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Colin Strobant

Abstract

In France, recycling bins have been adopted in almost all the cities only in the late 90s. In spite of being already present in the most part of the European capitals, they were adopted in Paris only in 2001. Since 2000, the country has, however, made substantial progress in the separate collection of the following materials i) plastic, cardboard, metals, paper ii) glass and iii) residual waste. Given the general concern about climate change, sustainable development and global warming, the European Union has, in order to deal with these issues, produced several directives. These also include prescriptions and targets concerning the management of waste. In spite of the progresses made, current figures show, however, that France would be unlikely to reach the target set for the municipal waste recycling rate. The development of the biological treatment channel has been one of the solutions recommended by the European Union.

The aim of this thesis is to investigate and compare the different biological treatments that a municipality could implement in order to recover biodegradable waste. The comparative cost-analysis of two different technologies is proposed. The technologies considered are anaerobic digestion and mechanical-biological treatment. The analysis is developed taking a net present value approach and running, in order to account for risk, Monte Carlo simulations on the net present values calculated for the base scenario. The analysis considers 4 potential scenarios where, apart from comparing the two technologies above, I check also for potential economies of scale. This is done allowing for the adoption of each of those technologies by two municipalities rather than only one (base case scenario).

The results of the cost-analysis revealed that anaerobic digestion, when adopted at a larger scale, is likely the most cost-effective technology. Narrowing the scope, I observe that, in general, anaerobic digestion, irrespective of the scale, is as cost competitive as it is a facility using a mechanical-biological treatment with a small capacity. To stress the solidity of my results, I have done a sensitivity analysis, which provides useful information for ranking different projects under uncertainties. Based on my model, I found that the results obtained by the cost-analysis were confirmed with the sensitivity analysis. This means that allowing certain parameters varying do not change the results of my cost-analysis and the conclusions are still valid.

Abbreviations

AD	Anaerobic Digestion
ADEME	French Environment and Energy Management Agency
BMW	Biodegradable Municipal Waste
CIWEM	Chartered Institution of Water and Environmental Management
CNIDD	Independent National Information Center on Waste [Centre National d'Information Indépendante sur les Déchets]
EEA	Environmental European Agency
EPA	United States Environmental Protection Agency
HCV	High Calorific Value Incinerable Waste
IRR	Internal Rate of Return
MBT	Mechanical-Biological Treatment
MCS	Monte Carlo Simulations
MSW	Municipal Solid Waste
NPV	Net Present Value
RDF	Refuse-Derived Fuel
SRF	Solid Recovered Fuel
VAT	Valued-Added Tax
WACC	Weighted Cost of Capital
WERF	Water Environment Research Foundation

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1 Introduction

Until the early 2000s, United States of America (U.S.A), Japan and the European Union were among the main generators of waste (Giusti, 2009*)*. More recently, figures have been changing and since 2004, China has become the world's largest generator of solid waste (World Bank, 2012). According to a study done by the World Bank, the current volume of waste should almost double by 2025. Over the last decade, institutions such as the Environmental Protection Agency [EPA] in the U.S.A. and the Environmental European Agency [EEA] have been targeting an increase in waste recycling and set directives in order to move in this direction (Xinhua, 2011; EEA, 2009; www, EPA, 2012). In particular, the European Commission, through the Waste Framework Directive and the Landfill Directive, has been setting the different targets concerning waste management that the members of the Union are expected to reach.

In 2000, France did not have a national recycling plan. Recycling bins, for instance, in spite of being quite common in the most part of European capitals from the late 90s, were adopted in Paris only in 2001 (www, Association d'éducation à l'environnement et au développement durable, 2014). Since 2000, the country has however made real progresses to set three garbage bins collection on a national level, namely, i) plastic, cardboard, metals, paper ii) glass and iii) residual waste[1]. To support the development of the French sustainable development strategy, specific laws, i.e., Grenelle I and II, have been introduced in 2009 and 2012, respectively. These laws apply to any activity falling into the category of sustainable development, such as the development of sustainable energy, the reduction of pollution or waste management to name a few.

Aware that the recycling solely will not allow countries to reach their national target, the European Union encouraged its members to also develop the biological treatment channel[2]. France followed these recommendations and the biological treatment channel is progressing.

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[1] Other bins are used for bulk items, batteries, electronic devices, bulbs, etc. The collection mode varies within the municipalities. It can be at source, in-store or in a recycling center where inhabitants drop-off their waste.

[2] In the context of municipality waste management, this biological treatment is a process aiming at transforming biodegradable waste into compost and/or biogas (see more detailed explanations page 9).

1.1 Problem background

1.1.1 Historical trend for waste management

Historically, the garbage bin was introduced in Paris in 1884 for hygienic reasons and in order to reduce the risk of diseases (Sandras, 2011). At that time, although there was only one garbage bin to be handled, the French population was quite reluctant at using it. The collection of waste was in fact considered time-consuming and perceived as a new charge by landlords (Sandras, 2011).

In the 1970s, France chose incineration as a main tool for the disposal of waste (Bourges, 2010). According to Bourges (2010), incineration was mastered and perceived as a clean solution, which facilitated its implementation in municipalities. Over the years, the country has equipped its territory with many incinerators. Currently, France has the highest number of incinerators in Europe. There are in fact 127 incinerators, that is, almost one third of the European total number (www, Centre National d'Information Indépendante sur les Déchets [CNIID], 1, 2014). The municipalities or the urban communities responsible for handling municipal waste are often engaged in long-term contracts, lasting even up to 20 years, with incinerators companies. Likewise, incinerators are set up on the basis of expected volume of waste to be processed. Since this determines their profitability, municipalities contracting with the incinerators are expected to supply a constant volume of waste during the contracted period (Bourges, 2010; Simon, 2014). This situation prevents many municipalities from considering alternative methods for the disposal of their waste (Direction Des Etudes Economique et De l'Evaluation Environnementale [D4E], 2006).

The statistical office of the European Union [Eurostat] (www, 1, 2014) reported that in 2012 incinerators processed the 33 % of the French municipal waste. It was followed by landfilling, which covered the disposal of 28 % of French municipal waste. Recycling and composting were used to dispose of the remaining 39 % with 23 % and 16 % of the total municipal waste treated, respectively. On the basis of these figures, incineration still represents the main treatment method used for waste disposal.

As observed by the *Association pour la Recherche Thérapeutique Anticancéreuse [ARTAC]* (2007), incinerators can be very harmful for the environment and for the health of the people living in their proximity. Although new laws imposed an upgrade of the existing incinerators, ARTAC claimed that incinerators are still emitting dangerous smokes. Apart from ARTAC, also other researches support the idea that incinerators can be harmful and that investments for upgrading the existing plants are still required (Bourges, 2010; www, Institut de veille sanitaire, 2003).

1.1.2 New trend for waste management

Although France was pro-active in introducing the garbage bins in the late nineteen century, it took over than one hundred years for the French government to enforce a law concerning waste selective collection. Indeed, only in 1992 a law concerning waste selective collection was signed (Bourges, 2010).

In 2012, France's rate of municipal waste recycled and composted was 39 %, so nearly below the 42 % (www, Eurostat, 1, 2014) observed at the European Union level. To reach this 39 %, policies were implemented in order to encourage investment targeting the construction of recycling and composting plants and facilities so that the share of waste landfilled or incinerated could have been lowered (French Environment and Energy Management Agency [ADEME], 2012). As shown by *figure 1,* the number of recycling and composting facilities has largely increased over the last 18 years. ADEME in its report (2012) estimated that the number of recycling facilities increased by 38 %, moving from 265 plants in 2000 to 366 plants in 2010. In the last few years, also composting facilities have been growing very rapidly. In fact, ADEME (2012), in their report, counted 593 active plants in 2010. However the size of these facilities remained quite small with an average of 6,300 and 12,000 tons per year depending on whether they were privately or publicly owned (ADEME, 2012). Finally the number of plants using organic waste to produce biogas remained quite low. In fact, in 2012, there were only 10 active plants, 6 providing the MBT of waste and 4 relying on anaerobic decomposition (ADEME, 2012).

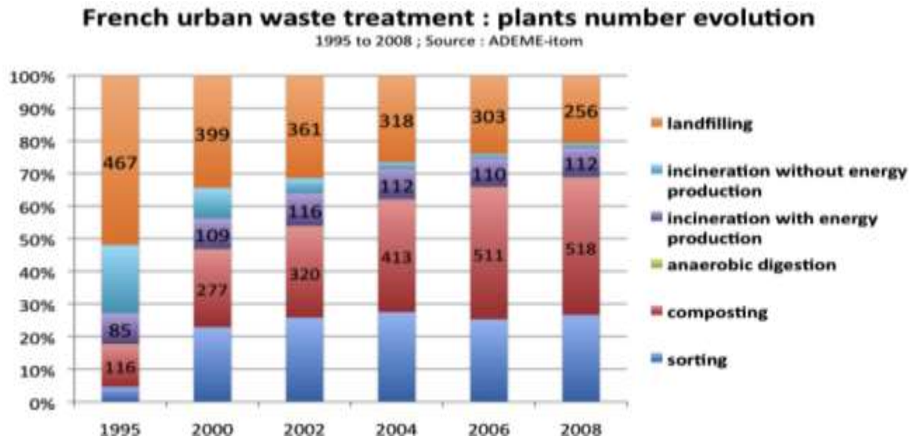

Figure 1. French urban waste treatment: plants number evolution (Cayrol, 2011)

As observed on *figure 2* the level of municipal waste biologically treated (composting and digestion) has fairly evolved over the last decade. It can also be noticed that the volume as well as the percentage of municipal solid waste (MSW) biologically treated has decreased since 2010 (www, Eurostat, 2, 2014).

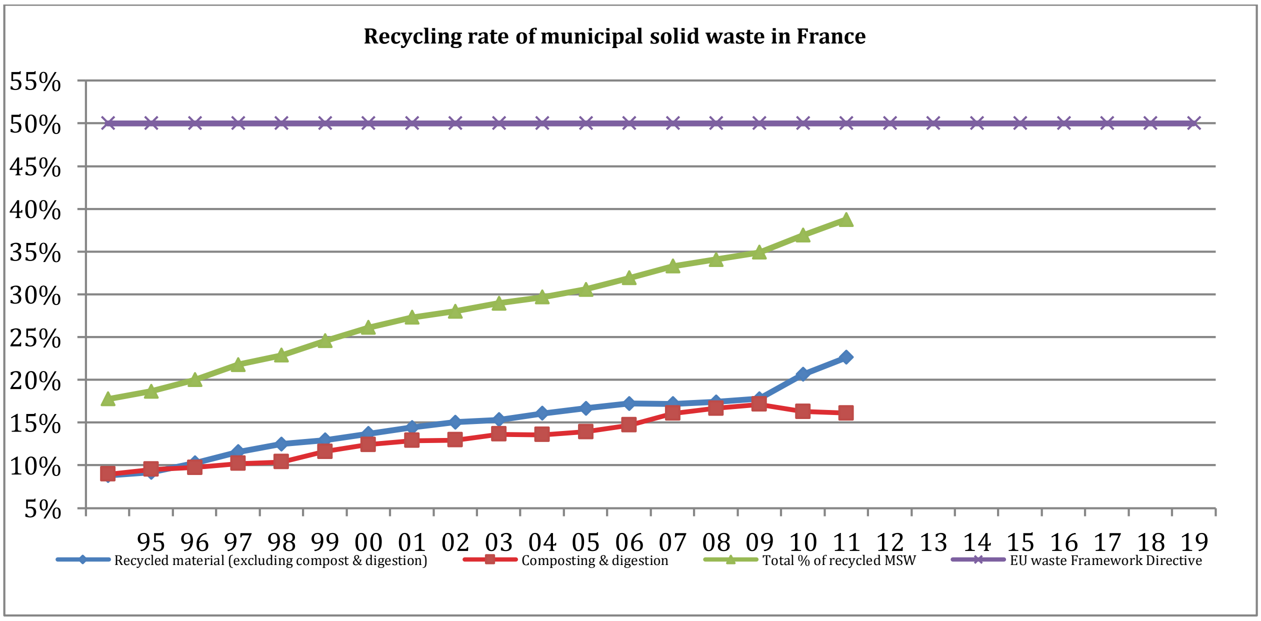

Figure 2. Recycling rate of municipal solid waste in France (own creation from www, Eurostat, 2, 2014)

1.2 Problem

As explained earlier in this study, the waste management of the municipalities is pretty topical among European and national institutions. The European Union provided two main directives. The first one is the EU landfill Directive, requesting the European members to limit the volume of biodegradable municipal waste they sent to landfill to 35 % of 1995 levels by 2016 or 2020 (European Commission, 2014a). The second one is the EU Waste Framework Directive, requesting the European members to reach at least 50 % of MSW recycling rate by 2020 (European Commission, 2014b). In a working paper, EEA (2013) stated that, given the historical trend, France would be unlikely to reach the target set in terms of MSW recycling rate while it should be likely reached the EU landfill 2016 objective (see *figure 3*).

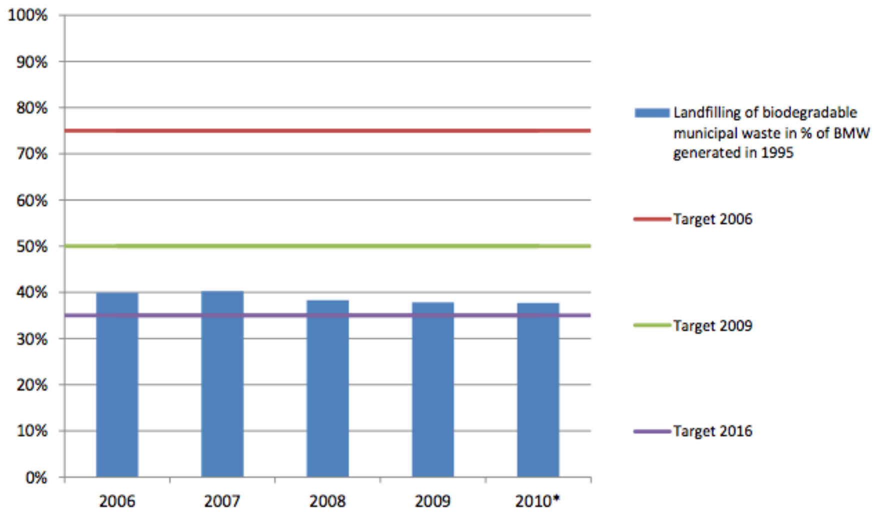

Figure 3. Landfilling of biodegradable MSW in France (EEA, 2013)

In its paper EEA (2013) observed that the decline of biodegradable MSW landfilled was closely related to the increase of organic recovery. However, since 2010, biological treatments are actually decreasing, negatively affecting the total MSW recycled (see *figure 2*).

The French government stated that encouraging the development of biological treatment plants was necessary in order to assist the country and reach the targets (www, Institut de veille sanitaire, 2003; www, Le Grenelle de l’Environnement, 2009). It considered, in order to treat the biodegradable waste, two biological waste disposal methods, namely AD and MBT.

The French government importantly supports the development of biological treatment channel legally and financially. However, the sector is still facing difficulties for what concerns its expansion; in 2013, in a paper AMORCE, a private association of urban communities and ADEME (2013) identified in fact 11 MBT and AD operational plants. The number of aerobic digestion is much higher with 518 facilities but the capacity of these facilities remains pretty low with an average capacity of 6,300 and 12,000 tons (AMORCE & ADEME, 2012). The report shows that aerobic digestion plants are mainly used for farming.

The thesis will provide a critical review of the financial stakes characterizing two specific waste disposal technologies, AD and MBT. To reach this aim I will conduct a comparative cost-analysis based on net present value calculations and, in order to take into account the impact of uncertainty, on Monte Carlo simulations (MCS). The analysis considers 4 potential scenarios where, apart from comparing the two technologies above, I also check for potential economies of scale. This is done allowing for the adoption of each of those technologies by two municipalities rather than only one (base case scenario).

1.3 Aim and Research Questions

The aim of the study is to investigate and compare the different biological treatments that one municipality could implement in order to recover municipal biodegradable waste. The focus will be set on the municipality of *Plaine Centrale du Val-de-Marne* and I will consider two possible scenarios, namely, i) the case where the municipality invests on its own and ii) the case where the municipality will invest together with the neighbor municipality *Les Hauts-de-Bièvre*. In both cases, I will consider the two alternative technologies, i.e., AD and MBT. This will lead to the definition of four different scenarios (see *appendix 1*). The following research questions will be addressed:

- Taking an economic and financial perspective, which is, among the ones available, the most cost-effective waste disposal method?
- To which extent the size of the municipality and the volume of waste affect the economic viability of a specific waste disposal method?

To reach this aim I will conduct a comparative cost analysis based on net present value calculations and, in order to take into account the impact of uncertainty, on Monte Carlo simulations (MCS).

1.4 Delimitations

This study will focus on the case of a specific municipality. The results will reflect specific local conditions, e.g. municipal volume of waste, geographical context, current figures for recovered waste volumes, etc.

The study will be limited to the consideration and comparison of the biological waste treatments recognized for French municipalities. Other methods, such as landfilling and incineration, will be excluded since, according to the French government, these waste management methods do not fall under the category of biological waste disposal (www, Le Grenelle de l'Environnement, 2009). Moreover, other methods, such as manure spreading, or animal feeding or fermentation, will be voluntarily excluded from the set of available options, since the adoption of these methods is i) marginal and ii) it can only handle a minimal share of the total biodegradable municipal waste.

For similar reasons, I will also not consider aerobic digestion plants. In fact, so far, existing plants are only designed for handling relatively small amount of waste, i.e., less than 12 000 tons per year. Hence, given also the time constraint set for the actual development of my thesis, I prefer to focus on the comparison between waste disposal methods that are currently widely recognized and adopted in France. This allows me abstracting, when considering AD and MBT, from the discussion about the actual feasibility of their adoption. In addition, last but not least, by considering these widely recognized methods, I can rely on the availability of data concerning the set-up and operation of existing plants.

In this study, I will neither investigate nor include waste reduction tools. This is because I want to focus on the study of biological waste disposal methods able to handle the actual total waste volume. In this respect, the methods and tools considered in this thesis are not consistent with waste reduction.

Finally, it must be highlighted that the analysis of the cost-effectiveness of the considered waste disposal methods does not include all the actual costs. In particular, environmental costs, due to their problematic assessment and to the limited availability of data, are not included in the analysis.

1.5 Outline

Chapter one provides an introduction to the problem background and to the problem statement and present study motivation, aim and research questions.

Chapter two provides an overview of the available technologies for waste disposal. This is done in order to introduce the reader to the terminology used in the thesis and to present the biological treatments methods.

Chapter three is describing and motivating the theoretical tools that will be used in the empirical study. The measures used for evaluating an investment will be presented.

Chapter four provides a review of previous researches, studies and publications undertaken in the area of waste management. A particular attention will be devoted to the literature using net present value approach and Monte Carlo simulations for the economic and financial analysis of different biological treatments.

In chapter five, the methodological approach will be presented and explained. This involves the justification of the data collection, data analysis and a proven acknowledgment of the consequences of the choices made.

Chapter six is focused on the case study. The first part is providing an empirical background, ensuring that all the elements regarding the municipalities and the technologies are clearly explained to the reader. The second part processes the empirical data of the case study with the net present value calculations, the sensitivity analysis and Monte Carlo simulations.

In chapter seven the empirical results are analyzed and discussed in order to answer the research questions, which were presented in the first chapter of the thesis.

In chapter eight the conclusions are presented. It also includes a discussion of the strengths and limitations of the thesis and suggests future paths for further research.

2. An overview of waste management technologies

This chapter provides a context to the study to ensure that the key terms and the comparison methods are clearly defined and shared by writer and readers. As explained by the European Environmental Agency (2013) different practices and definition can be used depending on the waste management practices. The overview presented in this chapter focused on the review of books, reports and publications related to the definition of waste categories and to the description of the waste disposal technologies considered in this thesis. Each technology is reviewed from a practical and technical point-of-view. This chapter is particularly important since it clearly defines the terms and concepts used in the thesis.

2.1 Definition of waste

As seen in the literature review, a blurry line exists between different types of waste such as organic waste, bio waste, biodegradable waste and residual household waste. A clear definition is essential to lead the reader to understand these specific categories of waste and more specifically municipal biodegradable waste, which are further analyzed in the empirical study.

2.1.1 Municipal Waste

2.1.1.1 Definition

According to Eurostat (www, 3, 2012) municipal waste consists of "[…] household and similar waste collected by or on behalf of municipal authorities”. Thereby waste generated by shops, small companies, offices and institutions are included as well as waste produced by the services of the municipality as long as they are collected by the municipality or on behalf of it or as long as they are similar in nature and composition to household waste (www, Eurostat, 3, 2012).

Eurostat (www, 3, 2012) pointed out that "street sweepings, the content of litter containers, market cleansing waste" might be included whereas “[…] municipal sewage network and treatment [and] municipal construction and demolition waste” should be excluded. However, in France, the municipal solid waste encompasses sewage sludge (EEA, 2013).

The European Union and its agencies are assuming that municipal waste as described above can also be named indistinctly municipal solid waste (European Environmental Agency, 2013). Thereby, from now on, municipal solid waste and municipal waste will be indistinctly used and referred to on the basis of the definition provided by Eurostat (www, 3, 2012) and by the European Environmental Agency.

2.1.1.2 Municipal Solid Waste Management in France

In France, municipalities have different options to manage their waste. Very often the municipalities are gathering to create an inter-municipal association that will be in charge of the waste management for all the municipalities engaged. This allows economies of scale when investing in new infrastructures and give bargaining power when negotiating contracts Bourges, 2010. These associations are usually called in French "communauté d’agglomération" or "syndicat intercommunal". They can choose to insource or outsource any activities characterizing waste management, namely from the collection up to the disposal. Even if acting on behalf of the municipalities, these associations still have to consult the municipalities regarding their activities, investments and pricing. Moreover, each municipality sets the waste fee for household and businesses, which represents the main source of income for the association (Senat, 2010).

2.1.2 Biowaste and Municipal Biodegradable Waste

As observed in the literature review, a clear definition of the key terms is important since the composition of the municipal waste may vary from one municipality to the other and across different countries. A distinction is clearly made between bio waste and biodegradable waste. Indeed, bio waste tends to refer to only garden and park waste, food waste from household, caterers, retailers and restaurants (European Union, 2014). Fermentescibles or putrescible wastes are sometimes used to refer to bio waste as well.

Biodegradable is defined as "Capable of being broken down (decomposed) rapidly by the action of microorganisms. Biodegradable substances include food scraps, cotton, wool, wood, human and animal waste, manufactured products based on natural materials (such as paper, and vegetable-oil based soaps)” (www, BusinessDictionary, 1, 2014). In the context of municipal waste, biodegradable waste is a broader concept if compared to bio waste, including the bio waste but also paper and cardboard (European Union, 2014, p.8). However as highlighted by EEA (2013b), other biodegradable inputs such as manure, sewage, human waste may be included. This makes, of course, difficult to work in terms of comparisons.

To avoid any confusion I will only use the concept of biodegradable municipal waste (BMW).

2.1.3 Organic Waste

Organic waste is defined as any biodegradable waste coming from plants or animals (www, Organic Disposal, 2014). To date the term remained quite abstract and has not been defined by any European institution. Therefore, to be as accurate as possible, this term will not be used at all in this thesis.

2.1.4 Residual Household Waste

The residual household waste, sometimes called mixed household waste represents the waste produced by households, which “[…] has not been collected for recycling or composting” (www, Friends of the earth, 2008, p.2). The composition of the residual household waste cannot be defined more precisely since it depends on the selective collection mode chosen. In France, plastics, cardboard, paper, metals and glass are usually collected separately. Bulky items, batteries, electronics devices and plant waste are either collected separately or brought on a voluntary basis by households to a waste-sorting center. Thereby, the residual household wastes do not include these elements. Household biodegradable waste can be considered as residual waste if no special collection is arranged. The concept of residual household waste is particularly important since it represents the inputs for a MBT facility.

Residual municipal waste can also be called mixed municipal waste. It is composed of residual household waste, but also residual waste similar in nature coming from other sources than households. It can come from the municipality itself or from other private and public bodies (www, Friends of the earth, 2008).

2.1.5 Summary of the different types of waste

The features characterizing organic, bio and biodegradable waste are illustrated in *figure 4*. The examples used for each category are quite representative but certainly not exhaustive.

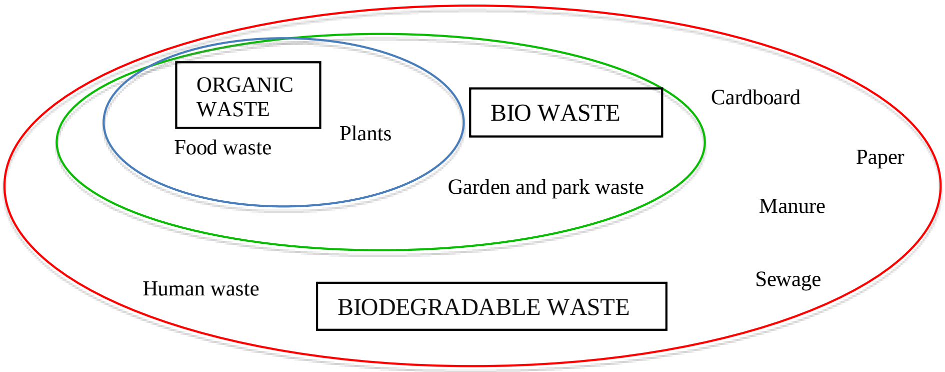

Figure 4. Different types of waste (source: own creation)

2.2 Biological Treatments

To reach the European and French recycling objectives regarding households' and municipalities' waste, many reports outlined the need to increase the biological treatment rate (EEA, 2013; www, Suez Environnement, 2013).

Biological treatment is a process in which the biodegradable materials are decomposed. In the context of municipality waste management, this process is aiming at transforming biodegradable waste into compost and/or biogas (methane), through anaerobic and/or aerobic decomposition (European Union, 2014). Biological treatment is an alternative waste management option "greener" than the ones currently used, i.e., incineration and landfilling.

When measured on a national level, biological treatments are often included in the recycling rate (Eurostat, 2012; EEA, 2013). However, it is important to understand the difference between the two concepts. Recycling is a process in which waste materials are transformed into new products, when they are decomposed with biological treatments.

2.2.1 Selective Waste Collection

Selective waste collection, also called source separated is the concept in which the biodegradable fractions of municipal solid waste are collected separately from the rest of the waste. In this thesis, I will only consider the AD plants since they encompass both biological treatments, anaerobic and aerobic decomposition.

2.2.1.1 Aerobic decomposition

The aim of this treatment is to produce compost that will be used as organic fertilizer or soil improver (European Union, 2014). Although diverse technologies of composting exist, compost is usually generated in the presence of oxygen (aerobic). The process duration, depending on the composition of the inputs and temperature, may vary from a week to months. This process is commonly called composting. The quality of the compost is importantly dependent on the quality of the inputs. In this respect, it is only the biodegradable waste that significantly contributes to enriching the properties of the compost. In contrast, quality is severely lowered by the presence of traces of non-biodegradable materials such as plastic, glasses, metals (European Union, 2014).

Although there are no European norms, except the European ECO label or EU regulations on organic agriculture, each state member can enforce a norm regarding the quality of the compost produced in its territory. In France, for instance, the norm called NFU 44-051 was introduced in 2009. It regulates the composition of the compost and limits the traces of undesirable materials such as zinc, copper, plastics, etc. (European Union, 2014).

2.2.1.2 Anaerobic decomposition

The anaerobic process relies on the decomposition of biodegradable waste in the absence of oxygen (anaerobic). When decomposing, the biodegradable material releases biogas. In particular, it may release approximately 40 up to 80 % of methane and 20 up to 60 % of Carbon dioxide. The methane produced is called biogas and can be used to fuel vehicles equipped with a proper engine, be burnt to produce electricity and/or heat or injected into the gas grid (European Union, 2014). The volume of methane produced will depend on the volume of waste decomposed but also on the composition of the input (Brunetti, Lore & Lotito, 2008). Indeed, each specific biodegradable material has a different methanogenic potential. This means that each specific biodegradable material, when decomposing, will release a different amount of methane (Brunetti, Lore & Lotito, 2008). At the end of the process, the digestate is mainly composed by solid and liquid residuals. Digestate is usually spread as liquid fertilizer or can go through aerobic decomposition to be later used or sold as compost (European Union, 2014).

When biodegradable municipal waste is separately collected, the AD plants are combining both anaerobic and aerobic decomposition. This type of plant has the advantage to generate revenue from two sources, namely, i) biogas and ii) high quality compost (EEA, 2009).

2.2.1.3 Limitations

The use of the selective waste collection for biological treatment concerns only biodegradable waste. Thereby, any municipality aiming at starting selective biodegradable waste collection must also continue to collect and dispose of the non-biodegradable and non-recyclable waste, through landfilling or incineration. In order to optimize the overall biological treatment, both anaerobic and aerobic decompositions are needed. A portion of the digestate can sometimes not be destined to aerobic decomposition and may require additional treatment or be disposed of using another method. The efficiency and the profitability of the facilities are highly dependent on the ability that households and other producers of biodegradable waste have when it comes to sorting out their biodegradable waste (EEA, 2009). Selective collection of this waste is progressing in France. Suez Environnement (2013), leading company in waste collection estimated that 3 % of the French population was covered with a selective collection of biodegradable waste in 2013.

2.2.2 Non-selective waste collection

In a non-selective waste collection biodegradable waste is collected together with the household residual waste. Households are not expected to use a specifc container for the biodegradable waste.

2.2.2.1 Mechanical-biological treatment

MBT is an alternative method for the selective collection of biodegradable waste (EEA, 2009). It was originally conceived for treating and reducing the volume of waste by combining mechanical sorting and biological treatment (EEA, 2009). Indeed, the plant can accept mixed municipal waste. The mixed municipal waste is mechanically separated into biodegradable and non-biodegradable waste. The mechanical treatment isolates the different types of waste by using a combination of different types of machines such as shredders, conveyors and magnets (Chartered Institution of Water and Environmental Management [CIWEM], 2013). The waste can be separated into recyclable materials, biodegradable waste, high calorific value incinerable waste (HCV) and eventually solid recovered fuel (SRF) or refuse-derived fuel (RDF). The recyclable materials such as plastic, metals are sent to their respective recycling channel (CIWEM, 2013). The HCV is burnt to generate energy. Solid recovered fuel (SRF) or refuse-derived fuel (RDF) can be used as a fuel in order to generate electricity or to produce in cement kilns. The non-biodegradable waste is sorted out to be injected into their respective recycling channel or to be landfilled or incinerated for energy recovery. Once the biodegradable waste is isolated from other waste, it undergoes biological treatment. The mechanical-biological facilities are often including anaerobic and aerobic decomposition (CIWEM, 2013). First, the biological waste is undergoing anaerobic decomposition generating biogas. Then the digestate is undergoing aerobic decomposition to be transformed into compost.

2.2.2.2 Limitations

MBT is a controversial technology. It attracted a lot of interest within the European and national regulations given the constraints set on landfilling and incineration. This interest is motivated by three main considerations. First of all, the combination of the mechanical and biological treatment may reduce the volume of waste by up to 60 % (www, CNIID, 1, 2008). Therefore, the volume of waste sent to landfill or incineration is lower. Second, the production of biogas and compost can generate income, reducing thereby the cost of waste management. Finally, this method does not require households to sort out the biodegradable waste and does not require the municipality to implement an additional selective collection for these particular wastes. So, theoretically, MBT is expected to help municipalities wanting to meet the European and national regulations at a low cost.

MBT is favorably considered by the French main providers of waste management services, *Veolia Environnement* and *Suez Environnement* but it is hardly criticized by several non-governmental organizations and associations such as, for instance, Zero Waste France (www, 2014) and Independent National Information Center on Waste (CNIID). The opponents to mechanical-biological facilities are questioning the real efficiency and economic viability by highlighting several issues. For instance, they stress that MBT is still depending on the incinerators and landfills to dispose of the remaining waste (www, CNIID, 1, 2008). In addition, the investment cost for these facilities is often under-estimated while the income generated by the sale of biogas and compost is often overestimated. CNIID (www, 1, 2008) argues in fact that extra costs should be considered given that the quality of the compost is often so poor that it must be landfilled or incinerated.

In 2012, AMORCE and ADEME (2012) investigated in a mutual paper 6 existing mechanical-biological facilities in France. As a result of this paper, it is observed that the actual volume of normed compost and biogas was more than 50 % lower than planned for 4 out of the 6 existing facilities. For the 3 facilities disclosing the information, the actual investment was 20 % more expensive than forecasted (AMORCE and ADEME, 2012). Moreover Zero Waste France and CNIID considered the French norm, NFU 44-051 as lax. They report the volume of heavy metals limits and plastic limits tolerated in the French norm compared to the European ECO label and EU regulations on organic agriculture. The comparison of these three norms is presented in *table 1.* The French norm is accepting more heavy metals than the level indicated in the European ECO label and EU regulations. Thereby, the farmers willing to use compost produced with a MBT plant may not be able to obtain the European label or certification. Moreover, the main concern is about having French normed compost that still contains large quantities of metals and non-desirable materials, which can be potentially harmful if spread on in farming land.

Table 1. Heavy metals limits in existing compost regulations and standards (European Union, 2014)

Country	Regulation	Type of standard	Cd	Crtot	CrVI	Cu	Hg	Ni	Pb	Zn	As
			mg/kg d.m								
France	NFU 44-051	standard	3	120	-	300	2	60	180	600	
EU ECO Label	Eco label	Voluntary	1	100	-	100	1	50	100	300	10
EU Regulation on organic agriculture	Compliance with limits requird for compost from source separated bio waste only	Statutory	0.7	70	-	70	0.4	25	45	200	

There are no European norms but only labels and regulations on organic production, each state member can enforce a norm regarding the quality of the compost produced on its territory.

3 Theoretical framework

This chapter provides the theoretical framework of this thesis. Moreover it helps clarifying the study and identifying the contextual variables that will be relevant (Yin, 2009).
From the theoretical perspective, I will be presenting the net present value approach (NPV), the concept of Internal Rate of Return (IRR), the concept of equivalent annual cost and rationale behind the use of Monte Carlo simulations. Each theory will be presented looking at its strengths and weaknesses and having in mind the need of evaluating as accurately as possible the economic performance of the different investment projects associated with each specific waste disposal technology.

3.1 Net Present Value

The use of the net present value method aims at determining "[…] the expected gain or loss from a project by discounting all expected future cash inflows and outflows to the present point in time, using the required rate of return" (Bhimani *et al.*, 2008, p. 420). For a layperson it may be difficult to understand the meaning of the net present value, since it requires understanding the discount factor and its role in the future cash flows (Proctor, 2009). Thereby the determination of cash flow, discount factor and the interpretation of NPV will be explained in the following sections.

3.1.1 Cash Flow

According to Proctor (2009) and Brealey and Myers (2003), although book profit is commonly used for annual report and for communicating with shareholders, it should not be used in order to take investment decisions. Brealey and Myers (2003) explained that accounting profit considers profit as it is earned rather than when it is received. Moreover, the cash outflows are separated into capital expenses and current expenses. Current expenses are deducted when calculating accounting profit but not capital expenses. Capital expenses are depreciated over the lifespan of a project or an investment. The accountant uses depreciation in order to reduce the net income by adding the depreciation charges to the book profit. As a result, accounting profit is biased including some cash flows and excluding others and including non-cash flows, such as depreciation.

Cash flow is an alternative measure to book profit that assists companies in assessing and ranking investment performances. Indeed, the cash flow is the amount of cash available over a certain period of time. The cash flow can be calculated using the income statement relative to the investment project under consideration (Samuels, Wilkes & Brayshaw, 1999). As Brealey and Myers (2003) pointed out, there is no single way to isolate a cash flow since it depends on which operations were made in the books. In this thesis, the cash flow will be determined using the following formulas:

Net Cash Flow = net income + depreciation – investment

or equivalently,

Net Cash Flow = EBITDA – interest payment – corporate tax - investment

In the first formula, the *net income* corresponds to the company's total gross income minus the company's costs, taxes, depreciation and other expenses (Brealey, Myers & Marcus, 2001). In the second formula, *EBITDA* stands for earnings-before-interest-taxes-depreciation-amortization. The *EBITDA* are given by the company's total revenues minus the company's production costs and operating expenses (Brealey & Myers, 2003). All costs such as interest, taxes and depreciation are not taken into account.

Interest payment corresponds to the money paid by the borrower to the lender for using his or her money. *Corporate tax* is a levy or charge imposed to corporations based on the accounting profits or other forms of income, depending on the regional and national laws (Brealey, Myers & Marcus, 2001). *Depreciation* corresponds to a share of an investment that could be deducted from taxable income (Brealey & Myers, 2003). *Investment* corresponds to the change in working capital, and is calculated as current assets minus current liabilities (Brealey & Myers, 2003). The number of cash flow calculations will depend on the estimated useful life of the investment (Glautier & Underdown, 1997).

Determining the future cash flow value can be difficult since one needs to anticipate all the future revenues and expenses. An unpredicted change in the market condition or within the company may severely alter the cash flow calculations. Moreover, since the estimated investment lifespan may be extended or shorted due to unforeseen adjustments, cash flow calculations may also need to be revised (Glautier & Underdown, 1997).

3.1.2 Discount Factor & Present Value

The discount factor allows the cash flow values of the investment to be transformed to present values, as if they are occurring at the same point in time. Discounting the cash flow values is essential in order to weight the time value of money. In other words, it allows keeping into account that 1-euro today has not the same value in ten years due to the opportunity cost[3] of using money (Proctor, 2009; Bhimani *et al.*, 2008). The discount rate, also known as opportunity cost of capital or required rate of return, is defined as "[…] the minimum acceptable rate of return on an investment… that the organization could expect to receive elsewhere for an investment of comparable risk" (Bhimani *et al.*, 2008, p.420). Although this rate is usually set by an individual or an institution funding an investment project, there is no way by which one may uniquely identify it.

Once defined the discount rate, the present values for each year of the investment lifespan can be determined using the following formula:

$$\text{Present Value} = \sum_{t=1}^{n} X_t(1+r)^{-t}$$

where $\sum$ stands for the operator summing the terms $X_t(1+r)^{-t}$ from period 1 up to period *n*, where *n* indicates the length of the project lifetime, X_t represents the periodic cash flow and *r* is the discount rate.

The net present value is then calculated by subtracting the initial investment cost from the total present value of the project's cash flows. This leads to the following formula:

[3] Opportunity cost is defined as"[…] value of something that must be given up to acquire or achieve something else" (www, BusinessDictionary, 2, 2014).

Net present value = Present value – investment cost

A convenient layout is very often used to combine the two above formulas:

Table 2. Conventional layout used for the net present value (source: own creation)

Year	Cash flow	Discount factor (e.g., 10 %)	Present value
1	X_1	0.909	$=X_1*0.909$
2	X_2	0.826	$=X_2*0.826$
n	X_n	…	…
		Total PV	$X_1+X_2+X_n$
		Initial investment	K
		NPV	Total PV -K

The choice of the discount rate and its effect on the corresponding present value will be further discussed in the chapter dedicated to the empirical analysis.

3.1.3 Interpretation

The net present value highlights the financial outcome of an investment taking into account, as discussed above, the time value of money and the cost of capital. If the net present value of an investment is negative, the investment should be rejected since the investor will earn less than the required rate of return. In contrast, if the net present value is positive, the investor should undertake the investment. When the net present value is equal to zero, the investor is neither earning nor losing money by undertaking the investment (Samuels, Wilkes & Brayshaw, 1999).

However, when evaluating the net present value for a long-term project investment, the cash flow forecasted for each year must be determined. For projects with an expected lifespan of 15 years, the net cash flow of the next fifteen years must be calculated before being discounted and used for the net present value. To overcome the uncertainty, Brealey and Myers (2003) recommend a sensitivity analysis.

3.2 Equivalent Annual cost

3.2.1 Equivalent Annual Annuity

It is worth mentioning that the net present value method has some limitations when one compares two or more projects with different lifespans. Indeed, the net present value does not take into account the length of the investment when comparing investments with different lifespans. Brealey and Myers (2003) suggested using the equivalent annual cost in order to handle this sort of situation.

The equivalent annual cost corresponds to the annual cost of owning and operating a plant, considering equal cash flows over the lifespan of the investment (Brealey & Myers, 2003). The equivalent annual cost is also a method often used in order to compare projects having different lifespans.
The traditional net present value approach considers the investment cost in year 0 and cash flows over the lifespans, as illustrated in *figure 5*. With the equivalent annual cost, the

investment cost is discounted and included in the present values, ensuring thereby equal present values for the entire length of the investment. The equal present values also called real, equivalent annual annuity (EAA), equivalent annuity or equivalent annuity cash flow.

To determine the equivalent annual costs, the net present values must be determined using the net present values calculations.

Net present value = Present values – investment cost

Once the net present value determined, the equivalent annual annuity can be calculating using the following formula:

$$EAA = \frac{NPV * r}{1 - \frac{1}{(1+r)^n}}$$

where *NPV* stands for the net present value, *n* indicates the length of the project lifetime and *r* is the discount rate.

The difference between the net present value and the equivalent annual cost is illustrated in *figure 5.*

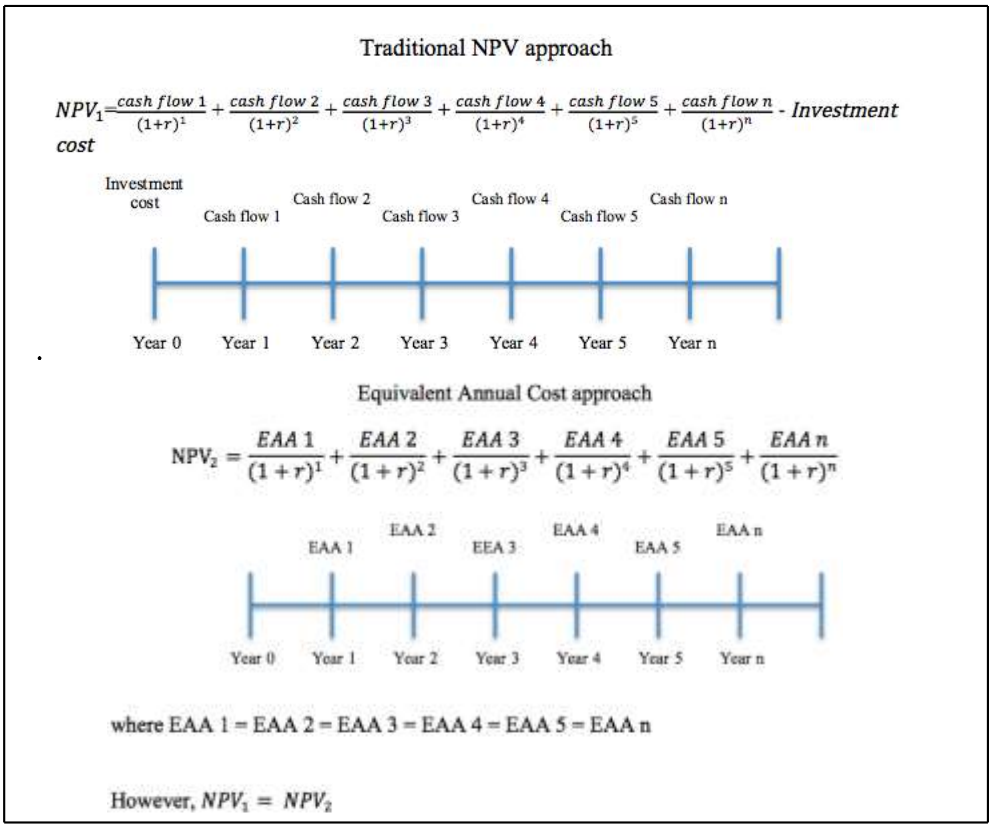

Figure 5. Comparison net present value and equivalent annual cost (source: own creation)

3.2.2 Projects comparison

To compare two projects with different lifespans, the equivalent annual cost is determining the equivalent annual annuity by "forcing" the compared projects to have the same lifespan e.g. 15 years.

Once the net present value is determined for each project, the equivalent annual annuity must be calculated using the *EAA formula* and the same value for *n* for all the compared projects.

3.3 Sensitivity Analysis

As stressed by Brealey and Myers (2003), when performing a cost-analysis, one must be well aware of the uncertainty that may characterize the scenario under analysis. The net cash flow, for instance, depends on several random factors such as the project's lifespan, actual costs and income, a given tax, the planned investments. An unexpected change of one of these parameters may affect the cash flows and the final net present value. Thereby, the sensitivity analysis assists the investor wanting to observe what would be the consequences on the net present value if certain parameters were varying or were misestimated. The most common way to set the sensitivity analysis is either to classify the different scenarios as pessimistic, expected and optimistic or to allow several sensitivity rates e.g. ±10 %, ±20 % and ±30 % of sensitivity for the chosen parameters. A difficult task, when evaluating a project, is the identification of the parameters that should be considered in the sensitivity analysis. Moreover the classification of the three scenarios pessimistic, expected and optimistic may not be crystal clear for all stakeholders.

As explained by Brealey and Myers (2003) the sensitivity analysis can be very useful when the user wants to observe the consequences of changing one parameter. The analysis can only accept one change at a time. This method can become complicated and time-consuming when multiple changes are done. To overcome the limitations and difficulties that a user may encounter when using the sensitivity analysis, the authors suggest complementing the analysis using Monte Carlo simulations.

3.4 Monte Carlo Simulations

A Monte Carlo simulation is a computerized mathematical tool that considers all possible combinations and possible outcomes and their probabilities. It can also show the extreme possibilities, median outcome (Brealey & Myers, 2003). The user needs to enter the different parameters, their initial value (expected value) and the range of uncertainties for each parameter of interest, e.g. ±10 %, ±20 % and ±30 %.

In a Monte Carlo simulation, some inputs are allowed varying within a range of possible values. Variations follow assumed probability distributions. This is done in order to account for the effect of the uncertainty that may characterize these factors in the reality. The choice of a specific probability distribution is, of course, opinable. Choices are then made on the basis of what may more realistically represent the investigated object (www, Palisade, 2014). Water Environment Research Foundation [WERF] (2012) argued that Monte Carlo simulations are relevant to "[…] understand the impact of various risks factors from uncertain assumptions on project benefits and costs" (p. 7). The simulation is calculating the outcome several times, using different sets of random values. Monte Carlo simulations are usually running hundreds or thousands of random values, given the probability distribution and the resulting outcomes. Interdependencies between parameters are extremely important to assist the simulation to take into account all consequences on the outcome, which is included in Monte Carlo simulations (Brealey & Myers, 2003). Monte Carlo simulations can also be useful to identify an interval of possible outcomes and its probability, which is particularly relevant for project economic appraisal.

3.5 Net present value and Monte Carlo Simulations

One of the most well-known Monte Carlo simulations products used for project management is Palisade's @Risk. This product is an add-in for Microsoft's Excel aimed at assisting decision makers to take into account uncertainties and analyze risks related to projects (www, Palisade, 2014). Monte Carlo simulations are often run using, as a basis, net present value calculations (Brealey & Myers, 2003). The use of the Monte Carlo simulations allows the user to take into account the uncertainty that may occur when calculating the net present value. The first step is to transpose the net present value data into Excel by adding all fixed and variables parameters used to calculate the net present value. The second step is to define the range of uncertainties for each variable parameter, once at a time. The interdependencies between parameters must be expressed to allow the simulation to take them into account. Then, the simulation is run several times in order to let parameters vary (Brealey & Myers, 2003).

3.6 Internal Rate of Return

3.6.1 Definition

As explained above, the net present value is highly dependent on the discount rate. However, the determination of the right discount rate remains pretty difficult due to the market conditions. An alternative discount rate can affect severely the final net present value and the acceptance of a project. This issue is particularly important when comparing different projects in order to choose one. The internal rate of return shows the return rate of the investment. The internal rate of return is the discount rate such that the net present value of the project considered is equal to zero. It represents the break-even rate of the investment. The internal rate of return is given by the following formula:

NPV(r) = 0

where *r* the internal rate of return to be calculated.

3.6.2 Calculations

One way to determine the internal rate of return is to consider a positive and a negative level for the net present value and then use interpolation (Proctor, 2009). In this case, the internal rate of return is given by the following formula:

$$IRR = A + \left\{ \frac{a}{a + |b|} \times (B - A) \right\}$$

where *a* represents the (positive) project's net present value calculated using the discount rate *A* and *b* represents the (negative) project's net present value calculated using *B* as discount rate. Note that in the formula the absolute value of *b* should be considered.

3.6.3 Interpretation

The internal rate of return represents the rate at which the investment breaks-even. This implies that if the cost of capital were below this rate the investment would be profitable, while if above the investment would be unprofitable. Moreover, the IRR is often used to present a project in front of non-financial managers (Brealey & Myers, 2003). If the compared projects have negative net present value, the internal rate of return could give indications about how profitable a project can be given a specific cost of capital (Samuels, Wilkes & Brayshaw, 1999).

3.6.4 Limitations

However the internal rate of return does not take into account the size of the investment. When comparing project investment, the IRR tends to favor short-term projects and smaller project, which are offering greater rate of return than long-term project and larger projects (Brealey & Myers, 2003). Long-term projects and larger projects can however repay better the investor. Additionally, the IRR does not consider the lifespan of a project when comparing two or more projects. That is to say if a project is expected to last two years and another one five years, after two years the money coming from the first project could be reinvested for another project. As explained Brealey and Myers (2003) when a project is presenting one or more negative cash flows, two or more internal rates of return are emerging, as seen in *figure 6.*

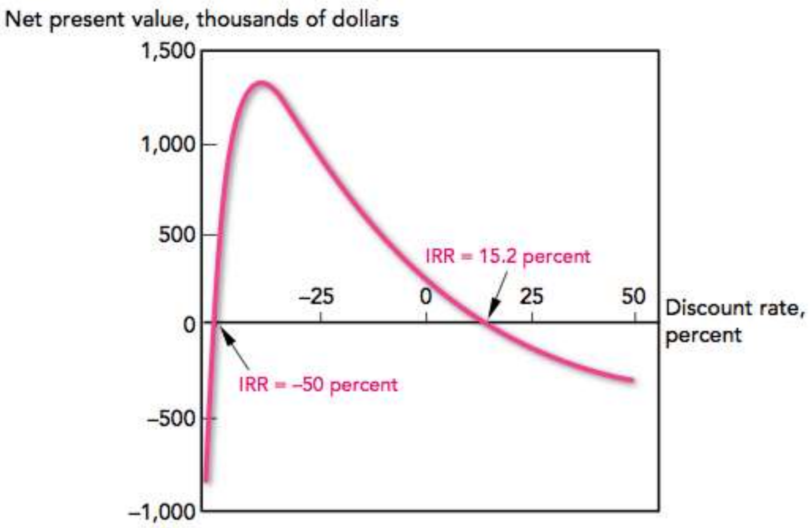

Figure 6. Example of two internal rates of return solutions (Brealey and Myers, 2003, p. 100)

3.7 Cost-effectiveness

One way to measure and compare economic and financial performance relies on the concept of cost-effectiveness. Cost-effectiveness is a concept in which the cost is critically assessed given a desired outcome, solution or result. In this thesis, the waste disposal methods are costly to the municipality and indirectly to the inhabitants who pay a fee for waste management. The desired outcome is to implement a biological treatment in the municipality at the lowest cost for the habitants. Therefore the most cost-effective method would be the one offering the lowest cost for the inhabitants of the municipality.

3.8 Summary of the theories

The theoretical chapter aimed at identifying the theories that can assist the researcher when responding to his or her research questions.

Both the net present value and the internal rate of return offer good financial tools to judge the economic viability of one or several investments. Brealey and Myers (2003) outlined that the internal rate of return is a useful tool, but very often used to help non-financial manager to understand an investment project. As long as the net present value meaning is understood, using the internal rate of return could only confirm the net present value or falsify the results if the projects have different lifespan and/or negative cash flows. Therefore I will be only using the net present value since it appears as a much stronger tool for the appraisal of different investment projects. The net present value will be used to calculate the equivalent annual cost useful to compare the investment projects having different lifespans.

To cope with uncertainties and the consequences they can have on the net present value of a project, I will provide a sensitivity analysis and run Monte Carlo simulations. The sensitivity analysis is easy to implement since it basically recalculates the net present value according to the change of a chosen parameter. Monte Carlo simulations will be run to study the impact that change in the parameters may have. This is done allowing for different levels of volatility. The analysis is then undertaken by observing, for each potential scenario, the likelihood of having a cost per habitant falling within a certain interval or below a given value.

By combining the net present value, equivalent annual cost, sensitivity analysis of the variable parameters and Monte Carlo simulations, I will be provided with a more detailed analysis of the investment projects, where uncertainties and the length of the investments are properly taken into account. I will be able to compare and appreciate the cost of the investment projects.

4 Investing in waste disposal: a Literature Review

In this thesis, the net present value is used to assess and compare the investment projects associated to the different biological treatments that one municipality could implement in order to recover the municipality biodegradable waste. Monte Carlo simulations are paired to the net present value to show the projects' net present value variability given uncertainties. As a support to this approach, this chapter will review the work of several authors who successfully used this combination.

Varadarajan (1995) used the net present value method to appreciate and compare the economic and financial performance of bio gas plants. In his study, Varadarajan (1995) selected 30 bio gas plants (anaerobic decomposition) in Thirumangalan, India aiming at producing gas for the inhabitants from Cattle Dung. He reported that the net present value was the most appropriate tool to assess the cost and benefit of the different bio gas plants. He found out that the size of the plant affected the cost of the plant, even if sometimes similar plants can have different costs. He also identified the lifespan of a bio gas plant to be 20 years.

Gebrezgabher *et al.* (2010) assessed the cost-effectiveness of a bio gas plant by using the net present value. In this study, the economic performance of an anaerobic digester processing a maximum of 70, 000 tons of input per year is assessed. The study is undertaken at a farm level and feedstock is the input considered. Although the inputs are different from my case study, the outputs, biogas and composts are the same. The authors found out that the net present values were positive only when subsidies were taken into account. This was then implying that the economic viability of anaerobic plants were dependent on national policies and subsidies.

As explained by Sasikumar and Sanoop Gopi (2009) the net present value helps decision-makers to assess different investment projects given different scenarios. The authors pointed out that in the case of municipal waste management, the net present value of the projects could be negative or close to zero indicating a need for cost reduction or additional income. In the case of the municipal waste management, the main source of income is usually the household's waste tax and therefore an adjustment of the tax can change the net present value of a project. Likewise a reduction of the cost can also assist in having a positive net present value. They reported that the cost-benefit analysis is one element to support a project but stakeholders' opinion is also important since their support or opposition may affect the feasibility and the costs of the project.

Perez Garcia (2014) used the net present value to assess the economic feasibility of a biogas plant in Bolivia under different scenarios. In her study, she chose to select a digester and a technology already existing and adapted to her case study, that is, the city of El Alto in Bolivia. She also reported that given the lifespans of the bio gas plants (15 to 20 years) the net cash flows used to determine the net present value are average values. She acknowledged that a variation of the costs or of the revenues could have an important impact on the net present value. A sensitivity analysis was made to appreciate the weight certain parameters' variation have upon the net present value e.g. a variation of 50 % of the compost price generated an increase of 60 % of the net present value. A sensitivity analysis helps to evaluate if a project remain the most economically viable under different variations. Perez Garcia chose to apply the sensitivity analysis only to the most attractive scenario.

WERF (2012) used the net present value to evaluate the cost-benefit of a project and run Monte Carlo simulations in order to assess the impacts of uncertainties upon the final net present value. The project under investigation was a combined heat and power project (CHP) generating biogas. WERF (2012) argued that for long-term projects such as biogas facilities, the use of short-term method such as payback periods was not adapted. They chose to assess the project with the net present value and Monte Carlo simulations. As seen in *figure* 7, they run Monte Carlo simulations a thousand times with a 90 % probability.

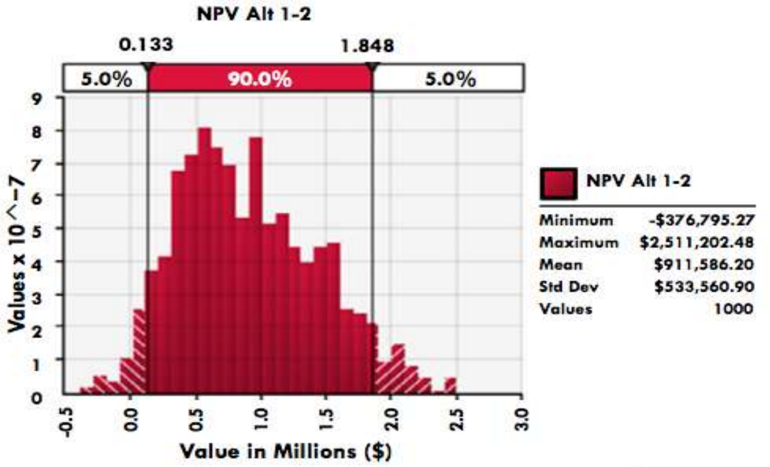

Figure 7. Frequency distribution of the net present value results (WERF, 2012, p. 8)

Pandyaswargo and Premakumara (2014) used the net present value to compare the cost-effectiveness of several aerobic plants in charge of the disposal of municipal waste. They selected five plants of different sizes in Asia. The net present values were presented in USD per ton waste treatment capacity, which made it easier when comparing the results and identifying the most efficient and optimal plant scale. A traditional net present value comparison would not have helped the decision maker to identify the most cost efficient solution. Three sensitivity analyses were carried out in order to identify the effects of certain subsidies upon the projects. In the study, the medium-scale composting plant appeared to be the most efficient and sustainable plant.

Estevez Weinstein (2006) provided a cost-benefit analysis for a plant aiming at transforming waste into energy (WTE) for two municipalities. The net present value of the plant was presented given the different components, including the gate fee. The author used Monte Carlo simulations in order to reveal the sensitivity of the project's net present value given the variation of different parameters, e.g. electricity price and discount rate.

Rajendran *et al.* (2014) studied the economic feasibility of treating municipality biodegradable solid waste with biogas plants. After setting 6 different scenarios, depending on the type of inputs, the volume of inputs and the plants' capacity, they ranked these scenarios using the net present value approach. The sensitivity analysis was carried out for all the different scenarios in order to reveal the role of certain parameters on the different scenarios.

To reach the aim of the study, the thesis will follow the work done by the authors mentioned before and investigate the different investments project with the net present value. A sensitivity analysis will be paired with the net present value calculations in order to appreciate the sensitivity of the projects given a range of uncertainties among the variable parameters. Finally, Monte Carlo simulations will be run to observe the impact that volatility may have in each specific project.

5 Methodological approach

The researcher should pay attention to the research design of the study. As explained by Flick (2008) the “research design is a plan for collecting and analyzing evidence that will make it possible for the investigator to answer whatever questions he or she has posed” (p. 38). Four elements are specifically highlighted when attempting to answer the research question: purposes, methods, validity and conceptual context (Flick, 2008). The presentation of the investigation must include: the type of research, the choice of the participants, the data collection and the instruments of the data collection in order to validate the method and the results (Zacharias, 2012).

Research design will assist the researcher to show methodological coherence in the research approach (Saunders, Lewis & Thornhill, 2012). Several scientific methods could be used to write a thesis. It is the writer’s responsibility to show a good understanding of the different methods and approaches and to motivate one’s own choices in order to be sure that the research received scientific credibility (Saunders, Lewis & Thornhill, 2012). To reach this aim, I will conduct an exploratory study. This type of study is useful when a deeper understanding of the problem is wanted. Moreover, this approach allows flexibility and adaptability to changes.

As part of the research design, I need to define what approach I will adopt. There are two approaches that are scientifically recognized, namely, quantitative and qualitative approach (Saunders, Lewis & Thornhill, 2012). Although the distinction between both methods is not crystal clear, researchers tend to separate them (Saunders, Lewis & Thornhill, 2012; Goddard & Melville, 2004; Zacharias, 2012). Quantitative approach is often used with numerical data retrieved from questionnaires, graphs and statistics and qualitative approach is more associated with non-numerical results and interpretative philosophy (Saunders, Lewis & Thornhill, 2012). When realizing a qualitative research, the researcher is subjective in the choice of the issue and the context s/he is giving.

Given the aim of the study, a multiple method will be followed, combining both quantitative and qualitative approaches. Qualitative research will be achieved in the selection of the municipality, the review and interpretation of the different biological waste disposal methods. Quantitative research will be done for the economical appraisal (Saunders, Lewis & Thornhill, 2012).

This study aims at investigating a case study in order to understand a phenomenon and to develop empirical generalizations; therefore the thesis will adopt an inductive research approach. As explained by Goddard and Melville (2004), taking an inductive approach, the theories are developed as the end of the research and as a result of the empirical observations. In this approach, the researcher aims at developing explanations and eventually theories from the results of the empirical study (Goddard & Melville, 2004).

5.1 Qualitative Case Analysis

When selecting a case study strategy, Yin (2009) highlighted the importance of choosing either a single-case or multiple-case study depending on the research and the aim of the study. Each approach has a different purpose. A multiple-case study is chosen to find out if the results can be replicated across the different cases (Saunders, Lewis & Thornhill, 2012).

Multiple-case studies may be more time-consuming and may request more resources. I chose to have a single-case study to get a better understanding of a particular phenomenon. The case study strategy is particularly relevant for exploratory research because it enables to answer to the questions ‘Why’, ‘What’ and ‘How’. However, as explained by Yin (2009), the case study is highly dependent on the context and contextual variables are strongly controlled, which therefore can limit the exploration and the result of the case study to the given context. Moreover, Yin (2009) pointed out the necessity to use several data collection techniques – *Triangulation* - when adopting case study strategy in order to ensure a good interpretation of the data.

This study will adopt a single case study since the focus will only be one municipality with a unique and critical approach. Indeed no previous research has been done in this municipality or in investigating the cost of the two biological waste disposal methods. Four different scenarios presented in *appendix 1* will be analyzed in order to compare the economic viability of each investment project. The net present value will be used to compare the cost-analyses. A sensitivity analysis of several inputs will be run to observe the economic viability of the scenarios under different levels of uncertainty. Finally, Monte Carlo simulations will assess the projects economic viability in a real life context. The data collection for these four scenarios will be feasible in the time constrained since data will be collected from secondary data sources.

5.2 Data Collection

To reach the aim and to answer to the research questions, data are required. As explained by Saunders, Lewis and Thornhill (2012) there are two types of data. Given a specific study, secondary data are “[…] data that have already been collected for some other purpose” (p. 304) and primary data “[…] collected specifically for the research project being undertaken” (Saunders, Lewis & Thornhill, 2012, p. 678). Thereby, the researcher needs to identify which data can be used to answer the research questions and appreciate the quality of these data.

The data collection employed for this study will be mainly based on secondary data. As argued by Saunders, Lewis and Thornhill (2012), I need to understand the suitability of secondary data in reaching the aim. If available and adapted to the study, secondary data collected by national governments, non-governmental agencies and other organizations are usually excellent data that were collected in a reliable and scientifically sensible way. Primary data can be more specific to the research questions, but given the confines the researcher can have constraints, e.g. money, time, access; the quality of the secondary data may be better compared to primary data.

Waste management strategy is gaining great interest in Europe and in France and thereby, data are regularly collected at the European, national and regional level by European institutions, French government agencies and non-governmental agencies. The triangulation of the different sources could ensure that the data are reliable.

5.3 Choice of the country and municipality

I decided to focus the thesis on the biological treatments in France because it is particularly topical on both national and regional level. Given the French’s waste management history and the current European targets, France and more concretely its municipalities will have to consider and eventually implement new waste management approaches. Moreover, the biological treatment facilities are all present on the territory and given the fact that the French agricultural production is the leader in Europe, the outlets for the compost should not be an issue. The biogas is also used to generate electricity, or as biogas. Both outputs of the biological treatments are used.

The choice of the municipality has been motivated by several factors. First, Municipality A representing the conglomerate of municipalities called *Plaine Centrale du Val-de-Marne,* has published its annual waste management report making possible the investigation (Communauté d'agglomération Plaine Centrale du Val-de-Marne, 2012). Second, the size of the conglomerate is enough large to undertake investment projects with over 150 000 inhabitants. Third, the conglomerate's contracts will end up in March 2016 and therefore a public tender offer will actually be made. Finally, the conglomerate is close to another conglomerate, see *appendix 2,* called *Les Hauts-de-Bièvre* where public tender offers are invited starting from January 2016 (*Les Hauts-de-Bièvre* communauté d'agglomération, 2012). Due to the urgency of the investment, over a year, I am not taking into account issues related to the optimal investment time.

The investigation will first focus on Municipality A contemplating the investment in one of the two available technologies. Then, a similar analysis will be conducted considering a joint investment initiative undertaken by both Municipality A and Municipality B. Summing up, these two moments will lead to the definition of four different scenarios (for details, see *appendix 1*). The comparison between the cases of i) Municipality A investing alone and ii) the two municipalities jointly investing in a specific facility, will allow answering the research question relative to the impact of the economies of scale.

5.4 Ethical approach

When conducting a research, I should be aware that the design and the research plan might affect people directly or indirectly involved. As a student, the research plan and design could affect the investigated parties but also the student's university and his or her supervisor. That is why I should adopt an ethical approach in my research. Saunders, Lewis & Thornhill (2012) defined ethics as "[…] standards of behavior that guide your [the researcher] conduct in relation to the rights of those who become the subject of your work, or affected by it" (p. 226).

In this thesis, secondary data are favored to build the empirical studies, but some people will be contacted to obtain reports, or other documents. Therefore, when I am contacting contacted people by email and phone I should clearly explain why the data are needed, answer any questions that they may raise and be transparent about the publication of the research' results (Saunders, Lewis & Thornhill, 2012).

It also important to clarify the aim of the study and the results since the topic of the thesis is pretty controversial and a misunderstanding could negatively affect the investigated municipalities and other stakeholders such as the manufacturers of the plants used in the comparison, e.g., Kompogas, Vinci Environnement, Valorga and the municipalities used in the comparison, *Plaine Centrale du Val-de-Marne* and *Les Hauts-de-Bièvre.*

Finally, I should try to adopt integrity and objectivity during the research. Given the topic, it requires diversifying the sources of data, acting transparently and promoting accuracy (Saunders, Lewis & Thornhill, 2012).

6 A Case Study

6.1 Empirical Background

This chapter is divided into three sections. Its aim is to provide an introduction to the empirical study. The first section is devoted to the description of the municipalities involved in the case study. The second section is dedicated to the presentation of the facilities representing the different technologies given the different scenarios. For the convenience of the reader, I provided below, in *table 3,* a summary of the different scenarios. The last section is dedicated to the presentation of the parameters chosen for conducting the cost-analyses.

Table 3. Summary of the different scenarios (source: own creation)

	Population	**Scenarios**	**Technology**	**Waste type**	**Average volume of waste collected (kg/year)**	**Total required capacity of the plant (ton/year)**
Municipality A	155 330	Scenario 1	Anaerobic digestion	Biodegradable municipal waste	123	19 106
	155 330	Scenario 2	Mechanical-biological treatment	Municipal waste	123	46 910 Considering 302 kg/hab
Municipality A + B	337 807	Scenario 3	Anaerobic digestion	Biodegradable municipal waste	123	41 888
	337 807	Scenario 4	Mechanical-biological treatment	Municipal waste	123	102 018 Considering 302 kg/hab

6.1.1 Municipalities

6.1.1.1 Municipality A

For the convenience of the reader, the conglomerate of municipalities called *Plaine Centrale du Val-de-Marne* will be hereafter named Municipality A.

Municipality A consists of three different cities: Alfortville, Créteil and Limeil-Brévannes. As shown in *Appendix 2,* Municipality A is located in the suburban area in the southeast of Paris. In 2001, these three cities decided to gather in order to jointly handle their waste.

According to the French census realized in 2010 by the National Institute of Statistics and Economic Studies [INSEE], Municipality A has a population of 153,330 inhabitants (Communauté d'agglomération Plaine Centrale du Val-de-Marne, 2012).

The municipality does not have a source-separate collection of biodegradable municipal waste. Household residual wastes, including biodegradable waste are currently sent to incineration.

6.1.1.2 Municipality B

As above, we will consider as Municipality B the conglomerate of municipalities called *Les Hauts-de-Bièvre*.

Municipality B encompasses seven different cities, *Antony, Bourg-la-Reine, Châtenay-Malabry, Le Plessis-Robinson, Sceaux, Verrières-le-Buisson and Wissous.* As illustrated in *Appendix 2,* also Municipality B is located in the suburban area southeast of Paris. The average distance between Municipality A and Municipality B is about 15 kilometers.

According to the French census realized in 2010 by the INSEE, Municipality B has a population of 182,477 inhabitants (*Les Hauts-de-Bièvre* communauté d'agglomération, 2012).

6.1.2 Volume of waste

In the thesis, four different scenarios, summarized in *Appendix 1*, has been set for comparison. Scenario 1 and 3, using AD, need biodegradable waste whereas scenario 2 and 4, using MBT, need household residual waste. In this section, I discuss how to determine the volume of biodegradable and residual waste that will be considered for the empirical studies.

As explained by Eunomia Research & Consulting (2002), data regarding AD plants can be problematic since scientific studies and business reports often provide (and rely on) different data. To overcome potential inconsistencies, Eunomia Research & Consulting (2002) suggested using data from existing plants.

As observed in the paper produced by AMORCE and ADEME (2013) the data provided by the manufacturers tend to be different for the reality for both the AD and MBT plants.

Thereby to identify a volume of biodegradable and residual waste as close as possible to the reality, I retrieved data from the existing AD plants and MBT plants (AMORCE and ADEME, 2013). I identified the average volume of biodegradable waste entering the facility per habitant for three currently active AD plants. Then I calculated the average amount of biodegradable waste per habitant given the results relative to the three plants considered. I then used the same method for the household residual waste entering the MBT plants. I identified the volume for six plants and calculated the average value. The average household residual waste, 302 kg per habitant is only relevant to identify the required size capacity of the plants in scenario 2 and 4. In the four scenarios, the average biodegradable municipal waste is identical and is equal to 123 kg per habitant. For the four scenarios, only the biodegradable waste will be considered for the calculations.

Results:
Average biodegradable municipal waste: 123 kg / habitant
Average household residual waste: 302 kg / habitant

These results are applied to the respective scenarios in *Appendix 1* in order to identify the volume of waste in ton[4] per year.

6.1.3 Cost of sorting out

In the case study, I am considering two technologies, AD and MBT. The two technologies are offering similar processes and outputs (biogas and compost); however MBT is also providing the biodegradable sorting out process. Indeed, with the AD, households must sort out and isolate the biodegradable waste from the residual waste, which is not the case with the MBT. Thereby in order to compare the total cost of both technologies, the cost of sorting out biodegradable waste at the household level must be considered when using AD, i.e., scenario 1 and 3.

Regardless if the municipality is handling through AD or mechanical biological treatment, households are expected still to separate recycling plastics, metals and glasses into their respective garbage bins. For this reason, the effort of sorting out these materials is voluntary ignored since it applies for both treatments.

A reasonable proxy for the cost of the sorting out is given by the willingness to pay for having it done. Berglund (2006) gathered data using 850 mail-out surveys sent to the inhabitants of Piteå in Sweden. He found out in his investigation that among his sample, individuals were ready to pay around 20 euros[5] to avoid the waste sorting out process. This figure represents the whole sorting out process. Today, no similar study has been done. I assume that the cost of sorting out is the same in France that the one found by Berglund.

A reasonable way to evaluate this cost is to consider that the cost of sorting out biodegradable waste is proportional to the share of biodegradable waste present in the total volume of household waste. ADEME (2010) evaluates that individuals are producing 594 kg per year.

Cost of sorting out biodegradable waste (per habitant per year): $(\frac{123}{594}) * 20 = 4.14$ euros

[4] 1000 kilograms = 1 ton
[5] USD 25 = 20 euros, given the exchange rate on November 11, 2014 (www, xe.com)

6.1.4 Facilities chosen

To provide a cost-analysis comparison of the different technologies corresponding to scenarios 1, 2, 3 and 4, I decided to use data based on existing facilities since data concerning investment cost, profitability and operative costs provided by the manufacturers or in the literature are often quite far from the reality (AMORCE and ADEME, 2013; Eunomia Research & Consulting, 2002). Once defined the volume of waste to be treated for each scenario, I have selected four existing facilities that would meet the requirements chosen for each scenario, the capacity to be treated and the technology. Note that in all the figures provided in the following section, i) a value added tax of 19.6 % is included and ii) since the cost of investment is presented separately, the cost of collection and treatment do not include any kind of amortization and depreciation. The cost of operation corresponds to the addition of both, the cost of treatment and the cost of collection.

The incomes generated by the biological recovery are included in the cost of treatment, but they are never covering the costs of treatment. However, these facilities tend, by generating income, to reduce the final cost. This in turn implies a lower overall cost for the municipality and its population. The main source of revenue for a conglomerate, excluded in the analysis, is the household waste tax. This tax varies from one municipality to another since this tax is set in order to cover the costs. If the overall cost is lower, the household waste tax will be lower.

6.1.4.1 Scenario 1

For scenario 1, I decided to use the facility located in Calais (north of France). The AD plant has a maximum capacity of 28 000 tons per year which is above the expected volume produced by Municipality A. The plant would be used at 88 % of its full capacity.

In the paper realized by AMORCE and ADEME in 2013, the indicated total investment cost is 22 543 472 euros and can be amortized upon the length of the plant which is 15 years. The cost of treatment is 59.48 euros per ton of biodegradable waste. The French Senate estimated the cost of selective collection of biodegradable waste at 130 euros per ton (Senat, 2010).

6.1.4.2 Scenario 2

For scenario 2, I chose the facility located in Vannes (West of France, Britanny). The MBT plant has a capacity of 53 000 tons of household residual waste per year. Given the data, I estimated that the plant would be used at 88 % of its full capacity. In Vannes, the existing plant is used at 90 % of its capacity; therefore my assumption to use the plant at 88 % of its full capacity is reasonable (AMORCE, 2011).

The paper by AMORCE and ADEME (2013) indicated for this facility an investment cost of 36 107 240 euros. The investment cost can be amortized upon the lifetime of the plant, which is 20 years. The cost of operation is 157.34 euros per ton of household residual waste.

6.1.4.3 Scenario 3

For scenario 3, I chose the facility located in Forbach (East of France). The AD plant has a maximum capacity of 45 000 tons of biodegradable waste per year. Given an expected volume of 41 550 tons, the plant would be used at 92 % of its full capacity.

The paper by AMORCE and ADEME (2013) indicated for this facility a total investment cost equal to 43 672 033 euros. This cost can be amortized over a useful lifetime equal to 15 years. The cost of treatment is 67.63 euros per ton of biodegradable waste. The French senate estimated the cost of selective collection of biodegradable waste at 130 euros per ton (Senat, 2010).

6.1.4.4 Scenario 4

For scenario 4, I chose the facility located in Varennes (southeast of Paris). The MBT plant has a capacity of 100 000 tons of household residual waste per year. The plant would be nearly too small (102 % of its full capacity). The expected volume of waste generated by Municipality A and B is based on the average data. The amount of household residual waste generated by Municipality A and B in 2012 and 2013 was below the average. Thus, it is likely that the actual amount would be lower; therefore the MBT plant would be good enough. The cost of treatment is 108.14 euros per ton of household residual waste. The cost of collection is 100.8 euros per ton of household residual waste (ADEME and AMORCE, 2013; Syndicat Intercommunal à vocation multiple de la vallée de l'Yerres et des sénarts, 2012).

When building up the plant, the re-use of materials has permitted to reduce the cost of investment to approximately 30 million of euros (Senat, 2010). To be able to compare the four scenarios, I need to identify the full investment cost from scratch. To determine this investment cost, I assume that the volume of tons processed and the investment cost are linearly related. Note that by this assumption, I abstract from any potential economy of scale that could be achieved by investing in larger plants.

On the basis of the paper realized by AMORCE and ADEME (2013), there are two plants that could be used for estimating the investment cost for the plant in scenario 4: i) a plant located in Anjou processing 90 000 tons per year which cost 67 932 800 euros and ii) a plant located in Montpellier processing 203 000 tons per year which cost 107 194 974 euros.

Thereby, using basic interpolation, the investment cost for a plant processing 100 000 tons can be calculated using the following formula:

$$\frac{I - I_1}{x - x_1} = \frac{I_2 - I_1}{x_2 - x_1}$$

where I_1 *and* x_1 are representing respectively the investment cost and size capacity of the plant in Anjou. I_2 *and* x_2 are representing respectively the investment cost and size capacity of the plant in Montpellier. I *and* x are representing respectively the investment cost and size capacity of the plant in scenario 4.

Rearranging the formula yields:

$$I = I_1 + [\frac{I_2 - I_1}{x_2 - x_1} * (x - x_1)]$$

Using the figures above, the investment cost of the plant in scenario 4 is 71 407 328 euros.

6.1.4.5 Summary of the data

Table 4 is summarizing the characteristic of each scenario.

Table 4. Summary of the numerical data used for each scenario (source: own creation)

Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Investment cost (euro)	22 543 472	36 107 240	43 672 033	71 407 328
Useful life of the plant/facility (year)	15	20	15	20
Cost of treatment (euro/ton)	59.48	157.34	67.63	108.14
Cost of collection (euro/ton)	130		130	100.8
Volume of waste (ton/year)	19 106	46 910	41 550	102 017

The conglomerates in charge of the municipal waste management are non-profit organizations. As shown in *table 4*, for all the projects the costs are higher than the revenues. The cost of operation corresponds to the cost of treatment and the cost of collection. The incomes generated by the sale of compost and/or biogas are included in the cost of operation but they are never covering the costs.

6.1.5 Discount factor

Setting the discount factor is an important task since all the present values will be discounted given this rate. In the net present value calculations, the discount rate reflects the risks related to the project investment. In this thesis, the investment projects are of public interest and are intended to serve municipalities. Differently from private investment, where the weighted cost of capital (WACC) is usually used as discount rate, the *Commissariat général à la stratégie et à la prospective* (2013) suggested to adopt a nominal 4 % discount rate in order to discount payoffs relative to any public project investment undertaken in France and lasting not more than 30 years.

By setting the discount rate, the decision maker is acting subjectively and needs to be aware that the results found may be different from the reality. To avoid taking decision based on only one set of parameters, the *Commissariat général à la stratégie et à la prospective* (2013) suggested using the sensitivity analysis testing thereby the outcome under different settings.

6.1.6 Sensitivity of the parameters

Knowing that the reality can be different from what planned, the sensitivity analysis allows taking into account uncertainties in the cost-analysis. The sensitivity analysis will be carried out for all the different scenarios in order to reveal the role of certain parameters on the final cost per habitant. From the base scenario, the parameters are, the cost of operation, the volume of waste produced per habitant, the investment cost and the cost of sorting out biodegradable waste. These parameters will be given a range of uncertainties of ±10 %, ±20 % and ±30 %, presented in *appendix 3*. The values presented in *table 4* are dependent on the municipality management, geographical situation, land price, demography, etc. The investment costs are dependent on the land rental value, labor cost, subsidies and cost of materials. The cost of operation is dependent on the price of petrol, labor cost, price of compost, price of biomethane. The volume of waste is depending on people's lifestyle and willingness to sort out for scenarios 1 and 3.

WERF (2012) suggested to run Monte Carlo simulations 1 000 times in order to obtain a correct amount of possibilities and reliable median outcome.

6.2 Empirical Study

In this section, I will present the scenario analysis. The analysis is calibrated on the basis of empirical evidence and data collected (AMORCE and ADEME, 2013; Senat, 2010; *Les Hauts-de-Bièvre* communauté d'agglomération, 2012; Communauté d'agglomération Plaine Centrale du Val-de-Marne, 2012). In the first part, a cost-analysis of the four scenarios based on empirical evidence and data collected will be presented. In the second part, I will present the results obtained by running a sensitivity analysis of the data input. Finally, in the third part, Monte Carlo simulations will be run in order to stress the impact that uncertainty in the main parameters has on the cost per habitant.

6.2.2 Cost-analysis results without sensitivity analysis

The numerical data used in the cost-analysis are presented in detail in *appendix 4.* As stated earlier, the net present value and equivalent annual cost analysis allow identifying the actual cost per ton for the municipality and cost per habitant. In the calculations I assume a lifetime corresponding to a 15-year period. By using the equivalent annual cost, I can compare the four scenarios over the same time period. Last, the following figures will be considered constant over the assumed lifetime: i) the volume of individual waste generated, ii) the cost of operation and iii) the volume of waste generated.

Thereby, even though the collection and treatments costs might increase due to the price of oil, labor, the revenue generated might also increase giving as a result a stable cost of operation. The results for the cost-analysis of all the scenarios are shown in *table 5.*

Table 5. Cost-analysis of the four scenarios given the expected values (source: own creation)

	NPV	Equivalent Annual Cost	Cost per habitant
Scenario 1	€ 62,793,448.69	€ 5,647,711.87	€ 40.50
Scenario 2	€ 69,529,930.16	€ 6,253,598.43	€ 40.26
Scenario 3	€ 134,971,539.54	€ 12,139,488.78	€ 40.08
Scenario 4	€ 167,931,736.72	€ 15,103,965.19	€ 44.71

To ease the comparison between the four projects, I will be using the cost per habitant solely. The net present value and the equivalent annual cost do not permit to easily identify which project has the lowest cost for the habitants. Moreover, to cover the waste management cost municipalities have implemented a waste fee that the habitants have to pay once a year (ADEME, 2010). The waste fee is set to cover the costs only (not a profitable activity for the municipalities). Using the cost per habitant allows determining directly the waste fee habitants would have to pay.

The table reveals that the four scenarios are giving results quite close to each other. The most cost-effective scenario is scenario 3 with 40.08 euros per habitant, followed by scenario 2, with 40.26 euros, scenario 1 with 40.50 euros and finally scenario 4 with 44.71 euros.

By comparing scenarios 1 and 4, one can observe that the habitants of Municipality A would benefit from gathering with Municipality B only if adopting AD. They could save 42 cents per habitant. In the contrary, cooperating with Municipality B with the MBT would actually increase the price per habitant by 4.45 euros.

These results represent the base scenario. The results presented in *table 5* are not taking into account uncertainties. To take into account any potential bias due to uncertainty, the results presented in *table 5* will be observed when parameters are given a range of uncertainty of ±10 %, ±20 % and ±30 %.

6.2.3 Cost-analysis results with sensitivity analysis of the data inputs

The sensitivity analysis will be carried out for all the different scenarios in order to reveal the role of certain parameters on the final cost per habitant. From the base scenario, the parameters are, the cost of operation, the volume of waste produced per habitant, the investment cost and the cost of sorting out biodegradable waste. They will be given a range of uncertainties of ±10 %, ±20 % and ±30 %.

The numerical data used in the cost-analysis are based on the secondary data from existing plants in France. Even though these data are trustable and reliable, these data remain average numerical data. To take into account uncertainty, I assess how much the variation of certain parameters affects the final cost per habitant. The parameters were varying in a range from - 30 % to 30 %, and the cost per habitant was measured every 10 %. I provided in *appendix 3* the numerical values corresponding to the ranges of variation of each parameter.

The input data evaluated are the following: cost of operation, volume of waste produced per habitant, investment cost and cost of sorting out biodegradable waste. These parameters were chosen because several assumptions were made in determining their values based on either the secondary data or existing plants. The sensitivity analysis was run for each parameter, once at a time, for the four scenarios. The term *original value* used in the following sections corresponds to the values found in the base scenario, 40.50 euros for scenario 1, 40.26 euros for scenario 2, 40.08 euros for scenario 3 and 44.71 euros for scenario 4.

6.2.3.1 Cost per habitant given the percentage of change of the total cost of operation

In *Figure 8,* I consider potential changes of ±10 %, ±20 % and ±30 % of either the cost per collection and treatment or the volume of waste produced per habitant. *Figure 8* shows that regardless the level of uncertainty, scenario 4 remains the most expensive solution, varying from 37.00 euros to 52.42 euros. However, as explained above, the plant is already using full capacity (100 %). Therefore, the solutions above the original value are only feasible if, respectively, i) the variation is due to the cost of collection and treatment or ii) the volume of biodegradable is increasing but the overall residual household waste is maintained to 302 kg or reduced.

The sensitivity analysis shows in a range from -30 % to -10 % of either the volume of waste produced or the cost of operation, the cheapest options are respectively scenario 3, 1 and 2. Scenario 2 became more interesting than scenario 1 when reaching the original value, and more interesting than scenario 3 with a variation of +10 %. Scenario 3 is always more cost effective than scenario 1 regardless of the variation of the data inputs.

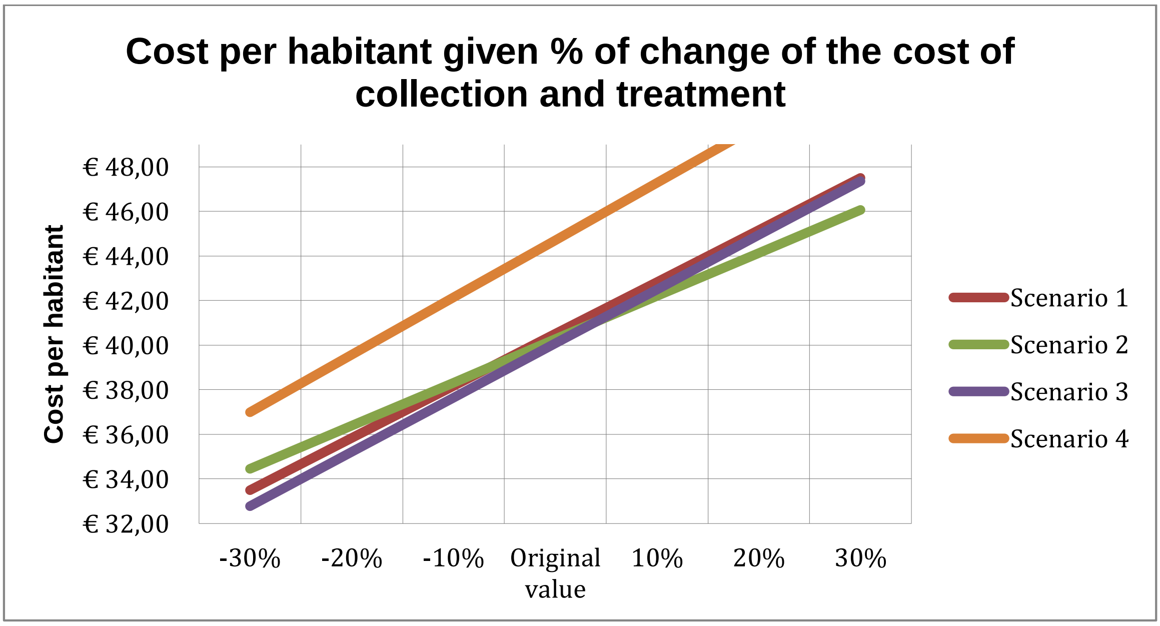

Figure 8. Uncertainties in the cost of collection and treatment (source: own creation)

6.2.3.2 Cost per habitant given the percentage of change of the investment cost

Figure 9 shows that all scenarios are affected by the variations in the investment cost. Scenario 3 appears to be the least affected with a variation of 6.97 euros. Scenario 2 is the most affected by the investment cost with a maximum range of 12.54 euros. With a variation of -30 %, the cheapest scenarios are 2 with 33.99 euros, 1 with 36.58 euros, 3 with 36.59 euros and 4 with 39.01 euros. In a range from -20 % to -10 %, the ranking is changing giving respectively scenarios 2, 3, 1 and 4. From the variation of -0.02 % of the original value, scenario 3 became more cost effective than scenario 2 and from a variation of +0.02 % scenario 1 became cheaper than scenario 2. Scenario 3 remains always cheaper than scenario 1 (except if the investment cost is over 29 % lower than the original value).

As mentioned in the previous chapter, the investment cost for scenario 4 was estimated based on other existing plants. However, scenario 4 is the most expensive option compared to all the other scenarios with at least 2 euros difference with the second least attractive scenario. However, to be economically viable compared to the original value of scenario 3, 2 and 1 the investment cost should be reduced by respectively 22 %, 23 % and 24 %. This represents a reduction of at least 17 million euros.

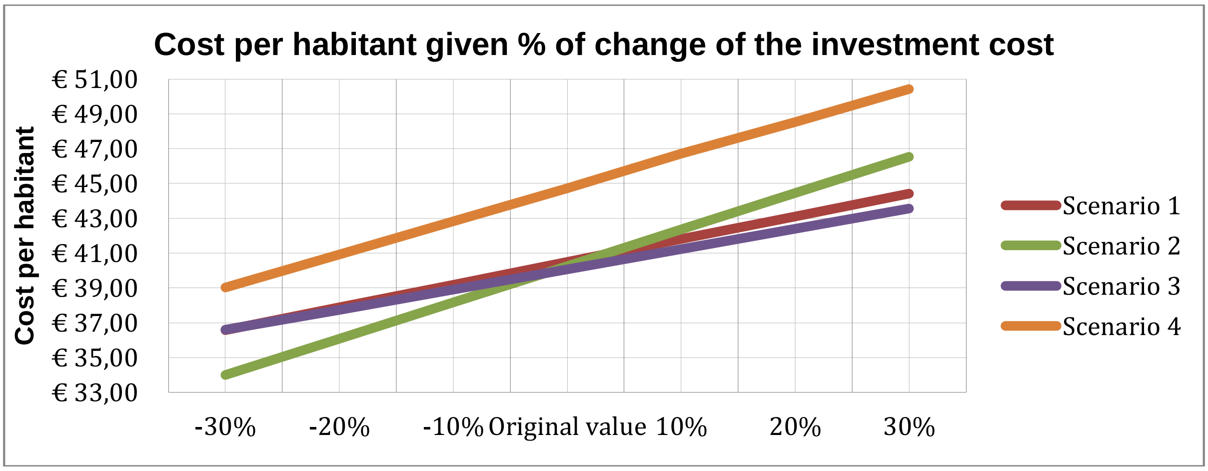

Figure 9. Uncertainties in the investment cost (source: own creation)

6.2.3.3 Cost per habitant given the percentage of change of the cost of sorting out biodegradable waste

As shown in *figure 10*, scenario 2 and scenario 4 are not affected by the cost of sorting out since this may only occur when considering plants adopting AD, i.e., scenario 1 and 3. As shown by the sensitivity analysis, scenario 1 and 3 are cheaper than scenario 2 when the cost of sorting out is up to -10 % lower than the original value. The breakeven point between scenarios 1 and 2 is reached when the cost of sorting out is 4.137572 euros, slightly below the original value. The breakeven point between scenarios 2 and 3 is reached when the cost of sorting out is 4.14183 euros, slightly above the original value.

It is important to stress that the cost of sorting out biodegradable waste has an important role in determining which scenario, among scenarios 1, 2 and 3, is the cheapest one. It is worth mentioning that the impact on the final cost per habitant is limited. Indeed, the cost per habitant is varying in a maximum range from 2.48 euros and 2.49 euros, respectively, in scenarios 1 and 3. Regardless the variation of the cost of sorting out occurring in scenario 1 and 3, scenario 4 remains the least attractive option with a cost per habitant stable at 44.71 euros.

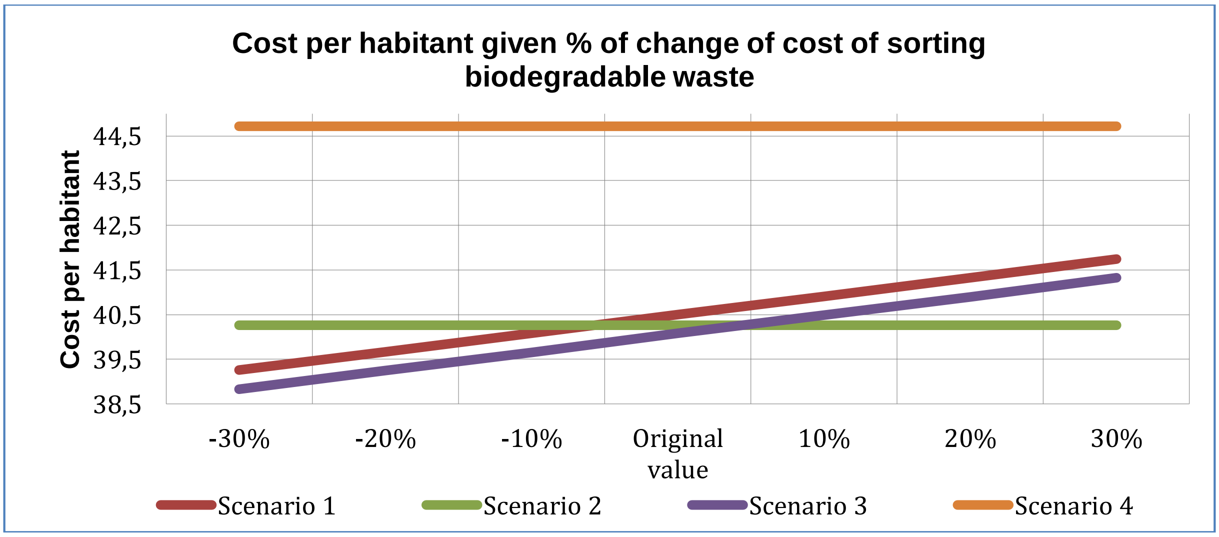

Figure 10. Uncertainties in the cost of sorting out biodegradable waste (source: own creation)

6.2.3.4 Summary of the sensitivity analysis

The sensitivity analysis showed that a decrease in the value of any of the four parameters is reducing the cost per habitant. In contrast, an increase of the value of any parameters is increasing the cost per habitant (except scenario 2 and 4 which do not vary when the cost of sorting out is changed). The variation of the cost of operation is affecting the cost per habitant in exactly the same manner than the variation of the volume of waste produced per habitant. This is due to the fact that the combination of the two parameters gives the total cost of operating the plant. Additionally the volume of waste is also the same for the four scenarios.

From all the parameters evaluated, the investment cost was the parameter affecting the most the cost per habitant and by consequence the economic viability of the projects when compared with each other.

The previous figures show that scenarios 3, 1 and 2 are often giving very close results, notably near to the value computed in the base scenario.

The ranking order between these 3 scenarios is very often changing when the values of the parameters are around the ones set in the base case scenario. This means that the values chose in the base case scenario are important and a variation, even small, can impact the ranking of the projects. The cost per habitant can range of up to ±3 euros compared to the value computed in the base scenario.

Additionally, the figures show that scenario 3 is always offering a lower cost per habitant than scenario 1 – except in one situation when the investment cost is more than 29 % lower, resulting in a cost per habitant 1 cent lower.

6.2.4 Monte Carlo simulations

Monte Carlo simulations are run assuming a normal distribution and setting both expected value and a standard deviation. Normal distribution, also called *Gaussian distribution* or Bell curve is a symmetrical frequency distribution curve, meaning that values below or above the mean are equally likely to happen. Most-frequent values are occurring around the mean value. Extremes high and small values may occur since no thresholds are set, but the further the value is from the mean, the lower is the probability that it actually materialize. In normal distribution, the 68-95-99.9 rule applies, meaning that 68 % of the values are included in a range of one standard deviation, 95 % of the values are included in a range of two standard deviations and 99.7 % of the values are included in a range of three standard deviations (www, BusinessDictionary.com, 3, 2014).

Monte Carlo simulations will run 1000 iterations. Palisade (www, 2014) defined an iteration as “a smaller unit within a simulation”. At each new iteration, the software determines a new random value given the probability distribution. First the simulation will run with three different levels of standard deviations, 10 %, 20 % and 30 %[6], respectively. Second, Monte

[6] In the sensitivity analysis, the variable parameter is forced to be calculated at the exact value e.g. +10 %, -20 %, +30 %. In Monte Carlo simulations, the probability of having a value in between the standard deviation is higher but still any value can occur.

Carlo simulations will be used to identify the probability to have a cost per habitant below 40 euros or between 39 and 41 euros.

6.2.4.1 Cost per habitant given the volatility of the total cost of operation

Figure 11 confirms the trend and ranking for the scenarios provided by the sensitivity analysis shown in *figure 8*. Scenario 3 and 1 are being more attractive below the values calculated in the base scenario, whereas scenario 2 is more attractive when the values are higher than the one computed in the base scenario. However, the values are much more volatile for the four scenarios. The cost per habitant may actually even double starting from about 25 euros to about 60 euros.

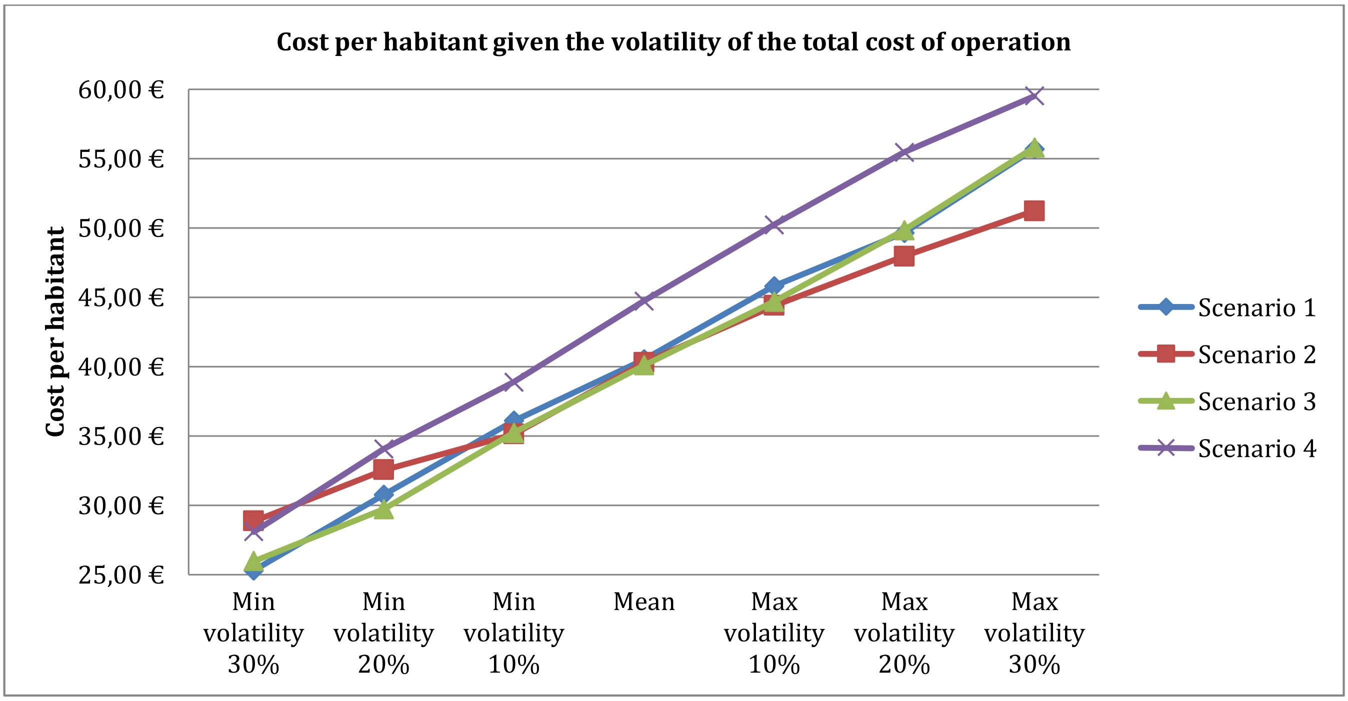

Figure 11. Volatility of the total cost of operation (source: own creation)

6.2.4.2 Cost per habitant given the volatility of the investment cost

Figure 12 reveals one difference compared to the sensitivity analysis of the cost per habitant (see *figure 9*). I notice that, first, scenario 4 tends to be more attractive when compared to other scenarios, which is not the case in the sensitivity analysis. Indeed, it is even more attractive than scenario 3 when the variation is 30 % below the base scenario. As a result the cost per habitant, by looking at all the scenarios, is much more volatile varying from around 28 euros to 55 euros. The other scenarios tend to be the same than in the sensitivity analysis in *figure 9*.

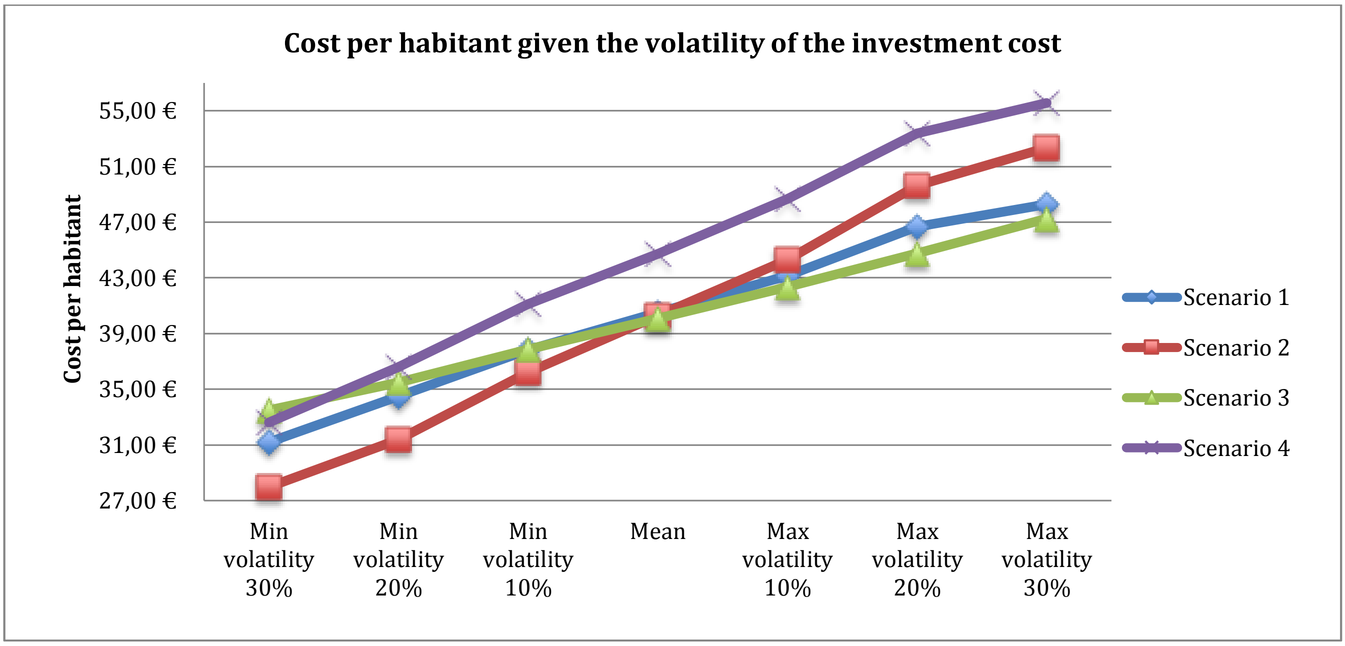

Figure 12. Volatility of the investment cost (source: own creation)

6.2.4.3 Cost per habitant given the volatility of the cost of sorting out biodegradable waste

In *figure 13*, the cost per habitant is kept constant for scenarios 2 and 4. This is needed since the cost of sorting out does not apply to the MBT. The Monte Carlo simulations are providing results in line with the ones obtained in the sensitivity analysis of the cost of sorting out biodegradable waste (see *figure 10*). The break-even cost between scenario 2 and scenarios 1 and 3 is very near the value set in the base scenario.

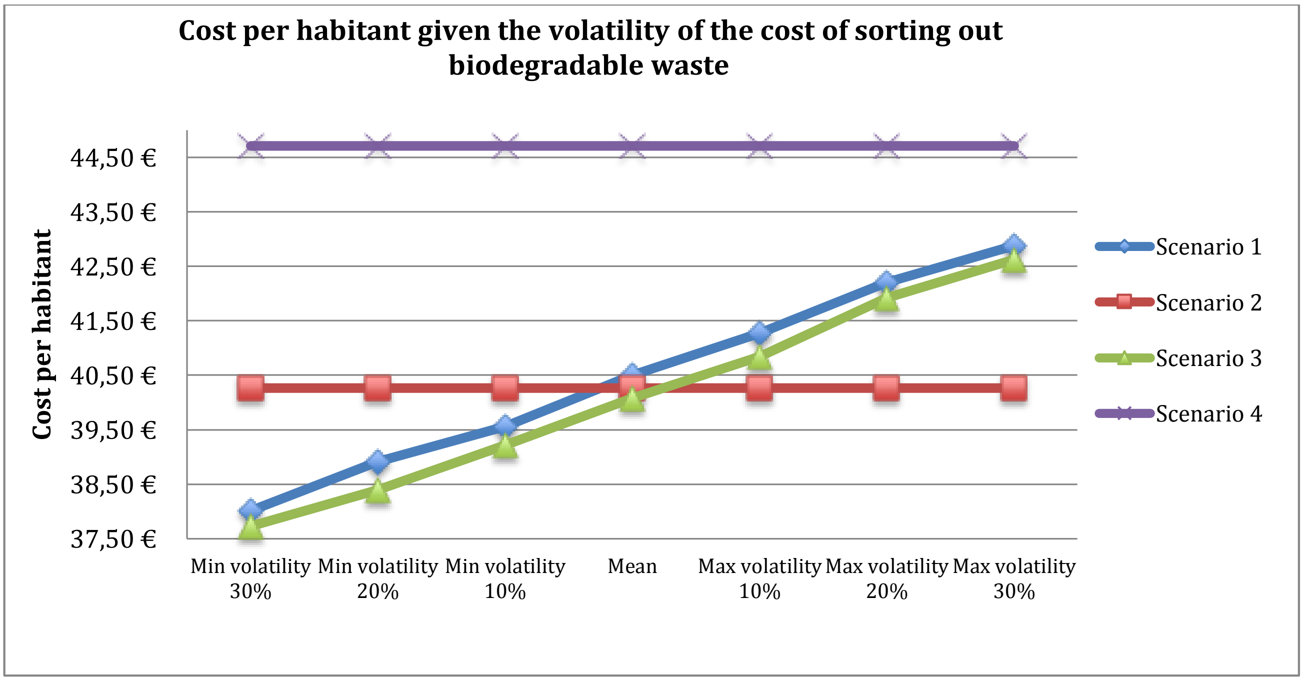

Figure 13. Volatility of the cost of sorting out biodegradable waste (source: own creation)

6.2.5 Monte Carlo Simulations – Probability

The Monte Carlo simulations can also provide information regarding the likelihood of having a specific value or a range of values. In my case, I am interested in identifying the probability of having a cost per habitant falling into a specific interval.

Figure 14 and *Figure 15* illustrate the probability distributions resulting from the Monte Carlo simulations. These two figures results from the definition of a specific set of parameter values. The results for all the scenarios are presented in *table 6*. The parameters cost of operation and volume of waste, investment cost and cost of sorting out biodegradable waste were allowed a volatility of 10 %, 20 % and 30 %. In the table, the values represent the probability of occurring. The values higher than 50 % are highlighted in light green and the values above 45 % are in bold.

Figure 14 is an illustration of the result obtained for scenario 1. I looked for the probability of having a cost per habitant equal or lower than 40 euros. The cost of operation is, in this case, allowed varying with a volatility of 10 %. The red columns represent the outcomes that M onte Carlo simulations found. The higher the column is, the more often the value was occurring. For instance, *figure 14* suggests that the likelihood of having a real cost per habitant equal or less than 40 euros is 36 %.

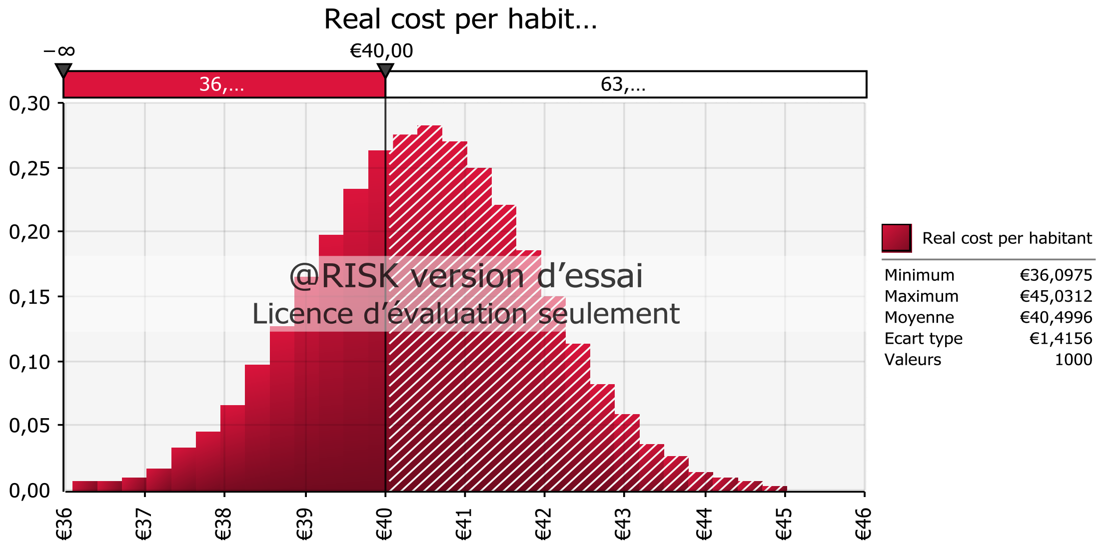

Figure 14. Cost per habitant equal or less than 40 euros (source: own creation)

In *Figure 15*, I am still considering scenario 1. Here, I am studying the probability of having a cost per habitant falling in the range 39-41 euros. In this case, the outcome is the cost per habitant; the cost of operation is given a volatility of 10 %. The probability of having the outcome falling within the interval 39-41 euros is about 49 %. These results can be explained by the probability distributions. Indeed, the interval 39-41 is surrounding the base scenario and given the probability distribution, values near the base scenario have a higher probability than values on the extreme tails.

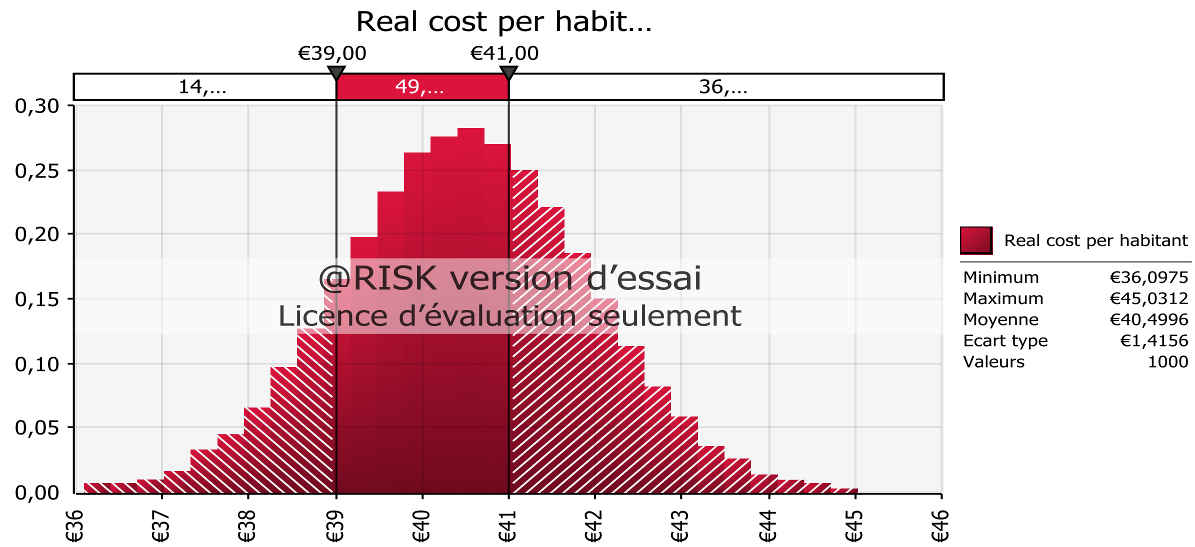

Figure 15. Cost per habitant included between 39 and 41 euros (source: own creation)

Scenario 1

Monte Carlo simulations show that the probability of having a cost per habitant equal or lower than 40 euros is lower than the one determined for scenario 2 and 3, regardless of the level of volatility of the cost of operation, volume of waste, investment cost or cost of sorting out biodegradable waste, as presented in *table 6.* The likelihood of having an outcome falling within the interval 39-41 euros is, however, higher than in scenario 2 when the investment cost is volatile. The probability of having a cost per habitant falling within the interval is up to 70 % when the investment cost has a low volatility. However, the probability is decreasing to 31 % when the volatility of the investment cost is 30 %.

Scenario 2

Based on the probability of having a cost per habitant equal or lower than 40 euros, scenario 2 is the second most cost-effective scenario, behind scenario 3. Indeed, the probability of having the cost per habitant equal or lower than 40 euros is increasing from 41 % to 47 % when the volatility is higher. In contrast, the likelihood of having an outcome ranging between 39 to 41 euros is decreasing when the volatility of either the cost of operation or investment cost is higher. Indeed, the probabilities are falling from 59.3 % to 22 % when the volatility of the cost of operation is increasing and 55.8 % to 20.7 % when the volatility of the investment cost is increasing.

Scenario 3

Scenario 3 has always the highest probability of having a cost per habitant equal or below 40 euros. The probability falls within the interval 38 % - 48 %. The volatility of the variable parameters is fairly affecting the probability of having an outcome equal or lower than 40 euros. The probability of having a cost per habitant within the interval 39-41 euros is quite high compared to the other scenarios and range between 50 % and 100 % when the variable parameters are facing low volatility. However, the probability is decreasing importantly when the volatility is equal to 20 % and 30 %. From a variation of 10 % to 30 % volatility in the cost of operation or in the investment cost, the likelihood of having an outcome falling in the interval, 39-41 euros, is lower and is equal to 32.4 % and 44.1 %, respectively.

Scenario 4

The table reveals that scenario 4 is very unlikely to have a cost per habitant equal or lower than 40 euros or a cost falling within the interval 39-41 euros. Actually, regardless of the level of volatility, there is more than 90 % chance that the cost will be higher than 41 euros.

Table 6. Monte Carlo simulations - results and probability (source: own creation)

Level of volatility of the variable parameters		Probability (in %)	Scenarios 1	Scenarios 2	Scenarios 3	Scenarios 4
Volatile cost of operation or volume of waste	10 %	39€ ≤ cost per habitant ≤ 41€	**49.3%**	59.3%	50.1%	0.8%
		Cost per habitant ≤ 40€	36.2%	41,2%	**48.0%**	0.2%
	20 %	39€ ≤ cost per habitant ≤ 41€	27.3%	32.7%	26.5%	8.4%
		Cost per habitant ≤ 40€	43.1%	**45.6%**	**48.8%**	6.6%
	30 %	39€ ≤ cost per habitant ≤ 41€	18.5%	22.3%	17.7%	10.3%
		Cost per habitant ≤ 40€	**45.3%**	**47.1%**	**49.3%**	15.7%
Volatile Investment cost	10 %	39€ ≤ cost per habitant ≤ 41€	70.5%	55.8%	80.3%	0.1%
		Cost per habitant ≤ 40€	26.5%	41.9%	45.7%	0.0%
	20 %	39€ ≤ cost per habitant ≤ 41€	**45.2%**	30.4%	52.0%	4.7%
		Cost per habitant ≤ 40€	37.7%	**46.0%**	**47.8%**	2.1%
	30 %	39€ ≤ cost per habitant ≤ 41€	31.8%	20.7%	36.2%	9.2%
		Cost per habitant ≤ 40€	41.7%	**47.3%**	**48.5%**	8.7%
Volatile cost of sorting out	10 %	39€ ≤ cost per habitant ≤ 41€	97.8%	-	100%	-
		Cost per habitant ≤ 40€	2.3%	-	38.0%	-
	20 %	39€ ≤ cost per habitant ≤ 41€	83.9%	-	95.1%	-
		Cost per habitant ≤ 40€	16.1%	-	44.0%	-
	30 %	39€ ≤ cost per habitant ≤ 41€	72.4%	-	81.2%	-
		Cost per habitant ≤ 40€	25.4%	-	**45.9%**	-

*Scenarios 2 and 4 are not affected by the volatility of the cost of sorting out biodegradable waste

6.2.6 Summary of Monte Carlo simulations

Monte Carlo simulations allow the decision-maker to apply a certain level of uncertainty to the cost-analysis realized in the section 6.2.3. Although Monte Carlo simulations do not give the exact consequences of uncertainty, they certainly allow the decision-maker to get a better understanding of uncertainty and its impact on the cost per habitant.

Once the probability distributions have been chosen, Monte Carlo simulations generate several outcomes, as illustrated in *Figure 14* and *Figure 15*. The simulation also reveals the probability of having a value falling within an interval or below a specific value, which can be useful to rank the different scenarios.

The simulations confirmed the scenarios' ranking and trend given the changes in the variable parameters. Monte Carlo simulations appear also very useful to observe the probability of having a desired cost per habitant for each scenario. The probability indicates that scenario 3 is more likely to be the best scenario based on the economic and financial considerations. Scenarios 2, 1 and 4 are respectively, the second, third and fourth choices.

7 Analysis and discussion of results

The most part of previous studies realized in waste management have analyzed either the economic viability of investing in an AD plant or the economic viability of investing in a mechanical-biological plant. Differently, in this thesis, the aim was to investigate and compare these two different biological treatments taking the perspective of a municipality that could adopt one of them in order to dispose of the municipal biodegradable waste. In this chapter, the findings will be analyzed and discussed in order to answer to the two main research questions posed in chapter 1.

7.1 Cost-effective waste disposal methods

Based on the calculation of net present value and equivalent annual cost, four different scenarios, where each of the two technologies is considered, are compared taking a financial and economic perspective. The results presented in *table 5* show that the two technologies are offering, at least for the first three scenarios, quite similar figures. AD seems however to be the cheapest waste disposal strategy with a cost per habitant equal to 40.08 euros in scenario 3 and equal to 40.50 euros in scenario 1. In contrast, MBT costs 40.26 euros and 44.71 euros, respectively. As observed, the three first scenarios are only varying by, on average, 20 cents. These results are based on the secondary data retrieved from the current existing plants. Therefore the parameters, volume of waste, cost of collection and treatment (also called cost of operation), investment cost and cost of sorting out biodegradable waste are estimated for the four scenarios. A more comprehensive analysis is proposed in order to appreciate which scenario and by consequence which technology is likely to be the most economically viable when different levels of uncertainty are considered.

The first observation is that regardless of the level of uncertainty and which parameter is varying, MBT used on a larger scale (Municipality A and B) is always unattractive. This MBT plant is combining an expensive cost of collection and treatment, over 200 euros per ton and an expensive investment cost over 70 million euros. This statement is confirmed also once run Monte Carlo simulations. In fact, the probability that this scenario may be competitive in terms of costs is low. The second observation is that based on the Monte Carlo simulations, AD used on a larger scale (Municipality A and B) has the highest probability to guarantee a cost per habitant below 40 euros. However, when considering the interval 39-41 euros, the ranking is much more complicated. Indeed the ranking is different according to the variable parameters.

Figure 8 and *11* reveal that the mechanical-biological plant sized only to handle the waste produced by Municipality A, i.e., scenario 2, is the most cost-effective technology if the cost of collection and treatment and/or if the volume of biodegradable waste produced per habitant is higher than the base scenario. In contrast, if Municipality A is expected to have a lower cost of collection and treatment and/or to have a lower volume of waste produced per habitant, AD would be more economically viable.

Figure 9 and *12* show that the investment cost also plays an important role in determining which technology is the most economically and financially viable for Municipality A. Should the investment cost be lower than the original value, set in the base scenario, the MBT is therefore more cost-effective for Municipality A when investing alone. Nevertheless, if the investment cost is likely to be higher than the original value, then AD becomes cheaper.

Above the values set in the base case scenario, AD is always cheaper regardless if Municipality A chooses to go alone or with Municipality B.

The investment cost is depending on many factors, such as land price, tax, availability of the materials and workforce etc. It is common practice to encourage businesses to settle down in a municipality by reducing tax or the land price for example. Moreover, the investment cost does not take into account any subsidies; however, subsidies exist in almost all waste management projects. The municipality, the region or the French government can subsidize waste management projects. Their impact on the final cost for the inhabitants is not insignificant, since the subsidies allow municipality to reduce the total investment cost.

Figure 10 and *13* reveal the economic viability of the scenarios given a change in the household's willingness to pay to avoid sorting out biodegradable waste at home. I used a value calculated in a Swedish survey. Therefore it is important to observe the results when this input is increasing or decreasing. The analysis revealed that the value used in the base scenario is pretty much a benchmark, meaning that if people are willing to pay more to avoid having to sort out at home, then the MBT is more economically viable. In contrast, if people are willing to pay less or to pay a lower waste fee, then the AD is more interesting.

The ranking of the scenarios is very sensitive to the cost of sorting out biodegradable waste. It may vary depending on people' income, concerns regarding waste management and individual habits. Unfortunately, today no research has been done in comparing the two technologies on an economic perspective. A further research could be done, using data from this specific area – southeast of Paris.

Although the ranking of the scenarios is varying according to the variation of the cost of sorting out, Monte Carlo simulations, in *table 6*, show that the impact is still pretty low. Indeed scenarios 1 and 3 have still respectively, at least 72 % and 81 % probability of offering a cost per habitant included between 39 and 41 euros.

The results of this thesis are confirming the environmental organizations' statement about the economic viability of the AD (www, Zero Waste France, 2014; CNIDD, 2008). At the same time, it also confirmed the governmental doubts about the actual cost of the MBT. The two technologies are economically comparable and depending on several parameters (size, population etc.), one may be cheaper than the other.

7.2 Potential economies of scale in biological treatment channel

Municipality A is actually a conglomerate of municipalities. Apart from comparing the two technologies, AD and MBT, I also check for potential economies of scale.

The thesis revealed that there is a potential economy of scale with the AD. Indeed AD plant based on a joint initiative undertaken by both Municipality A and B is in general offering a lower cost per habitant. However, it is important to report that the cost per habitant saved is relatively low, up to 1 euro only. The cost of having to gather with Municipality B may be cumbersome and an obstacle to collaborate. The cost of redesigning the collection maps, communicating about the change, additional transportation costs are not taken into account and may be expensive and time consuming. In contrast, collaborating may also reduce the costs by optimizing the use of trucks and the collection of waste.

The figures provided are only assuming the theoretical cost of implementing and running an AD plant. In practice, external factors such as people's willingness to collaborate or feasibility are worth being taken into consideration.

The MBT appears not to respond to the economy of scale. By collaborating with Municipality B, the cost per habitant is actually increasing from 3 to 6 euros. Municipality A is therefore not benefiting from the collaboration. Although the investment cost is reduced due to the presence of an economy of scale, the cost of operation increases with the volume of waste.

The management of biodegradable waste is not a profitable business. Even though income can be earned by selling the compost and biogas produced, the cost of operation remains too high to be profitable. Increasing the volume of waste is only increasing the cost habitants will have to pay.

In the scenarios under analysis, I considered the plants to be using around 80 % of their full capacity size, which is above the average rate in the currently active plants (AMORCE & ADEME, 2013). In spite of the optimization of the use of the capacity of the plants, the increase in the volume of waste processed produces an increase in the cost per habitant. These results allow understanding the French government's initiatives. First, their main concern is to encourage people to decrease their volume of waste and to motivate businesses or manufacturers to generate less waste. Second, the government through ADEME is subsidizing the municipalities' projects involving a selective collection of biodegradable waste. In this thesis, I showed that despite of the technology used and the size of the municipality, waste cost to a municipality. Encouraging habitants or businesses to reduce their waste is cost-effective. Moreover, the French government has already decided to subsidize MBT and AD plants to support their development.

8 Conclusions

The aim of this thesis was to investigate and compare the different biological treatments that one municipality could implement in order to recover the municipality biodegradable waste. A comparative cost-analysis of two different technologies, i.e., anaerobic digestion and mechanical-biological treatment was conducted to reach this aim. The analysis was based on net present value calculations and on Monte Carlo simulations. The results presented in this thesis considered four different scenarios for two biological treatments: anaerobic digestion and mechanical-biological treatment. I considered, in fact, the case where Municipality A invested alone and the case where Municipality A invested with Municipality B in the set-up of a unique facility serving both.

The anaerobic digestion involves a separate collection of the biodegradable waste, achieved at home by households. As a consequence, the municipality to transport biodegradable waste to the anaerobic digestion plant must do an additional collection. In contrast, the mechanical-biological treatment does not require a separation of the biodegradable waste, since this process is done mechanically at the facility. As a consequence, the investment cost is usually higher since the facility is more complex and the facility includes more options. On one hand, some parties, including the French waste leading companies *Veolia Environnement* and *Suez Environnement* argue that MBT is a cheaper technology. On the other hand, other parties, mainly environmental organizations such as CNIID and Zero Waste France argue that MBT has hidden costs and thereby anaerobic digestion is economically viable and better for the environment.

The accuracy of the data was important in order to ensure reliable results. That is why, data from existing plants were used and sensitivity analysis was run to take into consideration the uncertainty that would have affected the values used. The results of the cost-analysis revealed that anaerobic digestion, if adopted at a larger scale, was more likely to guarantee a cost per habitant equal or below 40 euros. With a more detailed scope, I observed that the anaerobic digestion, small or large scale, was as competitive as a small mechanical-biological treatment. The sensitivity analysis revealed important information regarding the ranking of the projects. Although the variation of the parameters was easily changing the ranking of the projects, Monte Carlo simulations showed that the values were not varying so much. The simulations showed that the values were very likely to range between 39 to 41 euros or even less than 40 euros, at least for the first three scenarios.

Anaerobic digestion is likely to be the most economically and financially viable technology, which is particularly true when the volume of waste sorted out by habitant and/or when the cost of collection and treatment and/or the cost of sorting out biodegradable waste are lower than in the base scenario. In contrast, if the investment cost of building any of the biological treatments; mechanical-biological treatment or anaerobic digestion is lower, then mechanical-biological treatment for Municipality A only, is cheaper.

Financially, anaerobic digestion is benefiting from the economy of scale, meaning that a bigger plant processing a much higher volume of biodegradable waste is more likely financially viable. In contrast, for the mechanical-biological treatment building a larger plant may not be economically and financially viable.

The impact of uncertain parameters is really important in determining which waste disposal strategy does better in economic and financial terms. The sensitivity analysis was carried out for the four scenarios to reveal the role of certain parameters on the final cost per habitant. The environmental impact must also be carefully considered. The compost produced by the anaerobic plant is recognized for its purity and high quality. Therefore it positively contributes to enrich the agricultural lands using the compost. The biogas produced is used internally to run the facility but also sold as biogas or as electricity to the community. This limits the pollution and energy waste related to the transportation of gas or electricity.

In contrast the environmental consequences of having a mechanical-biological treatment plant are not so well-known today. History showed leakage, explosion and air pollution.

This thesis contributes to the literature focusing on the adoption of new technologies in waste management. This is done by providing an application of investment appraisal under a net present value approach to a specific case. In the analysis, two different technologies are considered and the impact of potential economies of scale is examined. Apart from scholars, I believe that the frame developed in this thesis can assist decision-makers evaluating and assessing the solidity of project investments. In fact, by coupling economic appraisal and projects' ranking for a base case scenario with sensitivity analysis and Monte Carlo simulations, one may effectively measure the solidity and trustworthiness of the project evaluation outcomes.

European Commission (2014b) estimated that France would be unlikely to reach the EU Waste Framework Directive by 2020, requesting at least 50 % municipal recycling rate. Municipal biological treatment channel is fairly developed in France with less than 15 plants in 2013. From an economic point of view, the cost analysis of the two biological treatments should surely be compared to the cost of traditional methods, e.g. incineration and landfilling. However, the development of the biological treatment channel seems crucial to help France reaching the EU target.

In this thesis, I raised two research questions in order to reach the aim. However, further research could complement and enrich the results of this study. Another approach could consider a volume of biodegradable waste increasing over the years, which was often the case in the existing plants. A proper research on the French population willingness to pay to avoid having to sort out biodegradable waste at home could bring more accurate results. A further research could focus on the cost-analysis of the whole waste produced by households. The price paid by the habitant is used to cover the cost related to biodegradable waste but also residual waste, plastic, metals, etc. The technologies used to recycle, incinerate or landfill all the waste are affecting the waste fee habitants have to pay. Finally, another research could integrate the environmental costs and/or the cost in terms of human health connected to each specific waste disposal method. Indeed, the economic appraisal I use is correct, but one could also account for the environmental costs each technology would have. Likewise, assessing people's willingness to pay to protect their life from pollution, for instance, could assist in determining the economical cost of air pollution on health.

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Appendix 1: Description of the different scenarios

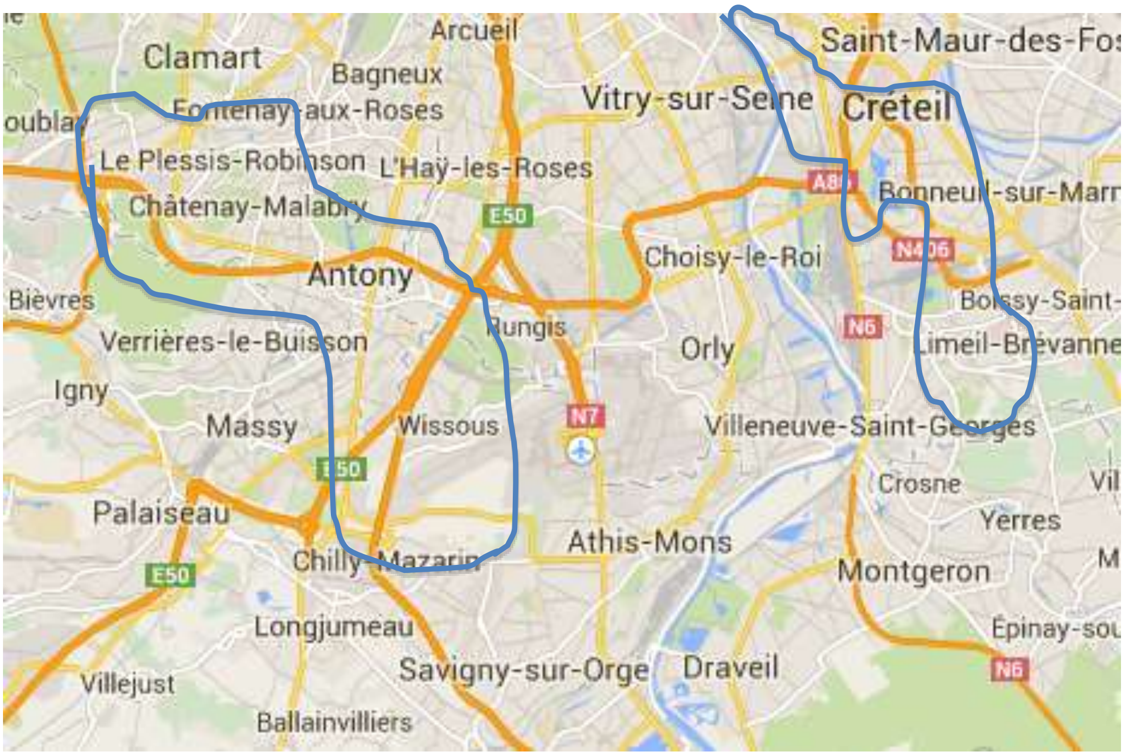
For scenario 2 and 4, the facility must have the capacity needed to process the total volume of residual waste, that is, 302 kg per habitant.

	Population	**Scenarios**	**Technology**	**Waste type**	**Average volume of waste collected (kg/year)**	**Total required capacity of the plant (ton/year)**
Municipality A	155 330	Scenario 1	Anaerobic digestion	Biodegradable municipal waste	123	19 106
	155 330	Scenario 2	Mechanical -biological treatment	Municipal waste	123	46910 Considering 302 kg/hab
Municipality A + B	337 807	Scenario 3	Anaerobic digestion	Biodegradable municipal waste	123	41 888
	337 807	Scenario 4	Mechanical -biological treatment	Municipal waste	123	102018 Considering 302 kg/hab

Appendix 2: Map of the municipalities

Municipality B

Municipality A



Municipality A and Municipality B

Appendix 3: A range of uncertainty of ±10 %, ±20 % and ±30 %

		Scenario 1				Scenario 2			Scenario 3				Scenario 4		
		Cost of collection and operation	Volume of waste per person	Investment cost	Cost of sorting out	Cost of collection and operation	Volume of waste per person	Investment cost	Cost of collection and operation	Volume of waste per person	Investment cost	Cost of sorting out	Cost of collection and operation	Volume of waste per person	Investment cost
Expected value		**€ 189.48**	**123.00**	**€22,543,472.00**	**€ 4.14**	**€ 157.34**	**123.00**	**€36,107,240.00**	**€197.63**	**123.00**	**€ 43,672,033.00**	**€ 4.14**	**€ 208.94**	**123**	**€71,407,328**
±10 %	Min	€ 170.53	110.70	€20,289,124.80	€3.73	€141.61	110.70	€32,496,516.00	€177.87	110.70	€ 39,304,829.70	€3.73	€ 188.05	110.7	€64,266,595
	Max	€ 208.43	135.30	€24,797,819.20	€4.55	€173.07	135.30	€39,717,964.00	€217.39	135.30	€ 48,039,236.30	€4.55	€ 229.83	135.3	€78,548,060
±20 %	Min	€ 151.58	98.40	€18,034,777.60	€3.31	€125.87	98.40	€28,885,792.00	€158.10	98.40	€ 34,937,626.40	€3.31	€ 167.15	98.4	€57,125,862
	Max	€ 227.38	147.60	€27,052,166.40	€4.97	€188.81	147.60	€43,328,688.00	€237.16	147.60	€ 52,406,439.60	€4.97	€ 250.73	147.6	€85,688,794
±30 %.	Min	€ 132.64	86.10	€15,780,430.40	€2.90	€110.14	86.10	€25,275,068.00	€138.34	86.10	€ 30,570,423.10	€2.90	€ 146.26	86.1	€49 985 129
	Max	€ 246.32	159.90	€29,306,513.60	€5.38	€204.54	159.90	€46,939,412.00	€256.92	159.90	€ 56,773,642.90	€5.38	€ 271.62	159.9	€ 92,829,526

Appendix 4: Details of the NPV calculations

The projects considered do not generate revenues, which may cover the costs.

Step 1 – Present values

To calculate the cash flow, I will need to use the cost of operation and collection, the volume of waste and the discount rate. The cost of operation and collection are added and then multiplied by the volume of waste.

For instance in scenario 1, cash flow = (130+59.48) * 19105 = 3 619 060.15

In order to determine the present value, the cash flow needs to be actualized.

At a discount rate of 4 %, we have

$$Present\ Value_{Year\ 1} = \frac{3\ 619\ 060{,}15}{(1+0{,}04)^1} = 3\ 473\ 865.53$$

A present value must be calculated for each year given the length of the investment. The volume of waste and costs are considered as constant for all the scenarios.

Step 2 - Net Present Value

The net present value results from a sum of all the present values and the investment cost.

For a given length of investment of 15 years, the net present value will be calculated using the following formula:

NPV = PV1+PV2+PV3+PV4+…+PV15 + Investment cost

For scenario 1, NPV = 40 238 112.89 + 22 543 472 = 62 781 584.89

Looking at the net present value suggests that scenario 1 will cost about 62 million euros.

Step 3 - Equivalent Annual Cost

The equivalent annual cost allows spreading in equal annuities the investment cost over the length of investment

I will be using the following formula:

$$\text{EAA} = \frac{\text{NPV} * \text{r}}{1 - \frac{1}{(1+r)^n}}$$

As observed in *table 2*, the length of investment or useful life of the plant is different between scenarios 1 and 3 and 2 and 4. To be able to compare the final results, I need to be sure I compared the project over a same period of time. Thereby, I need to “force” all the projects to have the same useful life in order to compare the results. I assumed to set this equal to 15 years. So *n=15* for all the projects.

It follows that:

$$EAA_{Scenario\ 1} = \frac{62\ 781\ 584 * 0.04}{1-\frac{1}{(1+0.04)^{15}}} = 5\ 646\ 644.83 \text{ euros per year.}$$

Step 4 - Cost per ton

Since the size of the municipalities and the volume of waste handled differ from a scenario to the other, we need to have comparable values. To do so, we will determine the cost per ton and the cost per habitant. After determining the equivalent annual annuity, I can determine the actual cost per ton by dividing the EAA by the volume of waste produced per year.

$$\text{Cost per ton per year} = \frac{EEA}{Volume\ of\ waste\ produced\ per\ year}$$

For scenario 1, this is equivalent to:

$$\text{Cost per ton per year} = \frac{5\ 646\ 644.83}{19\ 105} = 295.56$$

Step 5 - Cost per habitant

To determine the cost per habitant per year, we need to identify what is the volume of waste produced per habitant per year. The volume of biodegradable waste is 123 kg for the four scenarios.

This will then give:

$$\text{Cost per habitant} = 295.56 * \frac{123}{1000} = 36.35 \text{ euros}$$

However, as mentioned above, when considering scenarios 1 and 3 (anaerobic digestion), one should add to this figure also the cost of sorting out biodegradable waste. It follows that

Total cost per habitant = cost per habitant + cost of sorting out biodegradable waste = 36.35 + 4.14 = 40.49 euros.

Appendix 5: Excel Spreadsheets

Scenario 1

Parameters			
Population	155330	habitants	
Cost of collection and treatment (including revenues)	€ 191.37	euros/ton	
Rate	4%		
Investment	22,543,472.00		
Production of biodegradable waste per person	123	Kg/person	
Cost of sorting out biodegradable waste per inhabitant	€ **4.14**	euro/person	
Scenario data			
Volume of waste (production per habitant * population)	19106	tons	
Calculations			
Sum of the Pvs + investment cost	**NPV**	€ **63,195,276.91**	**euros**
	Equivalent annual cost	€ **5,683,852.74**	**euros/year**
Equivalent Annual cost / Volume of waste per year	**Cost per ton**	€ **297.50**	**euros/ton/year**
Cost per habitant per year given their actual production	**Cost per habitant**	**36.59211192**	**euros/hab/year**
cost per habitant adding the cost of sorting out	**Real cost per habitant**	€ **40.73**	**euros/hab/year**

15-year period of time				**Equivalent annual annuities - verification**	
Discount rate (1+4%)^n	YEAR	Cash flow cost of coll & trea * Volume	Present Value Cash flow / Discount rate		EAC/[(1+4%)^n]
1.040000	Year 1	€ 3,656,268.07	€ 3,515,642.37	EAC year 1	€ 5,465,243.02
1.081600	Year 2	€ 3,656,268.07	€ 3,380,425.36	EAC year 2	€ 5,255,041.37
1.124864	Year 3	€ 3,656,268.07	€ 3,250,409.00	EAC year 3	€ 5,052,924.39
1.169859	Year 4	€ 3,656,268.07	€ 3,125,393.27	EAC year 4	€ 4,858,581.15
1.216653	Year 5	€ 3,656,268.07	€ 3,005,185.83	EAC year 5	€ 4,671,712.64
1.265319	Year 6	€ 3,656,268.07	€ 2,889,601.76	EAC year 6	€ 4,492,031.39
1.315932	Year 7	€ 3,656,268.07	€ 2,778,463.23	EAC year 7	€ 4,319,260.95
1.368569	Year 8	€ 3,656,268.07	€ 2,671,599.26	EAC year 8	€ 4,153,135.53
1.423312	Year 9	€ 3,656,268.07	€ 2,568,845.44	EAC year 9	€ 3,993,399.54
1.480244	Year 10	€ 3,656,268.07	€ 2,470,043.70	EAC year 10	€ 3,839,807.25
1.539454	Year 11	€ 3,656,268.07	€ 2,375,042.02	EAC year 11	€ 3,692,122.36
1.601032	Year 12	€ 3,656,268.07	€ 2,283,694.25	EAC year 12	€ 3,550,117.65
1.665074	Year 13	€ 3,656,268.07	€ 2,195,859.85	EAC year 13	€ 3,413,574.67
1.731676	Year 14	€ 3,656,268.07	€ 2,111,403.70	EAC year 14	€ 3,282,283.33
1.800944	Year 15	€ 3,656,268.07	€ 2,030,195.87	EAC year 15	€ 3,156,041.67
	Sum of the PVs		**€ 40,651,804.91**	**Sum of the Equivalent annual annuities**	**€ 63,195,276.91**

Scenario 2

Parameters			
Population	155330	habitants	
Cost of collection and treatment (including revenues)	€ 175.34	euros/ton	
Rate	4%		
Investment	36,107,240.00 €		
Production of biodegradable waste per person	123	Kg/person	
Cost of sorting out biodegradable waste per inhabitant	€ -	euro/person	
Scenario data			
Volume of waste (production per habitant * population)	19106	tons	
Calculations			
Sum of the Pvs + investment cost	**NPV**	**€ 73,352,848.55**	**euros**
	Equivalent annual cost	**€ 6,597,435.91**	**euros/year**
Equivalent Annual cost / Volume of waste per year	**Cost per ton**	**€ 345.31**	**euros/ton/year**
Cost per habitant per year given their actual production	**Cost per habitant**	**42.47**	**euros/hab/year**

15-year period of time				Equivelent annual annuities - verification	
Discount rate (1+4%)^n	YEAR	Cash flow cost of coll & trea * Volume	Present Value Cash flow / Discount rate		EAC/[(1+4%)^n]
1.040000	Year 1	€ 3,349,911.02	€ 3,221,068.29	EAC year 1	€ 6,343,688.38
1.081600	Year 2	€ 3,349,911.02	€ 3,097,181.04	EAC year 2	€ 6,099,700.36
1.124864	Year 3	€ 3,349,911.02	€ 2,978,058.70	EAC year 3	€ 5,865,096.50
1.169859	Year 4	€ 3,349,911.02	€ 2,863,517.98	EAC year 4	€ 5,639,515.87
1.216653	Year 5	€ 3,349,911.02	€ 2,753,382.67	EAC year 5	€ 5,422,611.41
1.265319	Year 6	€ 3,349,911.02	€ 2,647,483.34	EAC year 6	€ 5,214,049.44
1.315932	Year 7	€ 3,349,911.02	€ 2,545,657.05	EAC year 7	€ 5,013,509.07
1.368569	Year 8	€ 3,349,911.02	€ 2,447,747.17	EAC year 8	€ 4,820,681.80
1.423312	Year 9	€ 3,349,911.02	€ 2,353,603.05	EAC year 9	€ 4,635,270.96
1.480244	Year 10	€ 3,349,911.02	€ 2,263,079.85	EAC year 10	€ 4,456,991.31
1.539454	Year 11	€ 3,349,911.02	€ 2,176,038.32	EAC year 11	€ 4,285,568.57
1.601032	Year 12	€ 3,349,911.02	€ 2,092,344.54	EAC year 12	€ 4,120,739.01
1.665074	Year 13	€ 3,349,911.02	€ 2,011,869.75	EAC year 13	€ 3,962,249.04
1.731676	Year 14	€ 3,349,911.02	€ 1,934,490.14	EAC year 14	€ 3,809,854.85
1.800944	Year 15	€ 3,349,911.02	€ 1,860,086.67	EAC year 15	€ 3,663,321.97
	Sum of the PVs		**€ 37,245,608.55**	**Sum of the Equivalent annual annuities**	**€ 73,352,848.55**

Scenario 3

Parameters			
Population	337807	habitants	
Cost of collection and treatment (including revenues)	€ 197.63	euros/ton	
Rate	4%		
Investment	46687510.86		
Production of biodegradable waste per person	123	Kg/person	
Cost of sorting out biodegradable waste per inhabitant	€ **4.14**	euro/person	
Scenario data			
Volume of waste (production per habitant * population)	41550	tons	
Calculations			
Sum of the Pvs + investment cost	**NPV**	€ **137,987,017.40**	**euros**
	Equivalent annual cost	€ **12,410,704.18**	**euros/year**
Equivalent Annual cost / Volume of waste per year	**Cost per ton**	€ **298.69**	**euros/ton/year**
Cost per habitant per year given their actual production	**Cost per habitant**	**36.73903792**	**euros/hab/year**
cost per habitant adding the cost of sorting out	**Real cost per habitant**	**€ 40.88**	**euros/hab/year**

15-year period of time

Discount rate (1+4%)^n	YEAR	Cash flow cost of coll & trea * Volume	Present Value Cash flow / Discount rate
1.040000	Year 1	€ 8,211,578.08	€ 7,895,748.16
1.081600	Year 2	€ 8,211,578.08	€ 7,592,065.53
1.124864	Year 3	€ 8,211,578.08	€ 7,300,063.01
1.169859	Year 4	€ 8,211,578.08	€ 7,019,291.36
1.216653	Year 5	€ 8,211,578.08	€ 6,749,318.61
1.265319	Year 6	€ 8,211,578.08	€ 6,489,729.44
1.315932	Year 7	€ 8,211,578.08	€ 6,240,124.46
1.368569	Year 8	€ 8,211,578.08	€ 6,000,119.67
1.423312	Year 9	€ 8,211,578.08	€ 5,769,345.84
1.480244	Year 10	€ 8,211,578.08	€ 5,547,447.92
1.539454	Year 11	€ 8,211,578.08	€ 5,334,084.54
1.601032	Year 12	€ 8,211,578.08	€ 5,128,927.44
1.665074	Year 13	€ 8,211,578.08	€ 4,931,661.00
1.731676	Year 14	€ 8,211,578.08	€ 4,741,981.73
1.800944	Year 15	€ 8,211,578.08	€ 4,559,597.82
	Sum of the PVs		**€ 91,299,506.54**

Equivalent annual annuities - verification

	EAC/[(1+4%)^n]
EAC year 1	€ 11,933,369.41
EAC year 2	€ 11,474,393.66
EAC year 3	€ 11,033,070.83
EAC year 4	€ 10,608,721.95
EAC year 5	€ 10,200,694.18
EAC year 6	€ 9,808,359.79
EAC year 7	€ 9,431,115.18
EAC year 8	€ 9,068,379.98
EAC year 9	€ 8,719,596.14
EAC year 10	€ 8,384,227.06
EAC year 11	€ 8,061,756.78
EAC year 12	€ 7,751,689.22
EAC year 13	€ 7,453,547.32
EAC year 14	€ 7,166,872.43
EAC year 15	€ 6,891,223.49
Sum of the Equivalent annual annuities	€ **137,987,017.40**

Scenario 4

Parameters			
Population	337807	habitants	
Cost of collection and treatment (including revenues)	€ 208.94	euros/ton	
Rate	4%		
Investment	€ 63,646,850.94		
Production of biodegradable waste per person	€ 123.00	Kg/person	
Cost of sorting out biodegradable waste per inhabitant	€ -	euro/person	
Scenario data			
Volume of waste (production per habitant * population)	41550	tons	
Calculations			
Sum of the Pvs + investment cost	**NPV**	**€ 160,171,259.67**	**euros**
	Equivalent annual cost	**€ 14,405,979.34**	**euros/year**
Equivalent Annual cost / Volume of waste per year	**Cost per ton**	**€ 346.71**	**euros/ton/year**
Cost per habitant per year given their actual production	**Cost per habitant**	**€ 42.65**	**euros/hab/year**

15-year period of time				Equivalent annual annuities - verification	
Discount rate (1+4%)^n	YEAR	Cash flow cost of coll & trea * Volume	Present Value Cash flow / Discount rate		EAC/[(1+4%)^n]
1.040000	Year 1	€ 8,681,511.53	€ 8,347,607.24	EAC year 1	€ 13,851,903.21
1.081600	Year 2	€ 8,681,511.53	€ 8,026,545.43	EAC year 2	€ 13,319,137.71
1.124864	Year 3	€ 8,681,511.53	€ 7,717,832.14	EAC year 3	€ 12,806,863.18
1.169859	Year 4	€ 8,681,511.53	€ 7,420,992.44	EAC year 4	€ 12,314,291.52
1.216653	Year 5	€ 8,681,511.53	€ 7,135,569.66	EAC year 5	€ 11,840,664.92
1.265319	Year 6	€ 8,681,511.53	€ 6,861,124.67	EAC year 6	€ 11,385,254.73
1.315932	Year 7	€ 8,681,511.53	€ 6,597,235.26	EAC year 7	€ 10,947,360.32
1.368569	Year 8	€ 8,681,511.53	€ 6,343,495.44	EAC year 8	€ 10,526,308.00
1.423312	Year 9	€ 8,681,511.53	€ 6,099,514.85	EAC year 9	€ 10,121,450.00
1.480244	Year 10	€ 8,681,511.53	€ 5,864,918.12	EAC year 10	€ 9,732,163.46
1.539454	Year 11	€ 8,681,511.53	€ 5,639,344.35	EAC year 11	€ 9,357,849.48
1.601032	Year 12	€ 8,681,511.53	€ 5,422,446.49	EAC year 12	€ 8,997,932.19
1.665074	Year 13	€ 8,681,511.53	€ 5,213,890.86	EAC year 13	€ 8,651,857.88
1.731676	Year 14	€ 8,681,511.53	€ 5,013,356.59	EAC year 14	€ 8,319,094.11
1.800944	Year 15	€ 8,681,511.53	€ 4,820,535.18	EAC year 15	€ 7,999,128.96
	Sum of the PVs		**€ 96,524,408.72**	**Sum of the Equivalent annual annuities**	**€ 160,171,259.67**
	4.45				