Study of the art state in the analysis of techno economic feasibility of waste-to-energy plant in Rio de Janeiro

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Abstract

Population growth and economic development in Brazil have increased the production of Municipal Solid Waste (MSW) in many big cities, causing sanitary problems. The utilization of MSW for energy production has been implemented globally for many decades. The uptake in Europe of Energy from Waste-to-Energy (WtE), incinerator plants has increased rapidly in recent years. Brazil, however, is still highly dependent on landfills for MSW management. This paper deals with a feasibility study model for utilizing MSW with energy recovery. The model will serve as the study basis to guide a techno-economic feasibility study to implement a project of a WtE plant. This paper will assist in the financial feasibility analysis that will guide stakeholder on the development of a WtE plant in Rio de Janeiro City and elsewhere. Carrying out a bibliographic review from annual reports, papers and through interviews, this paper provide recommendations for implement an incinerator and highlight the current issues and challenges faced by this kind of technology in Rio de Janeiro. An average heating value of 2.350 kcal/kg can be expected from MSW to be used as fuel for direct combustion in WtE plant. A typical design for a WtE plant is shown in this paper and also the main elements included in a modern plant. Approximately 198 MW of electricity can be generated from 9,000 tonnes of MSW per day in Rio de Janeiro City. We conclude that one of the major difficulties encountered by waste facilities is the appropriate selection of technology, capacity, site location, logistics, waste suppliers and heat/electricity localization consumers. This study will be of particular value to WTE plant developers, government authorities and researchers working within the sector of waste management and incinerator technologies.

Keywords: waste-to-energy, incinerator, energy recovery, municipal solid waste.

Introduction

MSW Incineration

The appropriate treatment and final disposal of Municipal Solid Waste (MSW), still represent a major challenge in many countries, particularly those in development. The incorrect disposal of waste, as well as cause environmental and health impacts may result in loss of recyclable material and waste potential energy. While incineration with energy recovery is growing in developed countries, it is practically non-existent in developing countries. High investment and operation costs, lack of technical training, cultural issues and a conception of conflict between recycling and energy use, can be listed among the issues for non-use of MSW incineration in several countries.

The MSW incinerator allow energetic recovery, in the form of steam and electric energy, from the released heat in the waste burning process [1,2,3]. Some authors emphasize the feasibility of using incineration technology as an option for solving environmental problems associated with the final destination of MSW [4,5]. The increase in the use of incineration in waste management systems in the European Union (EU), has resulted in the reduction of the least favourable option of landfilling, from 60% share in 2000, to less than 30% in 2015 [6]. Despite their high initial investment costs, which require a minimum capacity to obtain economic feasibility [7], MSW WtE is suggested as an important choice alternative to be considered for regions where landfilling is still the main route for waste disposal.

Considering the feasibility of using incineration as an option for solving environmental problems associated with the final destination of MSW [4,8,9] refer to the most recent technology with the modernization of the APC (Air Pollution Control), promoting conditions for a greater acceptability of units based on the thermal treatment of waste.

In the past, the main purpose of incineration technology was to reduce the mass, volume, and hazardousness of waste. WtE incineration facilities achieve complete destruction of hazardous organic waste. This results in minimising risks of pathogenic and virus infections. Waste incineration has the potential to reduce waste volume and mass by 80% to 90% and 70% to 80% respectively [10,11] reducing land usage for residual waste disposal.

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Currently, in addition to these same objectives, which can result in a mass reduction of more than 90%, the incineration technology appropriates the calorific value of waste of a combustible nature, and favours the use of thermal energy due to the combustion process itself. The emphasis on the application of the hierarchical scale of the Integrated Solid Waste Management (ISWM) model, which includes reducing generation, increasing material recycling and restricting the use of landfills, will imply the continuous development of solutions for WtE technology, and among them, the thermal processing of MSW treatment emerges [4]. In addition to the issues surrounding urban cleaning, the diversification of the energy matrix can make the application of incineration economically attractive. WtE has contributed significantly to renewable energy in European countries such as the Switzerland, Denmark and Sweden [12].

The WtE thermal process plays a crucial role in green energy production. The ratio of biogenic to fossil carbon in MSW is in the range 50% to 70% [12]. Thus more than 50% of energy recovered from waste is classified as biogenic. Accordingly, WtE promotes the goal of renewable energy strategies [13]. The goal of waste management is to protect man and the environment and conserve resources [14]. This is in line with the goals of sustainable development. Investigations indicated that WtE has made a positive contribution to this goal in developed countries.

WtE promotes divergence of waste from the landfill, thus decreasing the adverse effects of landfill. WtE facilities have become recycling facilities through recovery of materials. Metals can be recovered from air pollution control and bottom ash residue [14]. Countries that have used WtE show high recycling ratios [6]. This can serve as a proof that WtE is compatible with recycling. Modern WtE plants have managed to achieve the goal of sustainable waste management. Resources such as energy, material and land have been conserved through WtE initiatives. Implementation of WtE has significantly contributed to protection of the environment. The benefits derived from a proper MSW management include greenhouse gases emission prevention, pollutants reduction, energy saves, resources conservation, new jobs creation, development of green technologies and economic opportunities [6,15].

MSW Incineration in the World

WtE is an established option for MSW treatment, motivated by both the necessity to minimize the environmental stresses of landfilling and the aim to increase the share of renewable energy [16]. The energetic recovery is already a proven reality in developed countries.

The uptake in Europe of Energy from Waste (EfW) incinerator plants, or Waste-to-Energy (WtE) incinerator plants, has increased rapidly in recent years. In Europe, there are more than 533 active MSW incineration plants processing 88,41million tonnes of urban waste per year with a potential generation above 35 million MWh of energy per year [17]. On average, in the OECD (Organization for Economic Co-operation and Development) countries, 19% of municipal waste are incinerated, nearly all of them with some kind of energy recovery [18].

Some large-scale alternatives for WtE have been implemented in developed countries, such as Japan, Germany, Sweden, the Netherlands, Switzerland, Denmark, and the United Kingdom. For example, over 80% of the MSW in Japan is incinerated; Japan also has the largest number of incineration plants in the world and 10% are equipped with power generation facilities [19]. In Germany (year 2011), only 1% of waste was landfilled and the WtE share is approximately 35% of the waste treatment, which is higher than the EU's (Europe Union) WtE ratio approximately 24% [6,15]. Sweden is another successful example of WtE in the EU, where nearly 50% of waste is incinerated with energy recovery.

On a global scale, the incineration market still exhibits significant growth trends [20]. Market analysts forecast the global incinerator market to grow at a Compound Annual Growth Rate (CAGR) of 5.54% over the period 2013–2018 [21,22]. Overall, more than 800 thermal WtE plants are operated in nearly 40 countries globally; they treat approximately 11% of MSW generated worldwide and produces up to about 429 TWh of power [23].

The European scenery, in addition to proving the viability of energy recovery technology with incinerators, shows a trend for developing countries. According to CEWEP estimates, the potential production of energy from waste by 2020 amounts to 196 TW (76 for electricity and 120 from heat), and thence nearly double of actual figures [17]. Considering that energy from waste is 50% due to renewable materials contained in the waste flow, this also means that WtE offers a substantial contribution to the production of renewable energy and to the reduction of CO^2 [18], combusting MSW in WtE plants instead of landfilling it, decreases carbon emissions in.

One of the main factors supporting the growth of WtE plants in the world was the evolution of the treatment technology in the emissions from the incineration process. Emission characterization and treatment and Air Pollution Control of incinerator waste were the focus of many investigators [24,25,26]. Incinerators in Europe today operate under strict emission regulations and state-of-the-art technologies and have radically reduced harmful emissions compared to those produced in the early 1990's [25].

For each EU-28-member country, waste is disposed of in landfills, incinerated, recycled and composted. Based on data from CEWEP [17], considering the EU-28 member countries, the percentage of waste destined for WtE plants increased from 16% in 2011 to 28% in 2015. In the same sense was the growth of composting + recycling that increased from 29% in 2011 to 47% in 2015 according to figure 1 of historical evolution of waste treated in Europe by type of destination from 2001 to 2015.

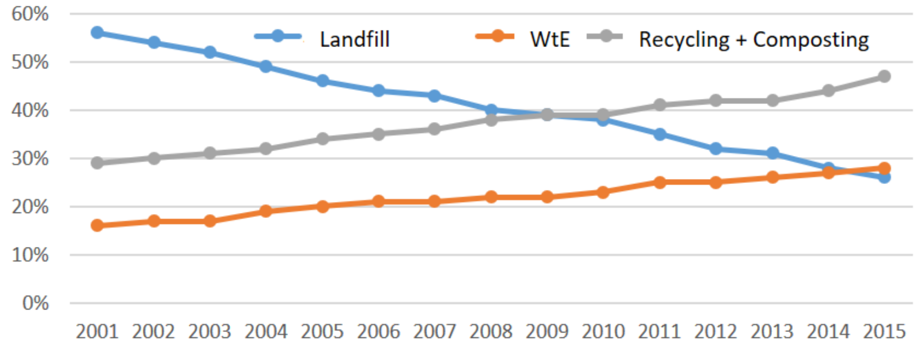

Fig. 1 Historical evolution of waste treated in Europe by destination type from 2001 to 2015

Changes in solid waste management in Europe can be largely attributed to local legislation, which sets targets for the evolution of the sector. As highlighted in European legislation, Directive 94/62 / EC should be cited, which determined that 50% of the packaging (and its waste) placed on the market should be collected by the year 2001 [27]. This goal was revised, predicting that 60% of the packaging (and its waste) should be collected by the end of 2008 [28]. Another factor influencing changes in the management of solid urban waste in Europe is limiting the area to landfills in close proximity to the sources of solid waste management (large urban center).

Also stands out Directive 1999/31/ EC, which deals with the disposal of waste in landfills [28]. This law sets progressive targets for reducing the disposal of biodegradable organic matter directly into landfills, which should be at most 35% of the total amount (weight) of biodegradable waste produced in 1995, by July 2016 [29].

The application of EU legislation (Guideline 31 - Disposal of Landfill, 1999) has resulted in a reduction in the disposal of MSW in landfills, particularly biological waste, to quantities equivalent to 35% of these wastes produced in 1995, by the year 2020, in the EU-28 member states. Germany, Sweden, Belgium, Denmark, the Netherlands and Austria have a share of waste deposited in landfills below 3%. In Denmark, Austria, Sweden and Germany it is not permitted to open new landfills. Greece is the only former Member State where the landfill has a percentage above 80%; all other members with such a high use of landfills are the new members [6]. In countries with high rates of waste incineration recycling rates are also high (Germany, Sweden, Belgium).

In Europe, 1.3% of the electricity on the global scale is obtained from waste. Considering those countries that incinerate the largest amount of waste, these numbers increase significantly [13]. The share of electricity generated from MSW incineration is 4.9% in Denmark, 3.3% in the Netherlands and 2.2% in Sweden. Even higher are the thermal energy rates obtained with a share of over 18% in Sweden and Denmark [13]. Considering that MSW energy is 50% due to renewable materials contained in the waste stream (biomass, ...), this also means that WtE makes a substantial contribution to the production of renewable energy and CO_2 reduction [18].

MSW Incineration as an opportunity face by MSW Brazil and Rio de Janeiro problem

In Brazil, the first MSW incinerator, characterized as 1st generation [30], was installed in Manaus, in 1896. The equipment had processing capacity of the order of 60 t/day, and was deactivated 62 years after its installation due to maintenance problems [8]. An overall, the first incinerators in Brazil were within the first generation, with outdated technology, whose main function was to reduce the volume of waste, and the gases generated were released directly into the atmosphere without treatment. Nowadays, in face of the demands of environmental legislation and the mobilization of public opinion through environmental entities, such systems are inconceivable.

On the other hand, incinerators for the treatment of hospital, airport and industrial wastes were also deployed in Brazil since 1970. A large number of incinerators of very small size and with a low processing capacity, less than 100 kg/hour, were installed in health facilities and services in the country, for the processing of hospital waste [8]. Most of these are deactivated or operated through high emissions of air pollutants and in disregard of environmental legislation [8]. As a result, thermal treatment in the country is still characterized by the large number of small incinerators, installed mainly in hospitals, which operate in a precarious way, without adequate maintenance and without control of atmospheric emissions. In addition, various difficulties occurred in the sense of its technical and economic feasibility, highlighting the lack of definition regarding the sources and value of the services provided and the offer of guarantees to the entrepreneur for the concession of long-term services, as well as the strong pressure exerted by public opinion, based on fear of the environmental impacts of the project [8].

The amount of MSW in many cities in Brazil has increased significantly due to the population growth and economic development. Open dumping and landfilling are basically the methods currently used for the final disposal of MSW, faces many difficulties due to the limited area available and resistance from surrounding communities mainly in the metropolitan regions. Currently, most of the collected wastes (58.7%) are sent to landfills, while (41.3%) are sent to inadequate units totalling more than 82,000 tons of waste per day, with a high potential for environmental pollution [31].

The Brazilian National Policy on Solid Waste (NPSW) instituted in 2010 was one of the most important political actions for determining the steps to be taken by the federal government. However, this policy does not specify mandatory actions, with targets and timetables, for the recovery of energy by the waste sector [32,33]. Despite this, it can be stated that the MSW incineration, based on WtE technology, is consistent with the objectives and guidelines of the NPSW, since besides satisfying the current atmospheric emission criteria, the optimization of the process depends on adequate screening and a prior separation of non-combustible waste, enabling the development of the entire selective collection chain, which includes the generation of direct and indirect jobs.

Despite this current scenario, within a long term perspective of Brazil, the National Energy Plan 2030 - PNE 2030 [34] considers the possibility of installing up to 1,300 MW in the next 25 years in thermoelectric plants using MSW, indicating that important advances are expected in the energy use of urban waste [34]. Incineration reduces the amount of waste deposited in landfills to about 10% of the original volume and 25% by weight. In the case of Rio de Janeiro, this means (if all waste is incinerated) extending the life of the current landfill to about 100 years.

This paper deals with a feasibility study model for utilizing MSW with energy recovery. The model will serve as the study basis to guide a techno-economic feasibility study for the implement a project of a WtE plant. This paper will assist in the finacial analysis that will guide stakeholder on the development of a WtE plant in Rio de Janeiro City and elsewhere.

Methods

The proposed methodology to evaluate the techno-economic feasibility for the implementation of a MSW incinerator in Rio de Janeiro city is based on the reference standards for the preparation of techno-economic feasibility studies (EVTE) foreseen in art. 11, item II, of Law No. 11,445, of January 5, 2007 - National Sanitation Law (LNSB), according to Ordinance No. 557 of November 11, 2016, Brazil [35].

The technical-economic feasibility study is a feasibility study that seeks to attest to the possibilities of success of an enterprise, considering technical, commercial, operational, social and financial aspects, hence the importance of adopting guidelines that will refer to the elaboration of these documents. The lack of well-founded projects is one of the issues that helps to ensure that projects do not progress as planned. The main aspects need to guide an economic technical evaluation for the implement a project of a WtE plant [35] are presented in figure 2:

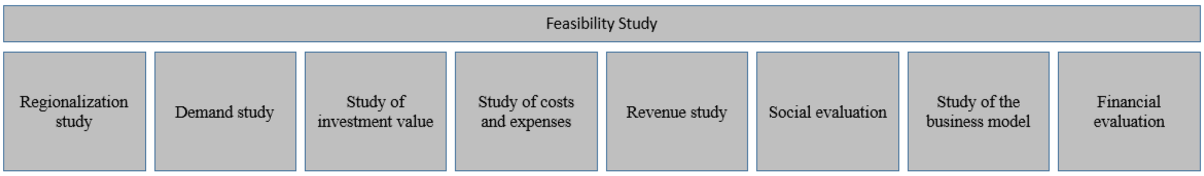

Fig. 2 Aspects need to guide an economic technical evaluation for the implement a project of a WtE plant

To establish the basic factors considered in the study of the value of investment and costs and expenses, it was necessary, preliminarily, to carry out an evaluation of the size and performance of the MSW incineration plant. Next, it is necessary to establish the basic factors for the design and yield of an MSW incineration plant such as: the composition of the processed waste; the amount of processed waste in this plant and the variation of the amount and composition of the waste as a function of the evolution of this composition over the years. So, data gathered on Rio de Janeiro City is provided. Since there is no MSW incinerator in Brazil, a baseline project is being settled up to establish the parameters of the incineration plant, referring, at first, to the incinerator projects from benchmarking in Europe. For this, a bibliographic review was carried out on the subject and the base project evaluated, based on the incinerator projects from Switzerland (benchmarking through technical visit in WtE SIG Geneva, WtE TRIDEL Lausanne, WtE Zurich Hagenholz and WtE ERZO Oftringen). To estimate the project investments (CAPEX and OPEX), the main cost elements are being evaluated in the different stages of the incineration and plant construction process. The base project of the incineration plant must also consider a mass balance estimate considering the emission levels of the incineration process, as well as the remaining waste (slag, ash, and wastewater) and their respective destinations.

A techno-economic feasibility study must consider the current regulatory requirements and constraints because they are directly related to the prerequisite project parameters. At the national level, there is a document of the Brazilian Association of Technical Standards (ABNT), called "MSW incineration - Performance Standard", which establishes requirements for the operation of waste ovens. About this, although it is not the focus of the proposed study, the paper also presents preliminary considerations on the main aspects of existing legislation on the subject nationally. Another specific objective is to identify the main issues and challenges faced by the WtE plant implementation and subsequently provide recommendations for further research. Additionally, the mains bottlenecks are summarizing to Rio de Janeiro city and the paper concludes by recommending opportunities to implement a WtE plant in Rio de Janeiro.

Results

Regionalization study

For a WtE plant, the regionalization study is fundamental to evaluate the appropriate scale for waste treatment and to allow comparison between different treatment technology options feasibility. Assessed proposals for regionalization should be aligned with the concepts and guidelines established in the National Sanitation Law (LNSB). The Regionalization studies should include, among others, the following aspects: the scaling of the optimal territorial scope for the provision of services and consortium possibilities, taking into account the regionalization guidelines; evaluation of the economic scale appropriate to the execution of the services, as well as their lower impact on the environment and human health, regarding to the achievement of the universalization goals and the spatial delimitation of services in view of institutional aspects, in particular the existence of a metropolitan region and other figures provided for in art. 25, paragraph 3, of the Federal Constitution [35]. To do this it is necessary to identify the origin, volume and characterization of the waste generated in the municipality/region.

The waste collected in Rio de Janeiro reached an average of 9,227 t/day [38]. Based on Brazilian Institute of Geography and Statistics (IBGE) the population estimated for the Rio de Janeiro city in 2016 is 6,498,837 inhabitants [36]. Rio de Janeiro uses landfill as the major MSW management strategy. Landfill was identified as the dominant MSW management strategy where 100% of the waste generated is landfilled [38]. Part of waste generated is not landfilled because there are a large number of informal collectors who scavenge MSW. They sell part of the waste they collect, either for re-use, for recycling, or as food waste for pig feeding. Most of their non-usable residue goes back to the formal waste management system, but part is either discarded indiscriminately in open fields. The composition of the waste in Rio de Janeiro are shown in table 1. The table shows the MSW composition in mass fraction respectively [38].

Table 1 MSW Composition in Rio de Janeiro

Component	Component (%)
Not recyclable	55,82
Organic matter	52,00
Leafs	1,00
Woods	0,42
Cloths and rags	12,00
Leathers	0,43
Recyclables	43,09
Paper and cardboard	15,62
Plastics	21,01
Glass	3,46
Rubbers	0,23
Metals	1,65
Inerts	1,12

The amount organic matter is predominant in the MSW (52.00%), while the potentially recyclable material represents 43.09% of the total. Of all the potentially recyclable materials present in the household waste, plastic in its different forms (polyvinyl chloride PVC, polyethylene terephthalate PET, among others), and paper/cardboard represent around 85%. In relation to the WtE facilities, it is important to know the energy content in the MSW, which can be calculated based on the LHV (Lower Heating Value) of the waste [38]. The calorific value of waste is a key element in the design of an incineration plant. In Switzerland, the calorific value is higher than 3,000 kcal/kg [9]. Based on the gravimetric analysis and based on the theoretical formulation [37], it is estimated the lower calorific value of MSW collected in Rio de Janeiro at 2,350 kcal/kg, considering a typical humidity index of 40%. This calorific value is higher than the minimum technical feasibility limit (2,000 kcal/kg), which allows mass burning without the need of adding combustible material.

Additionally, considering the household per capita deposited in Rio de Janeiro City landfills historical series from COMLURB [38], the estimate per capita generation of household waste in Rio de Janeiro city up to 2030 adopting the growth trend of this index provided by the dispersion of the real data from 1996 to 2015 [38], according to which it will rise at 2030 to upper than 2 kg/capita/day [38]. Considering the MSW composition in Rio de Janeiro, the gravimetric compositions can be estimated adopting similar growth trend function.

The location of the incinerator is a relevant factor considered in the study of economical technical feasibility. Therefore, in order to consider the location of the incineration plant in the municipality of Rio de Janeiro, the following a priori aspects are being considered: (a) proximity to a solid waste landfill that can receive the dross from the incinerator; (b) proximity to industrial zones that may consume the thermal and/or electrical energy produced by the incinerator; (c) proximity to an electric power substation so that the generated energy does not dissipate completely in the path; (d) proximity to transhipment stations; (e) proximity to the center with the highest population concentration and per capita waste generation rate and (f) the availability and average cost of the available area for the construction of the incinerator plant.

Typically, MSW plant are built within or close to industrial areas to obtain small heat distribution distances. Some MSW plants are also close to residential areas. The occupied area is categorized as built-up industrial area. Cultivation after demolition is not likely, rather reuse as industrial or residential area. For greater logistical efficiency is necessary to identify the origin, volume and characterization of the waste generated in the municipality/region. To identify the geographical location of the WtE plant, a mathematical model of logistic optimization using linear programming software is recommended.

In the case of Rio de Janeiro, in a preliminary qualitative analysis, one of the areas to be evaluated is the Cajú district due to the proximity of waste treatment station in Cajú already existing and because it is the waste treatment station that receives the largest amount of waste from the Municipal Cleaning Company (COMLURB). In addition, waste treatment station Cajú is home to a waste sorting cooperative and is next to Alegria sewage treatment plant. In this receiving center there is a transhipment and a material screening center and composting plant. The majority of MSW is transported by trucks to the landfill in the municipality of Seropédica, without any added value or added value. In case the incineration plant is located in Cajú, the installation would process part of the MSW and, this location would allow the optimization of logistics costs.

Demand study

A structured study of demand should consider the following aspects: identification of expected demand for services, referenced in population studies, discriminating physical data (volumes, mass of collected waste, residents served, among others); explanation of the methodology used, detailing the procedures, technical and bibliographic references, sources and criteria for data treatment, models and parameters of projection and sensitivity analyses, among others [35].

According to Electricity Company of Rio de Janeiro (Light Serviços de Eletricidade S.A) in 2015 the total annual electricity consumption (including residential, industrial, commercial, rural, public power, public illumination, public service) of Rio de Janeiro was 2,016 MW [39].

According to ANEEL (National Agency of Electric Energy) in 2015 there were 1,384 thermoelectric plants in operation in Brazil. Rio de Janeiro city has a thermoelectric plant located in Santa Cruz district. The Santa Cruz thermoelectric belonging to Furnas (mixed economy company that generates and transmits electricity) and has an installed capacity of 932 MW [40].

The total energy recovery of the modern incinerator is between 50 and 70% of the energy content in the MSW, of which 15 to 25% is electric energy and the rest is thermal energy [41]. EPE indicate, respectively, 600 kWh/t, 550 kWh/t and 769 kWh/t, as average values of electricity generation per ton of waste found in the current incineration plants [42].

The total waste collected in Rio de Janeiro reached an average of 9,227 t/day [38]. So approximately 198 MW of electricity can be generated from 9,000 tonnes of MSW per day in Rio de Janeiro City [31]. Thus, in addition to reducing the amount of waste sent to landfills, the incinerator could feed the city with an additional supply of electric and thermal energy in approximately 7% of the total offered. Considering the possibility of an incineration plant with processing capacity of 900 t/day (treating approximately 10% of the total waste generated in the city) [38], approximately 60 MW can be generated [31]. Additionally, it can be considered that the city of Rio de Janeiro could contain more than one incinerator.

Incineration is advisable for the thermal treatment of large quantities of solid waste (more than 160,000 t/year or 240 t/day), with average lines of 18 t/h [41]. The economic return from the use of WtE plant only shows a financial return in the cases and that, in addition to the commercialization of electric and thermal energy, final disposal fees are charged higher than USD 76.55 for units with a maximum capacity of 650 t/day and USD 45.93 for units with a maximum capacity of 1,300 t/day [41].

Study of investment value

The capital cost of the plant with capacity of 270,000 tons/year in Rio de Janeiro was estimated at US$ 243 million. The elements of CAPEX are detailed in the table as shown in table 2. This estimate was done on the basis of similar capacity recently built plants, assuming that the WtE technology has a high quality design with grate-fired furnace, empty vertical passes and a vertical boiler followed by a semi-dry flue gas cleaning and a 75m-80m stack. Since capital costs are very dependent on world steel price indices and on various local factors, the estimate is expected to be within +/- 20% accuracy. The CAPEX assumptions for incineration include also the area of the land required for the facility. There is a large amount of infrastructure that must be built around the incineration facility. This will include administration offices, roads and the necessary space for the stockpiling of a sufficient amount of waste. About 10 hectares will be sufficient for this and also takes into consideration the possibility of site expansion in the future [43].

Table 2 Main components of a conventional MSW incineration plant

CAPEX	% do CAPEX	Elements
A. Project	25% of CAPEX	Expenses with administrative authorities (various), environmental licensing cost, land cost (acquisition) + IPTU (Urban Land and Territorial Tax), contracting costs of engineering and architecture company, costs with tests and tests.
B. Civil works		Cost of paving, cost building administrative building, cost of construction of open zone of smoke purification and waste treatment, cost of construction of industrial infrastructure.
C. Scale input and waste reception area		Investments and costs with the infrastructure of the concierge, the scales for truck and the truck yard.
D. Area of unloading and storage of waste to be incinerated		Loading bays, MSW characterization area, MSW storage area, ashyard, ferrous waste yard, non-ferrous waste yard, scrap press for bulk waste, moving crane (main and reserve), and MSW receiving pit.
E. Other Expenses		Insurance coverage of damages in operation (breakage of machinery, damage of the interruption of operation caused by machinery failures, computer risks), internal logistics equipment, expenses with own and outsourced labor, computers and softwares between auxiliary equipment.
F. Incineration furnace and auxiliary equipment	35% of CAPEX	Load hopper, feeder, combustion chamber, combustion grate, refractories, feed hydraulic power station, slag extractor, auxiliary burners, fly ash evacuation system below the grate, fly ash evacuation system, primary combustion air circuit, secondary combustion air circuit and ash and slag conveyor belt.
G. Boiler and thermal apparatus for energy recovery	10% of CAPEX	Water reservoir, boiler feed pumps, boiler recovery, economizer, boiling system, heater, steam pressure regulating valve, air condenser, condensate material reservoir, condensate extraction pump, turbo alternators, system heat exchanger, hot air circuit and the primary air heater.
H. Smoke clearance and discharging section	30% of CAPEX	Compartimento de encaminhamento de fumaça da caldeira, filtro de poeira, equipamentos de resfriamento, torre de lavagem, ventilador, chaminé, sistema de injeção de água, injeção e sistema de armazenamento de soda cáustica, sistema de drenagem de água no primeiro estágio, sistema de remoção de água do processo de lavagem, neutralizador, tanque de decantação leito (roteamento de água tratada), prensa filtro, compartimento receptor para resíduos tóxicos, tanque de decantação, leito granular (ração tratada), caldeira de lodo (tanque decantador), prensa filtro, compartimento receptor de resíduos tóxicos, manganês e filtros adsorventes de carbono pó de silício.
I. Treatment of fly ash and dust		Silica from fly ash from the boiler and the filter, separation reactor, strainer press, washing water treatment system and filter press/dryer.

J. Treatment of solid waste extracted from the water of washing of the smoke	Sludge silo, cement addition system, reagent addition system (several) and the shipping area of the concrete cubes.
L. Electronic equipment and instruments for command and adjustment	Diesel generator, diesel generator, turbo generator (power house), water pump house, transformer lift and room panels/electric automation instruments.

The system to control the emissions to air from incineration of waste constitutes a major proportion of the cost, technological sophistication and space requirement of an incinerator [44]. In short, the thermal processing equipment (incinerator/boiler) represents 40%, the energy production equipment (turbines and generators) represents 10%, the APC system (flue gas treatment) represents 15%, the building (civil works) represents 25% and the miscellaneous (approvals, general site works, ash processing, electrical transmission and interconnect etc.) represents 10%, respectively, of total capital cost.

In China the average cost of capital is US $ 228 / ton as shown in the figure 3. In addition, the cost of the land considered was US$ 5 million, assuming a total area of 300,000 m^2 based on the value of m^2 in the region of Seropédica City (in Rio de Janeiro state).

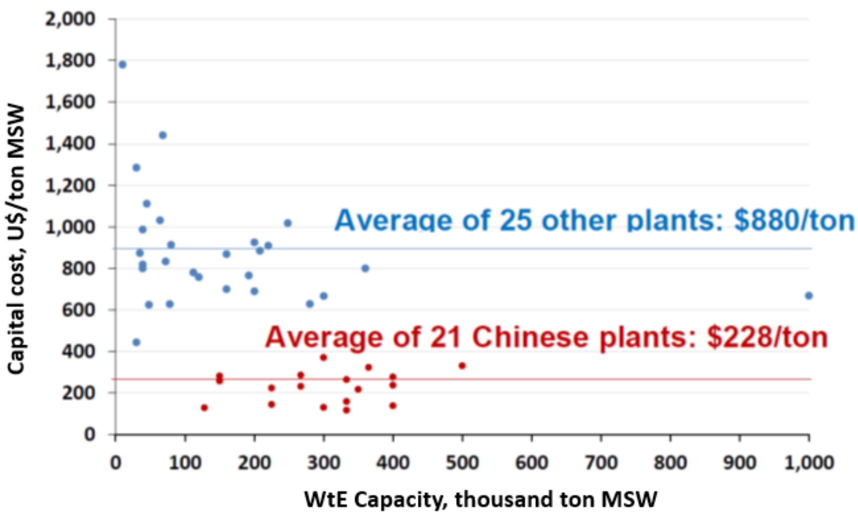

Fig. 3 Capital Cost x WtE Capacity

Study of costs and expenses

The estimated operating costs (also within +/- 20% accuracy) are of US$ 68 million per year and it also assumes that ash will be mixed (bottom and fly), and then used as landfill cover at the Rio de Janeiro landfill. Moreover, bottom ash and fly ash are equivalent to 20-25% and 2-3%, respectively, of the waste incinerated (by weight). Therefore, the average amount of ash for the proposed plant in Rio de Janeiro would be about 270,000 tons/year (about 750 tons/day).

The Operational Expenditure (OPEX) study considers the contract time horizon contemplating estimates of the main components of operating costs and administrative expenses, always presupposing the recovery of the costs incurred in the provision of the service in an efficiency regime and the methodology of cost and expenditure estimates shall be explained and substantiated [35]. The methodology of cost and expenditure estimates was carried out through the elaboration of a cash flow and statement of financial results of the WtE plant.

The operating costs for the incineration facility consist of labour, monitoring, maintenance, waste management, provision for contingencies and others. Each of these, barring provision for contingencies, will only begin to be accounted for in the first year of operations, year 5, and have been adjusted at the annual inflation rate of 5% from year 0. Many of these estimates have been adapted from plants in operation and changed where necessary on the advice of industry experts in personal interview. The main elements of operating cost are showing in Table 3.

Table 3 Operating costs assumptions for incineration financial model

Parameter	Detail

Labour US$9.72 million	Operating costs only begin once operations have begun in year 3 and are inflated from year 0. Thereafter labour is inflated by 5% per annum for the 30 years of operation. Much of the literature on labour needs of thermal plants looks at 40 staff required for system ranging from 100 000 tpa's (tons per annum) to 500 000 tpa's at average US$145 thousand staff/year. The estimate given is in line with the literature available and has been adjusted for Rio de Janeiro labour.
Monitoring US$0.7 million	Incineration requires that emissions are monitored at all times. Gas analysers that are in place will carry out this function and are fully automated. The only cost will be the monthly calibration that is required for each analyser, at US$10,000 per analyser per month. For incineration there are 6 analysers required to monitor carbon monoxide, sulphur dioxide, hydrogen chloride, hydrogen, oxides of nitrogen and particulates. All of these need to be monitored under the emission standards set by the European Union. It is these standards that must be use in the brazilian environmental regulation.
Maintenance US$24 million	Maintenance is estimated at 3% of capital cost of the technology. This is in line with estimates put forward by incineration companies in Europe and also available academic literature.
Waste Management US$9.2 million	This provision is given for the waste that will be present in the facilities stockpiles and also the residual waste and ash that will be present at the end of the process and will therefore require removal off-site.
Other US$3.1 million	Other costs cover both operating and organization costs that may not have been realised here. These include power, heat, supplies and other services which must be maintained irrespective of the amount of waste processed.
Provision for Contingencies US$2 million	Contingencies act as a buffer in plans to enable response to any change and risk that occurs. Contingencies are essential and are not a sign of poor planning. Most important is the degree of contingency that is built in and how it is allocated. This number is not accounted for during year 0 and year 1. In years 2 and 3 contingencies are estimated at 5% of CAPEX of those years respectively as additional contingencies may be required during the building of the facility. In the first year of operations, contingencies reverts back to US$2 million per year.

As part of the investments, the provision for contingencies should be quantified the costs of mitigating and compensatory measures of a social and environmental nature, which optionally, instead of being part of the investments, may be included in costs and expenses, unless there is a different provision in the contractual instrument [35].

The tax costs must be broken down and must comply with current legislation. For more accurate estimation of operating costs, it is necessary to calculate the plant mass balance. Table 4 shows the main elements of the mass balance of an MSW incineration plant. For calculation of taxes in the city of Rio de Janeiro it is necessary to calculate taxes obtained from the sale of the electric energy produced.

Table 4 Taxes on energy projects

Taxes	**Rate**	**Incidence**	**Jurisdiction**
COFINS*	7,6%	Gross Revenue	Federal
PIS	1,6%	Gross revenue	Federal
ICMS	0%	Gross revenue	State
IR**	15+10%	Profit before taxes	Federal
CSLL	9%	Profit before taxes	Federal

(*) COFINS: Permanent Contribution on Financial Transactions. PIS: Social Integration Program. ICMS: Tax on the Circulation of Goods and Services. IR: Income Tax CSLL: Social Contribution on Profit.
(**) IR = 15% up to USD 73.29/year + 10% above USD 73.29/year.

The ICMS is a state tax and as a result of the ICMS Agreement No. 107/2002, its rate is zero [45]. In the case of Industrialized Products Tax (IPI), the incidence of this tax was not considered (rate is zero) according to Decree n° 4542/2002 [46]. In table 4, the PIS/COFINS tariffs are non-cumulative. The incidence of Taxes on Services (ISS) on operations related to the sale of electric energy must be disregarded, pursuant to §3 of Article 155 of the Federal Constitution [47]. With respect to the taxation of the Reduced Emission Certificates (CERs) revenues, only IRPJ and CSLL are considered.

Revenue study

Expenses on investments required to build a municipal waste incineration plant may far outweigh the income from the sale of waste energy. Clearly, net costs also depend on the value of recovered resources. In the case of incinerators, these are for the electricity and heat. Further revenues may arise from the recovery of materials (e.g. metals) and from the reuse of ashes as an inert for the construction industry. Energy prices have their own degree of variability:

- Energy recovery efficiency depends on a number of variables (technology, quality of waste). An optimized plant treating pre-selected waste may recover 2–3 times more electricity and heat than a more traditional plant treating raw waste [48].
- Market price of electricity may depend on national market conditions, since the average market price in each country is a function of the technology mix (for example, in Italy it is significantly higher than in Germany). The price of energy volatility in the market must be mitigated through the adoption of long-term energy supply contracts.
- Market value of heat depends on local circumstances, namely the existence in the surroundings of industrial premises that can effectively use heat and/or the feasibility of district heating. Climatic aspects obviously matter, since they affect patterns of heating demand. Many studies conclude strongly in favor of cogeneration, but presume that the recovery of heat does not imply extra costs [49].
- On top of market prices, eventual subsidies have to be considered [49]: for example, some countries assimilate waste to a renewable resource and qualify WtE for green energy subsidies; others apply a tax on incineration. In China, the power grid is compelled to purchase electricity generated by incinerators at a special price that includes a subsidy [5]. In a social cost-benefit perspective, these subsidies should be omitted since they are clearing entries for the collectivity as a whole.

Four main sources of WtE plant revenues are considered in this study—electricity sale, gate fee, carbon credits and metals sale. The possible revenue from the sale of slag for asphalt production or civil construction was not considered in the present study.

Social evaluation

The use of WtE presents environmental risks, such as toxic air pollution and toxic ash. These plants require effective and efficient controls to avoid the emission into the air, land and water of harmful pollutants. The risks associated with the use of landfills are more relevant than those of WtE. For example, the landfill use can result in ground water pollution from leachates or toxic gases released as methane. A correct waste management depends on waste segregation (separation) at the source. A condition to achieve this goal is education and training. Not with standing there levance of the matter, this study does not evaluate the epidemiological issue of health effects in relation to WtE facilities. The frequently conflicting evidence on the association between waste incinerators and health effects is related to traditional incinerators and not to modern WtE processes [51].

In 1975, with the Directive 75/442/EEC [52], European Union introduces the waste hierarchy concept into European waste policy. The relevance of waste minimization is emphasized and political actions have to be regulated to ensure a high level of protection for the environment and human health. Although since 1989 Directive 89/369/EEC [52] of the European Economic Community have laid down specific conditions for the licensing of incineration plants, since 2000, the Directive 2000/76/EC [55] began to regulate the subject, making these conditions even more restrictive [54]. Incineration plants in Brazil are subject to the provisions of CONAMA Resolution n^{o}. 316/2002 [56], which regulates methods of thermal treatment of waste, and establishes operational procedures, emission limits, performance criteria, control, treatment and disposal end of effluents.

As shown in table 5, specific resolution of the São Paulo State Secretary of Environment (SMA 079/2009) establishes conditions for the control of emission of pollutants in MSW thermal processing plants, as restrictive as those recommended by the European Union, through the Directive 2000/76 of 2000 [55]. On the other hand, there is a greater flexibility in CONAMA Resolution n^{o}. 316/2002 [56], which provides for procedures and criteria for the licensing of these systems in Brazil:

Table 5 Main Conditions for control of emission of pollutants in MSW thermal processing plants

Parameter (mg/Nm³)	EU 2000/76	SMA/SP 079/09	CONAMA 316/2002
MP	10	10	70
NOX	200	200	560
SOX	50	50	280
HCL	10	10	80

CO	50	50	125
Hg	0,05	0,05	-
Cd + Ti	0,05	0,05	-
HF	1	1	5
Dioxins Furans	0,1	0,1	0,5

In Brazil we have an expressive set of laws applicable to be considered in the study of technical economic feasibility from the project phase to the implementation and operation of the plant. The application thereof and the purpose are set forth in table 6.

Table 6 Summary of applicable Federal Legislation

Applicable on	**Where**	**Objective**
Solid Waste	Decree n° 7.404/10	Regulates Law n°. 12,305, of August 2, 2010, which establishes the National Solid Waste Policy, creates the Inter-Ministerial Committee of the National Solid Waste Policy and the Steering Committee for the Implementation of Reverse Logistics Systems, and provides other measures [57].
	Law n° 12.305/10	Institutes the National Solid Waste Policy; Amends Law No. 9,605 of February 12, 1998; and makes other arrangements[58].
	ABNT/NB n° 10.004/04	Regulates the classification of solid waste [59].
	CONAMA Resolution n°316/02	Provides procedures and criteria for the operation of waste heat treatment systems [60].
	CONAMA Resolution n°307/02	Establishes guidelines, criteria and procedures for the management of construction waste [61].
	CONAMA Resolution n° 275/01	It establishes the colour code for the different waste types, to be adopted in the collectors and transporters identification, as well as in information campaigns for the selective collection [62].
Air Quality	CONAMA Resolution n° 418/09	Provides criteria for the elaboration of Vehicle Pollution Control Plans – VPCP, and for the implementation of Vehicle Inspection and Maintenance Programs - I/M by the state and municipal environmental agencies, and determines new emission limits and procedures for The evaluation of the state of maintenance of vehicles in use [63].
	CONAMA Resolution n° 382/06	Establishes maximum emission limits for atmospheric pollutants for fixed sources [64].
	Art. 28 of CONAMA Resolution n°316/02	It establishes the emission limits of atmospheric pollutants to be observed [59].
	CONAMA Resolution n° 03/90	Provides for air quality standards, as provided for in PRONAR [65].
	CONAMA Resolution n° 05/89	Establishes the National Air Quality Control Program – PRONAR [66]

Moreover, in the case of projects that have a direct impact on more than 100 (one hundred) thousand people, it is recommended to prepare an economic-social study contemplating the following aspects [35]:

- Benefits and economic costs identification;
- Estimate of positive and negative project externalities;
- Identification of the opportunity cost of the Public Power, through the social discount rate or other technically justified method;

- Integration of the economic-financial analysis in order to highlight: (a) an efficiency in the fulfilment of state missions and in the use of society's resources; (b) respect for the interests and rights of the recipients of the services and of the private entities entrusted with its execution; (c) financial sustainability and socio-economic advantages of the project;
- Result of the economic evaluation (the flow of revenues and economic costs must be brought to present value through the use of the social discount rate or other technically justified method).

Still on the social aspects, although not yet possible measurement, there are several fronts contrary to the WtE Plant in Brazil. During this research, several online media were identified describing critics regarding the adoption of WtE technology in Brazil. One of the largest states in Brazil, Minas Gerais, came to adopt a draft law that prohibits the use of this technology (nº. 4051/2013, which "Prohibits the use of incineration technology in the process of final disposal of urban solid waste"). The possible reasons for public opposition to WtE projects in Brazil are:

- Inadequate information to public as to benefits of WtE by Brazilian academia;
- Need for transparency of WtE emission data by government;
- Risk of odor emissions from the plant and related infrastructures.
- Risk of inadequate operating control of emissions by some WtE plants; and
- Risk of adoption of outdated technology with higher emission levels due to its lower investment cost (CAPEX).

Study of the business model

The study of the business model contemplates the following aspects [35]:

- Study of alternatives contemplating the evaluation of the various contractual models;
- Justification of the chosen contractual model, demonstrating its social, environmental and economic advantages in the short, medium and long term;
- Management model (definition of the scope of activities and services that should stay in charge of the contractor);
- Legal model of the contract;
- Simulation of the risk matrix (identification of the risks associated with the project, of the parties that must support them and of the mitigation measures);
- Performance indicators (should be described, justified and have their calculation methodology established so as to avoid redundancy or irrelevance of the indicator, and be accompanied by the value or range of values in which the service is considered to be being satisfactorily, partially, or that is not being minimally complied with).

Incineration in Europe started more or less everywhere in the public sector, with the notable exception of France, where delegation to private companies constitutes a typical feature in all local services [66]. In the last decade, however, a substantial trend towards a wide involvement of the private sector can be detected. According to [66], this is driven by privatization and merger of local public companies, especially in the energy field (e.g. Germany, Netherlands, Italy), but also by a wider recourse to Public Private Partnerships (PPP) for new initiatives (e.g. UK).

There is no comprehensive analysis of the institutional framework of WtE. The World Bank provides a detailed description of the most frequent management models and contracts [67], which range from the most classical procurement contracts to more sophisticated arrangements, in which the contractor's duties extend to design, operation and assumption of financial risks [66]. The table 7 illustrates their most typical features.

Table 7 Applicable tendering and contractual models for waste incineration plants

Tender model	Client's obligation	Contractor's obligation	Advantages	Constraints
Multiple contracts	Financing. Function specifications, tendering, project coordination, and construction supervision. Ownership and operation.	Supply and detailed design of individual parts for the plant.	Full client control of specifications. Possible to create the optimum plant based on most feasible plant components.	Absolute requirement for project management and waste incineration skills in the client's organization.
Turnkey contract	Financing. Function	Responsible for all project	One contractor has the full	Limited client control of

	specifications, tendering, and client's supervision. Ownership and operation.	design, coordination, and procurement activities.	responsibility for design, erection, and performance.	choice of plant components.
Operation contract	Multiple or single turnkey contract. Ownership. Supply of waste.	Operation of the completed and functional plant in a certain period.	Limited strain on the clients organization.	Difficult for client to secure affordable tariffs, (put or pay contract), control finances, and monitor contractors performance and service level.
Build operate	Financing, function specifications, tendering, and client's supervision. Ownership. Supply of waste.	Detailed design, project management, contractor's supervision, operation, and maintenance.	Contractor committed to wellfunctioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractors performance and service level.
Design build operate	Financing. Overall function specifications and tendering. Ownership. Supply of waste.	Detailed design, project management, supervision, operation, and aintenance. Ownership.	Contractor committed to wellfunctioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build own operate transfer	Overall function specifications and tendering. Ownership after transfer. Supply of waste.	Financing, design, project management, supervision, operation, and maintenance. Ownership until transfer.	Contractor finances, constructs, and operates the plant for a period after which the plant is transferred to the client. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build own operate	Overall function specifications and tendering. Supply of waste.	Financing, ownership, design, project management, supervision, performance guarantees, operation, and maintenance.	Client does not need to finance the project. Contractor committed to well-functioning and effective solutions. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.

Financial evaluation

The main elements present in the financial evaluation, together with assumptions and parameters assumed in the projection, are presented in table 8.

Table 08 Main elements of the financial evaluation

	Component (%)
A.	Income projection
B.	Capital cost (CAPEX) projection;
C.	Investments schedule;
D.	Projection of costs and expenses
E.	Amortization of investments
F.	Tax benefits arising from accounting depreciation of assets
G.	Any indemnities paid or received in respect of unamortized assets received at the beginning of the concession, or reverted to the grantor at the end of the concession
H.	Any amounts paid to the granting authority as a grant or onlendings for complementary investments
I.	Projection of the costs of mitigating and compensatory measures of social and environmental character
J.	In the case of concessions, including through public-private partnerships, and of program contracts: a) costs of own capital and third parties - by discriminating working capital and other types of credit; B) debt service coverage ratio; C) financing conditions.
L.	Insurance (engineering risk, operational risk, etc.);
M.	Guarantees;

N.	Tributes;
O.	Remuneration of regulation of services;
P.	Analysis of tariff impact or other forms of remuneration for services, when applicable, if their increase is necessary to make the investments feasible and other elements of the project
Q.	Possibility of ancillary revenues
R.	Sensitivity analysis (risk of revenue and increase of costs and investment);
S.	Determining the project cash flow;
T.	Estimate of net present value, discounted payback and the project internal rate of return.

For the analysis of the investment schedule (item C of table 9), a project schedule should be elaborated. According to good practices recommended by the PMBOK (Project Management Body of Knowledge) [68], the schedule is an essential tool for the success of any project, since it should portray the entire scope to be provided, as well as the necessary resources, deadlines and costs, and may include many other functionalities.

The WtE plant cost data and design parameters was obtained through interviews with representatives from four of the largest and most efficient WtE plant in Europe performed through benchmarking in Switzerland. Plant operating cost and revenue streams data was also obtained in these interviews and through a literature review.

Basic assumptions for a WtE incineration power plant financial model are shown in table 9. These assumptions are used as the base values for financial analysis.

Table 9 Financial model assumptions

Parameter	Unity
Base design capacity	tonne/year
Base design capacity capital cost	$/tonne
Additional capital cost: MSW	$/tonne
Maintenance cost	% of Capital cost
Electricity price	$/kWh
Tipping fees: MSW	$/tonne
Metal sales: Ferrous metals	$/kg
Metal sales: Non-ferrous metals	$/kg
Depreciation	%/year
Discount rate	%/year
Inflation	%/year
Interest rate	%/year
Tax rate	%/year
Capital Cost	$
Financed by a financial institution	% of Capital cost

The table 10 shows assumptions need to calculate the scenario's annual income.

Table 10 Assumptions need in calculating annual income

Parameter	Assumption
Average Labour cost	$/person/year
Overheads	% of total labour cost
Chemicals cost	$ per kg at rate of kg/ tonne of waste
Water	$ per kl at rate of litres/ tonne of waste
Maintenance cost	% of the total investment cost
Interest	% calculated on investor capital cost
Residue management cost	$/tonne at production rate of kg/tonne of waste
Electricity sales	kWh/tonne of waste
Process steam sales	kWh/tonne of waste
Ferrous metal sales	kg/tonne of waste
Non-ferrous metal sales	kg/tonne of waste

The proposed model to determine the financial feasibility of a WtE incineration plant for Rio de Janeiro city in Brazil begins by calculating the simple payback period (SPB) and return on investment (ROI). These are simple and broad economic feasibility indicators used for preliminary assessment [69].

Payback (SBP) is the period of time necessary to recover the initial investment in a project and/or venture, where it is calculated from the cash inflows [70]. Regarding the decision criteria from the payback, it states that if the payback period is less than the maximum acceptable recovery period, the project will be accepted. If the maximum payback period is greater than the maximum acceptable recovery period, the project will be rejected [70].

Return on Investment (ROI) is a performance measure, used to evaluate the efficiency of an investment or compare the efficiency of a number of different investments. ROI measures the amount of return on an investment, relative to the investment's cost [70]. To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment.

The analysis narrows down to specific financial feasibility indicators, namely: net present value (NPV) and internal rate of return (IRR). The net present value corresponds to "the difference between the present value of the net inflows associated with the project and the initial investment required" [71]. The NPV is a sophisticated budgeting technique [72]. The value is determined by subtracting from the initial value of a project the present value of net cash inflows, discounted at a rate equal to the cost of the company's capital [73]. Cites that "the net present value criterion provides an indication of the value creation potential of an investment" [57]. Using NPV for decision making facilitates the achievement of the financial officer's main objective, which is to maximize shareholder or owner wealth [73]. The financing lines for this type of enterprise are those from governmental development banks, in case BNDES (Brazilian Development Bank), via own lines of development. The typical conditions for such financing based on the BNDES Finem line are: Interest rate of 1.5 to 2.5% + Long-Term Interest Rate (TJLP), 20% offset and maximum amortization term of 14 years [41].

The IRR is the required rate of return that, when used as a discount rate, results in NPV equals zero [75,76,77,73,46]. Therefore, whenever the NPV is zero, the economic equilibrium point of the project is reached. In this way, there will be no creation or destruction of value [75]. With IRR, a single rate of return is used to synthesize the merits of a project. This rate is called internal, in the sense that it depends only on the cash flows of a certain investment, not on rates offered elsewhere [73]. In order to evaluate investment proposals, it is necessary to know the amounts of capital expenditure and the net cash flows generated by the decision, where the IRR represents the project profitability expressed in terms of the interest rate [78]. The IRR is an average rate that considers the entire economic life of the project and is expressed in annual terms. The decision criterion, when the IRR is used to make decisions, accept or reject a project, results in: if the IRR is greater than the cost of capital, the project is accepted; if it is smaller, the project is rejected [72]. With this criterion, it is guaranteed that the enterprise is obtaining at least its appropriate rate of return.

A positive NPV indicates a feasible project and a higher NPV generally indicates a more attractive investment. An IRR greater than the stated discount rate shows a feasible project [69]. WtE incineration plant capital budgeting for a life span of 30 years was carried out. These facilitated calculations of the NPV and IRR. Two major variables (electricity price and gate fee) that affect project economic performance were identified. NPV, ROI and IRR sensitivity analysis was then performed. An investment attractiveness scale can be formulating for both NPV and IRR sensitivity analysis results. An NPV value of less than zero is regarded as not financially feasible. An NPV value between zero and a quarter of the capital cost is considered financially feasible but not attractive. A financially feasible and attractive NPV value is in the range greater than a quarter and less than half of the capital cost. The most attractive NPV is greater than half of the capital cost [69].

An IRR less than the discount rate, 10%, is not considered financially feasible. An IRR between 10% and 15% is considered financially feasible and attractive. An IRR value greater than 15% has the highest investment attractiveness [69]. Financial analysis results for the two scenarios were calculated. A financial model with two different scenarios was formulated considering varying the bank interest rate and the capital cost level. The first scenario considers an interest bank rate lower than currently applied in similar projects in the Brazilian investment bank. The second scenario considers a reduction in capital cost (CAPEX) for the case of adoption of some kind of fiscal incentive by the public government. Both scenarios are compared to the base scenario. The scenarios were ranked according to performance in terms of NPV and IRR.

In addition, a sensitivity analysis should be considered as the main risk variables. The feasibility analysis must be based on international reported cost estimations, which inherently induce a degree of uncertainty. First, the sensitivity analysis must examine the sensitivity of the financial results Net Present Value (NVP) against the uncertainty of initial investment (CAPEX) and the annual operation costs (OPEX). Beyond these, the sensitivity analysis also included the effect of a potential variation of electricity marginal price, which may also affect the NVP results. Since the economic viability of WtE incineration solutions is directly reflected to the height of the gate fees required for sound economics, the sensitivity analysis must perfume against the gate-fee value.

Conclusions

The management of MSW can play a key role in tackling environmental pollution, and WtE plants represent a sustainable solution for unsorted waste management. An effective waste hierarchy focuses first on non-generation, reduction, reuse, recycling, solid waste treatment and environmentally appropriate MSW final disposal, but it is also finalized to minimize the landfill use.

WtE is considered an established option for MSW treatment, motivated both by the necessity to minimize the environmental stresses of landfilling and by the aim to increase the share of renewable energy. A WtE plant produces electrical and thermal energy from waste, and leads the country to greater energy independence (like other renewable sources). Technological development allows modern WtE plants be more sustainable then old incinerators, but strict controls are required to prevent their negative impacts on human health and the environment. Locational aspects, planning WtE plants to be close to main points of waste generation, allow to reduce the environmental impacts related with transporting waste over long distances. Furthermore, waste shipment has a high environmental impact in terms of CO_2 emissions.

Based on the national situation of urban solid waste in Brazil, and especially in Rio de Janeiro city, one of the major difficulties encountered by waste facilities is the appropriate selection of technology, capacity, site location, logistics, waste suppliers and heat/electricity localization consumers. Despite the costs involved in implementing a WtE plant, there are opportunities as potential revenue from WtE technology. Energy produced at a WtE plant, as thermal or electrical one, can be important for local supplies as a complementary and renewable energy. In the case of the city of Rio de Janeiro, the gains from sale of the electricity and heat generated from WtE plant will be important for economic viability, more so when including revenues from reception and also from avoided emissions.

The incineration of waste is still seen in Brazil as a highly polluting technology for MSW treatment and most of the population does not approve its utilization; on the other hand, the lack of space for new landfills in metropolitan areas, is forcing the municipalities to rethink the use of WtE options; the results of many studies confirm that WtE facility can be an alternative for landfills, being more efficient in energy recovery and having less environmental impacts. It is important to note that is necessary a review of air pollution rules in Brazil on the way to force the use of efficient pollution control equipment at the WtE plant to be constructed on country. Overall, barriers from the aspects of technology, finance, supplier and regulation can be encountered while implementing the WtE plant. All of them cannot be distinctly separated because policy mechanisms often act on more than one barrier simultaneously. Subsidies, in terms of direct regulation and transfers, preferential tax treatments, trade restrictions, and/or public funding, are often provided by the governments to fund popular forms of energy supply. However, a continuous attention to the restricted availability of specialized local suppliers must be consider before to perform techno-economic feasibility study.

The authors therefore consider that this study will provide valuable data for future research and will inform academics, plant operators, authorities and other stakeholders on the best practices for waste incineration. Further research is required to apply this model for Rio de Janeiro city and elsewhere according the city Integrated Solid Waste Management (ISWM).

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The authors declare that there is no conflict of interest.

Reference list

[1] Tchobaanoglous, H., Theisen, H., Samuel, A.: Integrated Solid Waste Management. McGraw-Hill, Inc., New Delhi (1993)
[2] Harrison, R.M., Hester, R.E.: Waste Incineration and the Environment. Royal Society of Chemistry (1994)
[3] Chirico, V.: Municipal Waste Treatment Plants. Zurich. Swiss Reinsurance Company (1996)
[4] Mavropoulos, A.: Thermal treatment in transition countries. Is there any future and how. International Seminar on Technologies and Management of Solid Waste, 1, Rio de Janeiro, RJ, Brazil, 26-28 May (2010)
[5] Rabl, A., Spadaro, J.V.: Health impacts of waste incineration. In: Issues in Environmental Science and Technology, Vol.18 Environmental Impact of Solid Waste Management Activities, pp. 171- 193. Royal Society of Chemistry, UK (2002)
[6] Eurostat (European Statistic): Statistics in Focus. Available at: http://epp.eurostat.ec.europa.eu/ (2016). Accessed 20 February 2017
[7] Cucchiella, F., D'Adamo, I., Gastaldi, M.: Municipal waste management and energy recovery in an Italian region. Waste Management & Research 2012; 30: 1290-1298 (2012).
[8] Henriques, R.M., Basto, O.L., Oliveira, A.: Energy Generation with Urban Solid Waste Cost Benefit Analysis (2004)
[9] Gandolla, M.: Incinerator. Translation authorized by the Chirico, V. in 2013. Translated portuguese by Gandolla 2013. M.Schweizer Rück (2013)
[10] Lombardi, L., Carnevale, E., Corti, A.: A Review of Technologies and Performances of Thermal Treatment Systems for Energy Recovery from Waste. Waste Manage. [Online]. 37, 26-44. Available: http://www.sciencedirect.com/science/arti cl e/pi i/S09 560 5 3 X 14005 273 (2015). Accessed 26 June 2017
[11] Tabasova, A., Kropac, L., Kermes, V., Nemet, A. Stehlik. P.: Waste-to-Energy Technologies: Impact on Environment. Energy. [Online]. 44 (1),146-155. Available: http://www.sciencedirect.com/science/articl e/pi i/S0360544212000199 (2012). Accessed 28 January 2018
[12] Maisiri, W., Van.Dyk, L., Kock, J.: A technological and performance comparison of waste-to-energy thermal technologies. pp. 170-176. SA UPEC, Johannesburg, SA (2015)
[13] IEA Bioenergy: Accomplishments from IEA Bioenergy Task 36: Integrating Energy Recovery into Solid Waste Management Systems (2007-2009). IEA, France. Available: http://www.ieabioenergytask36.org (2013). Accessed 26 July 2017
[14] Brunner, P. H., Rechberger, H.: Waste to energy key Element for Sustainable Waste Management. Waste Manage. [Online]. 37, 3-12. Available: http://www.sciencedirect.com/science/article/pii/S0956053XI4000 543 (2015). Accessed 19 October 2017
[15] Eurostat (European Statistic): Municipal waste generation and treatment, by type of treatment method. Available at: http://epp.eurostat.ec.europa.eu/tgm/ (2014). Accessed 17 February 2018
[16] Gohlke, O.: Efficiency of energy recovery from municipal solid waste and the resultant effect on the greenhouse gas balance. Waste Management & Research 27: 894-906 (2009)
[17] CEWEP (Confederation of European Waste-to-Energy Plants): CEWEP Energy Report III. Available at: www.cewep.eu/ (2016). Accessed 21 November 2017
[18] Manders, I.: The renewable energy contribution from waste across Europe, ISWA Dakofa Conference, December 3. Available at: www.cewep.eu/information/publicationsandstudies/studies/climate-protection/m_592 (2009). Accessed 21 December 2017
[19] Tanaka, M.: Municipal solid waste management in Japan. In: Pariatamby Tanaka M., editors. Municipal solid waste management in Asia and the Pacific Islands, Springer Singapore; 2014. pp. 157–71 (2014)
[20] Eckhard, R.: Global market for incineration technologies. SBI Energy (2013)
[21] Ecoprog: Waste to Energy 2013–2014. The world market for waste incineration plants. Available at: http://www.ecoprog.com/en/publications/energyindustry/waste-to-energy.htm (2014) Accessed 21 December 2017
[22] Market Research Report: Global Incineration Market 2014–2018. Available at: www.marketresearchreports.biz/analysis-details/global-incinerator-market-2014-2018?vsmaid=466 (2013). Accessed 04 February 18.
[23] Richard, M.: Global Waste-to-energy market to reach $29.2 Billion by 2022; March 23, 2012. Available at: <http://www.navigantresearch.com/newsroom/globalwaste-to-energy-market-to-reach-29-2-billion-by-2022> (2012). Accessed 21 January 2017.
[24] Amutha, R. D., Boccaccini, A.R., Deegan, D., Cheeseman, C.R.: Air pollution control residues from waste incineration: current UK situation and assessment of alternative technologies. Waste Management 28, 2279–2292 (2008)
[25] Porteous, A.: Energy from waste incineration—a state of the art emissions review with an emphasis on public acceptability. Applied Energy 70, 157–167 (2001)

[26] Sam-Cwan, K., Hwan, J.S., Il-Rok, J., Ki-Hun, K., Myung-Hee, K., Jae-Hyung, K., Jun- Heung, Y., Seung-Jin, K., Jae-Cheon, Y., Dong-Hee, J.: Removal efficiencies of PCDDs/PCDFs by air pollution control devices in municipal solid waste incinerators. Chemosphere 43, 773–776 (2001)
[27] European Commission: Directive 1994/62/EC of 20 December 1994. Official Journal of the European Communities L 182/1 (1994)
[28] Mannarino, C.F., Ferreira, J.A., Gandolla, M.: Contribuições para a evolução do gerenciamento de resíduos sólidos urbanos no Brasil com base na experiência Européia. (2016). doi: 10.1590/S1413-41522016146475
[29] European Commission: Directive 1999/31/EC of 26 April 1999. Official Journal of the European Communities (1999)
[30] Menezes, R., Menezes, M., Gerlach, R.J.: Estágio Atual da Incineração no Brasil. Grupo Kompac Energia e Meio Ambiente. Seminário Nacional de Resíduos Sólidos e Limpeza Pública, VII, ABLP - Associação Brasileira de Limpeza Pública. São Paulo, SP, Brasil (2000)
[31] ABRELPE (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais): Panorama dos Resíduos Sólidos no Brasil 2015. São Paulo (2016)
[32] Loureiro, S.M., Rovere, E.L.L., Mahler, C.F. Analysis of potential for reducing emissions of greenhouse gases in municipal solid waste in Brazil in the state and city of Rio de Janeiro. Waste Management 2013;33(5):1302–12 (2013)
[33] Cândido, L., Kindlein, W., Demori, R., Carli, L., Mauler, R., Oliveira, R.: The recycling ofmaterials as a design project tool. J Clean Prod 2011;19(13):1438–45 (2011)
[34] EPE (Empresa de Planejamento Energético): Projeção da demanda de energia elétrica para os próximos 10 anos (2011-2020). Nota Técnica DEA 03/11. Brasília: EPE (2011)
[35] República Federativa do Brasil: Lei 11.445, Techno-economic feasibility studies (EVTE) foreseen in art. 11, item II of January 5, 2007 - National Sanitation Law (LNSB), according to Ordinance No. 557 of November 11, 2016, Brazil (2016)
[36] IBGE (Instituto Brasileiro de Geografia e Estatística): Renda domiciliar per capita 2016. Rio de Janeiro: IBGE (2016)
[37] Themelis, N.J., Diaz, M.E., Estevez, P., Gaviota, M.: Guidebook for the Application of Waste to Energy Technologies in Latin America and the Caribbean. Columbia University (2013)
[38] COMLURB (Companhia municipal de limpeza urbana): Caracterização dos Resíduos Sólidos Domiciliares da Cidade do Rio de Janeiro – Relatório Técnico Interno. Rio de Janeiro (2017)
[39] Light Serviços de Eletricidade S.A (Electricity Company of Rio de Janeiro): Electricity consumption. Publishing PhysicsWeb. http://www.light.com.br/SitePages/default.aspx (2017). Accessed 26 November 2017
[40] ANEEL (National Agency of Electric Energy): Installed capacity. Publishing PhysicsWeb. http://www.aneel.gov.br/ (2007). Accessed 26 June 2017
[41] BNDES (Brazilian Development Bank): Energy use of solid waste. Publishing PhysicsWeb. http://www.bndes.gov.br/ (2014). Accessed 12 October 2017
[42] EPE (Empresa de Planejamento Energético): Plano Nacional de Energia 2030. Apresentação Mauricio Tolmasquim, Presidente EPE. Brasília: EPE (2007)
[43] IPPTS: Anaerobic Digestion. Available online at: http://www.wastetechnology.co.uk/AD/ad.html (2010). Accessed 23 December 2017.
[44] Griffiths, A.J., Willians, K.P.: Thermal Treatment Options. Waste Management World, July-August (2005)
[45] EPE (Empresa de Planejamento Energético): Avaliação Preliminar do Aproveitamento Energético dos Resíduos Sólidos Urbanos de Campo Grande. Nota Técnica DEN 06/08, Ministério de Minas e Energia, November (2008)
[46] Brasil, H.G.: Avaliação Moderna de Investimentos. Rio de Janeiro: Qualitymark (2002)
[47] BRASIL: Constitution of the Federative Republic of Brazil. Brasília, DF: Senado Federal: §3 of Article 155 (1988)
[48] Consonni, S., Giugliano, M., Massarutto, A., Ragazzi, M., Saccani, C.: Material and energy recovery in integrated waste management systems: project overview and main results. Waste Manag.. doi:10.1016/j.wasman.2011.04.016 (2011)
[49] Cossu, R., Masi, S.: Re-thinking incentives and penalties: Economic aspects of waste management in Italy. Waste Manag. 2013, 33, 2541-2547 (2013)
[50] China Research and Intelligence: Research Report on China's Dairy Industry, 2011-2012. Available at: www.cri-report.com/251-research-report-on-china=s=dairy-industry-2011-2012.html (2014). Accessed 12 October 2017
[51] Giusti, L.: A review of waste management practices and their impact on human health. Waste Manag 2009; 29:2227–39 (2009)

[52] European Commission: Directive 75/442/EEC of 15 July 1975. Official Journal of the European Communities (1975)
[53] European Commission: Directive 89/369/EEC of 8 June 1989. Official Journal of the European Communities (1989)
[54] Caixeta, D.M.: Geração de Energia Elétrica a Partir da Incineração de Lixo Urbano - O Caso de Campo Grande/Ms. Tese de Especialização. Universidade de Brasília. Centro de Desenvolvimento Sustentável. Brasília, DF, Brasil (2005)
[55] European Commission: Directive 2000/76/EC of 4 December 2000. Official Journal of the European Communities (2000)
[56] CONAMA: Resolution 316, The National Council for the Environment on Provides procedures and criteria for the operation of waste heat treatment systems. Brasilia: Ministry of the Environment (2002)
[57] BRASIL: Federal decree n° 7.404/10 - Regulates Law no. 12,305, of August 2, 2010. Official Diary (2010)
[58] República Federativa do Brasil: Lei 12.305, Política Nacional de Resíduos Sólidos. Brasilia: Publicação oficial do Presidente da República do Brasil (2010)
[59] CONAMA: Resolution 316. The National Council for the Environment on Provides procedures and criteria for the operation of waste heat treatment systems. Brasilia: Ministry of the Environment (2002)
[60] CONAMA: Resolution 307. The National Council for the Environment on Establishes guidelines, criteria and procedures for the management of construction waste. Brasilia: Ministry of the Environment (2002)
[61] CONAMA: Resolution 275. The National Council for the Environment on Color code for the different waste types. Brasilia: Ministry of the Environment (2001)
[62] CONAMA: Resolution 418. The National Council for the Environment on criteria for the elaboration of Vehicle Pollution Control Plans. Brasilia: Ministry of the Environment (2009)
[63] CONAMA: Resolution 382. The National Council for the Environment on maximum emission limits for atmospheric pollutants for fixed sources. Brasilia: Ministry of the Environment (2006)
[64] CONAMA: Resolution 03. The National Council for the Environment on Air quality standards. Brasilia: Ministério do Meio Ambiente (1990)
[65] CONAMA: Resolution 05. The Conselho Nacional do Meio Ambiente on National Air Quality Control Program. Brasilia: Ministério do Meio Ambiente (1989)
[66] Massarutto, A.: Waste management as a public utility: options for competition in an environmentally-regulated industry. Utilities Policy 15, 9–19. The World Bank, 1999. Decision makers' Guide to Solid Waste Incineration. The World Bank, Washington DC (2007)
[67] World Bank: Municipal Solid Waste Incineration – Technical Guidance Report. World Bank (1999)
[68] PMI: A Guide to the Project Management Body of Knowledge (PMBOK Guide). Pennsylvania (2008)
[69] Energy Management: Handbook-module 16, North-West University, Potchefstroom, pp. 1-11 (2014)
[70] Gitman, L.J.: Princípios de Administração Financeira. São Paulo: Addison Wesley (2004)
[71] Souza, A.B.: Projetos de investimentos de capital: elaboração, análise, tomada de decisão. São Paulo: Atlas (2003)
[72] Gitman, L.J. Princípios de Administração Financeira. 7º Ed, São Paulo: Editora Harbra (2002)
[73] Lemes, J.A.B., Cherobim, A,P,, Rigo, C.M.: Administração Financeira: princípios, fundamentos e práticas brasileiras. Rio de Janeiro: Elsevier (2002)
[74] Souza, A., Clemente, A.: Decisões financeiras e análise de investimentos: fundamentos, técnicas e aplicações. 4 ed. São Paulo: Atlas (2001)
[75] Ross, S.A., Westerfield, R.W., Jordan, B.D.: Fundamentals of Corporative Finance, 9th Edition, McGraw Hill/Irwin Hardcover (2009)
[76] Filho, A., Souza, J.C.F., Gonçalves, C.P., Cury, M.Q.: Finanças Corporativas. Rio de Janeiro: FGV (2003)
[77] Souza, A., Clemente, A.: Decisões financeiras e análise de investimentos: fundamentos, técnicas e aplicações. 4 ed. São Paulo: Atlas (2001)
[78] Assaf, A.: Finanças Corporativas e Valor, São Paulo, Atlas (2003)