 12%TS Vandevivere P., et al., 2000).

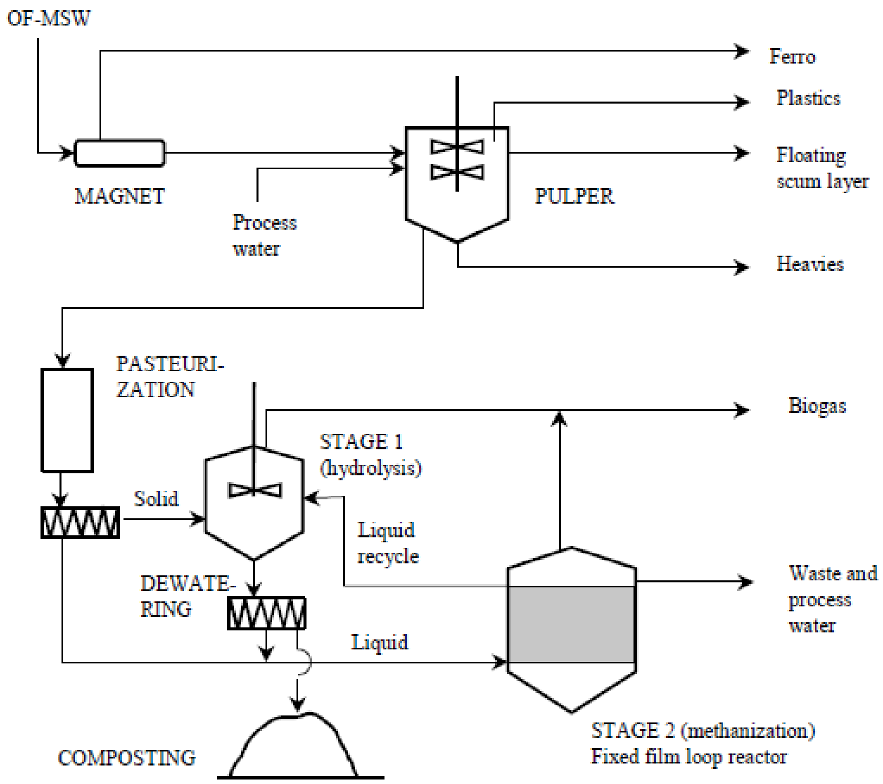



Figure 8. Two-stage“wet-wet“ design with a biomass retention scheme in the second stage (BTA process). The non-hydrolyzed solids are not sent to the second stage (Vandevivere P., et al., 2000).

In batch systems, digesters are filled once with wastes and then wastes are transferred other degradation steps sequentially in the 'dry' mode, at 30-40 % TS. Though batch systems seem like a landfill -in-a-box, they are run at higher temperatures and achieve 50- to 100-fold higher biogas production rates than that normally observed in landfills. Due to continuously recirculation of leachate and the dispersion of inoculant, nutrients, and acids (Figure 9).

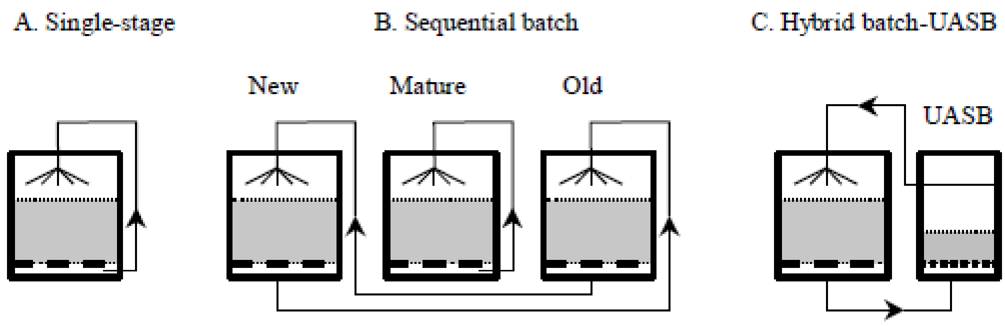



Figure 9. Configuration of leachate recycle patterns in different batch systems

Single-stage anaerobic digestion can be constructed in Izmir. It is estimated that total solid content of organic waste ranges from 30 to 40% in Izmir. In the dry systems, total solid content is kept around 30-40%. That’s why, water usage will be small and there will be no need for dewatering unit before composting process. On Table 7, biogas yield is given for different dry-anaerobic digestion technologies. As seen on table 4, the highest methane yield was obtained in the dranco process. Therefore, the system can be operated under the thermophilic conditions and the retention time can be determined as 21 days, like in the dranco process.

Table 9. Process parameters and biogas yields of thermophilic (50-56°C) anaerobic digestion of OFMSW (Walker L.R. et al., 2011)

| Process | Capacity | Waste | Total Solids During AD (%) | HRT (day) | Biogas Yield (m3/kg VS) |
|---|---|---|---|---|---|
| DiCOM | 900 $m^3$ | Mechanically - sorted OFMSW | 17 | 12 | 0.44 |
| BTA | 3,4 $m^3$ | Sourced - sorted (SS)OFMSW | 6--16 | 12 | 0.39 |
| DRANCO | 56 $m^3$ | Organic household waste-no paper | 30--35 | 15--21 | 0.45 |
| KOMPOGAS | 200 $m^3$ | Fruit, yard and vegetable waste | 15--40 | 13 | 0.39 |
| SEBAC | 3x0,7 $m^3$ | OFMSW ( paper, yard, food waste) | NA | 21 | 0.34 |

Several data samples were gathered and they summarized on Table 8. For dry anaerobic digestion systems, the mean of transfer coefficient of digestate, transfer coefficient of losses were calculated and they were 89.89±3.23, 9.73±2.65, respectively.

After anaerobic process, digested material will be composted.

$M_t$= $M_0$x ($f_O$+$f_1$ $e^{-k1xt}$ +$f_2$$e^{-k2xt+\dots\dots\dots\dots+}$ $fne^{-knxt}$) (3)

$M_t$= mass remaning time t

$M_0$= initial mass =73.44 kg/ca.a

$f_n$ = fraction of mass with a reaction rate of $k_n$

$f_o$ = non-volatile fraction=0.30 (Figure 1)

$f_1$ (fast) = the fast degrading volatile solids fraction=0.35 (Figure1)

$f_2$ (fast) = the slow degrading volatile solids fraction=0.35 (Figure1)

$k_f$ : 0.15 (Table3a-3b)

$k_S$: 0.05 (Table3a-3b)

Table 10. Transfer coefficients according to types of digesters and input, output values.

| **Types of wastes** | **Input w.w. (Mg /y)** | **Digestate w.w. (Mg /y)** | **$CH_4+CO_2$ w.w. (Mg /y)** | **Storage** | **Total condensed moisture w.w.** | **TK(D) (%)** | **TK (Losses) (%)** | **TK stock (%)** | **Average $CH_4$/ $CO_2$ (%)** | **$CH_4$ (%)** | **$CO_2$ (%)** | **VS degraded w.w. (Mg /y)** | **Vs reduction (%)** | **Types of Anaerobic digestion** | **Reference** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OFMSW | 1860 (kg) | 1730 (kg) | 130 (kg) | | | 93,00 | 7,00 | | | 60 | 35 | | | Dry TS: 25%-termophilic-single phase- 14 days | Karena Ostrem, 2004 |
| OFMSW | | | | | | 92-94 | 6--8 | | | | | | | Dry-termophilic-single phase- 14 days | R. Stegmann, 2005 |
| OFMSW | 197(t) | 177(t) | 20(t) | | | 90 | 10 | | | | | | 40 | Dry (TS:30%)-termophilic-single phase- 14 days | Walker, L.R. et al. |
| SS-OFMSW | 5426,504 (kg) | 4577421 (kg) | 726,650 (kg) | 122,433 (kg) | 12,526 (kg) | 84,35 | 13,4 | 2,25 | | 62.6 | 37.4 | | 75 | Dry (TS:28%)-termophilic-single phase- 21 days | Banks, C.J. et al., 2010 |
| SS-OFMSW | | | | | | 84 | 16 | | | | | | | Dry (TS:28%)-termophilic-single phase- 22 days | Pognani, M. et.al., 2011 |
| SS-OFMSW | | | | | | 92 | 8 | | | | | | | Dry conditions- TS >20% - 22 days | Kranert and Hillebrecht, 2000 |
| **Mean± DRY** | | | | | | **89.89 ±3.23** | **9.73 ±2.65** | | | | | | | | |
| OFMSW | | | | | | 86 | 14 | | | | | | | Kompogas | Kranert and Hillebrecht, 2000 |
| OFMSW | | | | | | 82 | 18 | | | | | | | Dranco | Sinclair and Kelleher, 1995 |
| OFMSW | | | | | | 81 | 19 | | | | | | | Biocel | Brummeler et al., 1992 |
| OFMSW | | | | | | 67 | 33 | | | | | | | Subbor | Vogt et al., 2002 |
| **Mean± DRY** | | | | | | **85.23 ±7.44** | **14.54 ±7.1** | | | | | | | | |
| OFMSW | 45251 | 41294 | 3595 | | 521 | 91,30 | 8,70 | | 57±3 | | | 4022 | | Wet conditions- TS<10% | Schievano, A. et al., 2011 |
| Biowaste | | | | | | 94 | 6 | | | | | | | Wet conditions- TS<10% | |
| Swine manure | 38544 | 33418 | 5006 | | 209 | 86,70 | 13,30 | | 55±4 | | | 5249 | | Wet conditions- TS<10% | Schievano, A. et al., 2011 |
| Swine+cow+ maize salige+ milk whey+ rice | 22745 | 20852 | 1594 | | 253 | 91,70 | 8,30 | | 63±4 | | | 2035 | | Wet conditions- TS<10% | Schievano, A. et al., 2011 |

Fast Degradation Phase (First 30 days)

$M_{40}$= 73.44x (0.3+0.35 $e^{-0.15x30}$ +0.35$e^{-0.05x30}$) = 73.44x0.38=27.90kg

$TK_{compost}$ =38% and $TK_{loss}$=62%

Curing (20 days)

$M_{40}$=27.90x (0.72+0.28$e^{-0.05x20}$) =27.90x0.82=22.96kg

$TK_{compost}$ =31% and $TK_{loss}$=69%

*During compost + anaerobic digestion, the transfer coefficient of losses is 69% and the transfer coefficient of mass is 31%.*

## 4.3 The Definition of Microwave Pretreatment

Microwaves are electromagnetic waves within a frequency band of 300 MHz to 300 GHz. In the electromagnetic spectrum (Fig.10), they are embedded between the radio frequency range at lower frequencies and infrared and visible light at higher frequencies. Thus, microwaves belong to the non-ionising radiations. But the microwave frequency range is also used for telecommunications such as mobile phones and radar transmissions. In order to prevent interference problems, special frequency bands are reserved for industrial, scientific and medical (so-called ISM) applications, where a certain radiation level has to be tolerated by other applications such as communication devices. In the range of microwaves the ISM bands are located at 433MHz, 915 MHz and 2450MHz; the first is not commonly used and the second is not generally permitted in continental Europe.

Outside the permitted frequency range, leakage is very restricted. Whereas 915 MHz has some considerable advantages for industrial applications, for microwave ovens at home the only frequency used is 2450 MHz. When the food is present inside the oven, the energy of the electromagnetic waves is transferred to the water molecules, ions, and other food components, raising the food temperature. Figure 11. shows two microwave ovens with various components.

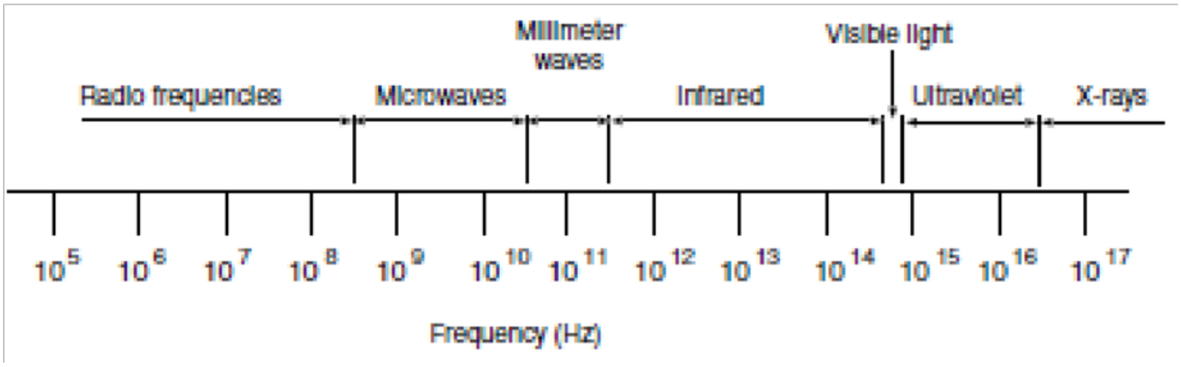



Figure 10. Electromagnetic spectrum (Datta, A.K., et., al., 2001).

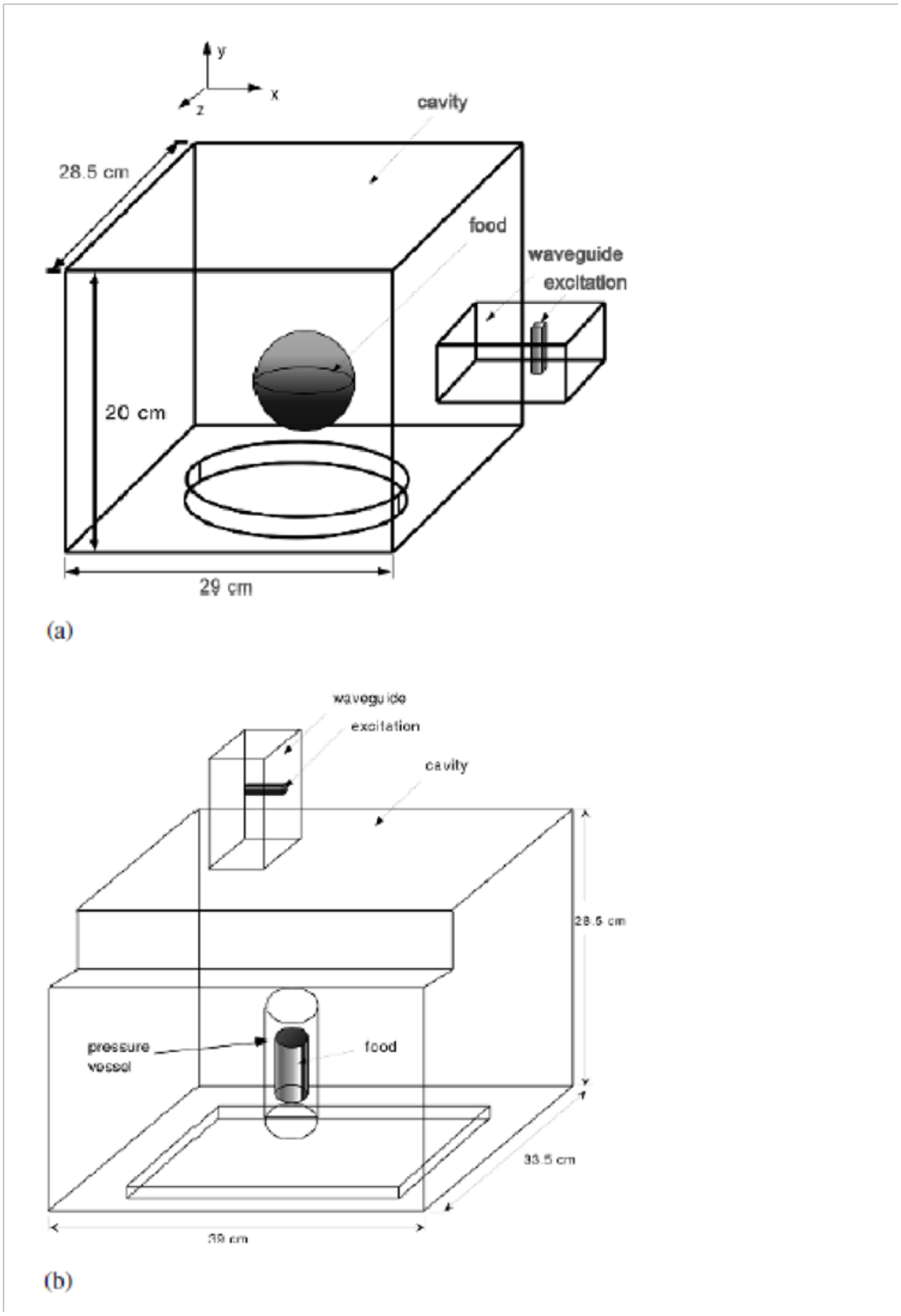



Figure 11. Schematic of two microwave oven systems used in some of the computational studies presented here: (a) General Electric, Inc., Louisville, KY, (b) MDS 2000 Microwave Digestion System, CEM Corporation, Matthews, NC. The rated power of the GE oven is 635 W and fort he CEM oven is 850W (Datta, A.K., et., al., 2001).

The two key issues in microwave heating of food are (a) the magnitude of the energy deposited by the microwaves and (b) the uniformity of the energy deposition. The magnitude and uniformity are affected by both food and oven factors such as (Schubert, H, et.al, 2005):

i. Strength and distribution of electromagnetic fields where the food is placed
ii. Reflection of electromagnetic waves from the food, as characterized by its property and geometry
iii. Propagation of the waves inside the foods, also characterized by the food properties and geometry

The dielectric properties of most materials vary with several different factors. In hygroscopic materials such as foods, the amount of water in the material is generally a dominant factor. The dielectric properties also depend on the frequency of the applied alternating electric field, the temperature of the material, and on the density, composition, and structure of the material. In granular or particulate materials, the bulk density of the air particle mixture is another factor that influences the dielectric properties. Of course, the dielectric properties of materials are dependent on the chemical composition and especially on the presence of mobile ions and the permanent dipole moments associated with water and any other molecules making up the material of interest (Schubert, H, et.al, 2005).

In microwave processing, energy is supplied by an electromagnetic field directly to the material. This results in rapid heating throughout the material thickness with reduced thermal gradients. Volumetric heating can also reduce processing times and save energy. The microwave field and the dielectric response of a material govern its ability to heat with microwave energy. Microwave is thus an alternative method for conventional heating and can give better results than classical thermal pretreatment. However, kinetics of methane production was increased; the time needed to reach the 80% value of ultimate volume of $CH_4$ was reduced by 4.5 days (Jackowiak, D., 2010).

In microwave processing, energy is supplied by an electromagnetic field directly to the material. This results in rapid heating throughout the material thickness with reduced thermal gradients. Volumetric heating can also reduce processing times and save energy. The microwave field and the dielectric response of a material govern its ability to heat with microwave energy. Microwave is thus an alternative method for conventional heating and can give better results than classical thermal pretreatment.

MW increases the kinetic energy of water dipoles bringing it to its boiling point very quickly. Although the quantum energy of MW irradiation may not be strong enough to break chemical bonds, some hydrogen bonded structures can be weakened or broken if exposed. The direct interaction of MW irradiation of biological samples at the molecular or cellular level is still poorly understood. Although no full scale studies using MW technology have been reported for solubilization of organic suspended solids, it seems to be a promising option for the treatment of numerous types of solid wastes. Due to its high moisture and suspended organic solids content, KW is a suitable candidate for MW irradiation pretreatment. The Pre-treatment helps to breakdown complex polymers into smaller molecules and promotes hydrolysis the rate limiting step in AD of suspended organics. The yield of methane production and volatile solids decomposition are increased during pretreatment process.

# 5 Scenario Development and Definitions

Definitions of municipal solid waste (MSW) vary between countries. A working definition is “wastes generated by households, and wastes of a similar nature generated by commercial and industrial premises, by institutions such as schools, hospitals, care homes and prisons, and from public spaces such as streets, markets, slaughter houses, public toilets, bus stops, parks, and gardens”(Chaturverdi, B., 2010). This working definition includes most commercial and business wastes as municipial solid waste, with the exception of industrial process and other hazardous wastes. Different countries or cities define municipal solid waste rather differently. So it is important to ask in each city what definition is. According to some experts all industrial and construction and demolition (C&D) wastes should be included in the definition of municipial solid waste.

First of all, the solid waste collection method used in Izmir is the mixed collection. Sanitary landfilling is the only option that is currently used for the management of the MSW (Figure 12. STAN/ Status Quo of Solid Waste Management in Izmir, 2010). All types of wastes- municipal, industrial, medical and hazardous- are disposed in Harmandali Landfill Site. The wastes from households, offices, restaurants, public facilities, industrial wastes and sludge have been disposed separetely within different three lots in landfill site which has an area of 170.000 $m^2$ for domestic waste, 19.000 $m^2$ for industrial, medical and hazardous wastes, 24.000 $m^2$ for sludge. Secondly, there is no source separation and recyclable wastes which are approximately 15% of total municipial solid waste have been collected by scavengers at the disposal bins for selling to informal collectors. As a result, approximately 15% of total municipial waste have been recycled at 70 kg / ca. year (Figure12).

## 5.1 Status Quo of Solid Waste Management in Izmir

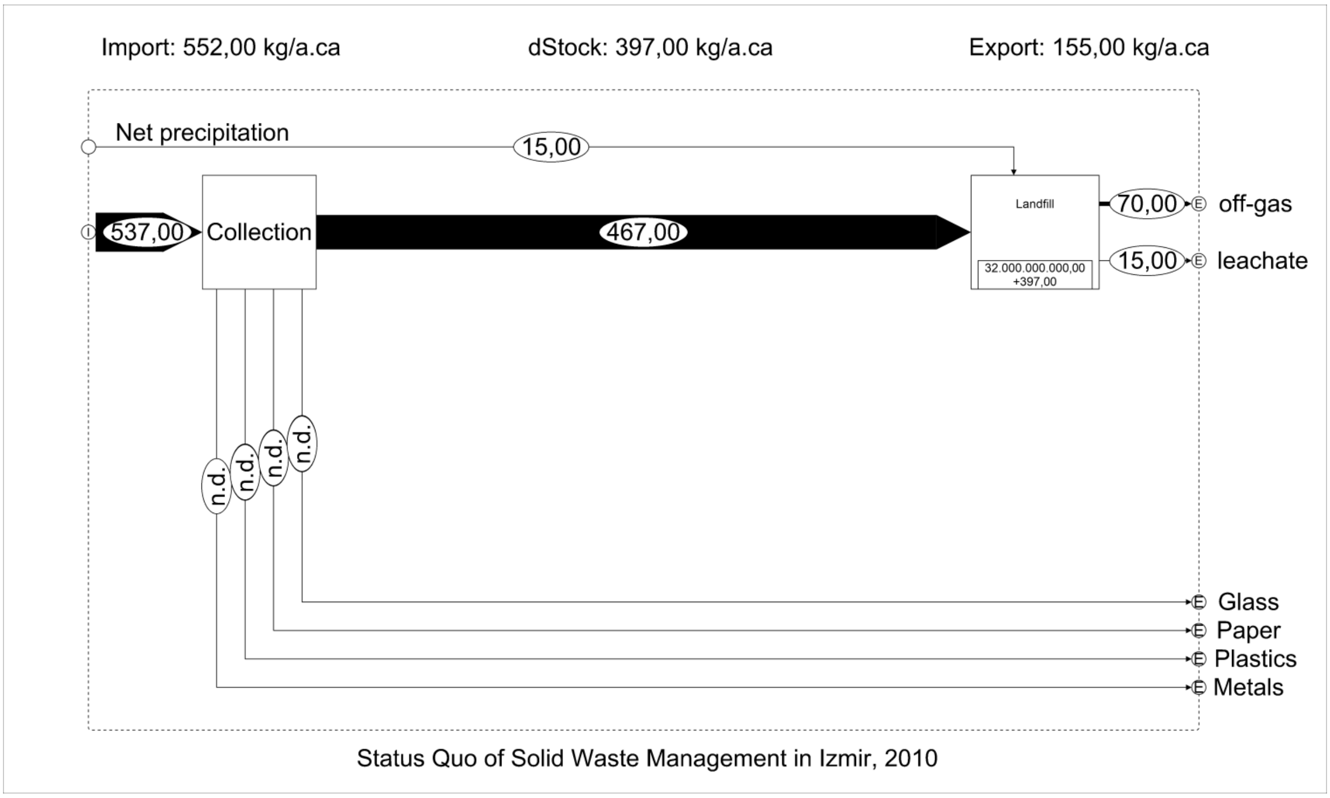



Figure 12. Status Quo of Solid Waste Management in Izmir, 2010

Izmir province consists of twenty eight municipalities: Bergama, Dikili, Kinik, Aliaga, Foca, Menemen, Cigli Karsiyaka, Bornova, Konak, Balcova, Narlidere, Guzelbahce, Gaziemir, Buca, Kemalpasa, Bayindir, Odemis, Kiraz, Beydag, Tire, Selcuk, Torbali, Menderes, Seferihisar, Urla, Cesme, Karaburun. In some towns, unsanitary landfilling is undertaken for the management of solid wastes. Due to the Law for Metropolitan Municipalities, some of them started to close unsanitary landfill sites. Today, all types of wastes- municipal, industrial, medical and hazardous- have been collected from twenty townships and have been sent to Harmandali Landfill Site, amounting to about 467 kg/ca.year.

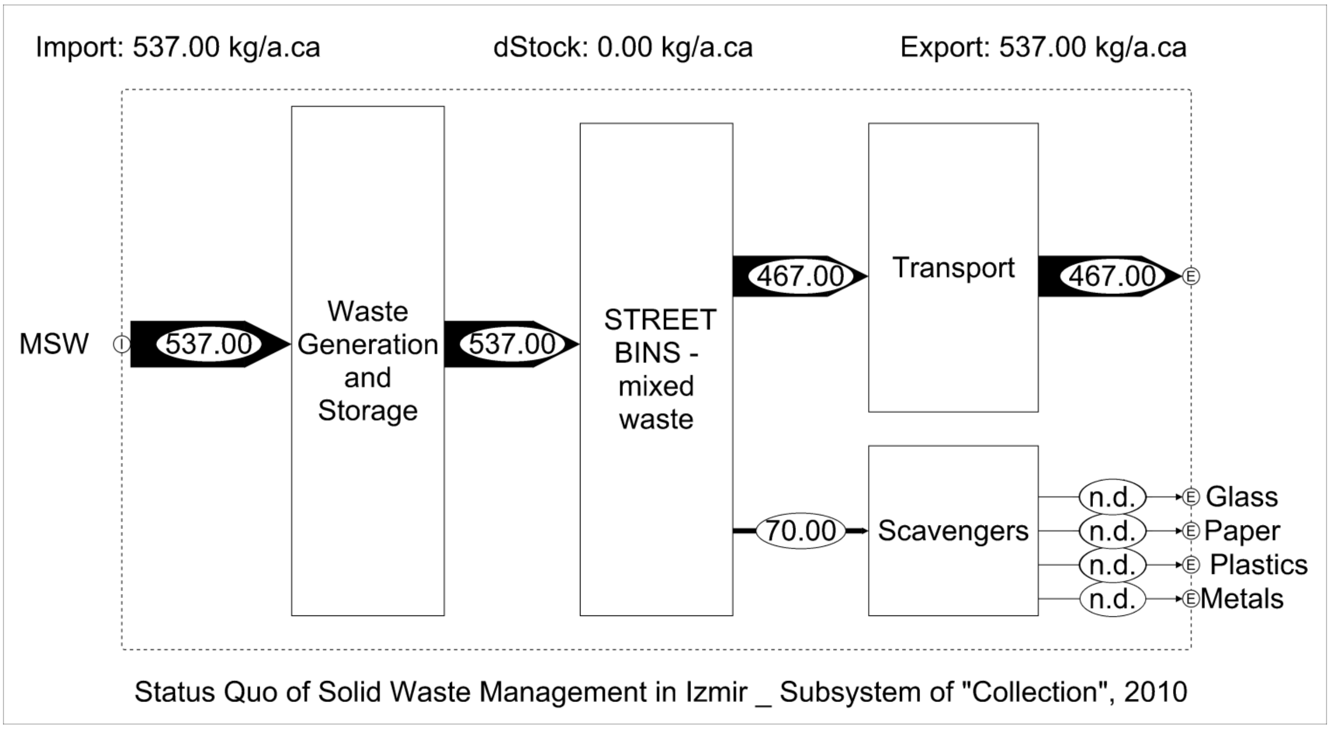



Figure 13. Status Quo of Solid Waste Management in Izmir_ Subsystem of “Collection”, 2010

The solid waste collection method used in Izmir is the curb-side collection method. Solid wastes are stored in containers, in sizes of 400 lt. or 800 lt. The dimensions and numbers of containers vary according to the quantity of waste. It is estimated that 15% of total generated wastes (Turkstat, 2010) which are recyclables; glass, paper, plastics, metals has been collected by scavengers, approximately 70 kg/ca.a (Figure 13). Materials are then recycled by specialized recycling companies. Before the trucks come, scavengers pick up recyclables. The rest waste is transferred to transfer stations. Then bigger trucks deliver larger amounts of waste to Harmandali Landfill Site which is 27 km away from city centre. There are nine transfer stations in Izmir; Halkapinar, Karsiyaka, Foca, Gediz, Kisikkoy, Torbali Gumuldur, Urla, Turkeli (Figure 14).

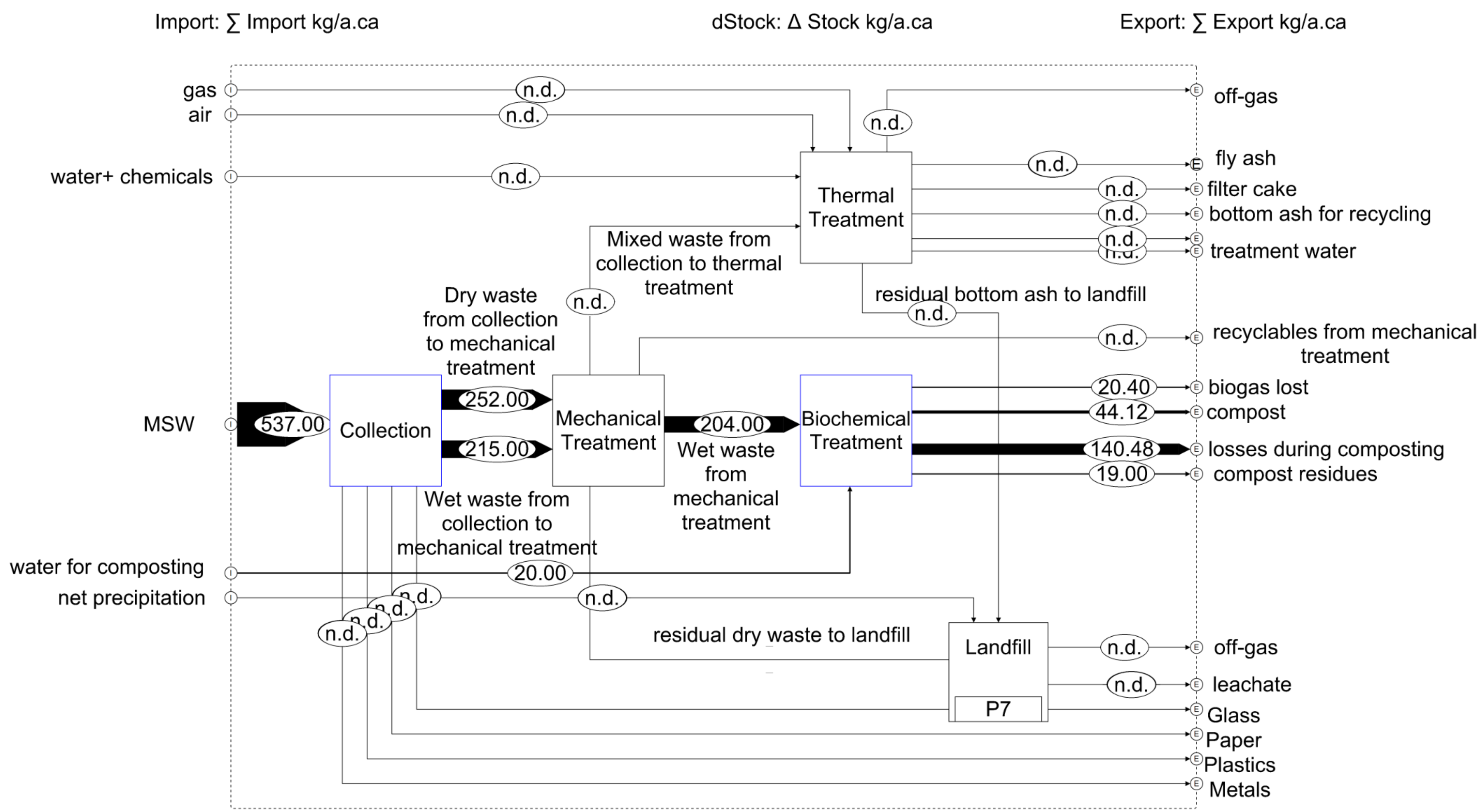

Figure14. Transfer Stations in Izmir

Main System of Solid Waste Management for Izmir

The main MFA system includes three typical processes: mechanical treatment, biochemical treatment and thermal treatment and controlled final disposal option (Figure15. STAN MFA Model_ Main system for Izmir, 2010).

To be able to obtain an effective waste management system, it is inevitable that MSW have to be made on source separation. Waste sorting can occur manually at the household and collected through curbside collection streams. Waste sorting means dividing waste into dry and wet. Wet waste typically refers to food waste usually generated by eating establishments, soiled food wrappers, hygiene products, yard waste, tissues and paper towels and any other soiled items that would contaminate the recyclables. Dry waste includes all recyclables that are paper, glass, plastics, electronic wastes, scrap metal and household hazardous wastes. Izmir residents will store wastes in green bins for wet waste and blue bins for dry waste.

After MSW are collected separately, they are delivered to mechanical treatment plants via transfer stations. Eight more transfer stations will be constructed as seen Figure16. During mechanical treatment process, recyclable materials are sorted manually at hand picking stations or are separated mechanically. This process typically involves conveyors, industrial magnets, eddy current separators, trommels, shredders. Mixed waste from mechanical treatment plant are send to thermal treatment plant, residual dry waste are send to landfill site and recyclables are send to recycling facilities. Wet waste are send to biological thermal treatment plant.




STAN MFA Model_ Main system for Izmir, 2010

Figure 15. STAN MFA Model_ Main system for Izmir, 2010

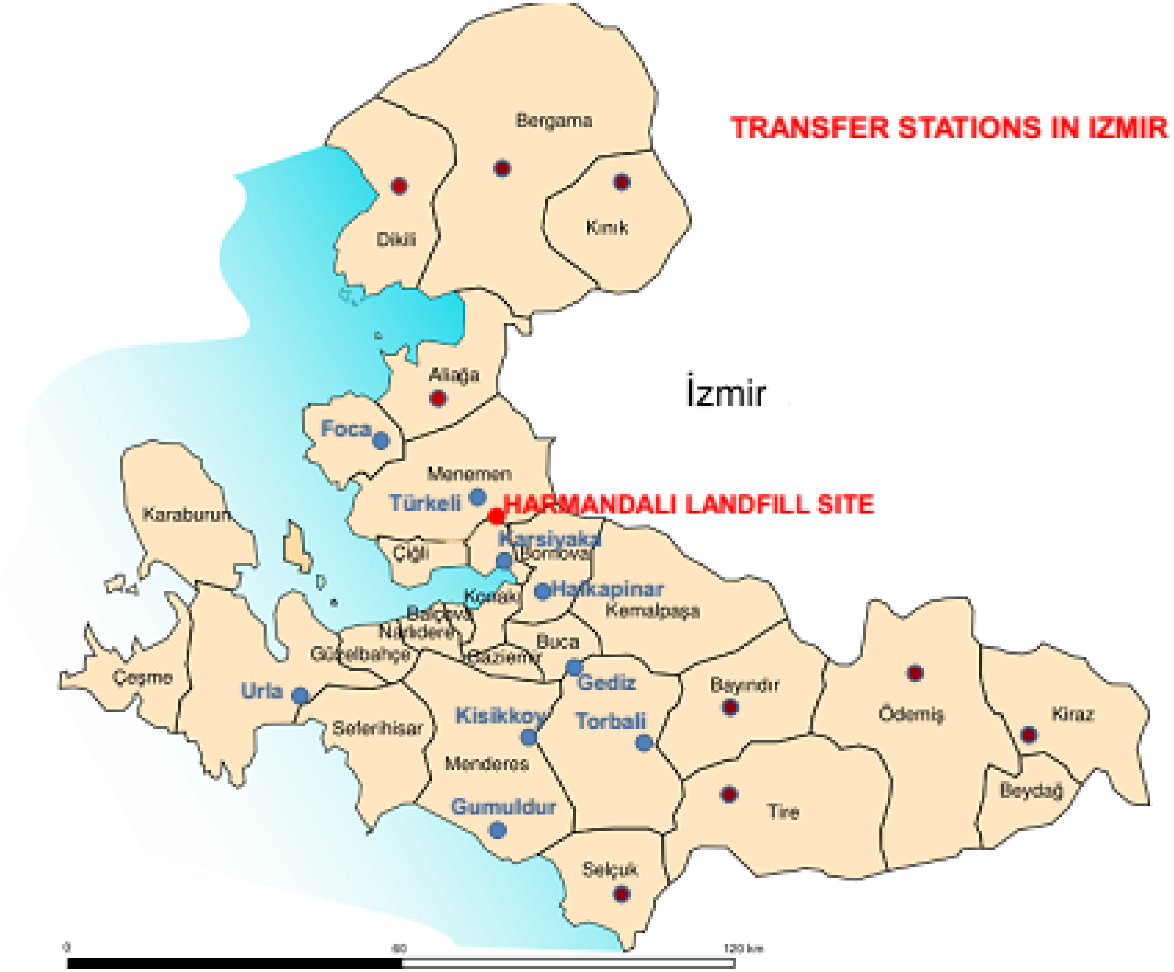



Figure 16. Transfer Stations in Izmir

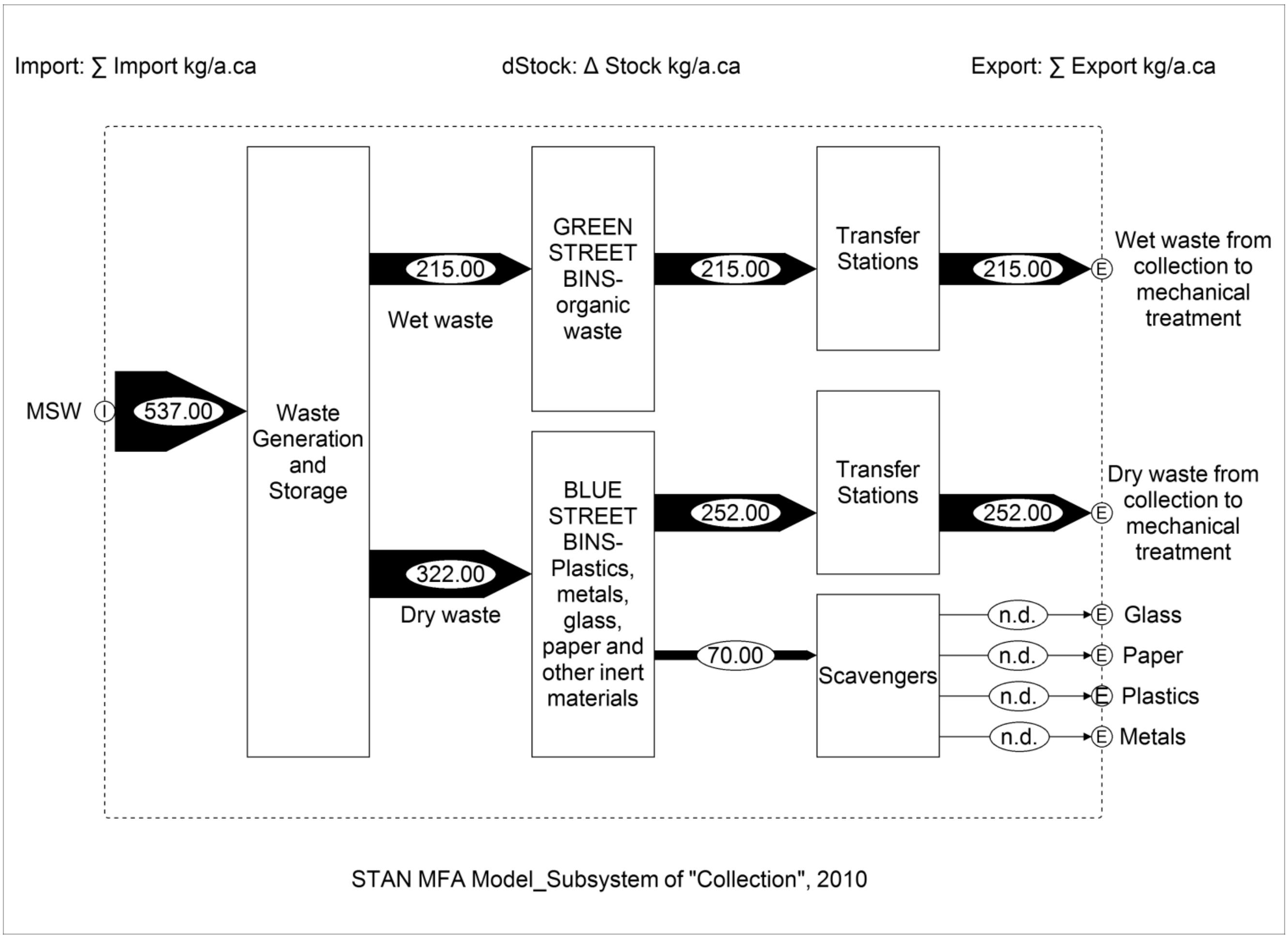



Figure17. STAN MFA Model _ Subsystem of “Collection”, 2010

In this study, three scenarios were developed for biological treatment process. In order to assist decisionmaker, this study compares the costs and benefits arising from Scenario 1, Scenario 2a and Scenario 2b. While scenario1 includes unique composting process, scenario 2a and scenario 2b consist of anaerobic digestion and composting processes, anaerobic digestion with microwave pretreatment and composting processes.

### 5.1.1 Scenario 1: Composting

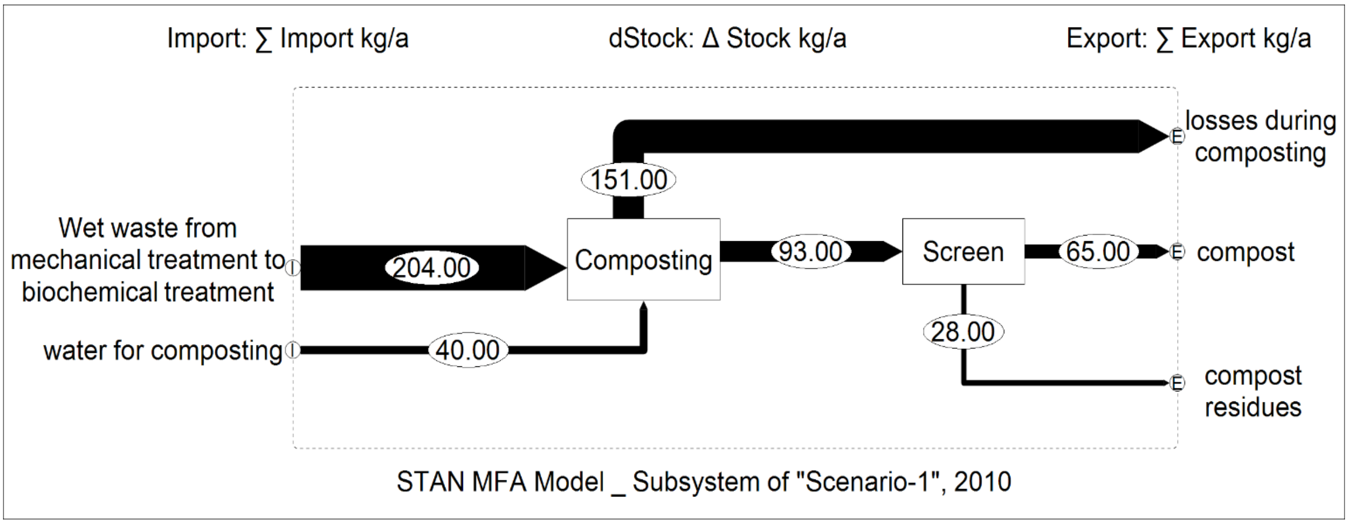



Figure 18. STAN MFA Model _ Subsystem of “Scenario-1”, 2010

*Procedures*

I. *Space and Time : Izmir, 2010*

II. *Boundries of MFA: Wastes have been collected from 28 townships in Izmir.*

III. *Assumptions, Collections of data :*

- Temperature can be kept between 40-55°C for stabilization and between 55°C to 70°C for sanitization.
- Moisture content should be kept around 60% during composting.
- During first phase, dry solid of waste includes 30% non-volatile solids (ash) and 70% volatile solids.

- During curing, dry solid of waste includes 72% non-volatile solids (ash) and 28% volatile solids.

- Retention time and turning frequency

First 40 days high-rate composting- turned every week; then curing phase, 45 days.

IV. *Transfer coefficients and reconciliation of data*

Based the datas on Table 4, It is estimated that $TK_{compost}$ and $TK_{loss}$ can be 38% and 62%, respectively.

### 5.1.2 Scenario 2a: Anaerobic Digestion and Composting

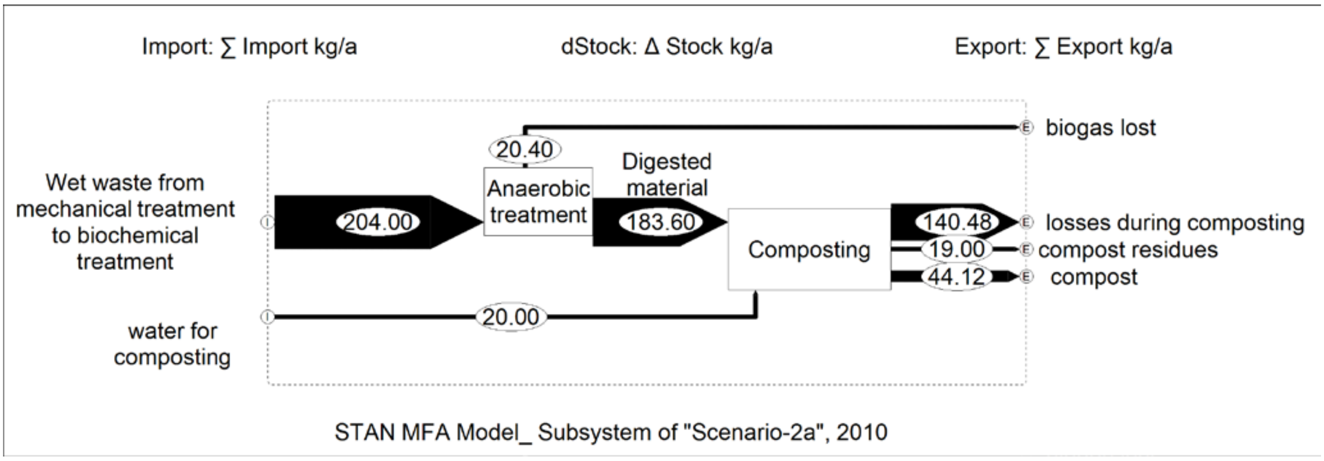



Figure19. STAN MFA Model_ Subsystem “Scenario 2a“,2010

***Procedures***

I. *Space and Time : Izmir, 2010*

II. *Boundries of MFA: Wastes have been collected from 28 townships in Izmir.*

III. *Assumptions, Collections of data :*

*<u>During Anaerobic Digestion</u>*

- Average moisture content of MSW is 65-80% in Turkey (Melikoglu, M., 2012). Thus, total solid content ranges from 20% to 35%.
- Type of anaerobic digestion system is a single- stage “DRY“system.
- Digester will be operated in the termophilic phase.
- Retention time: 21 days
- Transfer coefficients:

  TK (digested material): 89.89±3.23%

  TK (biogas lost):9.73±2.65%

*<u>During Composting</u>*

- Moisture content should be kept around 60% during composting.
- Moisture content must be 35-40% end of the composting duration.

- Temperature can be kept between 40-55°C for stabilization and between the 55 to 70°C for sanitization.

- During first phase, dry solid of waste includes 30% non-volatile solids (ash) and 70% volatile solids.

- During curing, dry solid of waste includes 72% non-volatile solids (ash) and 28% volatile solids.

- Retention time of composting : 50 days

- During compost + anaerobic digestion process, transfer coefficients:

  TK (compost): 31%

  TK (losses): 69%

### 5.1.3 Scenario 2b: Anaerobic Digestion with Microwave Pretreatment and Composting

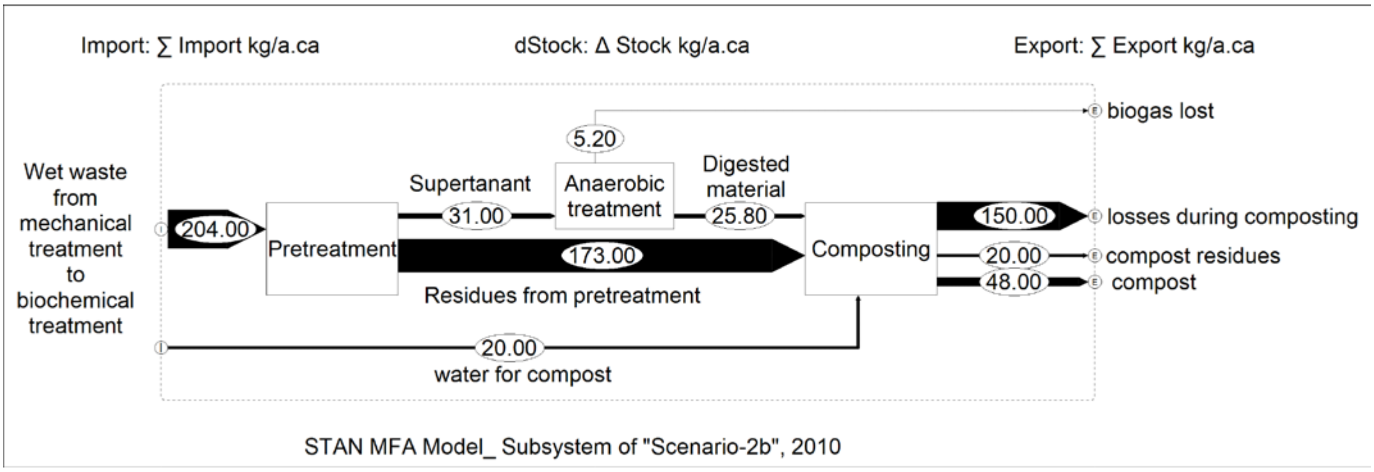



Figure 20. STAN MFA Model_ Subsystem “Scenario 2b“, 2010

***Procedures***

I. *Space and Time : Izmir, 2010*

II. *Boundries of MFA: Wastes have been collected from 28 townships in Izmir.*

III. *Assumptions, Collections of data :*

*<u>During Microwave Pretreatment</u>*

- Frequency of microwave: 2450 MHz
- Retention time: 30 minutes
- Heating: MW irradiation at 175 °C
- <u>Transfer coefficients:</u>

  TK (supertanant): 15%

  TK (residues from pretreatment): 85%

*<u>During Anaerobic Digestion</u>*

- Type of anaerobic digestion system is a single- stage “WET“system.
- Digester will be operated in the termophilic phase.
- Retention time: 12 days
- <u>Transfer coefficients:</u>

  TK (digested material): 20%

  TK (biogas lost): 80%

*<u>During Composting</u>*

- Moisture content should be kept around 60% during composting.
- Moisture content must be 35-40% end of the composting duration.
- Temperature can be kept between 40-55°C for stabilization and between the 55°C to 70°C for sanitization.
- During first phase, dry solid of waste includes 30% non-volatile solids (ash) and 70% volatile solids.
- During curing, dry solid of waste includes 72% non-volatile solids (ash) and 28% volatile solids.
- <u>Retention time and turning frequency</u>

First 40 days high-rate composting- turned every week; then curing phase, 45 days.

- <u>Transfer coefficients and reconciliation of data</u>

Based the datas on Table 4, It is estimated that $TK_{compost}$ and $TK_{loss}$ can be 38% and 62%, respectively.

- <u>During compost + anaerobic digestion process, transfer coefficients:</u>
- TK (compost): 31%

  TK (losses): 69%

Substance flow analysis were performed by means of the mass- balance model STAN, SFAs have been performed for carbon and nitrogen for each scenario. Transfer coefficients was calculated base on data from Christensen (2012) (Figure 21-22-23-24-25-26)

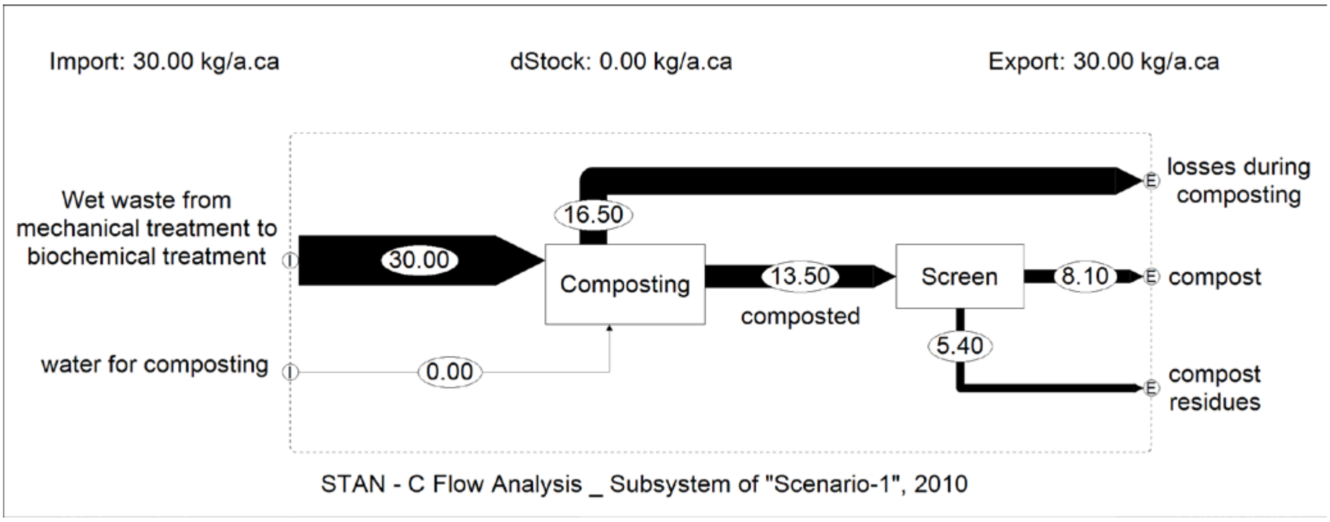



Figure 21. STAN C Flow Analysis_ Subsystem of “Scenario-1”, 2010

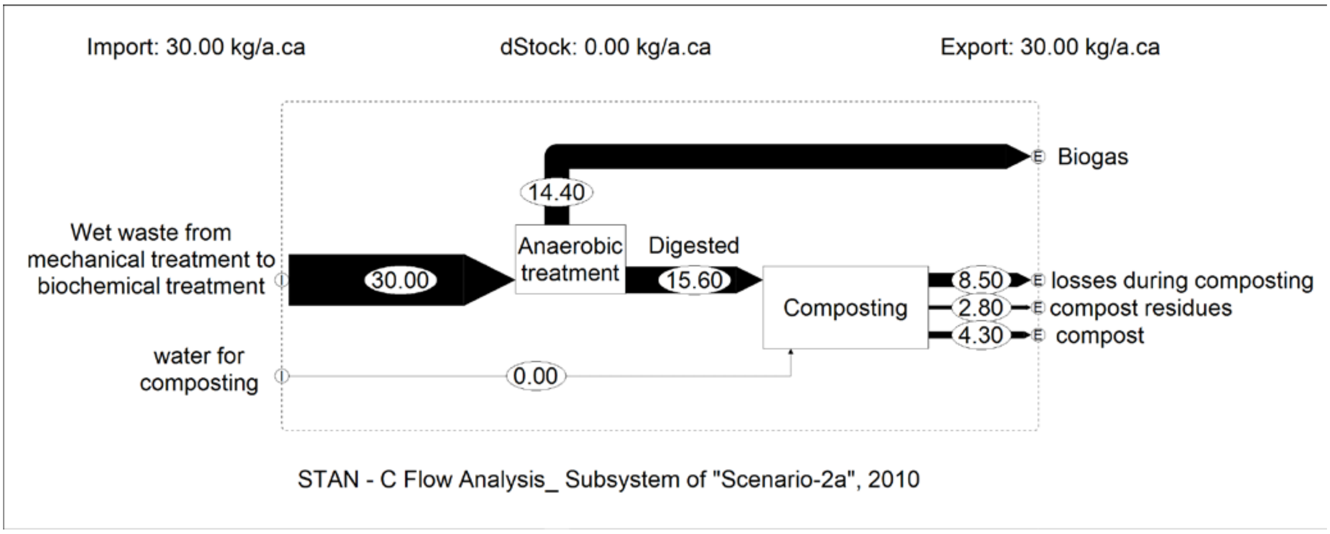



Figure 22. STAN C Flow Analysis_ Subsystem of “Scenario-2a”, 2010

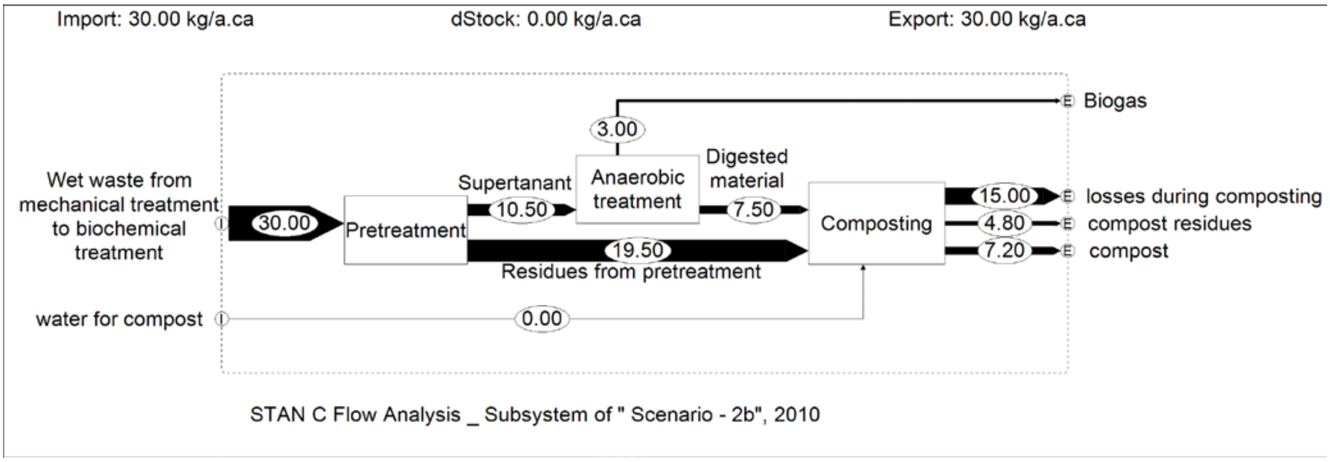



Figure 23. C Flow Analysis_ Subsystem of “Scenario-2b”, 2010

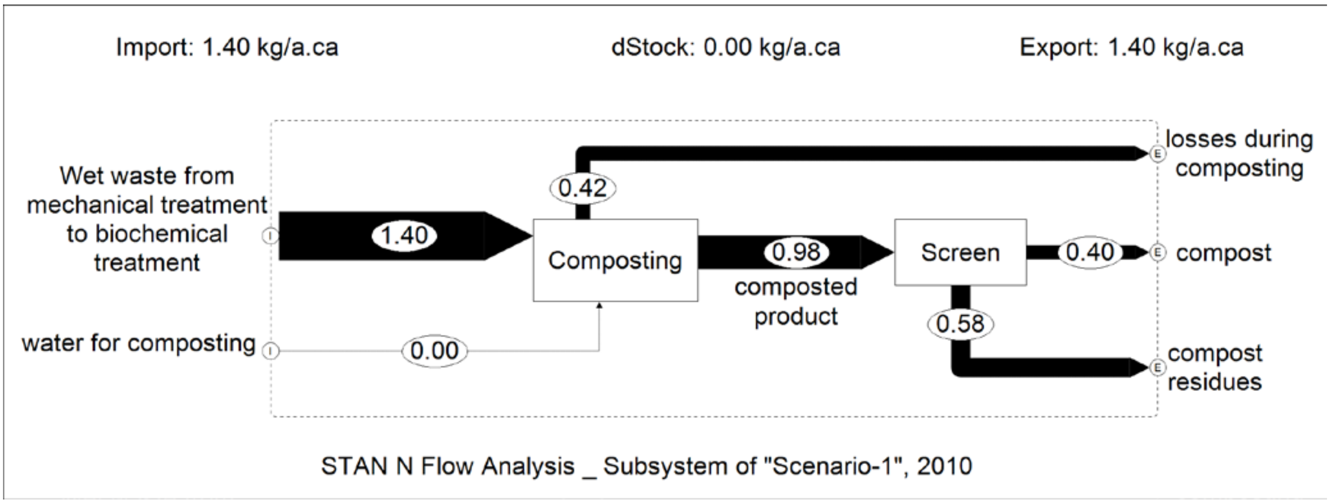



Figure 24. STAN N Flow Analysis_ Subsystem of “Scenario-1”, 2010

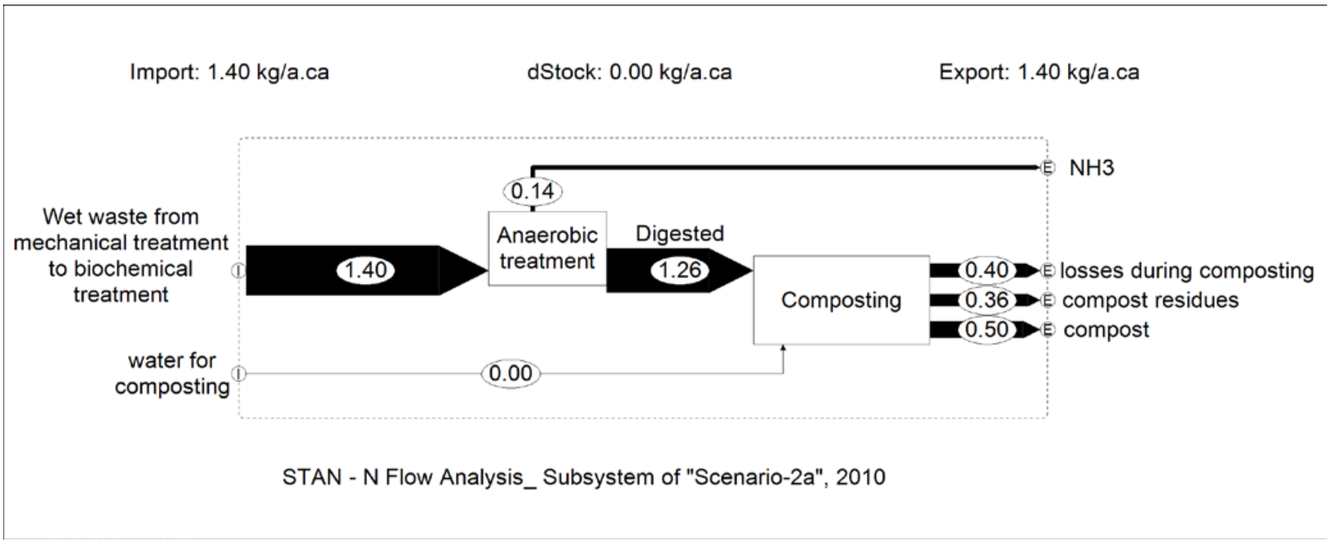



Figure 25. STAN N Flow Analysis_ Subsystem of “Scenario-2a”, 2010

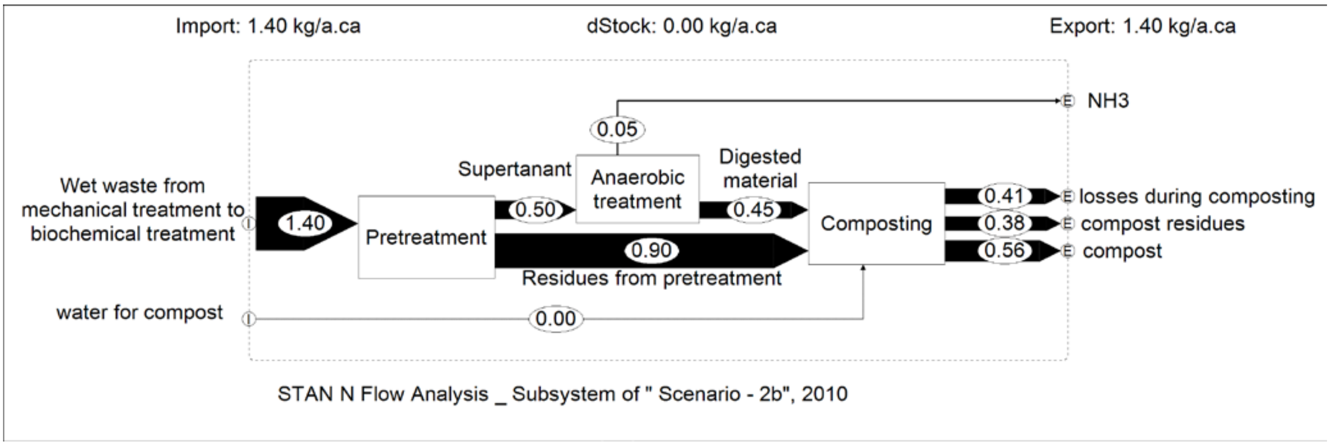



Figure 26. STAN N Flow Analysis_ Subsystem of “Scenario-2b”, 2010

It is obtained that the least carbon and nitrogen emissions have been released into the atmosphere in the first Scenario. Its contribution to global warming will be less than other scenarios.

## 6 Cost Analysis for all scenarios

The cost of initial capital invesment and operating costs are calculated using equations which are given on Table 9.

Table 9. Approximate cost functions for MSW treatment facilities in Europe (Tsilemou K., et.al., 2006)

| Type of facility | Suggested cost functions for Initial capital investment (€) |
|---|---|
| Open-air composting | $Y = 4000 \times W^{0.7}$ |
| Anaerobic digestion | $Y = 35000 \times W^{0.6}$ |

W: amount of waste

***Scenario 1***

*<u>The cost of composting plant</u>*

Amount of incoming wet waste to composting plant = 204 kg/ca. year (STAN Scenario-1)

204 kg/ca. year=0.5589 kg/ ca. day.

Population= 4,050,028 ca.

Design Capacity: 0.5589 x 365 x 4,050,028 =826,200 ton/year

Initial capital investment (€)=$Y = 4000 \times W^{0.7} = 4000 \times (826{,}200)^{0.7}$ =55,500,000 €

Depreciation period: 20 years. Discount rate: 6 %

Depreciation cost: 66,600,000 €/ 20 years

Operational cost: Y= 20 €/ton (Tsilemou K., et.al., 2006)

Annual operating cost: 20 €/ton x 826,200 ton = 16,524,000 €/ year

Total operating cost: 16,524,000 €/ year x 20 year= 330,480,000 €/ year

Total cost: 55,500,000 + 66,600,000 + 330,480,000 = 452,580,000 €/ 20 year

*<u>Total cost/ capacity= 452,580,000 €/ 20 year x 826,200 ton =27.40 €/ton</u>*

***Scenario 2a -Anaerobic digestion***

<u>Design capacity of anaerobic digestion plant</u>

Amount of incoming wet waste to digestion plant = 204 kg/ca. year (STAN Scenario-2a)

204 kg/ca. year=0.5589 kg/ ca. day.

Population= 4,050,028 ca.

Design capacity: 0.5589 x 365 x 4,050,028 = 826,200 ton / year

*<u>Initial capital investment</u>* (€)=Y= 35,000 x $W^{0.6}$ =35,000x $(826,200)^{0.6}$= 124,260,000 €

Depreciation period: 20 years. Discount rate: 6 %

*<u>Depreciation cost:</u>* 149,520,000 €/ 20 years

Operational cost: 30 €/ton (Tsilemou K., et.al., 2006)

Annual operating cost: 30 €/ton x 826,200 ton = 24,786,000 €/ year

*<u>Total operating cost:</u>* 24,786,000 €/ year x 20 year=495,720,000 €/year

Total cost: 124,260,000 + 149,520,000 + 495,720,000 = 769,500,000 €/ 20 year

Total cost/ capacity= 769,500,000 €/ (20 year x 826,200 ton)=46,57 €/ton

*<u>Revenue from sales of energy:</u>* 10 € /ton

Anaerobic digestion capacity: 826,200 ton/year

Moisture content: 60%

The amount of dry solid: 826,200 x 0.40 = 330,480 ton/year

The amount of volatile solid: 231,336 ton/year

Volatile solid reduction: 40%    Thus,

The amount of destroyed volatile solid production: 92,534 ton /year

Methane yield ($m^3$/kg): 0.36

Methane yield ($m^3$): 92,534 ton/year x0.36 $m^3$/kg x $10^3$kg/ton= 33,312,240 $m^3CH_4$/year

One cubic metre of $CH_4$ has a heating value of around 22,400 kilojoules/$m^3$.

33,312,240$m^3CH_4$/year x 22,400 kilojoules/$m^3$=7.4619x$10^{11}$ kilojoules

7.4619x$10^{11}$ kilojoules= 207,270,356 kwh

207,270,356 kwh x 4 cent= 8,290,815 €/year

8,290,815 €/year / 826,200 ton/year = 10 €

*Net cost for anaerobic digestion process = 47.5-10 = 37.5 €/ton*

***Scenario 2a - Composting***

Design capacity of composting plant

Amount of incoming wet waste to composting plant from anaerobic dig. plant = 183.6 kg/ca. year (STAN Scenario-2a)

183.6 kg/ca. year=0. 50 kg/ ca.day.

Population= 4,050,028 ca.

Design Capacity: 0.50x 365 x 4,050,028=739,130 ton/ year

Initial capital investment (€) =Y= 4000 x $W^{0.7}$ =4000 x $(739,130)^{0.7}$ =51,306,000 €

Depreciation period: 20 years. Discount rate: 6 %

Depreciation cost: 61,600,000 €/20 years

Operational cost: Y= 18 €/ton (Tsilemou K., et.al., 2006)

Annual operating cost: 18 €/ton x 826,200 ton = 14,871,600 €/ year

Total operating cost: 14,871,600 €/ year x 20 year= 297,432,000 €/ year

Total cost: 51,306,000 + 61,600,000 + 297,432,000 = 410,338,000 €/ 20 year

*Total cost/ capacity= 443,386,000 €/ (20 year x 739,130 ton) = 27.70 €/ton*

***Scenario 2b -Anaerobic digestion***

Amount of incoming wet waste to microwave pretreatment unit = 31 kg/ca. year (STAN Scenario-2b)

31 kg/ca. year=0.085 kg/ ca. day.

Population= 4,050,028 ca.

Design Capacity: 0.085x 365 x 4,050,028=125,652 ton/year

Initial capital investment = 20,000,000 € (Tsilemou K., et.al., 2006)

Depreciation period: 20 years. Discount rate: 6 %

*Depreciation cost:* 24,000,000 €/ 20 years

Operational cost: 30 €/ton (Tsilemou K., et.al., 2006)

Annual operating cost: 30 €/ton x 125,652 ton = 3,769,600 €/ year

*Total operating cost*: 3,769,600 €/ year x 20 year= 75,391,200 €/year

Total cost: 20,000,000 +24,000,000 + 75,391,200 =119,391,200 €/ 20 year

Total cost/ capacity= 119,391,200 €/ (20 year x 125,652 ton)= 47.50 €/ton

*Revenue from sales of energy:* 15 € /ton

Anaerobic digestion capacity: 125,652 ton/year

Moisture content: 60%

The amount of dry solid: 125,652 x 0.40 = 50,260 ton/year

The amount of volatile solid: 35,183 ton/year

Volatile solid reduction: 60%    Thus,

The amount of destroyed volatile solid production: 21,110 ton /year

Methane yield ($m^3$/kg): 0.36

Methane yield ($m^3$): 21,110 ton/year x0.36 $m^3$/kg x $10^3$kg/ton= 7,599,600 $m^3CH_4$/year

One cubic metre of $CH_4$ has a heating value of around 22,400 kilojoules/$m^3$.

7,599,600 $m^3CH_4$/year x 22,400 kilojoules/$m^3$= 1.70231 x $10^{11}$ kilojoules

1.70231 x $10^{11}$ kilojoules = 47,286,400 kwh

47,286,400 kwh x 4 cent= 1,891,456 €/year

1,891,456 €/year / 125,652 ton/year = 15 €

*Net cost for anaerobic digestion process = 47.5-15 = 32.5 €/ton*

***Scenario 2b -Composting***

Design capacity of composting plant

Amount of incoming wet waste to composting plant from anaerobic dig. plant=198 kg/ca. year (STAN Scenario-2b)

198 kg/ca. year=0. 54 kg/ ca.day.

Population= 4,050,028 ca.

Design Capacity: 0.54x 365 x 4,050,028 = 798,260 ton/ year

Initial capital investment (€)=Y= 4000 x $W^{0.7}$ =4000 x $(798,260)^{0.7}$ =54,145,335€

Depreciation period: 20 years. Discount rate: 6 %

Depreciation cost: 64,974,400 €/20 years

Operational cost: Y= 20 €/ton (Tsilemou K., et.al., 2006)

Annual operating cost: 20 €/ton x 798,260 ton = 15,965,200 €/ year

Total operating cost: 15,965,200 €/ year x 20 year= 319,304,000 €/ year

Total cost: 54,145,335 + 64,974,400 + 319,304,000 = 438,423,735 €/ 20 year

*Total cost/ capacity= 438,423,735 €/(20 year x 798,260 ton) = 27.46 €/ton*

***Scenario 2b –Microwave pretreatment***

Microwave Features

Frequency: 2450 Hz

Power: 750 W( adjustable)

Batch operation

Amount of incoming wet waste to microwave pretreatment = 204 kg/ca. year (STAN Scenario-2b)

204 kg/ca. year=0.5589 kg/ ca. day.

Population= 4,050,028 ca.

Design capacity: 0.5589 x 365 x 4,050,028 = 826,200 ton / year

*Initial capital investment* (€)=Y= 600.000 €

Depreciation period: 20 years. Discount rate: 6 %

*Depreciation cost:* 720.000€/ 20 years

*Total operating cost:* 500.000 €/ year x 20 year=10,000,000 €/year

Total cost: 600,000 + 720,000 + 10,000,000 = 11,320,000 €/ 20 year

Total cost/ capacity= 11,320,000 €/ 826,200 ton/year =13,70 ton

*Cost of Harmandali Landfill Site*

Amount of incoming mixed waste to lanfill site

1.28 kg/ca. year (STAN Status quo)

Total amount of MSW=32,000,000 ton

Initial capital investment (€)=1,600,000 €

Depreciation period: 20 years. Discount rate: 6 %

Depreciation cost: 1,920,000 €/ 20 years

Operational cost: Y= 6 €/ton (Tsilemou K., et.al., 2006)

Total operating cost: 6 €/ ton x 32,000,000 ton = 192,000,000 €/ 20 year

Total cost: 1,600,000 €+ 1,920,000 €+192,000,000 €=195,520,000

Total cost/ capacity= 195,520,000 €/ 32,000,000 =6,11 €/ton

Total cost / capita.year=195,520,000 / 4,050,028 x 20 = 2.4 €/ton.ca

Table 10. Estimated total costs

| Scenarios | Composting (€/ton) | Anaerobic Digestion (€/ton) | Microwave Pretreatment (€/ton) | Revenue from sales energy (€/ton) | Total cost (€/ton) |
|---|---|---|---|---|---|
| Status Quo (Landfill) | | | | | 6.11 |
| Scenario1 (Composting) | 27.40 | | | | 27.40 |
| Scenario2a (compost+anaerobic digestion) | 27.70 | 46.57 | | 10.00 | 64.27 |
| Scenario2b (microwave+compost +anaerobic digestion) | 27.46 | 47.50 | 13.70 | 15.00 | 103.66 |

*Evaluations*

Table11. Summary of outputs of Status Quo and Scenarios

| | $CO_2+H_20$ kg/ca.a | Biogas $CO_2+CH_4$ kg/ca.a | $CO_2$-eq kg/ca.a | $CH_4$-eq kg/ca.a | Compost kg/ca.a | Compost Residues kg/ca.a |
|---|---|---|---|---|---|---|
| Status Quo | | 70 | | | | |
| Scenario1 | 151 | | 23 | | 65 | 28 |
| Scenario2a | 140.48 | 20.40 | 30 | | 44.12 | 19 |
| Scenario2b | 150 | 5.20 | 25.50 | | 48 | 20 |

All scenarios were analysed in terms of their impacts on costs and goal-oriented parameters. The ratio of organic waste is circa 46% of total MSW. If the organic wastes are sent to landfill site after treatment, landfill volume will decrease 40%, greenhouse gas emissions CO2-eq. will be reduced within the ratio of 30%, also. Disposal ratio of organic wastes will reduce approximately within the ratio of 95%. Thus, direct impact on environment and indirect effect of human health of landfill sites will potentially decrease. The cost of landfill site will be decreased within the ratio of 40%. When wastes are collected separately, recyclables and compost product can be reused (Table 11-12 and Figure 27).

Table 12. Comparison of status quo and scenarios MSWM in Izmir

| | Status Quo | Scenario1 | Scenario2a | Scenario2b |
|---|---|---|---|---|
| Greenhouse gas emissions (CO2-equivalent) | 35 | 25 | 10 | 5 |
| Material recycling rate(compost) | n.d. | n.d.+21 | n.d.+21 | n.d.+24 |
| Disposal rate | 100 | 9 | 9 | 10 |
| Reduction of Landfill volume required for organic wastes | 0 | 40 | 42 | 42 |
| Cost / Capacity-year (€) | 6.11 | 27.4 | 64.27 | 103.66 |

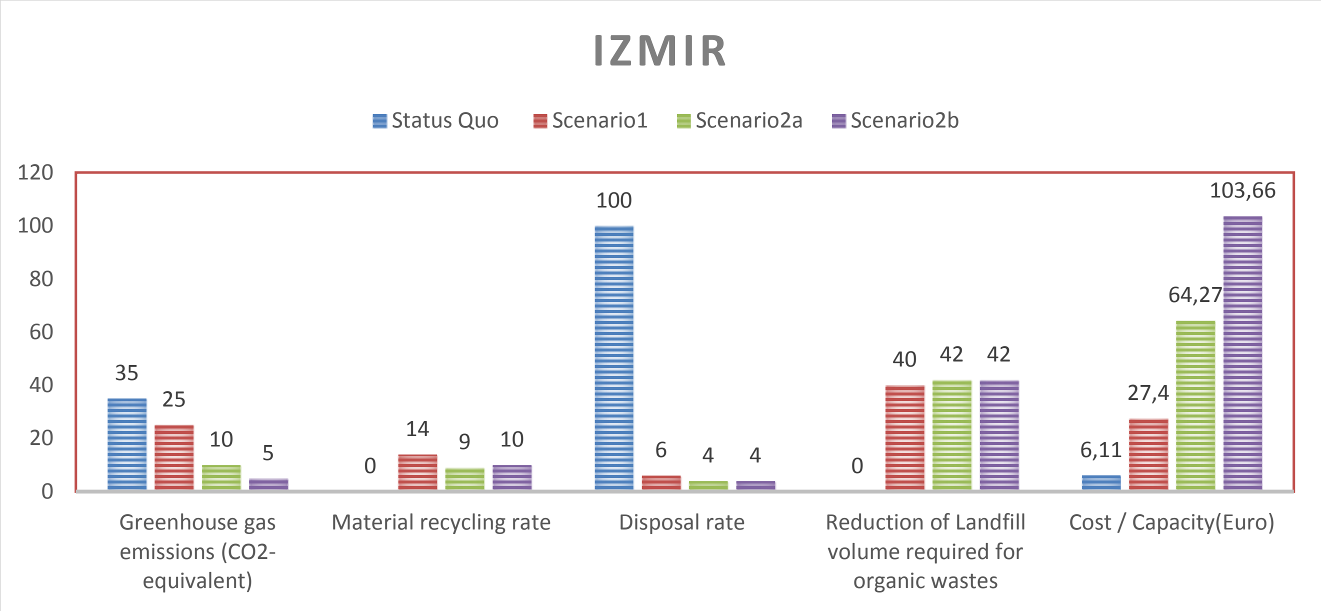



Figure 27.Changes of goal oriented parameters  for different scenarios of IMSWM in Izmir

Units: Greenhouse gas emissions ($CO_2$- equivalent), kg $CO_2$/ ca. year

Material recycling rate ; recyled material per total input, in tons

Landfill rate; recyled material per total input, in tons

Reduction of landfill volume required for organic wastes, in tons.

# 7 Conclusions

The aim of MSW management is protect human health and the environment, and to conserve resources. The most cost-effective method is the first scenario to reach the objectives of solid waste management. Because, according to foundings, municipality has been gathering 13.83 €/ca.year for whole solid waste management. Izmir municipilaty needs 27.4 €/ca.year to fulfill Scenario1. Thus, municipilaty should spend 21.4 €/ca.year more. This cost is also not included collection and transport expenses. It is recommended that Izmir municipilaty must determine and organize its economic capacity for waste management system to reach waste management goals.

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