Study of Influence Factors in Municipal Solid Waste Management Decision-making

Master of Science Thesis
Stockholm 2007
Kui Li

Study of Influence Factors in Municipal Solid Waste Management Decision-making

Supervisor & Examiner:
Monika Olsson

Master of Science Thesis
STOCKHOLM 2007

Presented at
Industrial Ecology
Royal Institute of Technology
ABSTRACT

Nowadays, municipal solid waste (MSW) has got great attention from world-wide decision makers in the field of waste management. When they are making a MSW management decision, there are lots of factors that may influence their final decision for picking up an optimal alternative. In order to find out the influence factors in municipal solid waste management decision-making, incineration and anaerobic fermentation techniques are selected as example for comparison. Literature study and interview are used for collecting theoretical and practical information respectively. A list of theoretical influence factors is created, which integrates environmental, social and financial aspects of incineration and anaerobic fermentation. This list can help the decision-maker to have a better choice when they are choosing an alternative from MSW management methods. Practical information is achieved by interviewing the City of Stockholm Waste Management Administration. Differences are revealed between theory and the Stockholm case. The priority of each influence factor is discussed in this paper. Base on the decision between theoretical factors and the Stockholm case, the result shows that the theoretical factors are not completely sufficient for the practical use in the city of Stockholm. The list of theoretical influence factors should be extended by integrating more factors and more MSW management alternatives to meet different requirements in practical cases. There is no clear definition on which factor has the highest degree of influence for the decision-maker. The priority of influence factors is depended on the local condition and subjective choice of decision-maker.

Key words: municipal solid waste (MSW), municipal solid waste management, decision maker, influence factor, incineration, anaerobic fermentation, Stockholm
# TABLE OF CONTENT

1. INTRODUCTION................................................................................................................ 1
   1.1. Aim and Objectives................................................................................................. 1
   1.2. Methodology .......................................................................................................... 2
   1.3. Background ........................................................................................................... 2

2. MSW MANAGEMENT TECHNIQUES FOR COMPARISON..................................... 6
   2.1 Anaerobic fermentation—Mesophilic one-stage dry digestion ................................ 6
   2.2 Incineration-Mechanical Stoker Incinerator.......................................................... 9

3. INFLUENCE FACTORS ................................................................................................. 12
   3.1 Legislation............................................................................................................... 12
   3.2 Geographic Location ............................................................................................. 12
   3.3 Collection and Transportation ............................................................................. 13
   3.4 Capacity ............................................................................................................... 14
   3.5 Composition .......................................................................................................... 15
   3.6 Potential risk to human health ............................................................................. 15
   3.7 Potential risk to environment .............................................................................. 16
   3.8 Investment ............................................................................................................ 17
   3.9 Revenue ................................................................................................................ 19
   3.10 Residues handling .............................................................................................. 20
   3.11 Other impacts to public ..................................................................................... 21
   3.12 Comparison of the factors ................................................................................ 22

4. CITY OF STOCKHOLM CASE STUDY ..................................................................... 24
   4.1 Introduction of Stockholm, Sweden ....................................................................... 24
   4.2 Present State of MSW Management in the city of Stockholm.............................. 26
      4.2.1 Waste collection and composition ................................................................. 26
      4.2.2 MSW treatment ............................................................................................. 28
      4.2.3 MSW management cost............................................................................... 30
      4.2.4 Research and Development of MSW management ..................................... 30
   4.3 View from a decision-maker of the city of Stockholm ........................................ 31

5. DISCUSSION ................................................................................................................... 36
   5.1 Differences between theory and practical case .................................................... 36
   5.2 What we can do with these influence factors ....................................................... 37
   5.3 What should be done next ................................................................................... 37

6. CONCLUSION................................................................................................................... 38

REFERENCES....................................................................................................................... 39

ACKNOWLEDGEMENT ...................................................................................................... 43
1. INTRODUCTION

Municipal solid waste (MSW), according to the definition from U.S. Environmental Protection Agency (EPA), is composed by everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. There are many methods existing in present MSW management. According to the definition in EU countries, waste hierarchy is classified as: waste prevention, recirculation, energy recovery, treatment and then landfill. Different types of MSW should be treated in different ways to ensure minimizing the environmental, social and economic impacts. Each method in the waste hierarchy has their own functions in the waste management. Choosing the appropriate method for municipal solid waste has already become a hot point for the decision-maker. There are lots of influence factors that may wave the final choice when the decision is done. Weaving with environmental, social and economic aspects, the influence factors are complicated and interact. When a MSW management decision is made, the decision-maker should consider the factors, which have influence in the MSW management project. In general, some influence factors have been wildly accepted. However, the influence degree of each factor may differ, depending on the various local conditions. To optimize the local MSW management, decision-makers coming from different places may have various concerns of MSW management. They could have their own priority of influence factors on MSW management, according to the local conditions. With the help of grading the influence degree of each factor, the choice could be made much easier when making a decision among alternatives.

1.1. Aim and Objectives

The main aim of this paper is to find out which factors in the process of municipal solid waste management, have an influence on the decision-maker, and to discuss the priority of these influence factors in MSW management decision-making.

Objectives which support to achieve the aim are listed below:

- Select two common MSW techniques for comparison.
- Find out the benefits and draw-backs of each MSW technique.
- Extract and list theoretical influence factors covering the following parts: environment, economy, social aspects, infrastructure, technical aspects, quality aspects of waste and residues after treatment, market for residues.
- Find out the differences between the two selected MSW techniques by comparing the performance on the influence factors.
- Find out different priorities among influence factors when the decision is made by the city of Stockholm.
- Find out the difference between theoretical study and practical case study of the city of Stockholm.
- Find out which factors will influence the choice of decision-maker.
1.2. Methodology

This paper is based on literature study and interview Renhållningsförvaltningen (The City of Stockholm Waste Management Administration). The approaches are listed below.

- Internet searching for commonly present used techniques of MSW management.
- Literature study to collect theoretical information about the techniques selected.
- Collect influence factors mentioned in literature and internet.
- Interview to Renhållningsförvaltningen (The City of Stockholm Waste Management Administration) to collect practical MSW management information of the city of Stockholm.
- Base on the theoretical influence factors, compare differences between two selected MSW management techniques
- Use figures from the city of Stockholm as a case study to verify the theory to use factors for decision making.
- Compare and discuss different priorities among influence factors

1.3. Background

Today, nearly half of the world’s growing population is living in the urban areas, causing great pressure on the local environment. Along with population explosion, municipal expansion, economic development and improvement of people's living standards, the amount of municipal solid waste (MSW) has been increasing rapidly and its composition has become more various. In 2003, U.S. for instance, according to the statistic presented by EPA, the municipal solid waste generated from residents, industry, businesses, and institutions were over 236.2 million tons before recycling, which is almost 2 times more than the year 1960 (88.1 million tons). From the microcosmic angle, it is approximately 1.8 kg of waste per day per person in 2003, nearly twice of the year 1960. (EPA, 2006) For the composition of municipal solid waste, some of them, plastics and metals for instance, may course serious environmental problems and health hazard without proper treatment, such as river contamination, heavy metal pollution etc. Particularly, in the large regions of the developing countries, inadequate waste management and immature treatment technology may even worsen this situation.

MSW contains some valuable material, as mentioned above, plastics, metals, glass etc. Fortunately, most of them can be easily recycled, so separation processes have been introduced into the pre-treatment of municipal solid waste. It aims primarily at reduction of the mass, volume, toxicity and biological reactivity of the waste, in order to minimize environmental impact from waste deposition. Moreover, most of the materials recycled can be reused by companies or put in to the market. Saving the cost of waste treatment is just the basic benefit of the recycling process; the recycled materials would be reformed or reused as substitutes of raw material in the related field. Presently, recycling is known as a cost-effective way to manage municipal solid waste. However, waste recycling is not omnipotent and always the best solution in all conceivable cases. A recycling process should always be estimated with respect to their ecological impacts. As a result, recycling is only advisable, if it produces less damage than waste disposal or more interest than production from raw material.
In 1996, Robert F. Curl, Nobel Prize winning Chemist, stated “This was the century of physics and chemistry, but it is clearly that the next century will be the century of biology.” (The Biotech Century, 1997). Now we are in this “biological century”, so the biology has been wild-spread using and playing an important role in the industry, agriculture and other social service, including municipal solid waste management surely. A combination of mechanical processes, biological processes of MSW management, is known as mechanical-biological treatment (MBT) (Archer et al., 2005). At the beginning, MBT was applied as a pre-treatment technology for reducing the mass, volume, toxicity and biological reactivity of the residues before landfill, in order to minimize the environmental impact of landfill, such as green house gases and toxic leachate emission. Recovery of waste components for industrial reuse is an integral part in the development of MBT, especially concerning the production of refuse derives fuels (RDF). In the past approximately ten years, the mechanical-biological treatment of MSW has been accepted by Germany, Austria and Switzerland on technical scale, and pilot plant scale for some developing countries. In Germany, 1.8 million tons of MSW are treated in 29 mechanical-biological treatment plants (German Federal Environmental Agency, 2001). In processing of MBT, mechanical process is fixed, which aims to extract the organic fraction from mixed waste, but the biological stage is optional. Normally, there are two biological alternatives to process the organic-rich materials, aerobic composting and anaerobic fermentation. Composting is the oldest form of recycling and has been used for treatment of municipal solid waste in many places in the last century. Composting, which favours the structural materials (tree cuttings and agricultural green wastes), converts wastes into heat and fertilizer (Barth, 2006). Heat can be used for internal reactor heating and the compost produced is proofed as high quality fertilizer for agriculture use. However, since open-air composting always brings terrible odour problems; the application of composting has been limited. In recent years, technological advancements have improved odour control capabilities of composting, as well as the quality of the end product. Another MBT technique, anaerobic fermentation, also called anaerobic digestion, is flexible for easy-degradable and high water concentration materials such as kitchen waste, restaurant waste and slaughterhouse waste. Due to the high energy lost in waste combustion of high moist waste, anaerobic fermentation has been becoming a new favourite in many countries. Recently, anaerobic fermentation of MSW has been deeply researched and developed by U.S. and several European countries. In the year 2000, there were more than 125 anaerobic digestion plants operating worldwide and a further 35 under construction using municipal solid waste or organic industrial waste as their principal feedstock, with a combined capacity of more than five million tonnes annually (Reynolds, 2005). In Germany and Switzerland, some 10 to 12% of the total bio-waste is processed by anaerobic fermentation (Schleiss, 2003). Organic and mineral materials are recycled and transformed into the form of high quality fertilizer by stabilization process. Anaerobic fermentation is also a source of renewable energy, which is another feature of processing this biological process. In general, by anaerobic fermentation, every ton MSW produces 100-200m³ of biogas, with a methane content of about 65%, 34% carbon dioxide and 1% trace gases (Schleiss, 2003). The biogas yielded can be converted to electricity by block heating and generation plant. Moreover, there is another option for the biogas. Biofuel can be produced from yielded biogas, if the methane are extracted and purified into a sufficient concentration. According to the AD-Nett database for the 15 members of EU, 1234.3 million tones total biomass is estimated to be produced in 2020, equal as 209 TWh and 753 PJ biogas energy (AD-Nett, 2002). Due to the strict requirement of operating conditions (such as temperature and pH), high quality equipments are required, which obviously rise up the cost. How to convert the biogas generated from fermentation to the energy market is another big problem which may influent the willingness of decision maker.
Limit to technique and investment, extracting organic fraction from mixed waste is a highly expensive and complicate process. In some developing and developed countries, MSW incineration is popular with high waste treatment efficiency. Burning MSW can generate energy, meanwhile reducing the amount of waste by up to 90 percent in volume and 75 percent in weight (EPA, 2006). The primary function of incineration has been mass and volume reduction and waste minimization. The energy recovery for heat and electricity generation has to be the secondary, but more and more important goal. In Europe, there were 304 waste incineration plants in operation at the end of 2000, and in the 15 EU members, there were 269 facilities (Bill, 2001). The total capacities of these units were 50.2 million tons of MSW and related waste. Energy recovery was 49.6 TWh/a, of which, 70% was used for heat and 30% for electricity generation (Sipilä, 2002). Averagely, the processing input of solid waste is 225,000 t/a, while power generated is 400 GWh/a (Sipilä, 2002). The bottom ash from incinerators has been widely used as structural material, e.g. road construction. The composition of bottom ash corresponds very closely to the composition of cement and traditional additives to cement. Average 250 kg of bottom ash and base 33 kg air-pollution control residues are produced from 1 ton of MSW (Clément, 2000). It makes sense to recycle this material in construction application, especially in the cement industry. However, waste incineration always goes with hard discharged and highly unenvironmental flue gas e.g. CO₂, NOx and fly ash, which may lead to environmental and social consequences such as global warming and regional toxic atmosphere. High cost, as well as inadequate technical support, may influence the further development of MSW incineration.

The majority of waste in developing countries continues to be disposed of in landfills, which is the least desirable option in the waste management hierarchy. At the beginning, the conventional landfill methods just dispose the MSW without materials recovered, which produced series of environmental and social problems, such as landscape breaking, farmland decreasing and groundwater polluting. During the last few decades, municipal governments have advanced from non-standard disposal of waste to a more controlled environment. The main focus of this evolution has been to close uncontrolled landfill plant and shift to more environmentally sound land disposal facilities. For example, in the 15 EU member countries, strict legislation has been implemented to minimize the potential human and environmental risks. According the Directive 99/31/EC on landfill of waste, standard of landfill waste acceptance has been published, operating criteria and information system has also been established (European Commission, 2006). In general, land disposal was, and is, a known entity and for the most part, readily available to municipal governments. In 2004, the EU 15 members, generated 580 kg MSW per person per year on average, 242 kg of these wastes disposed by landfill, corresponding to 41.7% (Eurostat, 2006). This means landfill is still the major and essential part of waste disposal. However, landfill needs large land areas, as well as generated poisonous leachate and green house gases. This results in not only serious environmental risks, but also social and economical problems. It makes waste landfilling gradually displaced by integrated modern waste treatment methods.

The current hot researching point is the middle level of the solid waste hierarchy, which is crucial in MSW management. It handles the waste from recycling decides the amount and volume of waste that has to be disposed of in landfill. Waste prevention and recycling is a problem of people’s attitude, and the waste recycling will be accepted all over the world sooner or later. But after recycling, what should we do to reduce the pressure of overloaded landfill plant and hazard emission (both air emission and leachate)? That is a most serious issue on the table of every local municipality and organization. In recent years, modern
incineration and anaerobic fermentation have attracted the attention of MSW decision-maker, because of their efficient reduction of mass, volume, toxicity and biological reactivity of MSW before the final disposal on landfill. Both of them have already been accepted by development and several developing countries, further improvement is under research and developing to optimize the environmental, social and economical performance. Presently, these two middle level processes of MSW hierarchy make really good sense in the aim of reducing the waste volume and mass, and at the same time generating energy in different forms. However, some negative impacts are congenital; for example, an incineration process is not efficient for low caloric materials, while anaerobic fermentation has a low treatment capacity. Thus, optimizing the MSW management efficiency and minimizing the negative impacts are depended on the choice of decision-maker, according to the local condition.

How to make an appropriate decision? There are three basic aspects of sustainable waste management that should be considered: protection of man and environment, economic compatibility and social compatibility. Technical implementation always involve with the performance of these three aspects, which will influence the willingness of local governments and decision-maker. Nowadays, techniques adapted to every kind of exploitation exist, but sometimes the market prices are not adapted to sustainable processing. For example, an important argument in favour of anaerobic fermentation is the production of energy. But the proceeds from the energy cover only at most 10% of the operation costs, since comparable oil and electricity price are much lower (Schleiss, 2003). Incineration plant has fine performance in energy recovery, but the toxic substances in flue gases may damage human health and environment. There are dozers of factors that can influence the choice of decision-maker, such as investment, interests and local residents’ attitude. To avoid unnecessary risks, environmental, economical and social performance of MSW management facility should be considered integrally. With the aim of taking the most fitting alternative, when analysing a proper MSW management method, an amount of factors should be considered and analyzed, in order to balance the three aspects. With the help of listing the present factors and analyzing the impacts, the sustainable waste management schemes will be made in a proper way to fit the local condition.
2. MSW MANAGEMENT TECHNIQUES FOR COMPARISON

In this paper, MSW management methods are chosen to be compared between biological techniques and incineration. For biological methods, composting and anaerobic fermentation are the most common process in using, while due to the odour emission and low treatment capacity, composting is not so popular as anaerobic fermentation. For incineration, the incinerator is the major difference among incineration methods. Stoker is one type of mass-burn incinerators for mixed waste, which is reliable and eligible, flexible for feedstock, and no per-treatment is needed. Thus, anaerobic fermentation and stoker incineration are selected as general MSW management techniques for comparison in this paper.

2.1 Anaerobic fermentation—Mesophilic one-stage dry digestion

![Anaerobic fermentation plant](image)

In Figure 1, an installed anaerobic fermentation plant is shown. Anaerobic fermentation (AF) techniques are classified by three major parameters: reaction temperature, steps and total solid (TS) content. This technique, with mesophilic condition, one-stage and dry process, has simple digester design, no moving parts within the reactor. Reaction takes place under the continuous condition, which means that the reactor can keep working continuously, even during the weekends. There is a buffer installed, that allows the feeding of the substrate, so that a continuous gas production is secured. Anaerobic fermentation can work in two reaction temperature periods: mesophilic (30-35°C), and thermophilic (50-55°C). For high reliability and low energy consumption, mesophilic method is concerned in this paper. One-stage system means the reaction takes place in one reactor. The reaction contains two steps: acidification and methane-generation. Due to the less expense and simple operation of one-stage compared to two-stages or multi-stages, the one-stage system has been wildly accepted by Europe countries, about 90% of the full-scale plants in use rely on one-stage systems (Lissens et al., 2001). Also, the AF technique is split into dry and wet system. The dry system can be defined as a digestion which takes place at rather high solid concentrations, in range of 20%-40% TS, depending on the waste composition. Consequently, only very dry waste (>60% TS) needs to be diluted by process water (Baeten et al, 1988). But this technique is weak for the feedstock
with low TS (<20%). Based on characters above, this AF technique selected is a flexible biological process which can be applied for MSW, organic fraction of mixed waste, food wastes, and other biodegradable wastes. In Figure 2, there is a simple illustration of anaerobic fermentation reactor.

In this type of AF process, the original refuse is subjected to pre-treatment by sorting, which permits biodegradable substances are extracted from the mixed solid wastes. Followed by shredding, homogenizing and sieving, the feedstock size has been strictly controlled by a screen (e.g. 40mm in Kaiseslautern plant, Germany) (ZAK, 2006). The oversize fraction is sent to thermal treatment and landfill. The organic fraction is subjected to be pumped into the sealed container with a tundish. Maintaining the temperature by a mesophilic conditions (30-35℃), anaerobic digestion is taking place during a period of 12-18 days, followed by a post-fermentation with a retention time of 2-3 days. The biogases will be extracted to the circular store through the pipe that located at the top of container. Residues will be pumped out through the bottom of container. The generated heat is used for digesters heating and drying the solids cake. The digested residue is extracted and subsequently dewatered by means of a press. The dewatered residue will be further pressed and broken to solids cake, and then sent to a post-composting system with the result to produce mature compost. This compost can be used as high quality fertilizer for farming use. Most effluent water will be recycled together with fresh substrate and pumped back into reactor. Wastewater could be centrifuged and evaporated by utilizing the waste heat from the gas engines (Baeten, 1988). In this manner, no wastewater is generated. A flow-sheet of AF process is shown in Figure 3.
Fig. 3. Flow-sheet of the AF process
(Baeten 1988)
2.2 Incineration-Mechanical Stoker Incinerator

Figure 4 shows a stoker-type incineration plant with three 200 ton/day reactors in Pusan Dadai, Korea. As a typical waste-to-energy technique of MSW management, mechanical stoker incinerator (MSI) has been very commonly applying all over the world. Based on the coal-fired technology, mechanical stoker incinerator integrates with special-designed moving furnace, air supply system, energy converter, ash collection equipment and flue gas cleaning system. Flexible to the composition of waste, pre-treatment is not necessary, various waste can be directly combusted together. Another feature of MSI process is high capacity, which is suitable for large amount of municipal waste. Divided by capacity, stoker incinerator can be classified into three types: small-scale (10-100 t/d), middle-scale (100-300 t/d) and advance large-scale (> 300 t/d), the largest stoker incinerator in China is located in Shanghai, whose capacity is 1000 t/d (Cen et al., 2003). Large waste treatment capacity is a remarkable feature of stoker-type incinerator. In this paper, large-scale stoker-type incinerator is concerned. All types of grate are working under the temperature of approximately 850°C-1300°C. Temperature, as well as pressure, is a key parameter for operating the combustor. Usually, the combustion temperature has to be higher than 850°C, in order to burn every type of waste. However, high temperature requires high quality durable material for the equipment, leading to high installation cost. Waste residence time is recommended more than 2 seconds to ensure complete combustion (Takuma et al., 2004). In recent years, novel technology is under research and development. Reducing the combustion air flow rate and enriching the oxygen are two significant improvements for preventing generation of toxic substances that will be applied in the next-generation stoker incinerator (Takuma et al., 2004).
Figure 5 shows the structure of one type of MSI grate. In the MSI technique, municipal solid waste is fed into the combustor through the hopper, which also plays as buffer to make sure the reaction continuous. The charged waste forwards into the combustion zone and burn together with air which usually comes from the bottom. To achieve the optimal incineration efficiency, secondary air (overfire air) can be injected over the fire to ensure the complicity of combustion. There are three main steps of waste combustion: drying, combustion and burn-out. First, the waste is dried by the exhaust heat from the main combustor, and then it will be transferred into the main great. With help of the moving great, the waste mixes air during the main reaction, burnt-out ash will be removed from the chute. The unburnt component will be moved into the burnt-out grate where the combustion will be completed with an auxiliary fuel burner (Mantia, 2002). In this type of mechanical stoker incineration, oil is used as the secondary fuel in the burnt-out step. The resulting ash drops from the grate and is collected by a water scheme at the bottom and carried away by a ridding conveyor. Heat is recovered from the exhaust heat boiler, and power generation is achieved by using steam turbines. The power generated is utilized for in-plant need and the surplus power is exported outside. Air pollution control (APC) process at the end-pipe is essential, for meeting the strict legislation of air emission. Bag filter is popular to collect the fly ash from flue gases and other physical or/and chemical methods will be applied to reduce the hazard level of flue gases. APC residues will be sent for deep treatment, such as washing and sintering, because of high concentration of hazard material, such as heavy metals and alkaline materials, and then landfilled (UNEP, 2003). Ash collected from bottom and boiler has a potential value for construction materials and cement industry. It can be used for bulk production, road building and cement addition materials. Figure 6 illustrates the model of MSI process for municipal solid waste.
Fig. 6. flow-sheet of MSI process
3. INFLUENCE FACTORS

When the MSW management decision is under processing, there are lots of factors that will influence the decision-makers’ choice, some of which are so vital that may have the power to deny the entire program. Integrated with environmental economic and social aspects, the decision makers have to balance the positive and negative impacts of each factor to make sure that the decision made is optimal. By comparing the performance between Mechanical Stoker Incineration (MSI) and Anaerobic Fermentation (AF), these factors are selected so that can have a stage to lay their features. Due to the complicacy of making a MSW management decision, there are amount of factors that may influence the decision-maker’s choice. It is impossible to list and analyze all of them. In this paper, the influence factors selected are based on some criteria. First of all, they have to cover environmental, social and economic aspect of MSW management to ensure the sustainable development. Then they are based on the literature study and knowledge accumulation. They are most frequently mentioned in the references or are the common ideas from the public. Following the criteria mentioned before, some potential factors to be considered are selected and listed below.

3.1 Legislation

Waste management strategies cannot be implemented without the support and guidance of legislative framework. Legislation should contain a series of ordinances and regulations aimed at managing solid waste, including procedures and methodologies for monitoring and enforcing the regulations. Consistent national policies on MSW legislation are needed. The policies should encourage cross-jurisdictions and inter-agency coordination, and facilitate implementation of economic instruments for improving waste management (World Bank, 2005). However, different region have different national legislations and local ordinances. For example, in EU countries, different MSW definitions are implemented. What’s more? Different legislations are implemented for different MSW management methods. Most European countries are aiming to limit MSW disposal to landfills to no more than 5% of the collected material and have increased taxes on landfilling (Verma, 2002). For MSI, this ordinance will ensure the solid waste is properly treated combustibility rather than buried in the ground. Electricity selling is also promoted by governments. The most public concern of MSW incineration is involved with significant emission of flue-gases, which may contribute to global warming and human health damage. Most ordinances for setting up a MSW incineration site are about limitation of air pollution. For AF, the advances of this technology have been supported by legislation. Since January 1st 2005, the Swedish government has banned disposing organic solid waste by landfill, which means food wastes from restaurants and institutional catering establishments are encouraged to be treated by biological methods. In Netherland and other EU countries, biogas from AF facilities is allowed for selling as a premium (Verma, 2002). Thus, as the macro monitoring framework, legislation should be the essential factor to influence the decision-making.

3.2 Geographic Location

Geographic location plays a very important role in deciding which technology of MSW management is suitable for the local region. In particular, potential risks on human health, crops, building materials, forests and ecosystems should be accounted (Brizio et al., 2004). The correct choice of technology for the local region can not only minimize the impacts to environment and residents, but also reduces the cost of pollution controlling and waste
collection and transportation. Besides of meeting the environmental legislations and economic requirement, MSI may not be located on the city center where the real estate cost is too high to be recovered by revenue (Granatstein et al., 2000). Because of high potential risk to human and environment, such as air pollution and noise, MSI should be located on the rural or suburban area where the impact may be minimized. However, selecting the location of anaerobic fermentation plant is much more flexible than that for the incineration plant. It is owing to the relative small land required and less direct impacts to society. It can be shared by several towns, applied in a single town or even installed for a single house. Odours emission have now been well controlled, that makes it possible to establish an AF plant for single-house family use where can reduce the cost of waste collection and transportation. For both of these two MSW management techniques, solid and liquid residues are generated. The end-pipe treatment plants, such as post-composting plant, cement factory or landfill plant, should be located nearby.

3.3 Collection and Transportation

In this paper, hazard waste and hospital medical waste are not included in consideration. For both of the two chosen techniques, current existing waste collection system for municipality is sufficient. They can share one series of waste collection system without any problem. However, transportation (waste transport and energy feedback) tends to be an influence factor to the decision-makers. For example, there are two simple transport models shown in Figure 7. Model 1 means each small town has an individual treatment plant to handle the waste that comes from their own resident. Meanwhile, heat electricity or biogas produced is used to cover the plant operation or feed backed to residents. Model 2 illustrates several towns share one large treatment plant, each of them collects the waste with storage center first. Collected wastes are then transported to the treatment plant and get energy back to the storage center where the energy is spread to the residents. Because of the flexibility of AF plant, it is applicable for both transport models, depending on which one is cheaper on total cost. For MSI, model 1 is not a cost-effective option, due to the high installation cost of incineration plant. Regarding transportation, model 2 has more expense than model 1. In a practical situation, much more problems take place, such as air pollution and fuel leakage. Thus, collection and transportation should be an influence factor that may affect the decision-makers.
3.4 Capacity

With fast increase of population and urbanization, more and more municipal solid waste is produced. The municipal waste management system is now under great pressure. So the capacity of waste treatment plant is coming up to the table of decision-makers. The capacity
of waste treatment plant depends on the quantity of municipal waste generation in the regional area. Usually, the more waste produced, the larger plant should be installed. MSI is able to handle large amounts of waste; generally the capacity is ranging from 100 t/d to 1,000 t/d. The small scale MSI plant has been washed out gradually by reason of high investment and low efficiency. Large-scale MSI plant (> 300t/d) is still popular right now by reason of high efficiency of waste treatment and energy conversion. It makes sense for the MSI to handle large amount of municipal solid waste. If the capacity is too large for only one town, it can be shared by several towns, to achieve its biggest value. For the AF plant, the general number of capacity is 30-250 t/d, the world’s largest AF plant is under building in Shanghai, China, and the capacity is approximately 800 t/d (Rugao, 2005). With a large population, Shanghai is an exceptional example with high amount of waste generation. An AF plant is more popular in rural and suburban areas where there is a low amount of waste production, due to relatively long waste residence time (about 22 days). The capacity of the MSW management facility has thus become a key factor, which may influence the decision-maker, according to the local condition.

3.5 Composition

Nowadays, waste composition is tending to vary and becoming an important factor which determines the further process and end-pipe treatment. Different composition of waste determines different waste management processes, while different processes lead to different consequences to environment, economy and society. MSI is flexible and can be applied to treat solid waste with any composition. No matter what composition of waste, organic and inorganic fraction can be combusted together. It is not necessary to pre-treat the original mixed waste from municipalities and industries. However, without pretreatment of mixed waste, the valuable fraction of waste cannot be recycled. This will reduce the income from recyclable materials, and the flue gases will be varied. AF plant is not convenient for any composition of waste, due to its sensitivity of toxic materials and inorganic fractions. AF plant is fitting to easily-biodegradable material which contains kitchen waste, green waste (garden and agricultural waste), and so on. Pre-treatment is crucial in anaerobic fermentation technique, toxic and inorganic fractions have to be separated from feedstock. Cost increase is unavoidable. On the other hand, the recyclable materials are identified and separated, in result of potential valuable products can be reused to the market. Meanwhile, reaction within untoxic materials, the hazard content will be reduced in residues. Another factor of waste composition that should be considered is the water content of the original waste. For MSI, high moist waste means a low caloric value, and the efficiency of energy recovery will be limited. For AF scheme, although water is an essential part of anaerobic digestion reaction, too high water content may lead to efficiency reduction of waste treatment and biogas yield in this type of dry digestion.

3.6 Potential risk to human health

Emission from the MSW treatment plant and their potential health impact associated with stack emissions has become a major public concern to MSW management technology. People consume the hazardous components emitting from waste treatment plants in the form of gas, solids and liquid, which all may serious affect the human health of local residents. Human health risk performance of these two techniques may be a vital factor that influences the decision-makers. Although MSI is an effective way of treating the municipal solid waste, the large emission is unavoidable. The main pathway of MSI impacting the human health is air
emission. Some of the chemicals emitted are constituents of the waste, which travel through the combustion chamber and are not captured by air pollution control devices. Toxic components, which emitted into the atmosphere, are directly consumed by humans through inhalation. However, these chemicals can also cross environmental media boundaries becoming distributed in different media: soil, vegetation, water, biota, etc (Meneses et al., 2004). As a result, human health can be indirectly affected through different pathways such as drinking water or groundwater, eating contaminated foodstuffs and so on. In particular, the presence of dioxins, are widely distributed throughout the food chain (POST, 2000). For example, polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), which are extremely toxic, found in the flue gases from incineration chimney. Cancer and some other diseases are suspected to be caused after long-time exposing in PCDD/F. Currently, there is little data on human health risk from AF plants. In some cases, although the hazardous materials are well controlled before digesting and the health impact to the residents is minimized, leakage from reactor and storage is unavoidable. Chemical components stream to affect the human health indirectly in the form of air, solid and liquid emission. For instance, leakage of heavy metals such as Cadmium can course serious problem to the health of local residents (Friends of the Earth, 2004). Moreover, biogas, 65% of which is methane, as a kind of explosive fuel, explosion is another potential risk that can not be neglected.

3.7 Potential risk to environment

To adequate the strict environmental criterions, environmental impact has already been wildly researched and applied in evaluating the performance of MSW management technology. Environmental impact always plays as a determinable factor which links to the social aspect (e.g. human risk) and economic aspect (e.g. residues disposal). As one of the most key factors, potential environmental impact of MSW management technology is placed in the essential position when the decision is made. Several potential environmental impacts are categorized below and compared between MSI and AF technology. Even if both of them are well equipped with pollution control facilities and under professional operation, certain unpredictable leakage is unavoidable. In this paper, all situations are based on assumption of unpredictable leakage existing.

- **Global warming**
  Potential global warming is contributed by the emission of greenhouse gases (GHGs), such as CO₂, CH₄ and NOₓ. When comparing the impacts, kg CO₂ equivalent is used as the unit, all emission is transferred into kg CO₂ equivalent to make it comparable. For the incineration scheme, incinerate of 1 ton of municipal waste in MSW incinerators is associated with the production/release of about 0.7 to 1.2 tons of carbon dioxide CO₂ (Johnke, 2006). Although this carbon dioxide is directly released into the atmosphere and thus makes a real contribution to the greenhouse effect, only 30-55% is climate-relevant (Johnke, 2006). For the anaerobic fermentation scheme, there is no direct GHGs emit from fermentation reactor, except when methane leaks from the reactor and storage process.

- **Acidification**
  Acidification potential, compared by the unit of kg SO₂ equivalent, is contributed by acid gases such as SOₓ, NOₓ. Due to the mass combustion, amount of SOₓ and NOₓ are significantly emitted to atmosphere from incineration flue-gases. Therefore, potential acidification effect is observed. For anaerobic fermentation, the organic fraction is separated for further reaction. Moreover, reaction takes place in the sealed anaerobic atmosphere, as a
result of few acid gases generated from AF reactor. Thus, regarding potential acidification, anaerobic fermentation is more preferable than incineration (Profu, 2004).

- **Eutrophication**
  Usually, eutrophication potential is compared by using the unit of kg NO$_3$ equivalent, but sometimes kg PO$_4$ eq. and kg O$_2$ eq. are suitable options. Averagely, eutrophication potential (as kg of NO$_3$ eq./t of waste) of incineration is 0.32 kg of NO$_3$ equivalent when combusting 1 ton of municipal solid waste (Honga et al., 2006). Gases such as NO$_x$ from waste combustion contributed much of the impact. However, this is still much smaller than the potential emission of nutrient from AF residues. The nutrient materials such as nitrogen, phosphorus can not be reduced by anaerobic digestion, thus there is high concentration of nutrition in the residues from anaerobic fermentation reactor (Chaya et al., 2006). Although most of the residues can be used in the fertilizer production by post-composting, the potential risk is existing. Therefore, waste incineration is expected to be a better alternative than anaerobic fermentation when regarding the potential risk of eutrophication (Profu, 2004).

- **Photo-oxidant formation**
  Photo-oxidant formation, caused by photochemical activity of hydrocarbons and volatile organic component (VOC), is normally measured with the unit of kg C$_2$H$_4$ equivalent (Profu, 2004). Incineration was found to have at worst very small negative impact relating to photo-oxidant potential. On the other hand, AF appeared to always have negative impact, which due to methane and non-methane VOC air emission (particularly linear chlorinated hydrocarbons) that cannot be removed by conventional off-gas treatment technology such as scrubbers and biofilters (Papadimitriou et al., 2005). Although the photo-oxidant potential of AF is rather higher than MSI, the real amount of emission is quiet small with advanced off-gas capture equipment.

- **Ozone depletion**
  Ozone depletion means decreasing of atmosphere’s ozone layer. Some scientists say man-made substance, particularly Chlorofluorocarbons (CFCs), cause the ozone depletion (Profu, 2004). Generally, ozone depletion potential is measured by the unit of kg CFC11 equivalent. There is no emission of ozone depletion substances from MSI facilities, since they are destroyed during combustion. The same result as incineration, anaerobic fermentation has very little contribution to ozone depletion (Edelmann et al., 2006).

- **Ecotoxicity**
  Ecotoxicity is a measurement which defined the toxic and poisonous degree to ecology. Bottom ashes from incineration plant contain variable amounts of heavy metals and other poisonous components, such as Cd and Hg, which are the main cause of ecotoxicity from incineration. These potentially noxious components can be released into the environment, in case of heavy rain for instance (Quilici et al., 2003). In the case of anaerobic fermentation, gaseous emissions of polychlorinated biphenyls were the principal cause of ecotoxicity. Although both of them have negative performance to environment, regarding ecotoxicity, incineration was found having a less impact than anaerobic fermentation since it recovers more amounts of both heat and power to replace fossil energy (Papadimitriou et al., 2005).

**3.8 Investment**

As one of the key factors of economic aspects, investment of MSW management has determinable function to the decision makers. It is also involved with the gain of MSW
management companies and waste fee paid by the local residents. Thus, how much the private companies can pay for the MSW management, is a very realistic question to the decision-makers. To achieve the high quality of environmental target, more expensive facilities are installed into the MSW management plant. The investment of municipal solid waste management services have raised steadily over the past decade. Local governments are trying to control MSW costs through a variety of measures, including restructuring waste services and encouraging waste reduction. However, making solid decisions and developing cost-effective waste management strategies can be difficult without complete cost information. Focus on the cost of MSW management technology, investment estimation has become a core factor being taken into account when the decision is processing. In this paper, it categorises into three aspects: infrastructures, operating and repairing cost and energy consumption.

- **Infrastructures**
  As a large fraction of MSW management investment, cost for infrastructures building includes waste service facilities, waste treatment plant, residues controlling facilities and other essential physical facilities. For the waste service, the first thing that has to be done is establishing a waste collection system for both MSI and AF. Moreover, the largest cost of incineration is in-site facilities, especially the high cost for the emission control system. According to a 36,500 t/a incineration case study in Greece, the best available emission control system was calculated as 26% of the investment (Zabaniotou et al., 2002). On the other hand, for the anaerobic fermentation plant, the cost for infrastructures is no cheaper than incineration. High costs are imposed by the superior technical requirements to provide adequate gas seals to prevent odour emission, safe gas handling and internal environmental controls and monitoring techniques, such as the detection of very low levels of concentrations of hydrogen (an intermediate product) (Anaerobic Digestion, 2005). Essentially, pre-treatment facilities are needed to separate the unbiodegradable materials from mixed solid waste for ensuring the feedstock is not toxic for the microorganism. Furthermore, if heat and electricity are expected to derive from biogas produced, combined heat and power plant is necessary, which is another heavy cost that has to be paid. The typical capital costs of biological municipal waste treatment facilities are compared below in table 1

<table>
<thead>
<tr>
<th>Capacity (t/a)</th>
<th>Incineration</th>
<th>Dry digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 000</td>
<td>-</td>
<td>€ 5.3-5.6 million</td>
</tr>
<tr>
<td>20 000</td>
<td>-</td>
<td>€ 9.5-10.0 million</td>
</tr>
<tr>
<td>50 000</td>
<td>€ 25 million</td>
<td>-</td>
</tr>
<tr>
<td>100 000</td>
<td>€ 45 million</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Plant cost excluding energy conversion gas engine, tax, planning and design fee.

- **Operating and repairing cost**
  Operating and repairing cost mainly link to the cost of labour and equipment accessory. Hence a new EU environmental directive drives the field to new higher operational standards and technology developments, having as consequence the increase of the cost related to investment and operation. According to the case study in Greece, the operational cost takes 6.5% of the total investment of building a 36,500 t/a capacity incineration plant (Zabaniotou et al., 2002). While AF has high safety criterions for handling the explosive biogases,
Educated employees are required. Thus, for both MSI and AF, the operational cost shares large part of the total investment. It is known that the better material used for construction, the more expensive it becomes, but also a less frequency of repairing is needed. Optimizing the cost-effective investment has become aspire of the decision-makers. For incineration, the temperature durability of stoker should be the focus, as well as the acid corrosion problem for the flue-gas cleaning system. The same as incineration, acid corrosion durability is the focus for anaerobic fermentation. The typical operating costs of biological municipal waste treatment facilities are compared below in table 2

Table 2. MSW plant operating cost
(MCOS/Cowi, 1999; Hjellnes Cowi AS and Cowi AS, 1997)

<table>
<thead>
<tr>
<th>Capacity (t/a)</th>
<th>Incineration</th>
<th>Dry digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 000</td>
<td>-</td>
<td>€ 220 000 p.a.</td>
</tr>
<tr>
<td>20 000</td>
<td>-</td>
<td>€ 400 000 p.a.</td>
</tr>
<tr>
<td>50 000</td>
<td>€ 950 000 p.a.</td>
<td>-</td>
</tr>
<tr>
<td>100 000</td>
<td>€ 1 750 000 p.a.</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Operating costs excluding the costs of transport, residue disposal, staff costs, income from sales of residue/by products and incomes from net sales of energy. Operating costs includes yearly maintenance costs estimated to 3% of the initial capital cost.

- **Energy consumption**

Both MSI and AF are negative energy-consuming processes, since the energy produced can completely cover the energy required for the treatment plant. However, energy consumption for running the facilities is also considerable high and cannot be ignored. For the incineration, running the incinerator also requires more energy—about three times more per ton of material processed—than running landfilling or material recovery facilities processing equipment (Denison, 1996). For anaerobic fermentation, the amount of energy required to run a digester (electricity and heat the fermentation tank) is directly related to the moisture content of the feedstock. High-moisture systems use more heat but require less electricity to circulate the fluid feedstock (Anaerobic Digestion, 2005).

### 3.9 Revenue

Although the main aim of MSW management plant is defined as to reduce the amount volume and toxicity of waste, the revenue derived from treatment plant cannot be neglected. The cost of constructing a MSW management plant has been proved increasing. The investment cannot always be supplied by the local government and organizations. The waste companies have been looking for their own method to cover the cost as much as possible. Consequently the Waste-to-energy plant was established, and the energy produced shares large part of MSW company revenue. The amount of revenue has become one of the most important parameter of evaluating the MSW management technology. How to minimize the negative impact to economy, as well as replacement of environmental and social impacts, has come up to the decision-makers. There are two major ways to consider the revenue of MSW management technology: energy production and energy selling and waste fee.
• **Energy production**
Since there is a serious shortage of energy production, energy is urgently demanded by both developed and developing countries. As a type of substitutable energy to reduce the current energy price, energy-from-waste facilities has been established, which can not only offset the internal energy consumption, but also contributes to replace the environmental impacts caused by fossil fuels, such as global warming, acidification, eutrophication, photo-oxidant formation, ozone depletion and ecotoxicity. For the incineration, EU for example, the calorific value of mixed waste ranges from 7,500 to 11,000 kJ/kg. At almost all municipal waste incineration plants, the heat produced during incineration is utilized through steam generation. In general, about 300 to 600 kWh of electricity can be produced by burning 1 ton of municipal solid waste, depending on plant size, steam parameters and steam utilisation efficiency (Johnke, 2006). In the case of the co-generation of electricity and heat, about 1,250 kWh of heat per ton of MSW can be produced in addition and supplied to external users, depending on the incineration plant's site-dependent heat supply opportunities as well as the geographical location of the country and the (long-distance) heat utilisation periods usual for that country (e.g. in Germany, 1,300-1,500 hrs/year out of a possible 8,760 hrs/year) (Johnke, 2006). For anaerobic fermentation scheme, AF is a net energy-producing process, in the form of electricity, heat and biofuel. In general, the specific biogas production of AF ranges from 100 to 200 m³ of biogas per ton of MSW, equal as approximately 170-350 kWh of electricity, which also depends on the plant-size (Schleiss, 2003). And with a methane content of about 65%, 34% carbon dioxide and 1% trace gases in biogas produced. The energy content amounts to about 6 kWh per m³ biogas. If all the biogas is used as biofuel, around 600-1200 kWh energy equivalent biofuel generated. Minus the electricity for consumption and heat for the fermentation tank, approximately 380-760 kWh net energy equivalent biofuel can be produced by anaerobic fermentation from 1 ton of MSW (Schleiss, 2003).

• **Energy selling and waste fee**
In recent energy market, electricity is frequently purchased for district and industrial usage and makes a contribution to the revenue of the MSW companies. According to EN31 Energy Price of European Environmental Agency (EEA, 2006), in the year of 2005, the electricity price of household use is € 0.115 per kWh, while € 0.06 per kWh for industrial use. The price of natural gas for household is € 9.5 per GJ (0.0342 €/kWh) and € 5.5 per GJ (0.0198 €/kWh) for industrial use. Biogases collected from anaerobic fermentation plant are expected to be the substitute of natural gas for selling. Heat produced usually is used by offsetting the internal use, such as heating the fermentation tank. However, heat also can be sold to the local residents who pay for it as a part of the house rent. It is normally charged by local government. MSW management charges are split into household and local business, paid through municipal fees. Households pay their municipal solid waste fee based on their property values. U.S. for example, in communities with pay-as-you-throw programs, residents are charged for the collection of municipal solid waste—ordinary household trash—based on the amount they throw away (EPA, 2006). The waste fees charged by the local government, who pays the MSW companies for waste collection and treatment.

### 3.10 Residues handling
Relevant to the environmental and social aspects, residues from MSW management facilities call for appropriate treatment to release the pressure of landfill space limitation and potential human and environmental risks. The original mission of waste treatment is to reduce the environmental impacts and protect human health. Residues could consist of hazardous waste which may damage the environment and human health. Moreover, some of the materials are
valuable and recyclable. Therefore, when a decision is in process, the decision makers can not only consider the efficiency of treatment technique, but also residues handling has to be taken into account. Generally, MSW incineration generated more solid residues to landfill than anaerobic digestion without recycle and reuse activity. For the MSI, approximately 90% or more (by mass) of residue are bottom ash, which has been long disposed of in landfill (Wang et al., 2003). To meet the sustainable MSW management, metal concentrates of incineration residue can be recycled to the metal refining industry and the mineral materials can be reused as the construction material. The fly ash, rich in heavy metals, could be treated chemically by extracting the metals (Zn, Pb, Cd) (Biollaz et al., 2006). Compared to incineration, where data exists, AF produces the least net air and solid emissions. However, anaerobic fermentation plant generates lots of waste water. This will have a high nitrite load and will need further processing before it can be disposed into sewage systems – although some water may be re-circulated during AF, particularly when the feedstock is dry (Friends of the Earth, 2004). The solid phase of AF residues can be used as the feedstock of fertilizer industry with post-composting. In some EU countries, the bio-fertilizer coming from organic waste fermentation is wildly utilized for farming use. Although there are some potential risks of this type of bio-fertilizer, due to high concentration of heavy metals and toxic materials, depending on the various waste compositions, the benefit to developing countries is obversed and further development is expected.

3.11 Other impacts to public

- **Employment**
   Although a MSW management plant cannot handle the problem of unemployment, it indeed provides positions for the public. For an incineration plant, a plant with extensive flue gas cleaning and combined heat and power production, in order to operate continuously, will require between 20 and 40 people, depending on plant size, but also on the number of administrative staff situated at the incineration plant and degree of outsourcing of maintenance work. For the anaerobic fermentation scheme, staff needed may vary from plant to plant i.e. 5–15 persons for 100,000 tonnes per annum per plant (Tsotsos et al., 2002).

- **Landscape**
   Comparing these two MSW processes, MSI uses more land than AF plant, regarding the plant size and capacity. For example in Taiwan province of China, the incineration plant in Xinzhu City of 900 t/d capacity takes approximately 55,000 m$^3$ land (Bamboo, 1999). While another Chinese city, Zhoushan with an AF plant of 400 t/d MSW capacity requires totally 37,210 m$^3$ land, including contracture, facilities and separated area (Zhoushan Environmental Protection Agency, 2006). However, either of them requires less land than landfill.

- **Noise**
   MSI plant is much noisier than AF plant, due to the loud noise of air supply system and grate during processing. Soundabsorbing material has to be used in the outside wall of MSI plant, the noise nevertheless can affect the local residents. Moreover, capital cost of infrastructure can be raised up for the expensive materials.

- **Odour**
   Limit to the few data of odour emission, the odour impacts to public can vary and be unpredicted. MSI odour consists of the uncaptured flue gases from the chimney, storage and handling. Odour from the AF plant is the gas leakage from storage and reactor.
3.12 Comparison of the factors

Table 3 shows a comparison between MSI and AF. Coming from literature study and knowledge accumulation, these factors are theoretical and valid for a general situation. In practical use, different situations may occur, according to the local conditions. That may lead to different results. Therefore, a case study and an interview (Chapter 4) have been made to validate the outcome of the literature study.

Table 3. Comparison between MSI and AF

<table>
<thead>
<tr>
<th>Factors</th>
<th>MSI</th>
<th>AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legislation</td>
<td>Encouraged$^1$</td>
<td>Encouraged$^1$</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>Restricted</td>
<td>Flexible</td>
</tr>
<tr>
<td>Collection and Transportation</td>
<td>Simplex alternatives$^2$</td>
<td>Multi alternatives$^2$</td>
</tr>
<tr>
<td>Capacity</td>
<td>Large and fast</td>
<td>Low and slow</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid content</td>
<td>Flexible for mixed waste</td>
<td>Organic waste only</td>
</tr>
<tr>
<td>Water content</td>
<td>Not efficient for high moist waste</td>
<td>Not efficient for high moist waste</td>
</tr>
<tr>
<td>Potential risk to Human health</td>
<td>Toxic substances in flue-gas</td>
<td>Low impact</td>
</tr>
<tr>
<td>Global warming</td>
<td>GHGs generated (CO$_2$)</td>
<td>GHGs generated (CH$_4$)</td>
</tr>
<tr>
<td>Acidification</td>
<td>Acid gases generated (SO$_x$, NO$_x$)</td>
<td>Few acid gas generated</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Low impact</td>
<td>High concentration of nutrition in residues</td>
</tr>
<tr>
<td>Photo-oxidant formation</td>
<td>Low impact</td>
<td>CH$_4$, VOC emission</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>Low impact</td>
<td>Low impact</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>Heavy metals</td>
<td>Polychlorinated biphenyls</td>
</tr>
<tr>
<td>Investment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructures</td>
<td>High cost</td>
<td>Low cost</td>
</tr>
<tr>
<td>Operation and repairing cost</td>
<td>High cost</td>
<td>Low cost</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>High, for starting up</td>
<td>High, for maintaining the temperature of reactor</td>
</tr>
<tr>
<td>Revenue and recycle</td>
<td>300-600 kWh of electricity per ton MSW</td>
<td>170-350 kWh of electricity per ton MSW</td>
</tr>
<tr>
<td>Energy production$^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy selling</td>
<td>Electricity, heat</td>
<td>Electricity, heat and biogas</td>
</tr>
<tr>
<td>Other impacts to public</td>
<td>Residues(^4)</td>
<td>Large amount</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Employment</td>
<td>20-40 persons</td>
<td>5-15 persons</td>
</tr>
<tr>
<td>Landscape</td>
<td>Large land occupied</td>
<td>Few land occupied</td>
</tr>
<tr>
<td>Noise</td>
<td>Noisy</td>
<td>Quiet</td>
</tr>
<tr>
<td>Odour</td>
<td>Low impact</td>
<td>Leakage</td>
</tr>
</tbody>
</table>

Notes:
1: Both MSI and AF are encouraged by current legislation.
2: Waste collection and transportation model is based on Figure 7.
3: All types of energy production are equivalent to electricity production.
4: Final disposal on landfill
4. CITY OF STOCKHOLM CASE STUDY

Since the influence factors of MSW management method could be different if the local condition is changed, a case study has been made in this chapter. City of Stockholm, Sweden, is selected. In this chapter, practical information of MSW management in Stockholm is collected. For the municipality’s attitude of MSW management, an interview has been made to test the influence degree of factors, when the municipality is making a decision. All the work done is to validate the results coming from Chapter 3, whether the influence factors listed are sufficient to the city of Stockholm. Difference between theoretical study and practical study in Stockholm will also be revealed. Then, a decision-maker can compare the influence factors between theory and a practical case, and an optimal choice could subsequently be made for the local condition.

4.1 Introduction of Stockholm, Sweden

Stockholm county is the largest county out of 24 counties in Sweden, with 1.8 million inhabitants. It is the most densely populated area in Sweden with about 4100 inhabitants per km² land (Stockholms Utrednings- och Statistikkontor, 2006:1). 90% of the population is living in flats and 10% in self-contained house (Stockholms Renhållningsnämnd, 2003). Within the region, there are 26 municipalities. The region is the core of the Swedish economic activities (Office of Regional planning and urban transportation, 2000). Stockholm county is located on the middle latitude of eastern coast of the country, where Lake Mälaren enters the Baltic Sea. Total land is roughly 6,500 km², two-third of which is covered by forest and agricultural land. The rest is urbanized area (930 km²) and regional green structure (1,300 km²) (Ducas, 2000). This means that in the city’s structure, the green space combined with nature and environment is even larger than the urban area. Generally, the geographic situation of Stockholm region is plain, there are no high mountains in this area, but it is divided by rivers, lakes and water. This composes the most prominent feature of the region is its archipelago of 24,000 islands, holms and skerriers, of which 150 are inhabited. However, it also brings lots of trouble to transportation and combined management. Thanks to the bridges, islands, holms and skerriers can be easily connected by roads, subways and railways. Meanwhile, shipping plays also an important role in transportation among islands.

Stockholm, capital of Sweden, is one municipality of Stockholm county. Stockholm is in possession of natural environment of rare quality. Originally established by Biger Jarl in 1250, the core of city consists of 13 small islands at the entrance of Lake Mälaren to the Baltic Sea. The islands near by are connected and form the ‘Staden mellan broarna’ or ‘City between the bridges’. Although Stockholm is founded more than 7 centuries ago, it did not become the official capital of Sweden until the mid-17th century. Today it reigns over a modern welfare state. As the capital of Sweden, some 710,000 people are living in the city of Stockholm, and more than 60,000 companies are based here (Alam, 2004). Stockholm is the largest city and the political, chief commercial, manufacturing, transportation and cultural center of the country. Major manufacturing fields include printed material, electric equipment, processed food, machinery, metal products, paper and chemicals. Government operations, tourism and shipping also are important to the city’s economic base.
Most part of Sweden has a cool temperature climate, within most of the year except short summer (June-August). Due to the long latitude span, the temperature differ from north to south of Sweden. The southern quarter of the country is relatively warmer than northern area. Located on the coast position in deflection south part of the territory, Stockholm has relatively warm climate when comparing with the cold areas in north Sweden located on the Arctic Circle. Normally, in winter time (Jan-Mar), the average temperature in Stockholm County is -2°C. The highest temperature is in Summer time (Jun-Aug), which is in average 16°C with high humidity (USK 2004).
4.2 Present State of MSW Management in the city of Stockholm

The responsibility of the municipal solid waste management is centrally charged and supervised by the Ministry of the Environmental Protection Agency at the national level. The most important regulations at national level are Environmental Code, the Waste Act and the ordinances on producer responsibility, which are complemented by several other ordinances and laws in relevant areas. While, since there is no clear MSW definition on national level, the MSW type is totally classified by local municipalities respectively at the regional level. At the regional level, the responsibility lies with the Renhållningsförvaltningen (The City of Stockholm Waste Management Administration), including the MSW type definition, disposal methods, infrastructures and facilities establishing, sequel controlling and statistic, and waste fee charging (Stockholms Stad, 2007). All in all, the local municipality has the full right and responsibility to regulate the local MSW management action, making the decision which can optimize benefits to the local government and minimize damage to the local residents. The municipalities decide themselves to apply the best way according to the local circumstance.

Generally, the municipality is responsible for all household waste, food waste and commercial waste, including hazardous wastes and bulky wastes generated from the household. But each municipality appoints different private company (like SRV, SORAB etc) to collect, transport and dispose the municipal solid wastes, after that the effluent wastes are taken to final disposal. However, wastes like paper, tyres and cars which have their own responsibility of the producer are excluded in the municipal collection. In fact, the municipality is not allowed to collect and dispose the commercial waste which should be charged by the producers (Lundkvist, 2007).

4.2.1 Waste collection and composition

As the capital of Sweden, Stockholm has a large population living in the city that generates a great deal of trash from both households and industries. In the city of Stockholm, municipal solid waste is collected by the contractors, whose services are hired by the municipality. There are totally 8 contractors responsible for manual collection, container collection and mobile vacuum collection. To guarantee the working efficiency, the municipality shifts contractor every 4-6 years to keep competition between contractors (Lundkvist, 2007). These municipal contractors charge only the mixed waste (garbage bags) from household. Meanwhile, classified trash bins with identified labels, where the household can pre-sort the trash, have been equipped to thousands of collect points around the entire the city of Stockholm. These recycle containers are the responsibility of producers, who pay collection and treatment fee for their own productions. Moreover, collection of food wastes from restaurant is independent from ordinary household wastes. In restaurant for example, food wastes and ordinary household wastes is respectively collected by two different trucks. Waste transportation is usually charged by garbage trucks, equipped with standardized lifts to suit the cans used for collection. To satisfy the large demand of waste management in Stockholm, there are about 75 refuse collection vehicles and 150 collection workers, running daily for household wastes collection around the city of Stockholm. Approximately 65,000 collections are carried out every week (USK, 2006). Waste other than household waste and food waste, like hazardous waste, electronic waste and bulky waste are collected and transported separately. For instance, bulky waste can be freely delivered to the recycling centers and hazardous wastes can be collected beside some petrol stations. Table 4 & Table 5, shows the sum of collected solid wastes in Stockholm of year 2000 and 2004.
Table 4. Waste Collected excluding recycling in Stockholm, 2000 & 2004  
(USK 2006; Bergqvist et al., 2006)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Household waste</td>
<td>212,999</td>
<td>228,415</td>
<td>384</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>280</td>
<td>636</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric/electronic waste</td>
<td>7,111</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal</td>
<td>481</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper and cardboard</td>
<td>2207</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulky waste</td>
<td>34,000</td>
<td>67,773</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Recycled household wastes in Stockholm, 2000 & 2004  
(USK 2006; Bergqvist et al., 2006)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled household waste</td>
<td>75,377</td>
<td>68,656</td>
<td>100.5</td>
<td>89.7</td>
<td></td>
</tr>
<tr>
<td>Small batteries</td>
<td>9</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car batteries</td>
<td>134</td>
<td>200</td>
<td>0.2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Refrigerators and freezers</td>
<td>1,147</td>
<td>2,095</td>
<td>1.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>12,307</td>
<td>11,403</td>
<td>16.4</td>
<td>17.3</td>
<td></td>
</tr>
<tr>
<td>Newspaper</td>
<td>61,039</td>
<td>53,598</td>
<td>81.3</td>
<td>72.4</td>
<td></td>
</tr>
<tr>
<td>Hard plastic</td>
<td>441</td>
<td>713</td>
<td>0.6</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>300</td>
<td>636</td>
<td>0.4</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

The household solid waste collected in 2004 is 228,415 tons, which is an increase from 212,999 tons of the year 2000. The household waste obviously shares the largest part of collected municipal solid waste (Bergqvist et al., 2006). This is probably because of the rapid increase of living standard. Along with the stepping up of the living standard level, people spend more on daily lives. The bulky waste is around doubled in 2004 than that in 2000. It could mean that people spend more money on goods such as furniture. The waste production of household and bulky waste is expected to continue to increase in the future (Bergqvist et al., 2006). However, the recycled waste is decreasing from 75,377 tons in 2000 to 68,656 tons in 2004. Newspaper fraction makes the most obvious contribution to this reduction, which is 7,441 tons less in 2004 than that in 2000. The data of recycled glass fraction is decreasing too. Recycled waste fractions, other than newspaper and glass, are increased respectively during 4 years between 2000 and 2004. For the household waste per person, 393 kg are collected in 2004, 9 kg more than 384 kg in 2000.
Fig.9. MSW composition in Stockholm
(Stypka, 2004)

The composition of mixed MSW in Stockholm are roughly shown in Figure 9, from which, it
is obviously that organic waste and paper share the largest part of the waste composition, 31%
and 29% respectively. Solid waste has a rather high share of paper, which is combustible,
biodegradable and recyclable. It means various methods can be easily implemented to handle
the solid waste in Stockholm. Recyclable solid wastes other than paper take 20% of total
MSW in Stockholm. They can be separated and recycled for renewable utilization. 20% other
waste, containing agriculture waste, hazardous waste and so on, can be partly biodegraded
and partly incinerated. As a result, more than 60% of total Stockholm solid waste is
biodegradable and at least 20 % can be recycled.

4.2.2 MSW treatment

Like any other city in Sweden, the emphasis on MSW management in Stockholm is reduction
and recycling. However, in the city Stockholm, there are several ways to manage the waste,
mainly by integrated waste management method, including recycling papers and glass,
biodegradation, incineration and landfilling. To meet the EU and Swedish environmental law
and legislation, MSW management is decided by the local municipality according to the local
demand. Table 6 represents the distribution of household waste treatment after recycling in
Stockholm. As we can see, nearly all of the mixed household waste (garbage bags) are sent to
incineration, and used for energy recovery. Only in the situation of equipment examination
and reparation in the incineration plant, waste from household will be directly disposed by
landfilling or other processes. Since the Swedish ban against putting combustible waste in
landfills from January 1st 2002, the proportion of incineration increased. In 2005, roughly
229,245 tons of household wastes were sent to incineration (SEB, 2006).

Table 6. Proportion of household waste treatment in Stockholm (%)
(SEB 2006; Bergqvist et al., 2006)

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incineration</td>
<td>97</td>
<td>100</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Landfilling</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Incineration has already become the most dominating method of mixed household solid waste
treatment. There are 22 incineration plants in Sweden, 4 of which are located in the
Stockholm region (Alam, 2004). One of them, Högdalenverket plant, takes the largest part of
domestic waste for energy-recovery. Here, the MSW are combusted and turned into electricity and heat. There are 4 massburn boilers where 70 tons of household wastes are burn per hour (Lundkvist, 2007). With the help of transform facilities, electricity and heat are generated for industrial utilization and local district heating. Every year, 500 GWh electricity is generated from Högdalenverket and approx. 2 TWh heat for the district heating. In the summer time, 100% of district heating in the city can be covered by this waste to energy plant, and in the winter time, 14% of city heating can be covered, the rest will be contributed by burning other fuels like coal and oil (Lundkvist, 2007). The residual products of the combustion process are slag (bottom ash) and fly ashes. The slag is recycled as a seal material of landfill site and construction material in close future. The fly ashes are disposed of on a landfill site for the moment.

Since the Swedish ban against putting organic waste on landfills from January 1st 2005, most of the household went to incineration. However, there are some barriers for organic wastes. Organic wastes mostly consist of food waste and park-garden waste. Both of them are highly biodegradable and low calorific containing. To utilize the organic waste more efficiently, biological treatment is introduced to handling the organic solid waste. Although the municipality has already paid attention to biological waste treatment, there is no sorting for the organic waste in the city of Stockholm. Development of biological treatment for organic household waste is restricted. Due to the complication and expense of separating biodegradable solid waste from the garbage bag, until 2003 in the city of Stockholm, there is no biological treatment facility (composting and anaerobic fermentation) for mixed waste from household. Existing biological treatment facilities are only available for food wastes from restaurants, institutional catering establishments (SEB, 2006). However, currently in Sweden, both composting and anaerobic fermentation exists. Shown in Figure 10, 3 out of 24 composting sites (orange dots) are located around Stockholm region (Huddinge, Uppsala, Vallentuna), 2 out of 15 anaerobic fermentation sites (orange squares) are also located around (Huddinge, Uppsala).

![Fig. 10. Composting sites (a) and AF sites (b) in Sweden 2006 (Klisch et al., 2006)](image-url)
For whole Sweden, 433,830 tons (10.4%) of the solid waste was treated by biological methods (composition and AF) in the year 2004, which correspond to about 48 kg/person. This includes 239,000 tons park and garden waste, 18,000 tons sorted household waste and 70,000 tons home-composted food wastes (Klisch et al., 2006). 2,189,500 Nm$^3$ biogas was produced from anaerobic fermentation, which is used as fuel in many applications. In the city of Stockholm, 32 of 85 municipal waste collection trucks are running with biogas fuel, and the rest will be replaced before 2010 (Lundkvist, 2007). The public transportation bus system is also gradually replaced by biogas-fuelled buses. This biogas bus is expected to equip the whole bus system in the city of Stockholm before 2010. The residual product from composting process is compost, which is mainly used as soil enhancer. Moreover, residue from AF sites is used as bio-fertilizer. In the year 2004 in Sweden, 211,000 tons high quality bio-fertilizer was produced from putrefaction in anaerobic fermentation. Due to the highly separate system of solid waste and food waste, fertilizer from AF site has a high quality of nutrition and ability to remain moisture in the soil. Therefore, 93 % of the bio-fertilizer was brought back to agriculture (Klisch et al., 2006)

4.2.3 MSW management cost

In Stockholm, MSW management fee is based upon a basic fee, collection fee and treatment fee, which are charged by the municipality. The municipality collects the MSW management fee directly from building-owners, then these building-owners collects the fee from each tenant. Averagely, the fee charged from every single-family house is SEK 1000-1200 per year for weekly collection. The industrial companies will pay the collection and treatment fees for the commercial wastes which are produced their own, such as products packaging recycling and treatment.

Although the basic fee is the same for all building-owners, the collection fee and treatment fee are different depending on the building scale and collection frequency. The more waste produced or more frequency demanded, the higher management fee charged. Since the waste management administration is a non-profit governmental department in municipality, all the MSW management fee charged are used for operation and investment. Primarily purpose of MSW management fee is paid to contractors for waste collection and disposal operation, and secondly for managing purpose (administrative). Thus safe and clean environment get a higher priority in designing the waste fee usage in the city of Stockholm.

4.2.4 Research and Development of MSW management

Stockholm municipality has made lots of efforts on MSW management in the past decades. Technically, there is no problem to dispose the solid waste in an environment-friendly way. Nowadays, they turn the focus to the residues, which can be reused as substitute of virgin material. For example, utilizing the bottom ash from incinerator as construction material has been under research, and a biogas-fueled bus is also promoted by the Stockholm government (Lundkvist, 2007).

Another effort made by the Stockholm municipality is strongly supporting environmental education. Every year, 6,000,000 SEK are spented on the education for MSW management information spreading (Lundkvist, 2007). The information like waste reduction and waste separation are frequently diffused in the form of exhibitions, brochures and leaflets, meeting with building-owners and education for school and children. It results in that people get more
information about the benefit of waste reduction and separation. Thus, the budget for waste treatment can be reduced at the source point. For the future development, education has played one of the most important roles for both environmental and financial purpose.

### 4.3 View from a decision-maker of the city of Stockholm

As the authoritative administration, Renhållningsförvaltningen (The City of Stockholm Waste Management Administration) takes the free hand responsibility of the city of Stockholm’s waste management, including municipal solid waste, waste water, and hazardous wastes. For MSW aspect, they have power to decide the program’s design, budget, contractor, development and so on. When they are preparing to start a MSW management program, decision-makers will consider a lot of factors involved with many aspects, some of which can influence the opinion of decision-makers, and even change the final decision. By comparing some selected influence factors between incineration and fermentation, we can roughly understand the municipal decision-makers’ attitude. This has been done by interviewing Renhållningsförvaltningen (The City of Stockholm Waste Management Administration). The factors listed in theoretical study (Chapter 3) are validated by grading the importance of each factor. The results are listed in Table 7.

Table 7. View from decision-maker of municipality

<table>
<thead>
<tr>
<th>Factors</th>
<th>Point&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legislation</td>
<td>6&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Principal factor, head of everything</td>
</tr>
<tr>
<td>Geographic Location</td>
<td>4</td>
<td>Involved with environment and finance</td>
</tr>
<tr>
<td>Collection and Transportation</td>
<td>1</td>
<td>Existing transportation-net can be utilized</td>
</tr>
<tr>
<td>Capacity</td>
<td>6&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Crucial factor, involved with significance and finance</td>
</tr>
<tr>
<td>Composition</td>
<td>1</td>
<td>Separated collection system</td>
</tr>
<tr>
<td>Long-term development</td>
<td>4</td>
<td>Involved with investment and finance</td>
</tr>
<tr>
<td>Potential risk to Human health</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global warming</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Acidification</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Photo-oxidant formation</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Potential risk to environment</td>
<td></td>
<td>They are equal, and very important to be considered.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Involved with human health and environment</td>
</tr>
</tbody>
</table>

---

<sup>1</sup> Values range from 1 to 7, with 7 being the highest importance.
Notes
1: The points represent the degree which factors affect the choice of decision-makers. Point ranges from 1 to 5, of which, 5 represents the most influence factor to the decision-makers.
2: Represents the extremely high influence degree.

From the Table 7, national legislation has extremely high priority with point “6”, which is over the scale. As the principal and basic factor of every decision from municipality, topmost priority is compulsory for the legislation permission. In every situation, national legislation is always the primary factor and should be complied. Political directions also have a high priority to be followed. Any decision against legislation will not be considered by the council, even if it has great profit in finance and society (Lundkvist, 2007). Part of the national legislation, all the environmental legislations are listed in Miljöbalken (Environmental legislation). It is essential to understand that the national legislation is the crucial factor, which has the direction function to be head of any decision. Alike national legislation, the local ordinances plays an important role in guiding the decision-maker’s choice in regional level. In the city of Stockholm, the regulations and ordinances could be ruled by the local government of the city of Stockholm.

Another principal factor that gets point “6” is waste capacity. Capacity of waste treatment facility is strongly connected with amount of municipal solid waste generation. The reason why it gets such high priority is when the municipality makes a decision it is involved with the significance of starting a new MSW management program. If the present MSW management facilities are sufficient for the solid waste produced in the city, it makes no sense to start a new MSW management program (Lundkvist, 2007). Since household solid waste and food waste are treated respectively, incineration takes the full responsibility of mixed household solid waste treatment and fermentation shares large part of food waste management. Whether to start an incineration or fermentation facility depends on the quantity of mixed household solid waste and food waste produced respectively. If we assume that the household
solid waste has a stable generation amount, it is not necessary to build a new incineration plant, the same as fermentation plant for food waste. Thus, waste amount has become the basic factor that evaluates whether a MSW management project makes sense, and has strong degree of influence on the decision-maker in the municipality.

Follow the factors of legislation and capacity, potential risk to human health and environment get point 5. Within the EU and Swedish environment and safety legislation permission, potential risk to human and environment always get top priority to be considered when the municipality is making a MSW management decision. Human health has currently got great attention by the decision-maker of the city of Stockholm, especially the potential and invisible risks, such as air pollution and groundwater contamination. Since environmental performance of MSW management facility is strongly connected to the potential human risk, it gets the equivalent priority and is considered along with potential human health risk (Lundkvist, 2007). The potential risk of environment can be divided into several aspects, global warming, acidification, eutrophication, photo-oxidant formation, ozone depletion and ecotoxicity. Although these factors may have different effect between incineration and fermentation, in the view of municipality, they are equal in macro-scale. The municipality has done large efforts on research and statistic to find out the environmental impacts of MSW management facility. On the other hand, there are lots of barriers on the way, such as few data about some factors like ozone depletion and ecotoxicity. Thus, the municipality has to consider these factors in entire environmental scale rather than respectively. Anyway, when the municipality is making a decision, potential risk to human health and environment is the first factor that they will consider after legislation and waste amount.

Besides potential human and environment risk, energy production and residues handling also get point 5. That is because the municipality consists them both as a part of recycling. In recent decades, Swedish Environmental Administration paid a lot of attention to the material recycling. The top position of waste hierarchy is waste prevention. However, the first step of MSW management is recycling the valuable materials. There is no doubt that energy production is a type of recycling, which converts the solid waste into valuable energy in form of heating and electricity. Local residents’ heating system is all relied on the waste-to-energy facility, such as hot water. Waste-energy covers all energy demand of the city of Stockholm in summer time, and shares part of it in winter time (Lundkvist, 2007). For residues from treatment facilities, they may cause terrible environmental impacts if they are disposed in landfill directly. On the other hand, with appropriate treatment, these residues can be converted into valuable materials. Thus, residues from waste management facilities arouse interests of researchers and municipality in the past few years. For example, residues from incinerator can be use for simple construction purpose, and residues from fermentation are turned into bio-fertilizer for farming (Lundkvist, 2007). These features can all be understood as reducing the environmental impacts and material recycling. This is why residues handling has the side by side position with energy production in influence degree.

Geographic location gets point 4, because it can be divided into two aspects. Firstly, it is involved with the social and environmental aspect (Lundkvist, 2007). Either of incineration or fermentation is planned to be set up. This may bring lots of environmental consequences according to the local geographic conformation, e.g. incineration facility can not be located in the upstream of wind, otherwise it will bring worse pollution than usual. Local residents’ attitude is strongly related to local environment changing. Some environmental consequences brought by MSW management facilities, such as noise and pollution, can interrupt the ordinary lives of local residents. Secondly, the location of MSW management facility can not
be far away from the resident community, since it has to produce benefit for the local residents, both in the form of heating and electricity (Lundkvist, 2007). If the facility is located far away from the community, there will be a lot of trouble in waste collection and energy transportation, which can increase the cost of MSW management. Thus, when the municipality makes a decision, the location of MSW management facility is an important factor that should be considered. However, the impacts come from geographic location are based on the environmental impacts and cost-efficiency, it gets less influence degree than environmental risk and energy production, which get point 5.

Involved with finance, people’s willingness and technique, the factor long-term development of MSW facility has been taken well care of by the local municipality of the city of Stockholm. Theoretically, there is rarely mentioned anything about the long-term development of MSW management facilities. However, this factor is considered as one of the essential factors when the decision is made. Since MSW management facilities should work for the future decades, present scale and technique may not suffice the waste demand in the future. When the decision is made, the municipality has to consider what will happen in the future, and how they can handle it. Then they will give a higher priority to the program which is easily-upgraded (Lundkvist, 2007). To suffice the long-term development, such as enlarging the facility scale and upgrading the technique, stable financial support should be guaranteed. Municipalities will prefer the program which has the ability to make investment sustainable (Lundkvist, 2007). The municipality does care about people’s attitude and acceptance. They believe that without the people’s support, any project can not exist for a long time. There is no reason to build up a facility that can not be accepted by local residents (Lundkvist, 2007). Sometimes, the municipality gives the voting right to the local people by sending questionnaires and leaflets; people can vote for the MSW management facility they prefer. Although future development has an important position in the view of decision-maker, the present situation can not be neglected. Some urgent issues should be handled immediately. This is why this factor gets lower priority than potential environmental risk and energy production.

Investment should be a dilemma factor for the decision-maker. The more investment, the more benefit, the better equipment, and the better environmental performance. Moreover, more investment means more professional workers and less frequency of equipment repairing and replacing. Energy consumption at starting up of the plant may also be reduced. On the other hand, too high investment budget may result in the project unaffordable for a while, and the cost can not be returned in a short time, people’s expense for waste treatment will be increased. Future development may be involved too. However, in the processing of a waste management program, the municipality is playing the role of a project-owner, who makes appointment with contractors (private companies). The real investment should be afforded by the contractor who finally gets the project (Lundkvist, 2007). Meanwhile, the municipality also plays as a macro-monitor, who makes an investment budget for the waste management project, to ensure the program is not unaffordable. Thus, the municipality has to concern the investment, but not the real investment (Lundkvist, 2007). Since the Waste Management Administration is a non-profit department in the municipality, all the revenue goes to the contractor for waste collection and treatment. Some additional fees are also paid, for the profit of these private companies. The basic fee is used for daily cost of operating this department and future development. In a word, the municipality can not get any profit from a waste management project (Lundkvist, 2007). Nevertheless, as a macro-monitor, the municipality may indirectly influence the price of residues, both energy and biogas.
Waste collection and transportation gets point 1, the lowest influence degree for the municipal decision-maker. This is because when the municipality is starting a MSW management program, they always locate the site in a traffic-free place. The advanced transportation-net can be utilized for waste collection and transportation. It is not necessary to create a new transport line special for waste. Another reason for this is overplus of present waste collection ability. If there is a new MSW management site under building, there is no need to increase the number of waste collection trucks, neither for mixed household waste nor for food waste (Lundkvist, 2007). Present transport ability is adequate for waste collection in the city of Stockholm. At least it is not urgent to concern this problem. The same as waste collection, waste composition gets the lowest influence degree too. Waste composition is involved with waste collection, environmental performance and residues. It seems this is a factor that should be at great concern for the municipality. However, the situation is a little different in the city of Stockholm. Here, separated collection system has been introduced into the urban waste collection, and makes the significant contribution for MSW management. In the city of Stockholm, there are two types of trucks working for waste collection, one for mixed household waste, another one special for food waste (Lundkvist, 2007). In other words, mixed household waste is collected separately from food waste. Daily, mixed household wastes are collected then sent to incineration site, and food wastes are collected then sent to fermentation site. This effort not only saves the sorting process, ensure the quality of residues from the fermentation site, but also guarantees the heating value of waste in the incinerator. Thus, waste collection and composition are not central influence factors for Stockholm municipality.

Other listed influence factors, like employment, landscape, noise and odour, get low priority too. From the view of municipality, these factors are involved with other core factors. For example, landscape is involved with site location; employment is involved with investment and revenue. Within the present action of municipality, the MSW management action taking place in the city of Stockholm is on a macro-scale, and these factors are too detailed to be considered carefully for this moment (Lundkvist, 2007).
5. DISCUSSION

MSW management methods are difficult to compare among countries, or even municipalities, where different classification systems and decision-makers’ concerns may vary. Different degrees of influence factor are also identified among countries when MSW management decision is in process. Therefore, a general conclusion on comparison of the influence degree of each factor is impossible. In this paper, comparison is based on the decision-making between incineration and anaerobic fermentation. A case study of MSW management in the city of Stockholm has also been made for testing if the theoretical factors are sufficient for the practical situation. Some discussions about theory and practical case are taking place.

5.1 Differences between theory and practical case

Theoretical factors achieved from literature study and knowledge accumulation, which objectively focus on the general situation. The practical decision-making is based on the local condition. It is subjectively made by the local municipality according to the local circumstance. Take the Stockholm case for example,

- **Waste composition**: It seems to be a big problem in theory because of the different waste composition requirements for incineration and fermentation. But in the city of Stockholm, mixed household waste and organic food waste from restaurant etc. are already separately collected on the source. It leads to the purified feedstock for fermentation. Thus, the factor waste composition will not influence the MSW management decision maker in the city of Stockholm today.

- **Residues**: In the theoretical study, this factor seems not to be of a high concern to the decision-making. Most of the residues from treatment plants are sent to be disposed in landfill, due to the investment and technical limitation. However, in the city of Stockholm, with the financial and technical support, residues can be recycled and reused as construction materials for incineration or bio-fertilizer for fermentation. Few residues are sent to landfill. Thus, this factor is considered as one of the most important factors in decision-making.

Theoretical factors focus on picking up the optimal alternative. But the practical case concerns the practical issues, which should be solved immediately. Take the Stockholm case for example,

- **Waste capacity**: Theoretically, this factor should be considered together with other factors such as investment and efficiency. But in the case of the city of Stockholm, this is considered as the top factor of MSW management decision-making, due to rapid increasing of waste amount.

- **Investment**: This seems to be one of the basic factors considered in theoretical study. But it does not get much attention of decision-maker in the city of Stockholm, due to the adequate budget from Stockholm government for MSW management today, since they do not need to invest in a new MSW treatment plant.
The theoretical factors put more attention on technical aspects for current issues. But in practical cases care not only about the current issues but also the long-term development of MSW management. Take the Stockholm case for example,

- **Long-term development**: This factor is rarely mentioned in the references, and it is not included in the list of theoretical influence factors. But through interviewing Renhållningsförvaltningen (The City of Stockholm Waste Management Administration), the decision-maker emphasize that this factor is one of the essential factors that will be considered during the decision-making.

### 5.2 What we can do with these influence factors

Because there are some differences between the theoretical and practical case, in some cases, the theoretical factors may not suffice to the practical situation. However, the list of influence factors is having a positive effect on decision-making of MSW management under the current situation. For example:

- The list of influence factors can be used as the basic framework for the decision-makers. They can consider the MSW management programme in a macro-scale with the factors list. Some factors usually ignored can be included into the consideration of decision-makers.

- Positive and negative performances of MSW management methods can be compared based on the influence factors. It is easier for the decision-makers choose a proper alternative according to the local condition.

- By grading each factor, different priorities of factors are indicated when the decision is in process. Current concern of local decision-makers can be revealed.

- The priority of influence factors can be used as the reference for future decision-makers or the decision-makers from other places. It may help them to make a better choice under their practical situation.

### 5.3 What should be done next

It is difficult to consider every influence factors and compile them together in one list, especially when dealing with the complicate issues of MSW management. There are some deficiencies in the influence factors list, which leads to insufficient to the practical usage in some cases. Some improvements should be carried out:

- Number of influence factors should be increased, so that it can cover more relative aspects of MSW management decision-making. After the major factors, the influence factors should be extended to detailed consideration. The factors should relate more close to the practical situation, in order to be more efficient when used in a practical case.

- The comparison should not only be taking place between incineration and fermentation. The comparison should be extended to other MSW management techniques, such as composting and recycling can be integrated. More techniques taken into account will result in more options for the decision-makers and help them making a better choice.
6. CONCLUSION

A list of theoretical influence factors for MSW management decision-making is created. A practical case study of the city of Stockholm is also carried out to validate the efficiency of the theoretical factors list. Based on a discussion on the differences and features between theory and a practical case, some conclusions are drawn:

There are 10 major theoretical factors suspected to have influence on the MSW management decision-makers. These influence factors can be divided into detailed factors and cover most part of environmental, social and economic aspects.

The list of theoretical influence factors (Table 3) can be used as a framework for comparing the performances between MSW management methods. They will help the MSW management decision-maker to make a proper choice.

The list of current theoretical influence factors (Table 3) is not completely sufficient for the practical cases, due to the various situations that may exist in different cases. Practical cases are too complicated to be limited in a list. The decision-makers have their own subjective opinions for MSW management decision-making. However, the list of factors can be used as a check list.

The priority of the factors can not be used in different cases, due to the local condition may be different from place to place. However, it can be used as a reference for future MSW management decision-makers.

To meet the different requirements of practical cases, the list of influence factors needs to be broader and deeper, so that it can cover various alternatives of MSW management, as well as practical considerations of decision-makers.
REFERENCES

EEA, EN31-Energy price, available at


European Commission, available at


Friends of the Earth, 2004. Briefing Anaerobic Digestion. Available at


Hjellnes Cowi AS and Cowi AS, 1997: 'Evaluation of cost data on alternative treatment concepts. Internal project report, prepared for Oslo Renholdsverk (waste company), Norway, on treatment facilities for biodegradable waste'.


Johnke, B., 2006. EMISSIONS FROM WASTE INCINERATION. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Page 455-468

Klisch, O., Prochazka, J., Rinaldi, S., 2006. Biological Treatment of Municipal Solid Waste in Ukraine, Sweden and Italy.


Maple Reinders Ltd. et al., 2006. Expression of Interest for MSW Residuals for GVRD. THE GREATER VANCOUVER REGIONAL DISTRICT, 4330 KINGSWAY BURNABY, BC, V5H 4G8

Copenhagen. In collaboration with Vestforbrændingen WTE Plant, Copenhagen, A. Beenackers, University of Groningen, Netherlands, J. Petts, University of Bermingham, M. Murphy, Murphy and Associates, Dublin.


Sipilä, K., 2002. MUNICIPAL AND COMMERCIAL SOLID WASTE FOR PYROLYSIS (OILS) AND GASIFICATION MARKETS, PGBW - Expert meeting in Strasbourg


Stockholms Renhållningsnämnd, 2003. Renhållningsordning för Stockholms kommun,
ACKNOWLEDGEMENT

I would love to extend my sincere gratitude and appreciate to my supervisor Mrs. Monika Olsson, who helped me through her abundant knowledge and practical experience in the field of MSW management. I also want to thank for her supervision, suggestions and guidance during my thesis period. With her help, encouragement and support, I can finish my thesis and master programme.

Special thanks to Renhållningsförvaltningen (The City of Stockholm Waste Management Administration), who gave me a chance to have an interview with municipality, especially the warm-hearted Mr. Nils Lundkvist, whose help is crucial for the study. My thanks also go to my dear friends, who gave me warmly support and encouragement.

Finally, I would like to thank my family, especially my parents, for supporting with fund and unlimited love to complete the master programme in abroad.