Contents

List of Figures & Tables

1 Introduction

Population growth, increasing urbanization and socio-economic development of low- and middle-income countries are factors for Municipal Solid Waste (MSW) which are expected to double in the coming ten years. Waste is a growing global problem that has its effects on human health, environment and causes economical losses. On daily bases millions of tons of waste is being generated and they need to be collected, sorted and finally treated in the best way possible (Ripa et al., 2017). This sets pressure on waste treatment methods to be more efficient and sustainable. Furthermore, it is crucial to dispose waste properly in order to decrease the hazardous materials polluting the environment. Waste treatment method can be explained as transformation of waste mechanically or chemically in order to decrease the negative effects of waste. The treatment of waste can be done in several methods of which there are, landfill, incineration, recycling and composting (Hollins et al., 2017).

Many of the developing countries uses landfill system in order to manage their domestic and industrial wastes. This system favors the economic means of waste disposal however, it can impact the environment negatively if it is not managed well. The biggest environmental challenge associated with landfills are the surface and groundwater contamination, greenhouse gas and odor emissions (Seshadri, Naidu, 2016). Differently from the European countries which use the incineration process, also referred as waste-to-energy process in order to recover heat and electricity from burning trash. This process is aiming for achieving high levels of reduction in waste volumes and eliminating wide range of pollutants. It is shown that Denmark and Sweden demand highly the energy that are generated through incineration. In 2005, Denmark consumed up to 4.8 percent of the electricity which was produced by incineration and the use of heat reached 13.7 percent. Further, the environmental impacts created through this process is controlled by both Waste Incineration Directive and Large Combustion Plant Directive. Their goal is to secure that the pollution limit is not exceeded (Eurostat, 2016; Buekens, 2012).

1.1 Background

As developed countries reach new and innovative ways to deal with Municipal Solid Waste (MSW), many developing countries still lie behind within collection, selection and disposal of this waste. Brazil is one country that falls in this figure, wherein the majority of the population lives in urban region and waste management (WM) has not developed to the necessary standards. According to Besen and Fracalanza (2016), over 3.000 cities still have open dump sites, posing a hazard to the local population and environment. Though these cities are in the process of changing towards landfills, this method is also becoming unsustainable due to overuse and greenhouse gases emissions (Besen & Fracalanza, 2016).

According to Besen and Fracalanza (2016), in Brazil over 50% of the MSW is correctly disposed in landfills, while over 10% is still disposed in open air dumps. That characterizes a deep issue for public health and life quality in vast areas of Brazil. The quantity of waste recycled – and organic waste composted – ranks barely over 2%, being nearly negligible (Besen & Fracalanza, 2016). Areas for correct disposal of solid waste are not the only documented problem, as several low-income neighborhoods – often called 'favelas' – have issues with the collection of waste due to complex urban layout (Polzer & Pisani, 2015).

However poor the current situation of the country, the National Policy on Solid Waste, approved in 2010, brought new targets and goals for WM throughout the country. Though the targets for ending with open air dumps and controlled landfills have not been met in the past years, the country is slowly marching towards a better waste management situation (Besen & Fracalanza, 2016). Lino and Ismail (2013) also suggest that several of landfills in the southeast region of Brazil have been collecting gas emissions and utilizing it to generate energy on local plants. Despite these advances, the limited capacity of most landfills, combined with limited terrain close to urban areas, still make landfills an unsustainable solution on the long-term.

It is also noteworthy that Brazil possesses a big regional gap in economical and living standards terms, wherein the southeast and south region are the most advanced. That is reflected by Besen and Fracalanza (2016), that shows how over 60% of the population in the south region is served by selective collection of solid waste. Comparatively, that value is under 7% in the northeast region. Moreover, as the south region has already dealt with most open dump sites, their most immediate issue in WM has become the overuse of landfills (Besen and Fracalanza 2016).

Through several developed and developing countries, the limitations of landfills are being coped with energy recovery technologies. These systems reduce the quantity of waste, while also generating energy in the process. According to Makarichi et al. (2018), the most traditional of these technologies is waste incineration, a method that has existed for very long, but only recently has gained acceptance as a sustainable practice. Though most of these energy recovery technologies fall under the concept of Waste to Energy (WTE), the term is most often used as a synonym to waste incineration. Thus, this term will henceforth be used solely to refer to waste incineration practices (Makarichi et al., 2018).

Though waste incineration has existed in Brazil, the practice has fallen in use through the past decades (Premier Engenharia, 2017). That is probably a result of poor public opinion of this technology, since in the past waste incineration did not focus on energy recovery or lowering emissions (Psomopoulos et al., 2009). However, the recent improvements in this technology could make it more accepted by the public opinion, making it a potential solution for the overuse of landfills in Brazil.

1.2 Problem Description

The state of Santa Catarina, in southern Brazil, has developed its waste management far ahead many other states in the country. According to Premier Engenharia (2017), there are currently 34 sanitary landfills in Santa Catarina, which receive urban solid waste from 295 municipalities, comprising therefore all the urban regions of the state. These landfills are located throughout Santa Catarina to facilitate for municipalities to dispose their waste without great logistical problems. Though the landfills share many similarities, their capacities could vary from 2 tons/day to 2.500 tons/day (Premier Engenharia, 2017).

However, due to high usage and limited capacity, many landfills are approaching their end of life. According to Besen and Fracalanz (2016) “landfill sites continue to be overfilled with waste” and with only 3,7% being recycled, this could become a huge issue for the current generation. Moreover, due to the absence of own landfills or expired ones, several municipalities dispose their waste in units with significant distances, greatly increasing the overall cost of handling the city with the transportation and disposal of solid wastes (Premier Engenharia, 2017).

This paper approaches the problem on overuse of landfills in Santa Catarina, which will continuously increase the cost of waste management through the state. New practices as necessary to cope with this issue, but there is an overall difficulty to implement solutions at a state level due to bureaucracy (Premier Engenharia, 2017). As municipalities have their own budget for waste management, the solutions must be studied at a municipal level.

1.3 Purpose and research questions

With the growing demand for solutions in waste management throughout Santa Catarina, several government bodies have envisioned waste-to-energy as a potential resolution. However, the lack of previous development of this technology in Brazil creates a difficult environment to start the construction of these facilities. The purpose of this study is to create a groundwork for further projects within waste-to-energy throughout Brazil, by carrying a pre-feasibility study for a waste incineration plant in Santa Catarina. The study will be done in cooperation with municipalities and regional stakeholders that have interest on the project.

With a focus on qualitative data, a careful situation analysis of the region is carried, comprising information of the current waste management, waste characteristics, socioeconomic aspects, regulations and the electricity sector. A preliminary selection of technical aspects for the incineration plant is then proposed, utilizing the regional data as a foundation. Finally, quantitative data is used to carry, economic, environmental and social analyses of the proposed plant.

Thus, this research should support the development of a pioneering waste-to-energy plant in Santa Catarina, while also creating a ground for further academic studies within waste-to-energy in Brazil. In order to fulfil this purpose, the following research questions are formulated:

RQ1. "*Why is Waste-to-Energy considered a better solution for waste disposal than traditional methods?"*

RQ2. "*How can waste-to-energy, as opposed to landfills, contribute to environmental and social sustainability in the region*?"

RQ3. "*How can the proposed plant optimize its profitability, based on the regional situation?*"

1.4 Delimitations

This research will study exclusively factors within the plant, therefore not including treatment of water before and after the usage in the plant. Pre-selection and transport of waste before processing at the plant will be studied, but not considered as a part of the process of the plant. Usage of steam, electricity, bottom ash and other outputs will also be studied, but not considered a part of the plant's process.

The data used will be regional specific, what might limit the generalization of the results. Aspects with regard to technical specifications of the plant, usage of steam, flue gas cleaning and electricity distribution will be based on data from previous research and systematic assumptions, therefore not incorporating decisions based on expertise. There is also a limitation to the data gathered, given that most of the work will not be carried on site, but rather constructed from databases.

1.5 Outline

The disposition of this paper is introduced as following: Starting with chapter 1 where it introduces the study's topic, and it highlights the problem formulation. Furthermore, the purpose and the research questions are presented and merged with the problem formulation that later will be used to answer the aim. Lastly in the first chapter, the scope and the delimitations has been set in order specify the study's path.

Chapter 2 of this study gives a description of the chosen method approach with regard to the research questions. Moreover, to be able to reach the aim of the study as well as the methods that have been used to obtain the theoretical framework and the empirical result sought. Chapter 3 includes the secondary data (mostly quantitative) gathered through literature review, that describes various technologies, process and concepts that are of vital importance to the study. Chapter 4 is presenting the data gathered from Santa Catarina State that later been analyzed considering Regional background, technical, economic, social and environmental aspects. Discussion of method and findings is presented in chapter 5, where analysis of the collected empirical data linked to the theoretical framework with purpose of proposing a suitable incineration plant for the municipality. Finally, in chapter 5 a conclusion is reached and future research in this field is being suggested.

2 Method

This study aims to create a ground for further projects within waste-to-energy throughout Brazil. To achieve the goals, fulfill the purpose and research questions, different techniques have been used to gather and analyze the necessary data. Initially, the literature review is directly connected to RQ1. As it investigates the role of WTE according to the current literature, the review brings enough information to answer this research question.

The secondary data will be analyzed with regard to the current literature, attempting to answer RQ2 by determining how WTE can contribute to the region. The results from RQ1 contribute to these findings, by providing the literature's perspective on benefits from waste to energy. The input from secondary data enables the current literature to be specified into the regional setting. Finally, RQ3 is also investigated by using mainly empirical data, but also directed by the current literature. The economic perspective of WTE in is specified to the regional setting, wherefore the findings answer this research question. As this paper also present a sustainability perspective, RQ2 and RQ3 are connected, as they together present the three pillars of sustainability for the plant as shown in figure 1.

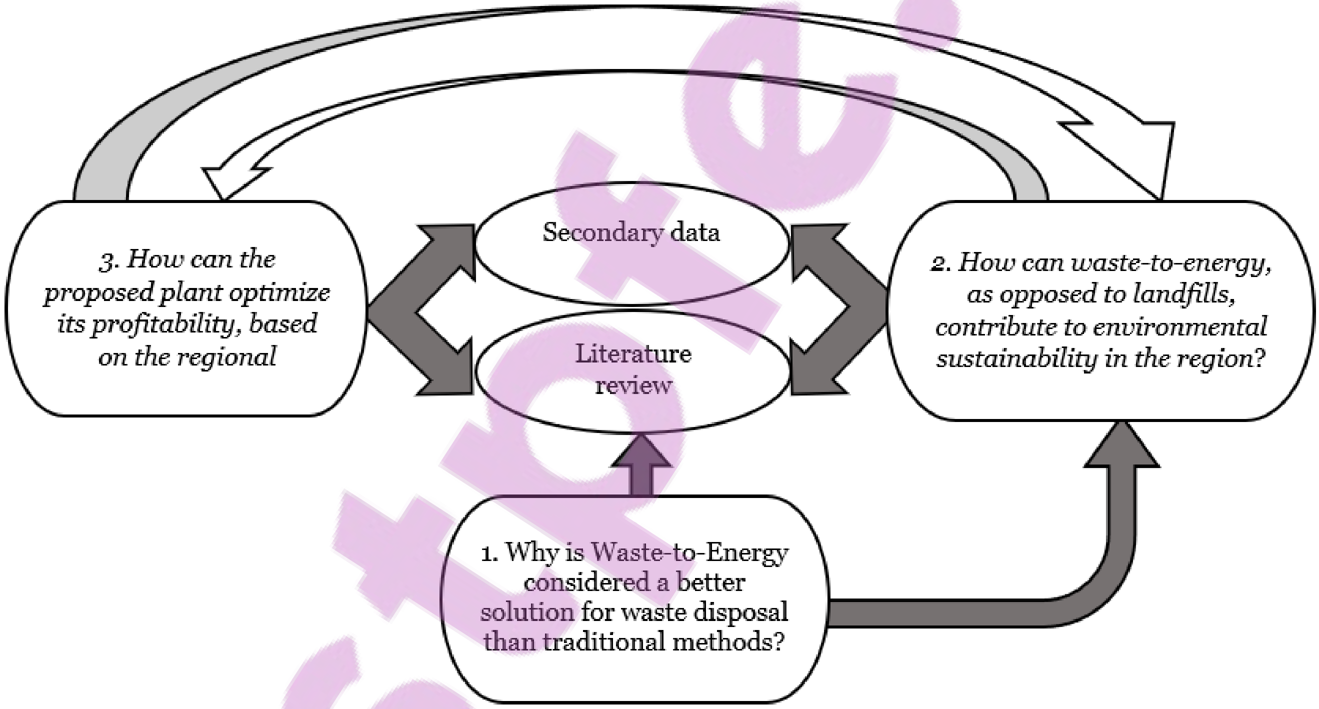

Figure 1 - Link between Method/Techniques and Research Questions
[Source: Own elaboration]

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2.1 The working process

This research follows a flexible design, where the working process is non-linear. An initial study on the field has been conducted to clarify the problem and define a purpose for this study. Once the goals were set, the process begins by studying the current literature to identify the key aspects of waste incineration. The literature review aims to create an overview of the alternatives within WTE. Following the literature review, secondary data is gathered through a document review, initially regarding the situation of the region studied. Data from Swedish and European databases are used as means of comparing the regional situation.

Once the situation is well detailed, the paper begins a technical analysis of that data with regard to the theoretical framework. After determining details of the WTE plant, a secondary document review begins to technical and economic data on the selected subprocesses. This part aims to review technical and economic aspects for the plant. The document review continues after the technical and economic data, with an analysis of the economic, social and environmental implications of a WTE in the region. These analyses takes into consideration the data from European countries as means of comparison. Figure 2 pictures this process.

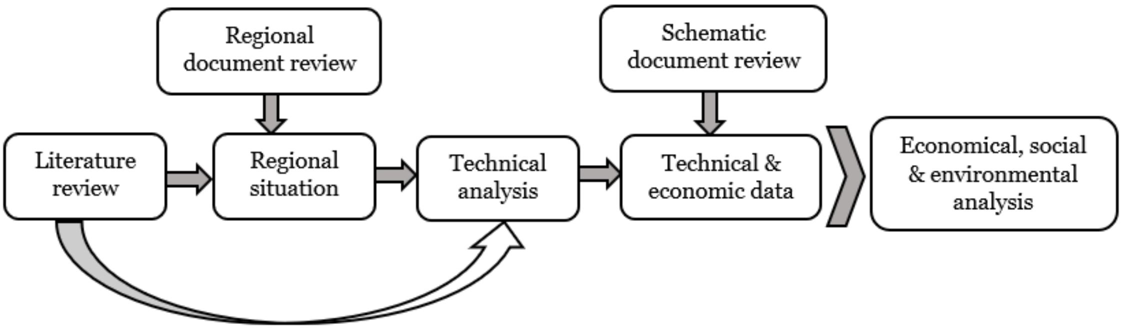

Figure 2 - The Working Process [Source: Own elaboration]

A discussion of method and findings was carried, answering the proposed research questions. The paper then draw conclusions and propose further research within this field.

2.2 Approach

This research has been carried by using mainly qualitative data, as it seemed fit to fulfil the goal of the study. A qualitative approach aims to answer how, when and why a phenomenon occurred (Meyrick, 2006). According to Creswell (2018), the study can be strengthened by using two or more methods or techniques to investigate the problem. Thus, the paper gathers qualitative data from both document reviews and a literature review. Moreover, it will neutralize the weaknesses of each form of data. Thus, this paper uses both types of data to increase the validity and reliability of the results.

The research was based on reviewing existing documents of the selected municipality and analyzing them, using the theoretical background as a framework for these analyses. Lastly, conclusions were drawn from a sustainable perspective, consequently a deductive research approach was applied. A deductive research approach means that existing theories are tested in the empirical data, wherefore conclusions are drawn with base on the theory (Söderbom and Ulvenblad, 2016).

To conduct the pre-feasibility study of a waste incineration plant in Brazil in an orderly manner, similar cases were reviewed. The aim on to find relevance in the planning and execution of the work.

2.3 Design

This paper used a flexible design approach, as most of the data gathered will be of qualitative nature. Moreover, the data collection and analysis process are non-linear, with different parts influencing each other. That creates an argument in favor of a flexible design, which is most often used in non-linear studies (Williamson 2002).

The primary method that has been used in this research is a case study. Case studies are characterized by investigating one instance, to be studied in detail and in several dimensions. In qualitative research, case studies are commonly used, providing a wider amount of evidence than other methods. Matthew (2006) backs that claim by arguing a case study is the best possible source of description in its own way. Furthermore, it enables a more in-depth examination of a particular case, which provides leads that otherwise might never be found (Brewerton and Millward, 2001). Thus, as this project approaches a subject of little development in Brazil, the use of a case study becomes highly useful to fulfill the purpose.

As the purpose of this paper involves supporting the construction of a WTE plant in Brazil, the paper is also connected to a feasibility study. However, as described by Mackenzie and Cusworth (2007), the application of feasibility studies has often been wrong, most often due to misunderstanding of the study phases. The ultimate goal of a feasibility phase in a study is to determine if the project is feasible or not, which is not the goal of this paper.

Thus, following Mackenzie and Cusworth (2007) argument of study phases, this paper will primarily use the structure of pre-feasibility studies. That is to evaluate different alternatives for the WTE plant, determining which is the most suited for the region. This structure includes determining preliminary technical and economic aspects; consider different processes and project configurations; propose the best option to proceed for a feasibility study; identify key stakeholders; assess the risks; identify requirements for the project completion. These aspects are addressed throughout the report (Mackenzie & Cusworth, 2007).

This study is not a comparison study. The design of the research follows an exploratory approach, using different techniques to collect data and analyze the current situation. Then propose a plan for installing a waste-to-energy plant in the chosen municipality, while also judging the feasibility of the project. The research has been carried in partnership with government bodies in Brazil. In 2017 a delegation of Brazilian representatives visited Sweden, in a series of events organized with Jönköping University. The goal was to find commercial partners and areas for mutual cooperation, wherein the delegation visited a Waste to Energy plant. From this start point, a project to open such a facility in Santa Catarina began, expanding the cooperation between these two countries. The project studied in this paper has its ground within this cooperation, wherefore the data collection was facilitated. Therefore, Sweden and the EU have been used as basis of comparing the data gathered from Brazil.

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List of research project topics and materials

2.4 Empirical Data Collection

2.4.1. Literature Review

Prior to the pre-feasibility study carried in this research, there was the need to better understand the technical and operational aspects of waste-to-energy plants. To achieve that, a structured literature review was conducted, initially carrying a careful literature search. The aim was to identify the most useful articles in the field, also considering data from case studies in developing countries, due to similarities with Brazil.

The search was conducted in ProQuest Central and ScienceDirect, with a focus on Waste to Energy and its subprocesses. Delimitations were set on the results, englobing only articles and reviews in English and written since 2000. The total of articles identified within the initial search were 163, including duplicates. An abstract screening was then conducted, eliminating articles that were deemed irrelevant for the study. That resulted in 21 articles, which possessed valuable data to construct a base for the theoretical framework.

The initial sample provided, therefore, the basic understanding of how WTE plants operate. The main technologies and practices are explained through these different articles and reviews. However, information on the subprocesses of the plant was incomplete, requiring further literature to complement the chosen papers. Subsequent searches were carried with focus on the specific processes, and articles retrieved from bibliographies of the initial sample. The papers gathered complemented the necessary information, allowing this research to draft the processes within different types of WTE plants.

The literature review also approaches RQ3, to determine if waste to energy should be considered better solution than traditional disposal methods. The social and environmental aspects served as means to measure whether WTE has a positive or negative impact. Economical aspects were also put into consideration, using therefore the three pillars of sustainability to address the impact of WTE.

2.4.2. Document Review

Ideally this case study would gather primary data and up-to-date evidence, ratifying the reliability of the research. However, limitations in resources and time frame do not allow this research to be carried on site, making necessary the sole use of secondary data. This has been carried through an extensive review of selected documents.

The documents reviewed in this case study can be divided into two sets: (1) regional situation data and (2) technical and economic data. A further set of data was also gathered from Sweden and the EU, in order to provide a basis for comparison with the regional data. Most of the empirical data refer to the regional situation, being displayed in the region background epigraph. In this part, the situation of the municipality study is described in detail, what allows further analyses in economical, technical, social and environmental aspects. The data from technical schematics is present in the technical and economic data epigraph, where the review was influenced by the first data set.

Most of the data required to address the regional situation has already been gathered by government studies in Brazil. Regulations have pushed municipalities throughout the country to conduct studies in their current waste management, allowing them to create waste management plans. These studies bring information to the detail, carefully analyzing each aspect of the region that may affect their municipal solid waste management. Several documents from the European Union present detailed data regarding technical aspects of WTE plants, serving the needs of this report. These two main sources, complemented by other documents provided by stakeholders, enabled the different analyses of this paper.

The regional documents were reviewed with a focus on data from the municipality. The relevant information was extracted and carefully translated to English, being compiled and analyzed in this paper thereafter. Other documents with focus on the technical schematics were presented in English, where a review was directly influenced by the regional situation data and the theoretical background.

The following table 1 provides the documents that were reviewed, a description of the information available and a description of the reviewing process for each document.

Table 1 - Details of document review

Document	Description of Data	Description of Review
Regional Integrated Waste Management Plan	Descriptive data of waste management in a group of municipalities, addressing key characteristics and issues of the region.	Review of Data from Chapecó (selected municipality), with a focus on factors influential to Waste-to-Energy
State Waste Management Plan	Descriptive and comparative data of all regions in the state, comprising all landfills used, socioeconomic factors and simplified waste characterization	Review of Data with focus on missing aspects from the first review. A preliminary review of state situation has also been used in the Introduction.
Documents Regarding Emission Regulations	Different resolutions with regard to emission from incineration, on national and state level, as well as European Guidelines.	Review of data applicable to emissions from Chapecó or related data. Focus on comparing emission limits from Europe and Brazil.
Documents Regarding the Electricity Sector	General view of all data around electricity production, on documents from Brazil and Sweden.	Review of data with focus to installed capacity on these countries, prices, and other factors for comparison.
Schematics and details for a Waste-to-Energy plant	Highly detailed orientations to technologies used on WTE, studies on their application, costs, revenue streams, etc.	Review of data considering the selected technologies on the Technical Analysis.

[Source: Own elaboration]

2.5 Data Analysis

Prior to the data analysis, the theoretical framework brings into light the process involved in such facility, as well as its subprocesses. That allows the research to conduct the regional document review with a focus on the relevant information, constructing a base of empirical data. Thereafter, the data analysis begins, being divided into three different parts: technical analysis; economic analysis; and social and environmental analysis.

The first part of the data analysis was to investigate the technical details that the WTE plant would require. This was done by employing the regional situation data into the theoretical framework, to propose what equipment and processes would be suitable for the region. These technical details are then analyzed simultaneously the document review of technical schematics, addressing the different aspects involved in the proposed plant.

The analysis takes its second part by using the detailed technical aspects to investigate the economic aspects of the plant. Figures for investments and operational costs are thereby proposed, also employing the second set of document data. Break-even and payback-time were considered in this process, as well as a brief discussion of the economic benefits of the plant ahead landfilling.

The third part was to conduct an environmental and social analysis, considering the impacts a WTE would cause in the region. That was done by observing the technical aspects of the plant, the relevant literature and the characteristics of the region. The impact of greenhouse gases emissions and other pollutants in the environment, and the population of the region, was carefully studied. Within this scope, a comparison of WTE with landfilling and other disposal methods was carried. Finally, this part reviews how environmental regulations, and people’s behavior, would impact in the success or failure of the incineration plant.

The data analysis attempts, therefore, to carefully study all the collected data from a holistic view. This should bring better conclusions to the project and help to fulfil the purpose, by considering all aspects of influence to the WTE plant.

2.6 Credibility

Throughout the work, the validity and reliability has been considered to increase the quality of the research. It is important that both validity and reliability are in a certain relationship, since it is not possible to concentrate only on one and exclude the other (Jacobsen, 2002).

2.6.1. Validity

There is a distinction between internal and external validity. Internal validity is about securing the data that has been measured, let others check the operationalization of the study. While external validity has to do with how the study can be generalized to other situations, companies, countries etc. With the reason that the study can be compared with other cases that resemble one's own (Jacobsen, 2002).

The internal validity of this study has been secured in two different ways. Firstly, the data review has been achieved in a systematic way by using only reliable databases, such as ProQuest. Where the delimitations in the study contributed to the literature being selected only relevant to the purpose. The other way is by using mixed methods, according to Jacobsen (2002) if the methods gives the same results, we can claim that is the internal validity is good.

External validity is usually achieved with a probability sampling, where that makes the study generalized with a known degree of certainty. However, in this case only one sample has been chosen from the whole Santa Catarina region, makes it impossible to generalize in this way thereby, an analytical generalization has been used. The researchers then strive to generalize a certain set of results to a more general theory, by basing the findings of a study on other literature the external validity will increase (Jacobsen, 2002; Yin, 2007).

2.7.2. Reliability

According to Yin (2007) to achieve reliability one needs to set steps that if other researchers are willing to follow, they should get the same results and conclusions or equivalent results. The aim is to minimize all errors and distortions in the process because if the process is unreliable then there is a big chance that the study does not count as valid.

The reliability of this study depends mostly on the secondary data that has been collected using document reviews. The documents that has been used, were all pre-gathered by the stakeholders of this project. As the main documents used refer to studies from professional consulting firms, contracted by government bodies, the data thereby displayed should be of high accuracy and reliability.

Before conducting the document reviews, a literature review was performed in which the problem formulation, the purpose, research questions and the theoretical framework was influenced by. That made it easier to acknowledge the necessary information needed to achieve the purpose of the study. According to Yin (2007), a good circumstance for reliability is that everything is documented carefully, which was done with both literature and document reviews. During literature review all the steps was documented starting from which databases has been used to the number of articles found. Given that data collection took the form of literature review and document review, triangulation could have been used, which Yin (2007) believe it reinforces the study's reliability.

3 Theoretical Framework

3.1 Waste Management and Energy Recovery

As global population continues to increase, the production of municipal solid waste accelerates at an exponential level (Qazi et al., 2018). Waste management has become a crucial strategy to cope with this issue in most countries, wherein the decisions are most often based on how much waste is produced and how to dispose the waste (AlQattan et al., 2018). Though these are two distinct aspects, they are also interconnected, as the disposal may depend on how much waste is produced in the region.

The most common method of waste disposal is through landfills, a method that has provided great improvements over open dump sites and uncontrolled waste incineration (Psomopoulos et al. 2009). However, landfills have also been noted to emit high levels of greenhouse gases, pollute local water sources and cause health hazards to the local population (Qazi et al., 2018). Qazi et al. (2018) also notes that the disposal of recyclable materials results in the loss of natural resources and value.

The world scenario during the late 20th and early 21st century, showed a continuous growth in energy consumption. At the same time, most energy sources used globally have been from fossil fuel, deemed as unsustainable. In this scenario, the use of waste as means of energy generation has grown vastly, with several technologies for energy recovery being developed. Municipal solid waste has been commonly classified under the spectrum of biomass, being therefore considered a renewable source of energy (AlQattan et al., 2018).

Thus, energy recovery systems have been vastly studied and applied, in order to cope with the growth of municipal solid waste production. AlQattan et al. (2018) explains there are three main routes for energy recovery from waste, with several technologies developed under each route as it is shown depicted in figure 3. These are: (1) Biochemical; (2) Thermochemical; and (3) Physicochemical (Mechanochemical). The first route uses general conversion of organic waste into liquid or gaseous fuels. The thermochemical route converts the waste into heat and electricity through the application of high temperatures, such as through waste incineration. In the physiochemical, organic waste is transformed into energy through chemical agents (AlQattan et al., 2018).

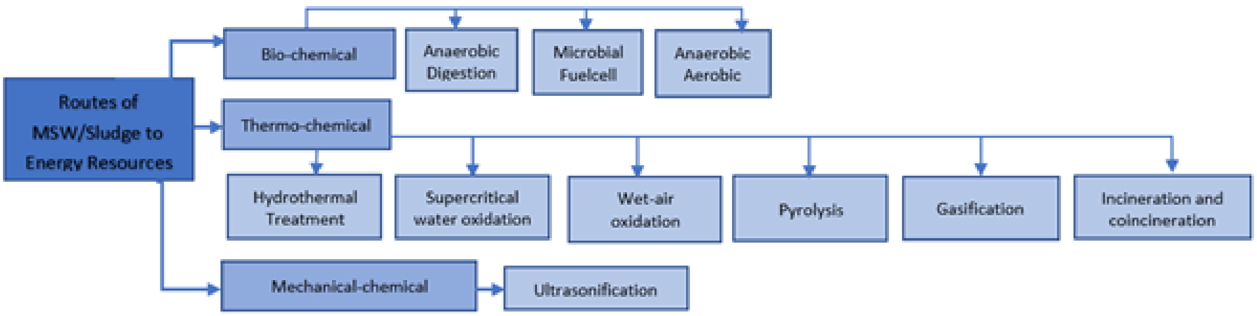

Figure 3 - Energy Recovery Routes [Source: Adapted from AlQattan et al. (2018)]

The most vastly applied method of energy recovery is waste incineration – in this paper also called Waste to Energy – a thermochemical process (Kumar & Samadder, 2017). The low capital cost, and relative low complexity of certain waste incineration technologies, makes this method one of the best alternatives for being implemented in populous countries (Psomopoulos et al. 2009; Kumar & Samadder, 2017). Therefore, this is the energy recovery method of main study in this paper. Details regarding other methods of energy recovery can be found in AlQattan et al. (2018).

3.2 Waste to Energy

Waste to energy has been widely used in developed countries as means of reducing the amount of waste going to landfills, whilst generating energy in the process. As Makarichi et al. (2018) describes, waste incineration is not a new technology and has been vastly used in the past. However, due to the lack of environmental awareness, these technologies were highly pollutant and serious health hazards to the population, as waste incineration often emit highly toxic gases. Psomopoulos et al. (2009) argues that this has produced a bad image of waste incineration, that lasts until today.

This technology has evolved throughout the years, developing methods for minimizing the emission of pollutants and toxic gases. Shareefdeen et al. (2015) argues that "Flue gas cleaning is perhaps the most important part of the incineration process" (p. 1838), particularly due to the strict regulations imposed by governments to avoid health hazards. After the changes of air pollution control in these facilities, the U.S. Environmental Protection Agency concluded that WTE became one of energy sources with least environmental impact (Psomopoulos et al. 2009).

Thus, with a reduced environmental impact and strict government regulations, waste to energy has often been considered as one of the best solutions to cope with the problem of MSW. It is capable of reducing the amount of waste destined to landfills in 70 to 80% of the total weight, and up to 95% of the total volume (Qazi et al., 2018).

Though the waste incineration process can vary depending on combustion methods, heat recovery and flue gas cleaning, the ground of the process is essentially the same for most grate incinerators (Tabasová et al., 2012). The waste is initially disposed in a chamber, being thereafter placed in an incinerator, which usually has temperatures between 850 and 1000 degrees Celsius (Qazi et al., 2018). The simplified result of this combustion is the production of ashes from incombustible material – namely Bottom and Fly Ash – and flue gases. The ashes then pass through a process for recovery of metals, being reused or disposed at landfills thereafter.

The flue gas produced is used to recover heat, usually through a boiler that generates steam. The steam is then applied to the generation of electricity and, in several cases, used for district or industrial heating. Finally, the flue gas passes through an extensive mechanic and chemical process, in order to eliminate most hazardous substances before it is released into the atmosphere (Tabasová et al., 2012). Figure 4 present a simplified scheme of a municipal solid waste incinerator (MSWI).

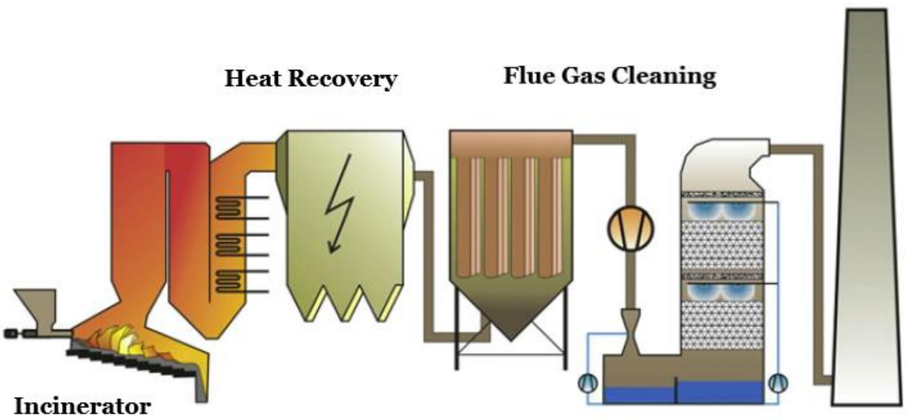

Figure 4 - Simplified Scheme for MSWI [Source: Adapted from Tabasová et al. (2012)]

3.3 Combustion Technologies

Amidst the process of energy recovery in waste incineration, the perhaps most basic part is the methods for incineration and combustion of waste. These methods may vary depending on the types of waste, their characterization and calorific value. According to Tabasová et al. (2012), the three main methods for incineration of waste are: moving grate, rotary kilns and incineration in fluidized bed. Thus, these three processes will be studied in this paper.

3.3.1. Moving Grate

In a moving grate incinerator, the waste is continuously moved inside the combustion chamber. That allows a mixture of the waste, exposing all parts of the waste into the heat and maximizing the combustion (AlQattan et al., 2018). Facilities with grate incineration are technically simpler and do not require a particularly high capital cost, being the most common WTE through the US and parts of Europe (Psomopoulos et al. 2009).

This method is most commonly applied for treatment of municipal solid waste (MSW), as the requirements for pre-selection of the waste are low. The waste is incinerated between 850 and 1100 degrees Celsius, and addition of other non-hazardous waste could be applied (Bosmans et al., 2013).

3.3.2. Rotary Kiln

Rotary kiln is a combustion technique very similar to moving grate, but the waste is incinerated in a rotating chamber (Miranda & Hale, 1997). According to AlQattan et al. (2018), rotary kills have “a cylindrical vessel spinning around its axis, by means rollers that are located under it, conveys waste by means of gravity” (p. 102).

Rotary kilns are most commonly used for the incineration of hazardous and medical waste, as the system allows the incineration of waste in most states of matter. The waste is usually combusted between 850 and 1300 degrees Celsius, wherein toxic materials can be further destructed in a post-combustion chamber (Bosmans et al., 2013).

3.3.3. Fluidized Bed

Fluidized bed is a process where the waste is placed over a bed of inertial materials – usually sand and ashes – which allows a constant air flow from beneath the bed. This method generates a higher combustion, while also minimizing the production of certain hazardous gases. However, the process requires a deeply pre-processed waste, not being suitable for unselected MSW (Miranda & Hale, 1997).

This method, and its subcategories, is most commonly used to recovery energy from sludges, or other pre-selected wastes with high calorific value. Co-combustion can be applied in certain subcategories of this method, allowing for a wider range of calorific values of the waste, but still requiring an extensive pre-selection. The temperatures in the freeboard may vary from 850 to 950 degrees Celsius, while the fluidized bed must have a higher temperature than 650 degrees Celsius (Bosmans et al., 2013).

3.4 Heat Recovery Technologies

In Waste to Energy plants with focus solely on electricity generation, the heat recovery system plant usually consists of air pre-heaters, steam generators (boilers) or other types of heaters. The flue gas released from the incinerator move to a boiler where water is converted into steam and the gases are cooled down. Thereafter, the steam turns a turbo generator in order to convert its power into electricity. Thus, the process consists of a closed loop, wherein the steam that has passed the turbos goes into a condenser and the water returns to the boiler, as shown in Figure 5 (Shareefdeen, et al., 2015; Tabasová, et al. 2012).

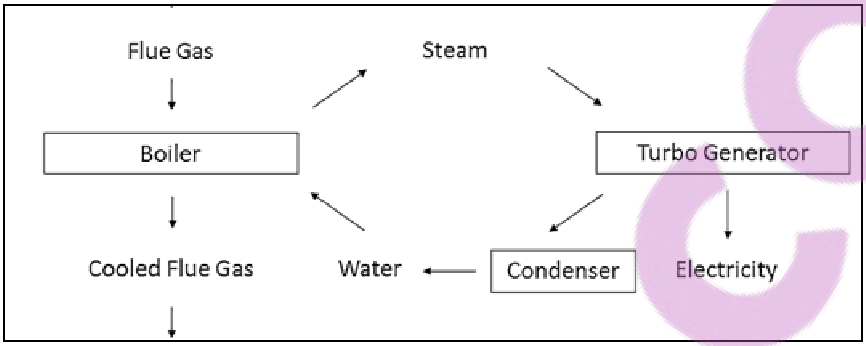

Figure 5 - Closed Loop Heat Recovery [Source: Shareefdeen, et al. (2015)]

Though the recovery system described by Shareefdeen, et al. (2015) maximizes the electricity generation, it may increase the risk corrosion of boiler pipes. That suggests the profit gained from electricity will increase, with trade-off of decreased operating life of the plant (Tabasová, et al. 2012).

Plants with focus on selling steam uses other types of heat recovery systems, often combining electricity generation with steam production. The process is similar to the aforementioned one, where it uses boiler to generate steam and to cool down the flue gas. However, the course of the steam changes and so does the output of the plant respectively. As the plant will produce both electricity and steam, the steam is cleaned and sold for industrial or district heating, instead of being reused in the process (Fruergaard & Astrup, 2011). As shown in Figure 6 the flue gas released from the incinerator move to a boiler where water is converted into steam and the flue gas are cooled down. Thereafter, part of the steam turns a turbo generator in order to convert its power into electricity, while another part bypass this system. The steam does not return to the boiler but exits the process, wherefore water must be added regularly to the system (Shareefdeen, et al., 2015).

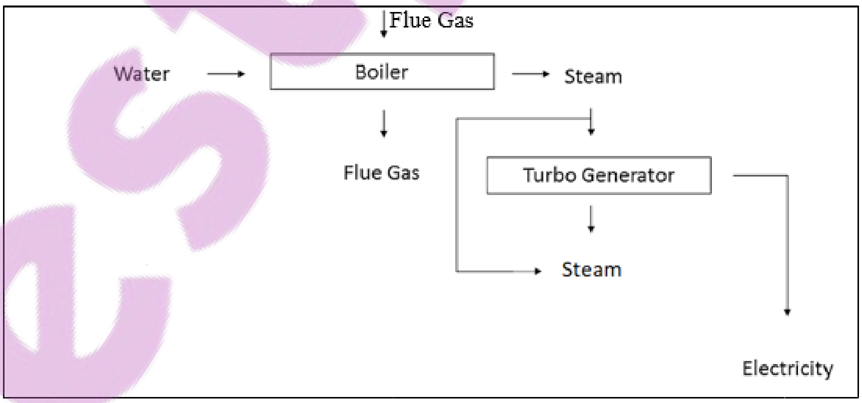

Figure 6 - Open Loop Heat Recovery
[Source: Adapted from Shareefdeen, et al., (2015) and Tabasová, et al. (2012)]

3.5 Flue Gas Cleaning

Flue gas polluted out of municipal solid waste (MSW) incineration contains extremely harmful products such as acid gases (SO_2, NOx, and HCl, etc.), particulate matter, heavy metals, and organic compounds (Xiaowen Su, 2015). These products/emissions pose a serious concern to human health and the environment if not treated correctly (Nixon, et al. 2013). Grieco and Poggio (2009) highlights four commonly used technologies that are currently applied to remove the acid gases from the flue gas. The methods are: (1) dry treatment with $Ca(OH)_2$ or (2) with $NaHCO_3$, (3) semi-dry process with $Ca(OH)_2$ and (4) wet scrubbing. However, these technologies are not enough to reach the international standards. Thereby, different types of filtration systems such as catalytic filtration (CF), and secondary bag filter were added to optimize the existing cleaning systems (Xiaowen Su, 2015).

Each treatment technology requires specific temperature on the flue gas, that can directly affect the performance of the steam generator. Beside the temperature, some technologies have limit of the quantity of auxiliary steam used in the process which in its way is limiting the energy generation performance (Grieco & Poggio, 2009). In the section below the treatment methods will be introduced and their requirements will be highlighted additionally to the filtration systems.

3.5.1. Dry treatment with $Ca(OH)_2$ or with $NaHCO_3$

For the dry treatment two kinds of chemicals is being used: $Ca(OH)_2$ or with $NaHCO_3$. Acid gas neutralization with $Ca(OH)_2$ is efficient mainly because of the hydrated salts inside the pores of the chemical subject. Often the neutralization happens to a temperature close to 130 C to avoid clogging of the fabric filters that comes after this stage. However, the neutralization with $NaHCO_3$ require a higher temperature, optimally between 160-200 C, (200 C) is the optimal temperature for sodium bicarbonate activation (Grieco & Poggio, 2009).

3.5.2. Semi-dry process with $Ca(OH)_2$

for Semi-dry treatment, calcium hydroxide $Ca(OH)_2$ is injected into the flue gas together with water which promotes the reaction of the acid gases and enhances the adsorption of acid gases. Since the water decreases the temperature of the flue gas, it is required to have the temperature close to 200 C (Grieco & Poggio, 2009).

3.5.3. Wet scrubbing

Wet scrubbing retains solid particles using fine water-drops fog. Usually there are 3 stages on this procedure to be performed. The first stage consists of venturi-scrubber the second and third consists of packed column that uses water drops to eliminate acid gases from the flue gas. However, the water used has to be re-treated because it captured most of the chemicals in the flue gas (Tabasová, et al. 2012).

3.5.4. Filtration systems

In order to maximize the removal efficiency of the cleaning systems filtrations has to be added in the process (Xiaowen Su, 2015). Catalytic filtration, bag filter and fabric filters are commonly used with the dry and semi-dry treatments in order to ensure the flue gas released is within the regulation limits (Grieco & Poggio, 2009).

3.6 WTE Process Overview

The process of energy recovery in a waste incineration plant is, as previously stated, based on three main parts: the combustion; the heat recovery and conversion into electricity; and the flue gas cleaning system. To simplify the characteristics of these subprocesses, as well as the setting in which they are optimal, figure 7 presents an overview of the whole process.

Figure 7 shows the boundaries of the study. Four basic processes are presented: (1) Pre-treatment, (2) Thermal conversion, (3) Products utilization, and (4) Flue gas treatments. Each section consists of more than one process or technology that can be used depending on specific variables of the environment of the plant.

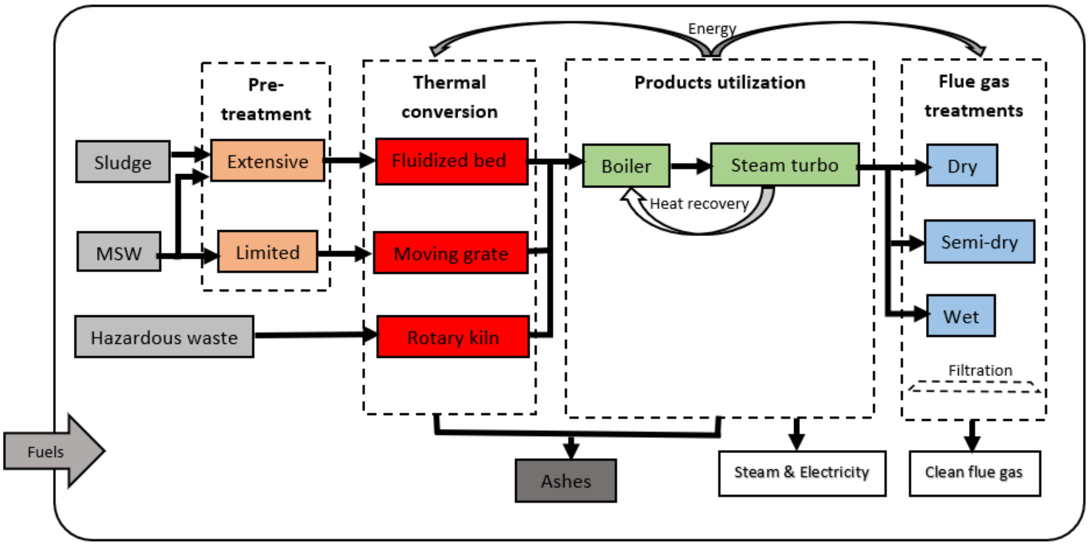

Figure 7 - Overview of WTE Process and Alternatives [Source: Own elaboration]

Directly from the beginning of the process, the input of waste feedstock may require an extensive pre-treatment, in case the combustion technology used is fluidized bed. The nature of the waste also plays a role in the selection of the combustion technology, as rotary kilns are most often used to cope with hazardous waste and moving grate is usually applied with MSW. It is also noteworthy that rotary kilns and moving grates also require a certain input of combustible material (such as fuel), to deal with variations in the calorific value of the waste (Qazi et al., 2018).

The heat recovery systems are mainly determined based on external factors, considering what outputs would be optimal for the local market. If the local industries or districts require steam for heating, then placing a higher focus in the sale of steam could increase profit margins. However, if the requirement of steam is minimum, the plant might focus in the production of electricity instead. Pavlas et al. (2011) suggests that focusing on electricity production tends to highly reduce the efficiency of moving grates. An alternative to increase efficiency of the plant in that situation, is to use a steam-gas combined cycle. In that situation, natural gas is used to generate electricity in a generator. The heat loss of this generator is instead used to increase the heating of the boiler in waste incineration (Pavlas et al., 2011).

The choice of flue gas cleaning system is also nearly independent from the previous subsystems. All three major combustion technologies can be linked to any of the mentioned flue gas cleaning systems. What differs between these technologies is the efficiency of acid gas removal and the required temperature for optimal results. Lastly, a filtration is used to rid of the remaining metals that the previous treatment is not capable of.

3.7 Economic Aspects

Population growth, increasing urbanization and socio-economic development of low- and middle-income countries are factors for consumption of goods and energy to increase. That leads to increase in generation of waste and dependency of energy. Thereby, turning waste into energy could be a key factor to solve these types of issues or at least minimize the waste and resources used (Malinauskaite et al., 2017).

EU has been trying to make waste management a more sustainable process then what it has been in the previous years. The European commission indicate that waste streams are a potential secondary raw material sources which is being wasted. Thereby, EU's economy currently loses a significant number of reusable sources. The renewable energy from waste is a step forward for a better environmental solution and it could be economically efficient in a longer term (Malinauskaite et al., 2017).

A study was conducted by Panepinto (2016) regarding the costs of a WTE incineration plant, three elements were then presented, (1) start-up cost, (2) management cost and (3) maintenance cost. The start-up costs refer to the expenses during the construction period of WTE incineration projects, usually they are fixed costs depending on the size/capacity of the plant. Meanwhile, the machinery and the thermal are chosen based on the waste type input (Xin-gang et al., 2016). While, management cost category contains the costs of staff, materials (fuels), services, cost of disposal and so on. Lastly, maintenance costs contain the ordinary maintenance cost and programmed maintenance (Panepinto, 2016).

3.8 Environmental and Social Aspects

The environmental and social hazards of waste incineration were very significant in the past, as previously stated in this paper. But the development of advanced flue gas cleaning systems, transformed an unsustainable practice into a highly recommended waste disposal method (Psomopoulos et al. 2009). Despite that, waste to energy is still a source of pollution that can cause prejudicial effects to the environment and regional population.

Municipal solid waste has always been a concern to the population and environment. The link of diseases and health hazards to the unproper disposal of waste has been drawn by scientists long ago, wherefore the use of proper disposal methods vastly through the 19th and 20th century (Makarichi et al., 2018). On this prospect, landfilling became one of the most acceptable solutions both from the social and environmental perspectives. However, the population growth and social behavior has caused an explosion in the municipal solid waste production, causing serious problems of overuse in landfill throughout the world (Margallo et al., 2015).

Waste to energy has had an increasingly important role to solve that issue. It reduces the amount of waste going to landfills, the emissions of greenhouse gases, while also enabling energy recovery (Qazi et al., 2018). The process of waste to energy has three main residue outputs that must be controlled: Bottom Ash (BA), Fly Ash (FA) and Air Pollution Control (APC) (Margallo et al., 2015). FA and BA often have high concentrations of heavy metals, that if not properly controlled could pollute water bodies and terrain near the landfill of disposal. At the same time, APC can't completely stop toxic gases from reaching the atmosphere, making waste to energy potentially hazardous for the population (Qazi et al., 2018).

Thus, though the impact of waste incineration has been highly reduced in recent years, following strict government regulations, the hazards they may cause to the environment and society has not been nullified. Moreover, these effects could be particularly severe in countries with poor environmental regulations (Qazi et al., 2018). That does not deny the importance of waste to energy, but rather limit its role within waste management.

AlQattan et al. (2018) proposes the use of the 'Waste Treatment Hierarchy' (Shown in Figure 8), by displaying the methods of preferred action to the society and to the environment. Through this hierarchy, energy recovery (i.e. WTE) is deemed as a better solution than disposal (i.e. landfills), but not better than recycling or reusing. Thus, WTE can be seen as a fundamental part of waste management, highly preferable to direct use of landfills, even if it should not be seen as a fully environmental or social sustainable practice.

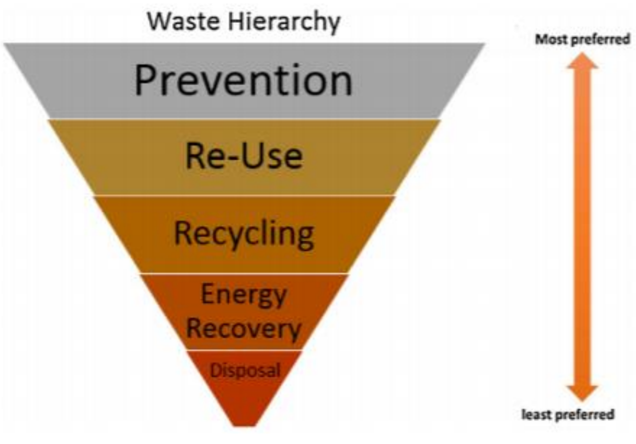

Figure 8 - Waste Treatment Hierarchy [Source: AlQattan et al. (2018)]

4 Findings and analysis

4.1 Regional Background

Chapecó is a city in the west of the state of Santa Catarina, located in southern Brazil (Fig. 9). The city was founded in 1917, as a large municipality with mainly rural population, wherein the population density was 0,78 people per km². This changed heavily during the second half of the 20th century, as Chapecó began to grow in urban population as job opportunities rose in the city. The municipality also grew smaller in area, as other smaller municipalities emancipated from Chapecó. Today, Chapecó has 620 km² and a population of over 202.000 habitants (data from 2014), leading to a density of 323 people per km², highly different from the time of its foundation. Over 90% of this population lives today in the urban areas of the city, with the rural population being rather small (PGIRS, 2015).

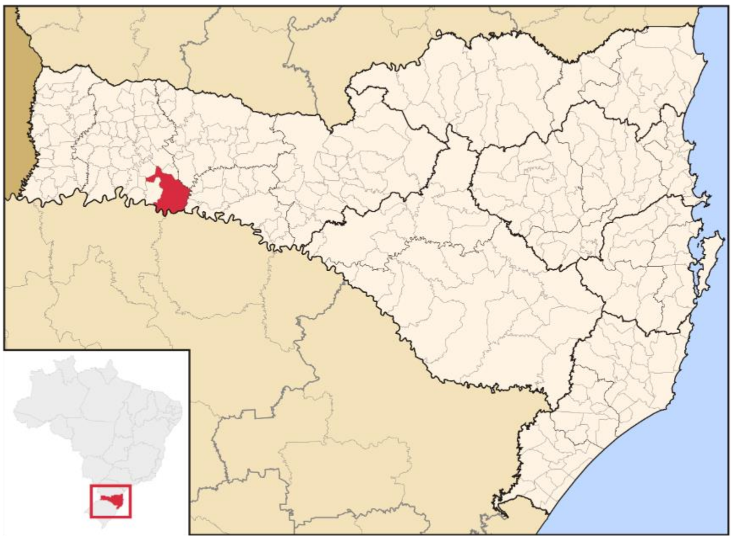

Figure 9 - Location of Chapecó [Source: By Darlan P. de Campos]

The economy of Chapecó is majorly commanded by the agroindustry, being a regional leader in this area. With the local economy historically built upon the agroindustry and processing of its products, the industry of the region has been diversifying to supply the needs of these companies. Several companies in the metalworking branch have grown in the region, selling to regional, national and even international customers. Moreover, the region has presence of the plastics and packaging, transports, beverages, biotechnology in meat processing, among other industries. Services have also been an important part of the regional economy, as in any urban center in the country (PGIRS, 2015).

Socioeconomic indicators present a view of how Chapecó has developed through the years. The city ranked first within the state of Santa Catarina on the Municipal Development Index studied, conducted by the Brazilian Institute of Geography and Statistics (IBGE). The city also presented a great development in the early 21st century in reducing poverty, increasing average income and decreasing the Gini coefficient. Gini coefficient is used to determine the income distribution in a region, where a smaller number means more equality. Table 2 present the changes in these socioeconomic aspects in the past three studies carried by IBGE (PGIRS, 2015).

Table 2 - Socioeconomic Indicators

Income, Poverty and Equality	1991	2000	2010
Income per capita (R$)	437,01	674,35	1.017,34
Percentage living in extreme poverty	10,55%	5,33%	0,65%
Percentage living in poverty	28,01%	14,71%	2,70%
Gini coefficient	0,56	0,57	0,48

[Source: Adapted from PGIRS (2015)]

4.1.1. Waste Generation

According to PGIRS (2015), Chapecó generates on average 5.872 tons of municipal solid waste per month. Though monthly variations occur, a causal link cannot be strictly detected between the seasons and quantity of waste generation. The origin of MSW comes from conventional collection, selective collection, urban cleaning and scraps. The conventional collection accounts for most of the waste generated in the city, while the selective collection has been expanding through recent years. The quantity of MSW generated in the city is accounted in table 3. Though this data presents values of the waste collected, the entire municipality is provided with these services, wherefore the waste generation can be accounted as the same quantity of waste collected (PGIRS, 2015).

Table 3 - Waste Generation (2014)

Origin	Quantity (tons/month)
Conventional Collection	3.990
Selective Collection	480
Urban Cleaning	877
Bulky Waste	615
TOTAL	5.872

[Source: Adapted from PGIRS (2015)]

The Urban population of Chapecó is expected to continue growing, with projections to increase from the 202.000 in 2014, to nearly 260.000 citizens by 2034 (PGIRS, 2015). That amounts to an increase of waste production and need to locate means of disposing the waste.

4.1.2. Current Waste Management

Currently all operations in Chapecó related to municipal solid waste are outsourced to private companies. The government retains the management, which falls under the responsibility of the Urban Infrastructure Secretary. According to PGIRS (2015), the municipality has two distinct waste collection services, the conventional and the selective collections. The former regards MSW that is untreated and disposed by households without any pre-selection, whilst the latter regards collection of recyclable waste previously divided by households. The conventional collection is also carried through automatized trucks, in certain locations, reducing the need to employees to physically collect the waste. Both the selective and conventional collection of waste reach 100% of the urban population in the municipality (PGIRS, 2015).

The waste from the selective collection passes through a screening to divide it into the recycling groups, and eliminate the waste deemed contaminated or unrecyclable. The recyclable materials are then sold to the recycling industries, while the rejected waste is disposed in landfills, together with all the waste from conventional collection (PGIRS, 2015). Due to the screening and processing of the waste from selective collection, its gravimetric composition has been deeply studied. The waste from conventional collection, however, has not been characterized yet (PGIRS, 2015).

The gravimetric composition studies indicate that an average of 70% of the selective waste collected was recycled, indicating a total of 336 tons of recycled waste per month in 2014. The selective and conventional collections – which regards all the household waste generated – amounted a total of 4.470 tons of waste per month (PGIRS, 2015). Ergo, the recycled waste englobes only 7,5% of the total waste generated from households. The other 92,5% of household waste was directly deposited in landfills.

Comparing with Sweden on the same year (2014), Avfall Sverige (2018) indicates that nearly 36% of its household waste recycled, while 15,8% were destinated to compositing and other organic recycling. The report also shows that roughly 47,6% of the waste from households was used in WTE plants, mainly through incineration. Finally, only 0,7% of the generated household waste was disposed in landfills. Figure 10 presents a comparison between the Swedish recycling and the municipality of Chapecó.

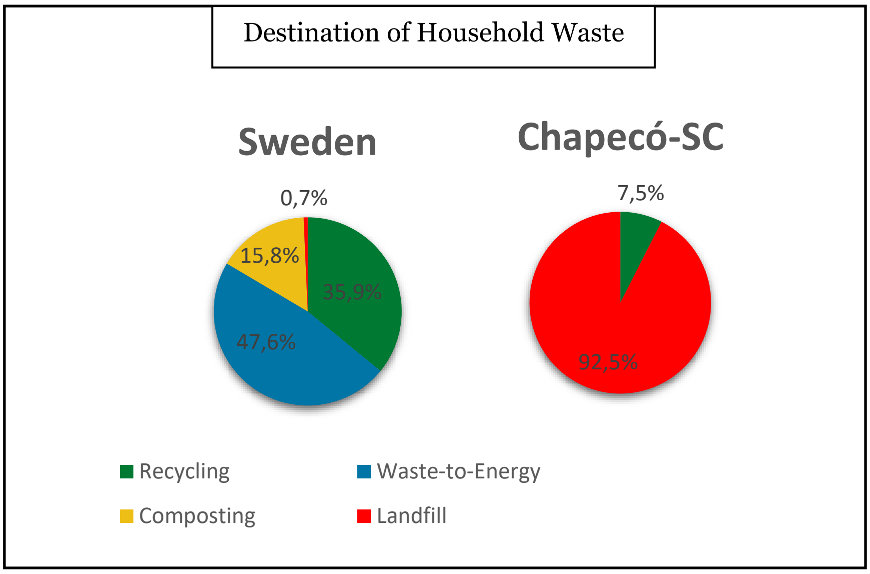

Figure 10 - Destination of Household Waste in 2014

[Source: Based on PGIRS (2015) and Avfall Sverige (2018)]

All MSW from Chapecó is disposed in the landfill of Saudades, owned by the same company in charge of most waste collection in Chapecó: 'Tucano Obras e Serviços' (TOS). The landfill is located over 50km away from the city center, causing the need of constant transport to dispose the waste. Moreover, the expected end of life cycle of the landfill is by 2022, due to limited capacity (Premier Engenharia, 2017).

4.1.2.1. Collectors ("Catadores")

Brazil has over 500 thousand collectors of recyclable waste in the streets, that make a living from collecting and selling recyclable materials. The size of this group allowed them to be recognized as self-employed people, actively contributing to solutions for recycling waste. Santa Catarina has approximately 3.700 collectors of recyclable waste, where it is estimated that over 400 of them are under 14 years old.

Chapecó is home to over 500 collectors, which are members in 6 different associations or autonomous. These associations are involved in the entire process to screening recyclable waste (including the waste collected by the municipality), dividing it into categories and eliminating the unrecyclable. The level of satisfaction with their job ranges up to 85% among the collectors, and the municipality is engaging in projects to better integrate them to the society.

4.1.3. Electricity Production

Brazil has its main source of electricity based on its hydrography. The massive amount of water bodies allows the country to serve electricity to its citizens mainly from hydroelectric plants, a renewable source of energy. In Santa Catarina, the situation is not different. According to EPE (2018) Santa Catarina has an installed capacity of 5.570 MW, of which 4.247 MW are in hydroelectric power. Further 1.083 MW are available in thermoelectric plants, while there are only 236 MW and 4 MW comes from wind and solar sources, respectively. Comparatively, SCB (2018) indicates that Sweden has an installed capacity of 39.798 MW, where 16.502 MW are from hydropower, 6.611 from wind power, 244 MW from solar power, nearly 9.000 from nuclear power and 7.442 from thermal power. Figure 11 compares Sweden and Santa Catarina based on the sources of electricity.

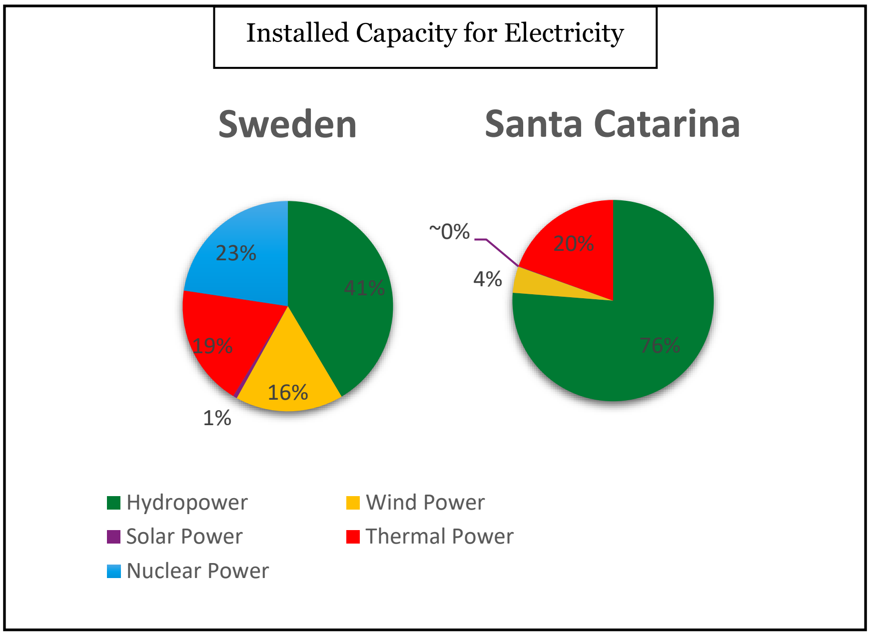

Figure 11 - Electricity Installed Capacity

[Source: Adapted from SCB (2018) and EPE (2018)]

The cost for the electricity can vary a lot depending on the region. In Santa Catarina – as in many other states of Brazil – the electricity production and distribution is controlled by a state-owned company (Andrade, 2017). EPE (2018) says that the average national price for domestic electricity in Brazil is of 200 USD/MWh, while de industrial electricity averages at 170 USD/MWh – both after taxes.

4.1.4. Laws and Regulations on Emissions

The environmental regulations in Brazil are determined by CONAMA, the National Council for Environment. CONAMA stablishes a national standard for air quality, wherein the states are allowed to develop their regional laws for emissions. CONAMA establishes general limits for emissions from incineration but they are specified to the industries, such as natural gas incineration or oil combustion. Since waste incineration plants have not been widely implemented in Brazil, they have not been integrated into one of these categories. Thus, the law indicates that the emission limits must be determined by regulating bodies during the licensing of the project (URE Barueri, 2013).

Due to the absence of WTE plants in Santa Catarina, general rules have not been determined for the state. However, the municipality of Barueri, in São Paulo, has been in the process of constructing the country's first WTE plant. The state of São Paulo has, therefore, already addressed this issue and established norms for emissions from WTE plants. Being the first specific regulations for this industry in the whole country, it is the most reliable data to estipulate how these regulations will be in Santa Catarina. Table 4 compares the maximum limit for emissions applied in WTE plants, from the European Union and the State of São Paulo, Brazil. Certain values are divided between limits for a 24-hour period or 30-min period.

Table 4 - Waste Incineration Emission limits according to European and São Paulo Guidelines (Values in mg/Nm^3 Dry at 11% O_2)

Basis Measurement	**European Union**		**São Paulo**	
	24-hour	30-min	24-hour	30-min
HCI	5	10	10	10
SO (SO_2 +SO_3)	25	50	50	50
HF	1	2	1	2
NOx (NO_2)	200	400	200	200
CO	50	100	50	100
Particulate	5	10	10	10
Heavy Metals				
Cd +TI	0,05		0,05	
Hg	0,05		0,05	
Sb, As, Pb, Co, Cr, Cu, Mn, V, Sn, Ni	0,5		0,5	

[Source: Adapted from Licata (n.d.) and URE Barueri (2013)]

It is notable from the table that the regulations are not so different between the European Union and Brazil, if speculating the regulations from São Paulo would be similar to the rest of the country. While Brazil tolerates higher emissions of HCI, SO and particulate in a 24-hour period, the limits in a 30-min period is the same. Moreover, the EU has looser regulations to the emission of NOx than Brazil. All other substances have the same limit of emissions, including all heavy metals emitted in WTE processes.

4.2 Technical Analysis

The development of a Waste-to-Energy plant must take in full consideration the regional situation, needs and capacities. The data collected from the region of Chapecó allows a preliminary study on what subsystems would be better adapted for them region.

4.2.1. Combustion Technology

The combustion method, as described in the theoretical framework, is majorly defined by the level of pre-treatment of the waste generated in the region. Though selective collection has expanded vastly through the region in recent years, the levels were still under 10% of the total from household waste collected. The lack of pre-processing on most of the waste suggests a Fluidized Bed would not be the most suitable for the region. If the municipality was engaged in developing an extensive composting system and pre-processing of conventional waste, a Fluidized Bed could be seen as an option for higher efficiency. However, costs of investment would increase greatly, and a major restructuring of the waste management system would be required.

Rotary Kilns do not seem to provide major advantages for this type of waste. Furthermore, the mixing of organic waste with dry waste during collection also characterizes an unstable calorific value of the waste. This suggests that the combustion chamber should be ready to receive other fuels. Thus, Moving Grate seems to be the most suitable to the regional condition, as it is the most developed technology for the aforementioned conditions.

4.2.2. Heat Recovery Technology

The boilers and alternatives for converting the heat into usable energy directly affects the mainly revenue stream of the plant. That depends on the demand for industrial and district heating in the region, that will determine rather the plant has customers for steam. Chapecó has an economy mainly based on agroindustry, with several metalworking and packing companies stablished there to attend the demands of the aforementioned industry. Einstein et al. (n.d.) suggests that both the metal industries and the plastic industries do have a considerable use of steam in their processes. Thus, a WTE plant could find potential customers for steam in the industry sector.

However, the climate in the region requires little heating through the year, wherefore the demand from the industry sector should be considered low when compared to European or North American plants. Furthermore, the city has no district heating or cooling being used and houses most often use heating from electric sources. Though the prospect of selling steam for heating is not negligible, it is not an area of safe investment. A focus on production of electricity could be more suited for the region, with other technologies applied to boost efficiency.

4.2.3. Flue Gas Cleaning

Regulations for emission from waste incineration are not available yet in Santa Catarina, as previously mentioned. However, the state of São Paulo has already stablished these parameters, where it is assumable that these values will be highly similar to the ones eventually used in Santa Catarina. The emission regulations stablished in São Paulo are slightly looser than the guidelines from the European Union, though the values are very similar. Moreover, the tightening of environmental regulations around the world suggest that these numbers will not get looser, wherefore the flue gas cleaning system should be at least as efficient as those currently used in Europe.

The complexity of flue gas cleaning systems goes beyond the basic systems defined in the theoretical background. Though the methods thereby described are the main ones, other subsystems are available for different parts of the cleaning process. Furthermore, the selection of these methods will highly depend on detailed-oriented schematics of the plant and deeper studies on the waste of the city. Ergo, the cleaning systems must be selected at a more advanced points of research, during the feasibility study of the plant. Appendix 1 refers to the main cleaning technologies available for the process, displaying their applicability.

4.3 Technical and Economic Data

4.3.1. Moving Grate Incinerators

Moving grate incinerators can be divided into two categories, either using air or liquid for cooling the grate. The liquid-cooled moving grate has almost the same characteristics as the air-cooled, but is applicable to slightly different situations. The liquid-cooled moving grate operates with a Lower Calorific Value (LCV) – which represents the calorific value of the waste including its moisture – between 10 and 20 GJ/t, slightly higher than the LCV rage of air-cooled grates. That brings the advantage of treating waste with higher heat values, as well as a higher control of combustion. However, it requires a higher capital investment and the system is more complex. Table 5 presents the characteristics and particular data for these different systems.

Table 5 - Comparison of Moving Grate Combustion Techniques

Technique		**Moving grate – air cooled**	**Moving grate – liquid cooled**
Key waste characteristics and suitability		• Low to medium heat values (LCV 5 – 16.5 GJ/t) • municipal and other heterogeneous solid wastes • can accept a proportion of sewage sludge and/or medical waste with municipal waste • applied at most modern MSW installations	Same as air-cooled grates except: • LCV 10 – 20 GJ/t
Throughput per line		1 to 50 t/h with most projects 5 to 30 t/h. Most industrial applications not below 2.5 or 3 t/h	1 to 50 t/h with most projects 5 to 30 t/h. Most industrial applications not below 2.5 or 3 t/h
Operational and Environmental information	**Advantages**	• Very widely proven at large scales • robust - low maintenance cost • long operational history • can take heterogeneous wastes without special preparation	As air-cooled grates but: • higher heat value waste treatable • better combustion control possible
	Disadvantages	Generally not suited to powders, liquids or materials that melt through the grate	As air-cooled grates but: • risk of grate damaging leaks • higher complexity
Bottom ash quality		• TOC 0.5 % to 3 %	• TOC 0.5 % to 3 %
Flue-gas volume		4000 to 7000 Nm^3/t waste input. Depends upon the LCV. Typically 5200 Nm3/t.	4000 to 7000 Nm^3/t waste input. Depends upon the LCV. Typically 5200 Nm3/t.
Cost information		High capacity reduces specific cost per ton of waste	Slightly higher capital cost than air-cooled

[Source: Adapted from BREF (2006)]

4.3.2. Heat Recovery Systems

Since the plant would have to focus on electricity generation, given the uncertain demand for heat in the region, two main systems could be considered. Both systems use a steam extraction turbine and parameters of 400° Celsius, where the water is in a closed loop. The second technique differentiates from the first as it incorporates an existing power plant in the region, inside the loop. That means the steam is being used to improve the efficiency of the secondary power plant. However, this technique comes at a higher investment cost and requires a partnership with another power plant in the region. Figures 12 and 13 display these different systems.

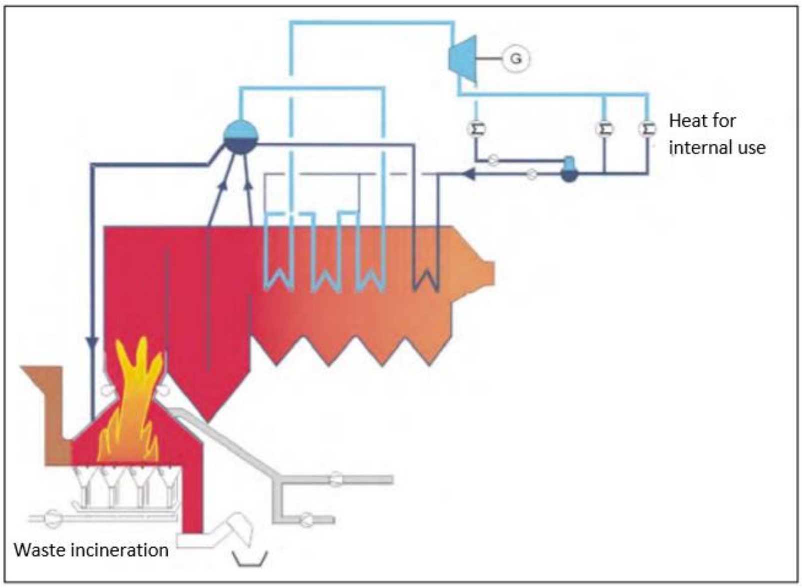

Figure 12 - Water-Steam Cycle for Technique 1 [Source: Adapted from BREF (2006)]

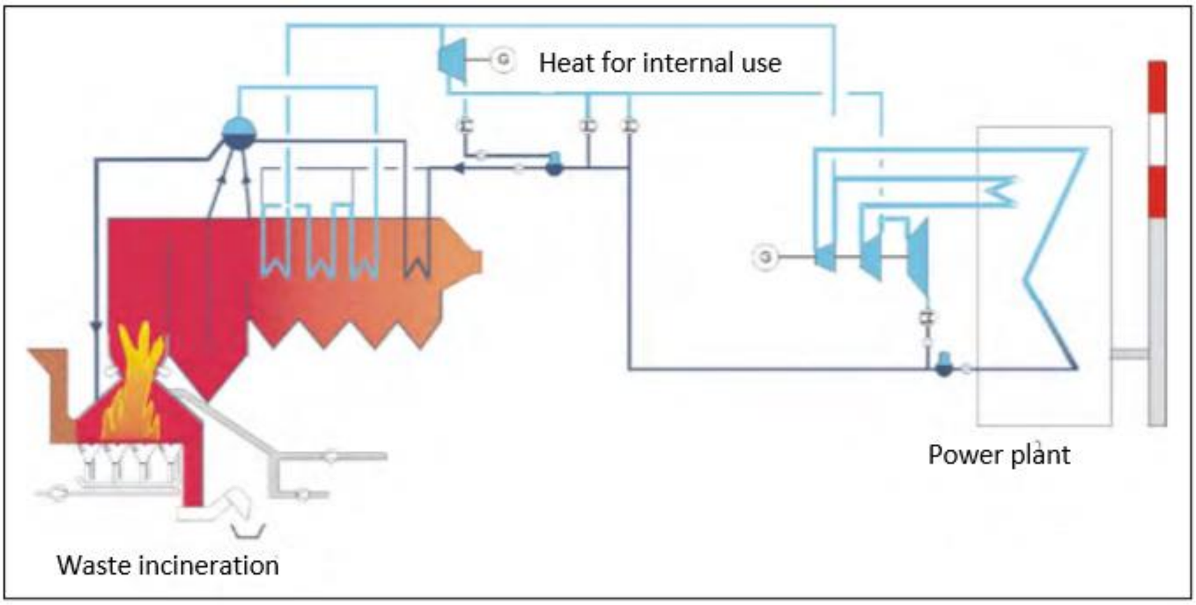

Figure 13 - Water-Steam Cycle for Technique 2 [Source: Adapted from BREF (2006)]

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4.3.3. Cost Considerations

The total cost of WTE incineration project are typically divided into investment costs and operations costs (input dependent and independent). The investment cost mainly includes site, construction, machinery, etc. Meanwhile, the input independent operation costs include the expenses of raw materials, manpower salaries, etc. Thus, input dependent justifies the costs of the plant while running, meaning that depending on how much waste is burned one can calculate the fuel cost, treatment cost, etc. Observe, that the economic aspects of incineration differ significantly between regions and countries, not only due to technical aspects but also depending on waste treatment policies. The following figure presents a cost structure that has been shaped of the data gathered from BREF 2006. See appendix 2 for a clearer view.

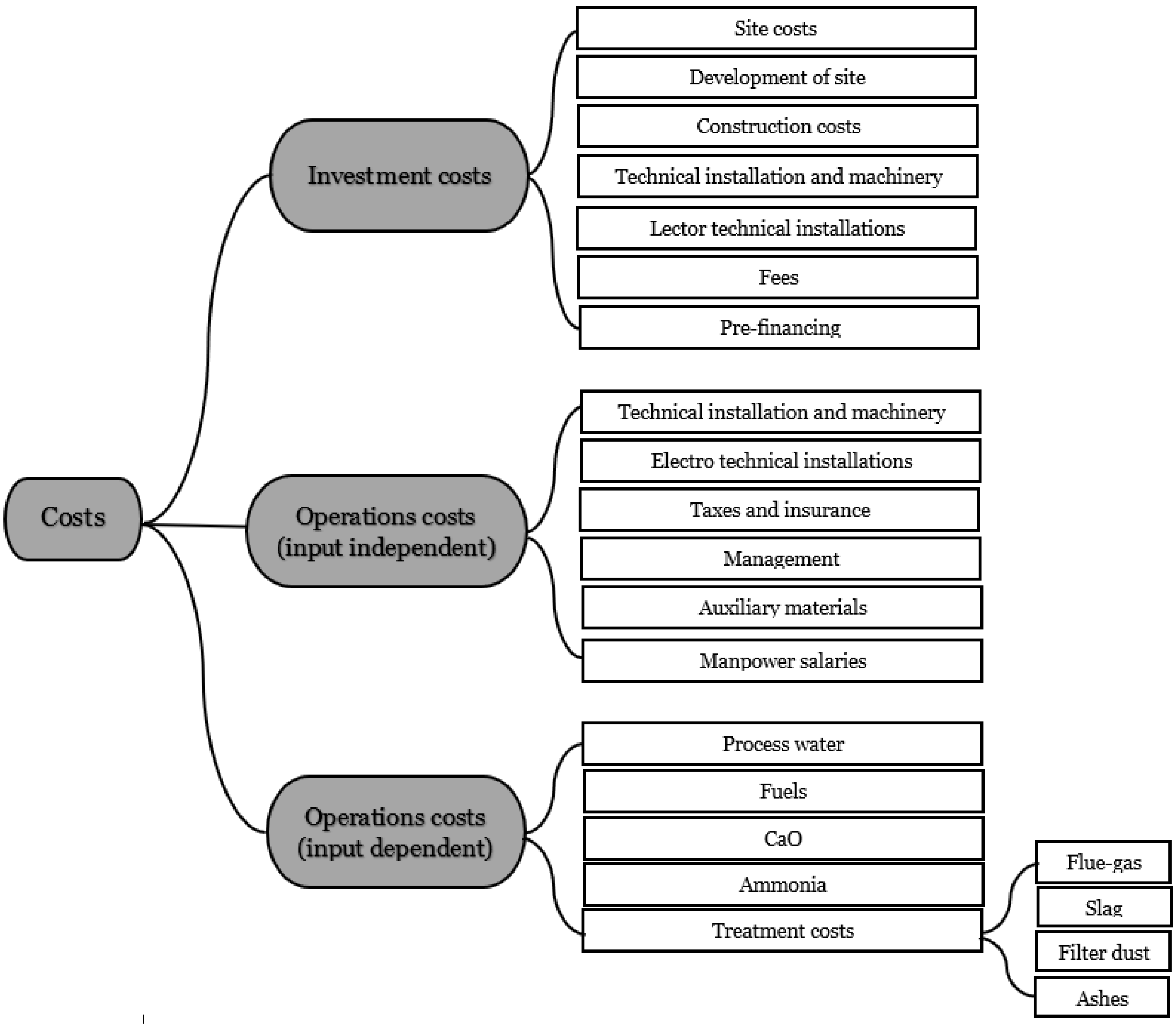

Figure 14 - Grate MSW incinerator cost factors [Source: Based on BREF (2006)]

Waste incineration plant have high investment costs and operations cost however, they can produce and sell electricity, steam, and heat, and recover other products, such as bottom ashes for the use as construction material. The price paid for the incineration plant is regained from the revenues that are received for energy sales. Similar to the cost, revenues from the energy produced could vary depending on which region, country the plant are located in.

4.4 Analysis

The changes in socioeconomic factors on the region of study, as well as the forecasts for population growth, endorses the need to find solutions for the MSW in Chapecó. The high amount of trash being directly destinated to landfills, suggests that the region requires not only to increase the treatment of the waste, but also find alternatives to reduce the use of landfills. The latter is often approach through Waste to Energy in many countries, wherefore it should be considered as a potential solution for the region of study.

4.4.1. Economic Analysis

Several aspects must be considered before creating a cost-benefit analysis of a WTE plant in the region. The European commission indicate that waste streams are a potential secondary raw material sources which is being wasted. Thereby, the renewable energy from waste is a step forward for a better environmental solution and it could be economically efficient in a longer term. According to Panepinto (2016) WTE incineration plant has good economic returns but it has high costs as well. There are three elements of costs one must know to calculate the total cost of an incineration plant. (1) start-up cost, (2) management cost and (3) maintenance cost. Whereas in the document BREF that was reviewed, similar aspect where found however with a slight change in names, investment costs and operations costs (input dependent and independent).

There are several different types of technologies applied in incineration of waste, with different capacities, costs and revenue streams. In the technical analysis, a scope of technologies and methods was defined, attempting to narrow down which methods would be the most suitable. The most advisable system was determined to be a moving grate, with a focus on electricity generation with a close loop. The choice of moving grate, between a liquid- or air-cooled system would highly depend on the calorific power of the waste. Liquid-cooled grates have more benefits, but it comes at a greater cost. Air-cooled grates are cheaper and more suitable to low calorific waste, what might make it a better option for waste with high humidity. Thus, though moving grate is certainly the best option, the cooling system highly depends on further studies and the size of investment.

Though the technical data suggests this system could be integrated to a thermal power plant, to increase the efficiency of electricity output, the little use of such power source in Santa Catarina advises otherwise. As the regional data suggests, the existing thermoelectric plants serve most often as a buffer when hydroelectric plants cannot supply all the demand. Thus, the system would be characterized by a common closed loop, with only internal use of steam. That suggests a low efficiency to the plant, since part of the heat would be wasted. Though electricity prices are somewhat high in Brazil, that is majorly due to taxes over the sale. Since most of the electricity in the region is supplied by hydroelectric power, the current price of electricity production should be rather low. Due to limited revenue streams, the WTE could be required to increase the gate-fee to remain profitable, what might cause political issues.

An alternative previously discussed in this paper was to use a stem-gas combined cycle, to increase the efficiency of electricity output. This method would require a natural gas electricity generator, where the waste heat from said generator would be applied into the boiler of the WTE plant, increasing its efficiency. Increased efficiency could support profitability at lower prices of electricity.

However, all the electricity production in Santa Catarina is currently managed by the state-owned company. This monopoly suggests that prices are not determined by the customers, wherefore a governmental cooperation could allow the company to sell its electricity by a higher value. In any case, the two main sources of revenue – be it electricity and gate-fee – would be subject to the will of the government, a factor that must be deeply addressed to guarantee the return on investment.

4.4.2. Environmental and Social Analysis

Considerations regarding the sustainability influences of the plant are extensive, but could be generalized as positive. As described in the theoretical framework, energy recovery is an essential part of waste management, but not an ideal solution. Reducing, reusing and recycling are far more important measures that must be addressed in waste management and are preferred over waste incineration.

A recycling program is operational and available to all the population in the region, but it still doesn't reach its full capacity. Using Sweden as a model, recycling could be applied to over a third of all the waste, but the rest would still need to be disposed. Energy recovery and composting are the remaining alternatives for the unrecyclable waste, where the latter is exclusive for organic waste. Thus, it becomes clear that Waste-to-Energy has an essential long-term role to reduce the amount of unrecyclable waste directed to landfills.

The benefits of Waste-to-Energy are also available in a medium-term spectrum. There is a need to find alternatives to the current system, since 92,5% of the waste is being directly dumped into landfills. The landfill used by the municipality is located over 50km away from the center, which requires the waste to be transported for long distances. Moreover, since the landfill has a limited capacity, other landfills would need to be constructed, requiring more investments and potentially longer distances for waste disposal. Since recycling projects could take very long to develop to their full potential, WTE has the capacity of reducing the recyclable waste that is currently being disposed in landfills.

From an output perspective, the plant would support the generation of renewable electricity. However, if a steam-gas cycle is used to improve the efficiency of electricity generation, the plant would be using fossil fuels in its process. That could reduce the society view of WTE as sustainable, but does not minimize its importance for reducing the environmental damage of landfills. Output of bottom ash must also be correctly treated or disposed, with consideration to the recyclable or hazardous materials within it.

Regarding emissions, the regulations that are expected to apply for the region are nearly as strong as the European guidelines, what suggests that the flue gas cleaning must bring as an extensive control. As described by Psomopoulos et al. (2009), it is common that the population shows a resistance to waste incineration. That is because it was considered a highly unsustainable practice in the past, as not gas treatment was carried. Instead, highly hazardous emissions would come from these facilities, what caused the shutdown of many plants around the world. However, with the modern flue gas cleaning, the hazardous emissions have become nearly negligible, minimizing the dangers for the population and the environment.

At the same time that it becomes necessary to explain to the population that waste incineration has become sustainable, that could cause backlashes. Though WTE highly contributes to reducing the use of landfills and minimizing the disposal of unrecyclable materials, it could have a negative impact in the recycling programs of the region. That is because, if the population view it as sustainable, the method could be generalized as good as recycling. Thus, the importance of recycling could be diminished, and the recycling programs damaged. It is important for the society to understand that, though waste incineration has become a sustainable practice, it is not an equivalent to reducing, reusing and recycling.

The development of the plant could have a positive impact in the group of "collectors", that work with recycling of materials. Despite efforts from the government, this people are mostly informal workers with low wage jobs. However, they could be seen as potential employees to the plant, which would in turn formalize their jobs and help to integrate them to the society.

Thus, it is paramount for the success of WTE, to consider its position in the waste hierarchy and not view it as a single sustainable solution. Instead, it must be viewed as a small part of major changes in waste management that must be carried in the region. The impacts of waste to energy into the environment and society will highly depend on how the outputs are treated. With correct disposal and emission control, the positive effects of the plant should outweigh its negatives.

5 Discussion and conclusions

5.1 Discussion of method

The method hereby used on this paper was a case study, with the main structure of pre-feasibility studies. The first set of data collected from documents – namely the regional situation – proved to be poorer to the expected, with low detailing on the waste characteristics among other aspects. However, this has correctly shifted the attention towards the targets of a pre-feasibility study. The study successfully addresses preliminary economic and technical aspects; different processes and available configurations; requirements for the project's success; and other considerations prior to a feasibility study. Thus, though the quality of the first data set was worse than expected, the use of a pre-feasibility study successfully allowed the use of this data in a proper manner.

Besides, the data were mainly in Portuguese making it very important to translate the extracted data correctly, without including any own assumptions. Secondly, the data was not from the same region, due to the nature of that data and the limitation within the field of waste management in Brazil. Anyhow, it is still arguably valid to use considering the fact that it is the only document available in Brazil up to date.

Certain improvements could be applied to increase the validity of this study. Most of the technical data used in the second data set, was derived from an official document published in 2006 (BREF). However, that was the most recent official data provided by the European Union, since the following reference document had not been ratified by the time of this paper's conclusion. Still, the document provides valid information about incineration plants in details with all sources mentioned making it a credible document to use.

Although, the document BREF were designed and written about EU countries and has affected the content to a certain level. Yet, generalization could be made since plenty of the data had its similarities with the theory section (that is based on countries around the globe). Since the purpose of this study was to conduct a pre- feasibility study in a Brazilian municipality, it was crucial that the data used are not to specified to a country but could be used in other content as well.

Both validity and reliability have been met in this paper. According to Jacobsen (2002) if the methods give the same results, it can be claimed that the internal validity is good. Meanwhile, the external validity was met by analytical generalization where the results matches the general theory. And the findings of the study had its base on other literature, which increases the external validity.

Reliability require one to set steps that if other researchers are willing to follow, they should get the same results and conclusions or equivalent results. This paper arranges a table that provides the documents that were reviewed. A description of the information available and a description of the reviewing process for each document making the process of the study relatively easy to follow. According to Yin (2007), a good circumstance for reliability is that everything is documented carefully, which has been accomplished.

5.2 Discussion of findings

RQ1. "Why is Waste-to-Energy considered a better solution for waste disposal than traditional methods?"

The importance of Waste-to-Energy is majorly discussed in the theoretical framework. WTE plants are capable of highly reducing the volume of waste produced, while generating a sort of renewable energy in the process. State of the art facilities have very low emissions, can support recycling projects and reduce the use of landfills, which also reduces the risk of soil contamination. However, Waste-to-Energy is not necessarily the best form of disposing waste. It is vital to consider it as an improvement over landfills, but it cannot substitute recycling or other methods of reducing waste generation. The Waste Hierarchy as described by AlQattan (2010), serves as a guide to when WTE is the most suitable choice for treating waste.

RQ2. "How can waste-to-energy, as opposed to landfills, contribute to environmental and social sustainability in the region?"

Traditionally, waste incineration has been viewed as an unsustainable practice by the public. But the most recent technologies, adapted to the 21st century regulations, have been considered far more sustainable than the use of landfills. In the region of study, all the MSW is directed to one landfill over 50km away from the city. That causes extra costs for transportation, while the disposal still poses risk to contamination of the regional soil. This landfill also has a limited capacity, and the constant creation of new landfill generates extra costs for waste disposal to the entire population.

Waste-to-Energy contributes both in medium-term, to reduce the immediate overuse of landfills; and in long-term, to reduce the disposal of unrecyclable waste. Though the environmental contributions are clearer, through the reduction of landfills, the impact on the urban society is less clear. Cost reduction for waste disposal is unlikely due to regional characteristics, while the electricity generation should not be cheaper than the current sources. With that said, the negative impacts on the society should be negligible, as long as the outputs from the process are well treated.

RQ3. "How can the proposed plant optimize its profitability, based on the regional situation?"

The regional characteristics are not highly favorable for the profitability of the company. Negligible use of heat for district heating, with a small winter season, highly limits the sale of steam. It is still an option to investigate potential industrial customers in the region, as well as consider the installation of district cooling systems. That may, however, come at higher investment costs for the construction of these delivery systems. From the electricity perspective, the high use of hydropower in the region should also hold a considerable low cost of electricity production. Such limitations of revenue sources and size could complicate the profitability of the plant.

Should cogeneration be considered implausible for the plant – i.e. due to lack of customers – other measures to increase the efficiency may be required. The most suitable of these alternatives would be to incorporate a natural gas generator into the plant, using a steam-gas combined cycle to increase boiler efficiency. This alternative, however, causes the plant to use fossil fuels, damaging its image as a sustainable solution. It should also be considered that, since governmental bodies would be responsible for buying the electricity and paying the gate-fee, the majority of revenues would come from the government. That means that potential subsidies could be discussed to assure the profitability of the plant, though it would depend on the political stability of the municipality and state.

5.3 Conclusions

Waste incineration is well known method of recovering energy from waste. It is broadly applied in municipal solid waste (MSW) across several developed and developing countries. Its application in Brazil, however, has been very limited. That could be generalized to a common aversion from the population to old methods of waste incineration, which showed little regard to emission control. The technologies today have developed passed those issues, where hazardous emissions have been minimized and pose a negligible threat to the population or environment.

The structured followed was that of a pre-feasibility study, which aims to construct a path for future feasibility studies in the region. However, the paper also aimed to determine why WTE would be a suitable solution for the municipality, always considering the three pillars of sustainability. The findings show a challenging business environment, but where the technologies are required to cope with growing waste generation. The region, oppositely to other areas in Brazil, has already both conventional and selective (recyclables) collection of MSW covering the whole population. A small portion of this waste is recycled, while the vast majority is destinated to a landfill over 50km away from the city. To avoid overuse of landfills, the region requires other solutions to cope with the waste generation.

Waste-to-Energy appear as an integral solution to this problem. The different technologies within the process if waste incineration have been studied in this paper. The process was categorized in three different parts: (1) Incineration; (2) Heat Recovery; and (3) Flue Gas Cleaning. The incineration method found most suitable was Moving Grate, due to its vast application and little requirement for pre-processing.

Heat recovery, on the other hand is most dependable on the local demands for steam. Cogeneration is preferable, but if there is no demand for steam, then the use of a steam-gas combined cycle is advisable to increase the efficiency of the boiler. Emission regulations suggests that flue gas cleaning must be as effective as the current technologies used in Europe, but the choice of specific technologies require further studies.

Given that a proper control over emissions and output of bottom and fly ash is carried, the negative effects the plant would have on the environment are near-negligible. The upside of reducing the use of landfills and generating renewable energy are far more significant. From a social perspective, the eventual strategy chosen to retain profitability of the plant could affect costs for disposal of waste, or electricity generation, in a negative way. That may cause the population some dislike to the new disposal methods, an issue since waste incineration is already unpopular.

The amount of waste being disposed in landfills is far to big to consider it a sustainable alternative in the long-term. Waste-to-Energy could resolve the issues of the city in the medium- and long-term perspectives. However, safe revenue streams must be further explored to determine the degree of investment required for this plant.

5.3.1. Further Research

Since this paper is structured based on a pre-feasibility study, it is naturally followed by a feasibility study. The region should attempt to gather primary data to ratify the findings of this study, while also advancing to determine values on revenues and costs; specific investment cost; degree of incineration from the waste; flue gas cleaning technologies; among other factors.

However, as addressed in the purpose, the research can also be a start point for other studies through Brazil. A vast part of data used from the region could be generalized to other regions in Brazil, wherefore the preliminary technical and economic aspects might be applied to other regions. It is suggestable that further studies on this direction, attempt to confirm the application of the methods hereby suggested, before carrying a feasibility study.

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7 Appendices

7.1 Appendix 1 – Flue Gas Cleaning Systems

Reduction of Dust Emissions

Dedusting refers to methods of reducing dust emissions. That could be applied at the beginning or end of the flu gas cleaning processes. There are three main methods for pre-dedusting: (1) Cyclones and Multicyclones; (2) Electrostatic Precipitators (ESPs); and (3) Bag Filters (BFs). Table 6 defines the emission concentrations for which each method is suitable, as well as their advantages and disadvantages. Further information regarding applicability, operational data, among other details on dust removal systems can be found between pages 317 and 327 of BREF (2006).

Table 6 – Comparison between Dust Removal Systems

Dust removal systems	Typical emission concentrations	Advantages	Disadvantages
Cyclone and multicyclone	- cyclones: 200 – 300 mg/m^3; - multicyclones: 100 – 150 mg/m^3.	- robust, relatively simple and reliable. - applied in waste incineration.	- only for pre-dedusting - relatively high energy consumption (compared to ESP)
ESP - dry:	<5 – 25 mg/m^3	- relatively low power requirements. - can use gas temperatures in the range of 150 – 350 °C - widely applied in waste incineration.	- formation of PCDD/F risk if used in range 450 - 200 °C
ESP- wet:	<5 – 20 mg/m^3	- able to reach low emission concentrations - sometimes applied in waste incineration	- little experience in waste incineration - mainly applied post-dedusting - generation of process waste water - increase of plume visibility
Bag filter	<5 mg/m^3.	- widely applied in waste incineration - the layer of residue acts as an additional filter and as an adsorption reactor	- relatively high energy consumption (compared to ESP) - sensitive to condensation of water and to corrosion

[Source: BREF (2006)]

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Reduction of Acid Gas Emissions

The three main methods used for reduction of acid gas emissions are the same as described in the theoretical background: (1) Wet Scrubbing; (2) Semi-Wet Scrubbing; and (3) Dry Treatment. Additional measures that must be considered are the use of Wet Scrubbing after FGT processes, flash dry systems and recirculation of gases through FGT systems. The following tables describe the applicability of each of these methods. Further information for descriptions, economical and operational data may be found between pages 328 and 349 of BREF (2006).

Table 7 – Applicability of Wet-Scrubbing Systems

Criteria	Evaluation/comment
Waste type	• suited to most waste types • generally less capable of dealing with very highly variable inlet concentrations than wet scrubbers
Plant size range	• applied at all size ranges
New/existing	• applied at new plants and as a retrofit
Inter-process compatibility	• flue-gas outlet temperature (120 – 170 °C) requires reheat for subsequent FGT systems e.g. SCR • separate (pre-) collection of fly ash possible • bag filter provides effective gas cleaning step for subsequent SCR or wet system (if used as pre-deduster).
Key location factors	• no effluent is produced and no discharge required • availability/cost of solid residue outlets

[Source: BREF (2006)]

Table 8 – Applicability of Semi-Wet Scrubbing

Criteria	Evaluation/comment
Waste type	• can be applied in principle to any waste type • particularly suited to highly variable inlet gas compositions (e.g. hazardous wastes)
Plant size range	• not restricted but generally applied at medium to larger plants where economies of scale exist
New/existing	• widely applied at many existing plants
Inter-process compatibility	• low flue-gas outlet temperature (approx. 70 °C) requires reheat for subsequent FGT systems e.g. bag filters and SCR • separate (pre-) collection of fly ash possible
Key location factors	• increased plume visibility (unless counter measures taken) • salt water effluent (post treatment) requires discharge (or evaporation which requires energy) • can permit recovery of HCl, salt, gypsum

[Source: BREF (2006)]

Table 9 – Applicability of Dry Flue Gas Treatment

Criteria	Evaluation/comment
Waste type	• Applied to a full range.
Plant size range	• Modern dry systems applied to wide size range
New/existing	• no restriction
Inter-process compatibility	• higher operational temperatures makes the process well suited to combination with downstream SCR
Key location factors	• low plume visibility • no effluent produced • residue treatment/disposal needs consideration

[Source: BREF (2006)]

Table 10 – Applicability of Flash Dry Systems

Criteria	Evaluation/comment
Waste type	• all waste types except where inlet concentrations are highly variable e.g. merchant hazardous wastes • currently applied to: MSW, RDF, wood wastes
Plant size range	• mainly applied at small to medium scale plants owing to increased scale of filter required (to accommodate re-circulated residues)
New/existing	• no specific restrictions • filters need to be larger than other systems to accommodate re-circulated
Inter-process compatibility	• can provide pre-dusting for SCR system • can be operated with SNCR
Key location factors	• small footprint • less suitable where outlets already exist for treatment/recovery of segregated fly ash

[Source: BREF (2006)]

Table 11 – Applicability of Recirculation of Flue Gases through FGT systems

Criteria	Evaluation/comment
Waste type	• all waste types except where inlet concentrations are highly variable e.g. merchant hazardous wastes, unless in combination with another system for these pollutants • currently applied to: MSW, RDF, wood wastes
Plant size range	• no restriction
New/existing	• no specific restrictions • filter need to be larger than other systems to accommodate re-circulated
Inter-process compatibility	• compatible with FGT systems other than wet systems
Key location factors	• space required for larger reactor

[Source: BREF (2006)]

Reduction in Emissions from Nitrogen Oxides

There are two main methods of reducing emissions from Nitrogen Oxides: (1) Selective Catalytic Reduction; and (2) Selective Non-Catalytic Reduction. The former is usually applied after dedusting and acid gas cleaning, requiring reheating of the gas for it to be operational. It is not commonly used prior to these two processes. The latter is applicable to similar situations, but requiring lower investment costs as well as lower operational costs. Further information for descriptions, economical and operational data may be found between pages 349 and 360 of BREF (2006).

Table 12 – Applicability of Selective Catalytic Reduction

Criteria	Evaluation/comment
Waste type	• can be applied to any waste type
Plant size range	• can be applied to any size plant but most often to medium to larger plants for economic reasons
New/existing	• often a tail-end process that can be applied to new or existing processes
Inter-process compatibility	• mostly requires pre-dedusting of the flue-gas and may also require SO_2/SO_3 removal. HCl removal may also be required. • minimum inlet temperature required for operation • use of SCR can allow lowering of NO_X emissions without additional techniques if lower ELVs applied
Key location factors	• locations with high NO_X sensitivity may benefit from additional NO_X reductions achievable with this technique • space is required on site for the additional process unit

[Source: BREF (2006)]

Table 13 – Applicability of Selective Non-Catalytic Reduction

Criteria	Evaluation/comment
Waste type	Any
Plant size range	Any
New/existing	Locating injection points may be problematic in some existing plants
Inter-process compatibility	Higher dose rates (and hence lower NO_X emissions) may be used without ammonia slip when used with downstream wet scrubbing (which absorbs the excess ammonia). In such cases an ammonia stripper may be required to reduce NH_3 levels in effluent – stripped NH_3 can be re-fed to the SNCR injection.

[Source: BREF (2006)]

Reduction of PCDD/F Emissions

As in several of the aforementioned pollutants, PCDD/F can be reduced through the use of techniques prior to combustion. However, methods to reduce it in the Flue Gas Cleaning process do exist, being 6 main methods used: (1) Selective Catalytic Reduction; (2) Catalytic Bag Filter; (3) Re-burn of Absorbers; (4) Active Carbon Injection; (5) Static Coke Filter; and (6) Carbon Impregnated Materials in Wet Scrubbers. Further information for descriptions, economical and operational data may be found between pages 360 and 374 of BREF (2006).

Table 14 – Applicability of Selective Catalytic Reduction

Criteria	Evaluation/comment
Waste type	• can be applied to any waste type
Plant size range	• can be applied to any plant size, but most economical for medium to large size installations due to capital costs
New/existing	• when applied as a tail-end technique (most common), the system can be added to any process • more complex to retrofit as non-tail end
Inter-process compatibility	• particularly beneficial where substantial reductions in NO_X are also required • reheat of flue-gases usually required to reach SCR operational range
Key location factors	• space is required for the SCR reactor

[Source: BREF (2006)]

Table 15 – Applicability of Catalytic Bag Filter

Criteria	Evaluation/comment
Waste type	Any
Plant size range	Any
New/existing	Applicable to both new and existing processes
Inter-process compatibility	Need to consider Hg abatement in addition
Key location factors	None

[Source: BREF (2006)]

Table 16 – Applicability of Re-burn of Absorbers

Criteria	Evaluation/comment
Waste type	Any
Plant size range	Any
New/existing	Can be applied to new and existing plants
Inter-process compatibility	Mainly only suited to residues from specific PCDD/F dioxin absorption stages (e.g. static coke beds and wet scrubber dioxin absorber inserts) where there are other provisions to avoid mercury build up and potential release.
Key location factors	None

[Source: BREF (2006)]

Table 17 – Applicability of Active Carbon Injection

Criteria	Evaluation/comment
Waste type	• any
Plant size range	• any
New/existing	• applicable to both – easily retrofitted in most cases
Inter-process compatibility	• may be easily employed where there is an existing bag filter system
Key location factors	• none

[Source: BREF (2006)]

Table 18 – Applicability of Static Coke Filter

Criteria	Evaluation/comment
Waste type	• any in principle • particularly suited to highly heterogeneous and hazardous wastes where PCDD/F may be high due to difficult combustion conditions
Plant size range	• size does not matter
New/existing	• applied at existing and new processes
Inter-process compatibility	• generally applied as a tail-end polishing stage • most suited down stream of a wet scrubber • can be used up stream of SCR with reheat (more for wet system)
Key location factors	• space required for the additional process unit

[Source: BREF (2006)]

Table 19 – Applicability of Carbon Impregnated Materials in Wet Scrubbers

Criteria	Evaluation/comment
Waste type	Any
Plant size range	Any where wet scrubbers are used
New/existing	Applicable to new and existing installations
Inter-process compatibility	Only applicable to wet scrubbers
Key location factors	It is easier to implement in packing tower, using caustic soda

[Source: BREF (2006)]

Reduction of Mercury and other Emissions

The reduction of mercury is often carried in Wet Scrubbers, where several tools and techniques exist. These techniques, descriptions, applicability, economical and operational data may be found between pages 374 and 382 of BREF (2006). Other emissions and possible treatments are also available on pages 382 through 384 of BREF (2006).

7.2 Appendix 2

The tables below show in detail the cost factors in each segment of an incineration plant, Investment costs, input independent operational costs and input dependent operational costs. Keeping in mind that some factors could vary depending on the location of the plant. They have been adapted from BREF (2006).

Table 20 – Total investment costs

TOTAL INVESTMENT	**Investment (EUR)**	**Payback Period (y/s)**	**Rate %**	**Annualised cost (EUR/yr)**	**Specific costs (EUR/t)**
Site costs					
Development of site					
Construction costs					
Technical installation and machinery (Grate)					
Electro technical installations					
Fees					
Pre-financing					
TOTAL					

[Source: Adapted from BREF (2006)]

Table 21 – Total operational costs, independent of the input

OPERATIONAL COSTS, independent of input	**EUR**	**Percentage**		**Annual costs EUR/yr**	**Specific Costs EUR/t**
Technical installation and machinery					
Electro technical installations					
Taxes and insurance					
Management					
Auxiliary materials					
		Number	EUR/person/year		
Manpower (Directors, workers, accountants)					
TOTAL					

[Source: Adapted from BREF (2006)]

Table 22 – Total operational costs, dependent on the input

OPERATIONAL COSTS, input dependent	**EUR**	**EUR/m^3/year**	**EUR/m^3**	**Annual costs EUR/yr**	**Specific Costs EUR/t**
Process water					
Fuel					
		EUR/t	EUR/t/ year		
CaO					
Ammonia					
	Kg/input				
Treatment of slag					
Treatment of Ashes					
Treatment of filter dust					
Treatment of flue-gas					
TOTAL					
TOTAL Cost per Year					

[Source: Adapted from BREF (2006)]