PRE-FEASIBILITY STUDY OF A WASTE-TO-ENERGY PLANT IN SANTIAGO, CHILE

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EXECUTIVE SUMMARY

The objective of this study was to assess the viability of the usage of post-recycled materials as a source of energy for a Waste-to-Energy (WTE) plant, using as starting points two earlier Columbia studies of energy recovery from municipal solid wastes (MSW) in Chile. The study is divided into three parts: Chapters 1 and 2 describe the current situation in terms of waste management and the energy sector in Chile. Chapter 3 provides information of the WTE technology, inputs and outputs, and projected WTE plant costs and benefits. Finally, Chapters 4 and 5 develop financial and sensitivity analyses of the project, in which some break-even points will be evaluated

The results of this study indicate that there has been little progress in waste management in Santiago in the last 10 years. Chile is at the bottom of OECD countries in waste treatment since the country has neither the technology nor the infrastructure for the recovery of materials and energy.

In the community there is much misinformation regarding the energy recovery technologies that are widely used in developed countries. This is unfortunate as the familiar old incinerators that were known for their high pollution and environmental impact have been replaced by modern Waste-to-Energy facilities that have very advanced pollution control systems and generate more than 14 billion kWh of renewable electricity worldwide.

The new Framework Law on the Management of Waste that entered into force in June 2016, known as Extended Producer Responsibility, aims to reduce landfilling and increase recycling rates. Based on different recycling targets, it is estimated that this proposed 3-line facility could process up to 1 million tons per year. This would reduce by 60% the waste generated in the Metropolitan Region that otherwise would be buried in landfills, assuming the most ambitious recycling scenario of 40%.

The cost-benefit analysis of building a Waste-to-Energy facility in Santiago was conducted, and the capital cost was estimated to be $305MM. This facility would be privately owned, with a capital structure of 20% equity and 80% debt, paid at a 5% interest rate for 10 years.

This project has been proven to be feasible with a NPV of $31MM and an IRR of 11.76%, based on reasonable expenses and less-than-favorable assumptions; potential profit streams such as carbon credits, metals recovery, and lower transportation costs have been ignored.

It was determined that this project remains profitable up to a capital cost of $337 per ton of annual capacity. In addition, analysis of NPV was conducted for different electricity prices and gate fees, resulting in break-even points of $42/MWh for electricity, and $13.5 per ton for gate fees, respectively. In addition, it was estimated that a minimum amount of waste processed per year of 903,000 tons is required, with a minimum heating value of 7.3 MJ/kg, in order to make the project profitable.

As for recommendations, first it is necessary to expand the culture of reuse, reduce and recycle in the society. In addition, it is imperative to inform and educate the community and policy-makers about the benefits of energy recovery technologies, and the important role that they could play in the sustainable management of waste.

Secondly, it is recommended to maintain an updated database in order to make accurate estimations regarding waste management. This information should include, among other things: amount of waste generation per municipality annually, and costs of collection, transportation and disposal. In addition, with the new initiatives, it will be essential to have a record of recycling and composting rates.

Finally, it is suggested that a more detailed study of the ideal location of this plant be made, considering several parameters crucial to its construction. As an example, a 10 hectares plot that complies with the necessary regulations, that is in the vicinity of an in-service substation, and that minimizes total transportation costs, would be optimal.

Acknowledgments

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Introduction

According to The World Bank, Chile has been one of Latin America's fastest-growing economies over the past decade. As a result, the country has reduced poverty rates and increased the well-being of the population (World Bank, 2016). However, this accelerated growth has been associated with an increase in waste generation, as well as a high-energy demand, that is mostly dependent on fossil fuels.

The OECD Environmental Performance Review of Chile states that 80% of municipalities do not have a waste management plan, and the resources are insufficient to run adequate waste management programs. As a consequence, data from 2011 indicates that 69% of the waste was dumped in sanitary landfills, 22% in landfills and 9% in garbage dumps. Those dumping sites, numbering about 40, are mostly concentrated in lower-income regions, and adversely affect the quality of life of people living in these areas (OECD, 2016).

In view of current international agreements on sustainable development and climate change that Chile is a part of, it is important to develop strategies that contribute to the achievement of the proposed goals. One of the most important targets in terms of waste management is the increase of recycling rates through the new Framework Law on the Management of Waste, promulgated in June 2016. However, even in the most ambitious recycling scenarios, there is still a large amount of post-recycled waste that will continue ending in landfills, without any treatment.

This study aims to assess the viability of the usage of post-recycled materials as a source of energy for a Waste-to-Energy (WTE) plant, using as starting points two case studies of energy recovery from municipal solid wastes (MSW) in Chile. The first was developed 10 years ago for Santiago (Estevez, 2006), and the second, for Valparaiso, in 2013 (Themelis et al., 2013).

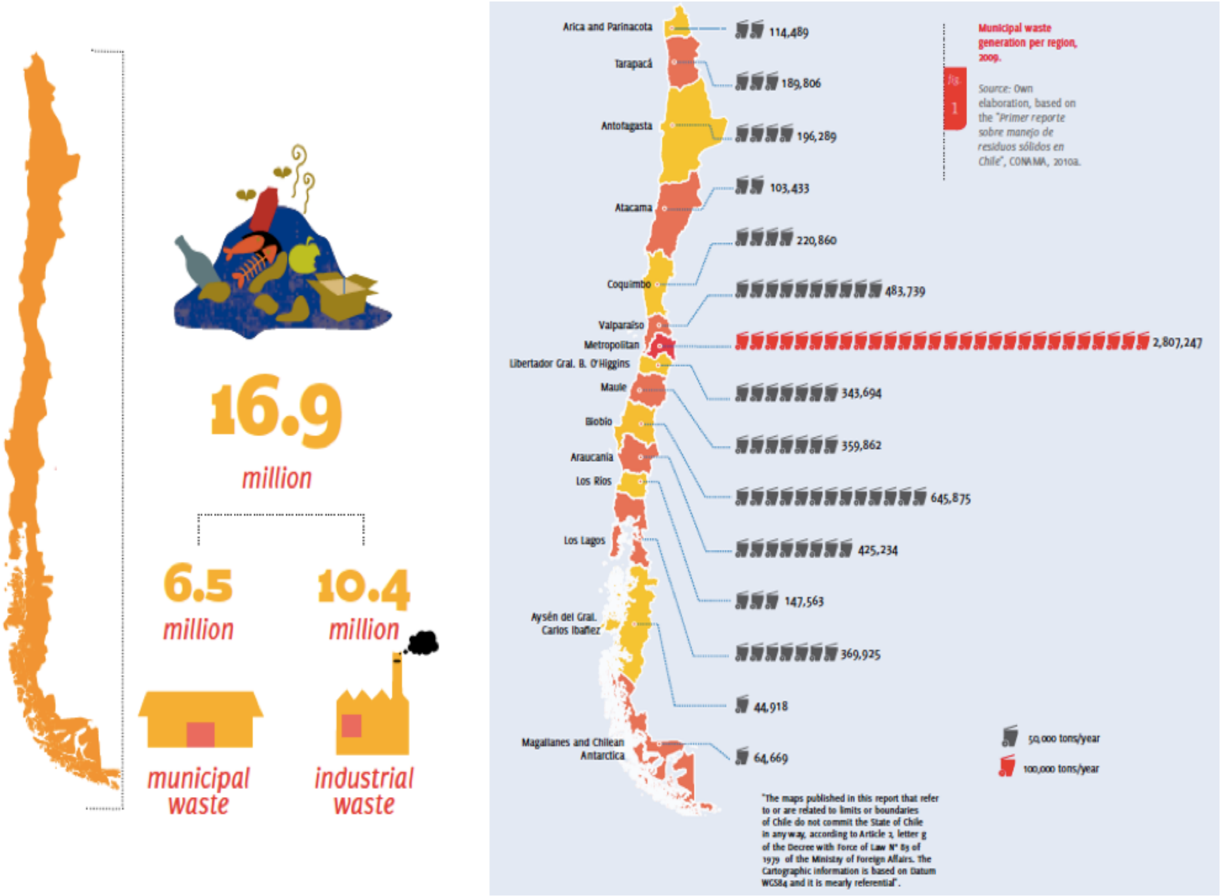
This analysis will also provide some basis for the development of future incentive programs that encourage the use of cleaner energies.

1. Waste Management in Santiago

1.1 General Overview

The problem of waste management in Chile is an issue that affects all the society, and is explained by the high density of people living in the cities, as well as increased consumption by the growing population. The total population of the country was 17.9 million in 2015, and the most populated region in Chile is Santiago, the capital, with 7.2 million inhabitants by 2016 (World Bank, 2016).

A study, developed by the National Corporation of the Environment (CONAMA) between 2009 and 2010, revealed that 16.9 million tons of waste were generated in the entire country, of which 6.5 million tons were municipal solid waste (MSW) and 10.4 million tons were industrial waste, as shown in Figure 1. Of the total MSW, 2.9 million tons were generated in the Metropolitan Region of Santiago, which constitutes 47% of the total waste generated in Chile (MMA, 2011).



Municipal waste generation per region, 2009.

Source: Own elaboration, based on the "*Primer reporte sobre manejo de residuos sólidos en Chile*", CONAMA, 2010a.

"The maps published in this report that refer to or are related to limits or boundaries of Chile do not commit the State of Chile in any way, according to Article 2, letter g of the Decree with Force of Law N° 83 of 1979 of the Ministry of Foreign Affairs. The Cartographic information is based on Datum WGS84 and it is mearly referential".

Figure 1. Waste generation in Chile
MMA (2011)

In Chile, two out of three municipalities lacked access to sanitary landfills in 2010. The government has therefore developed plans to increase the number of sanitary landfills by 2020; however, strong regulations that promote recycling and reduce waste generation may be a more effective alternative to the expansion of landfills (OECD, 2016). In comparison with OECD countries, Chile is in the last place of the OECD countries in the treatment of their waste, since it does not have the technology and the infrastructure for the recovery of materials and energy, as shown in Figure 2 below.

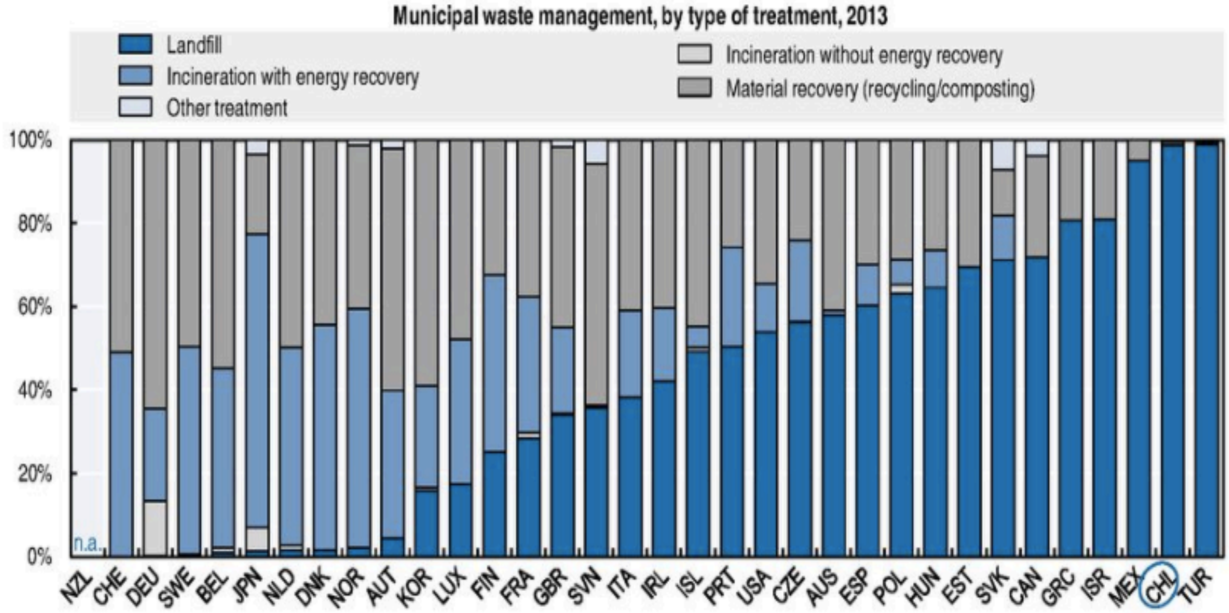


Figure 2. MSW management, by type of treatment, 2013
OECD Environment Statistics database (2015)

1.2 Collection, transport and final disposal of MSW in Santiago

Data from the National Institute of Statistics (INE) estimates a total population of approximately 1.6 million inhabitants for the communities of Puente Alto, Maipú, and La Florida in 2016 (INE, 2016). These three municipalities are responsible for nearly 25% of the total waste generation within the Metropolitan Region [Figure 3], producing in 2009 more than 670,000 tons of MSW per year according to information provided by the Ministry of the Environment (MMA, 2011). There is evidence that this amount is increasing due to two reasons; the increased population density, and the increased per capita consumption due to improving living standards.

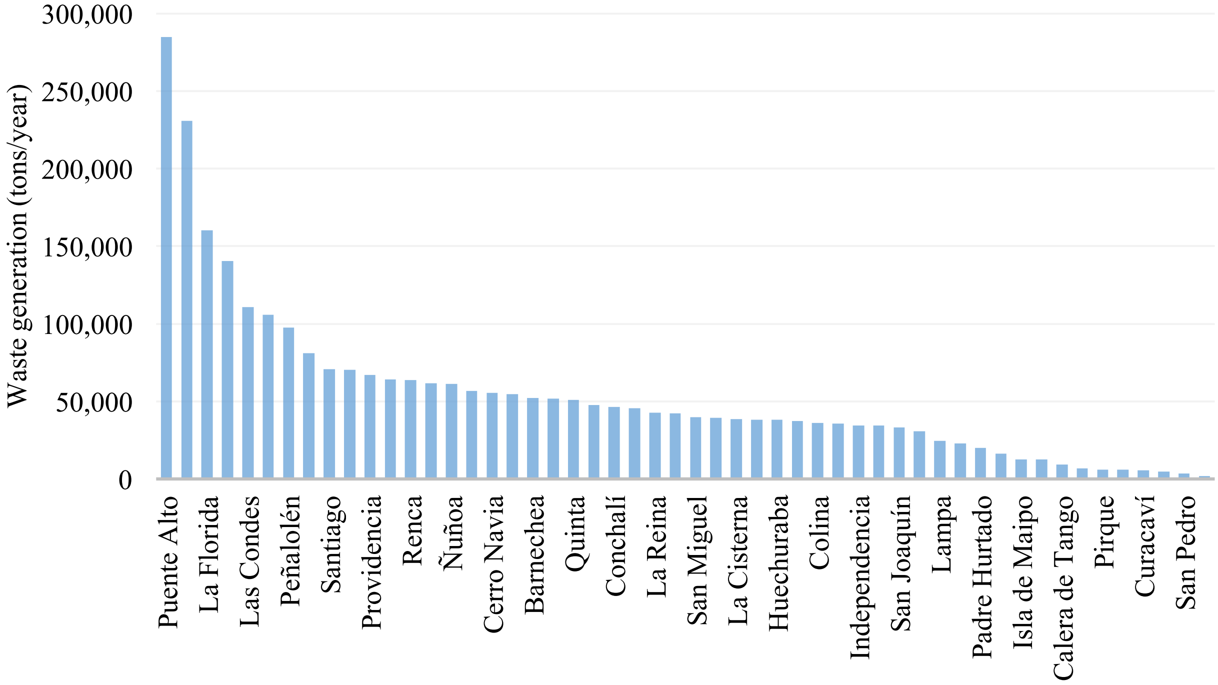


Figure 3. MSW generation per municipality

Currently, there are three sanitary landfills in the Metropolitan Region of Santiago: Loma Los Colorados (Til Til), Santiago Poniente (Maipú) and Santa Marta (San Bernardo), which comply with regulations and technical requirements for sanitary landfills, according to the SD N°189 of Ministry of Health. As stated earlier, as of 2011, 69% of the waste was dumped in sanitary landfills, 22% in landfills and 9% in garbage dumps (MMA, 2011).

The cost of final disposition of MSW in the Metropolitan Region is, on average, $18/ton, which is significantly lower than the gate fee in developed countries. This disparity in disposal costs is driven partly by compliance with strict regulations in developed countries and partly by effective local opposition to siting landfills. By contrast, developing countries have neither stringent regulatory requirements for waste disposal nor adequate enforcement efforts to ensure compliance. In addition, many less-developed countries do not have adequate disposal facilities for their own MSW (Kitt, 1995).

According to information provided by the Metropolitan Municipality in August 2015, there is a register of 40 illegal dumping sites, with plans to turn them into parks and public spaces by 2018. These places, which do not comply with any sanitary authorization, occupy a total area of 990 acres, and are all located in the municipalities of Puente Alto (8), Pudahuel (7), Quilicura (7), Lampa (5), San Bernardo (5), Buin (4) and La Pintana (4) (Salvo, 2016).

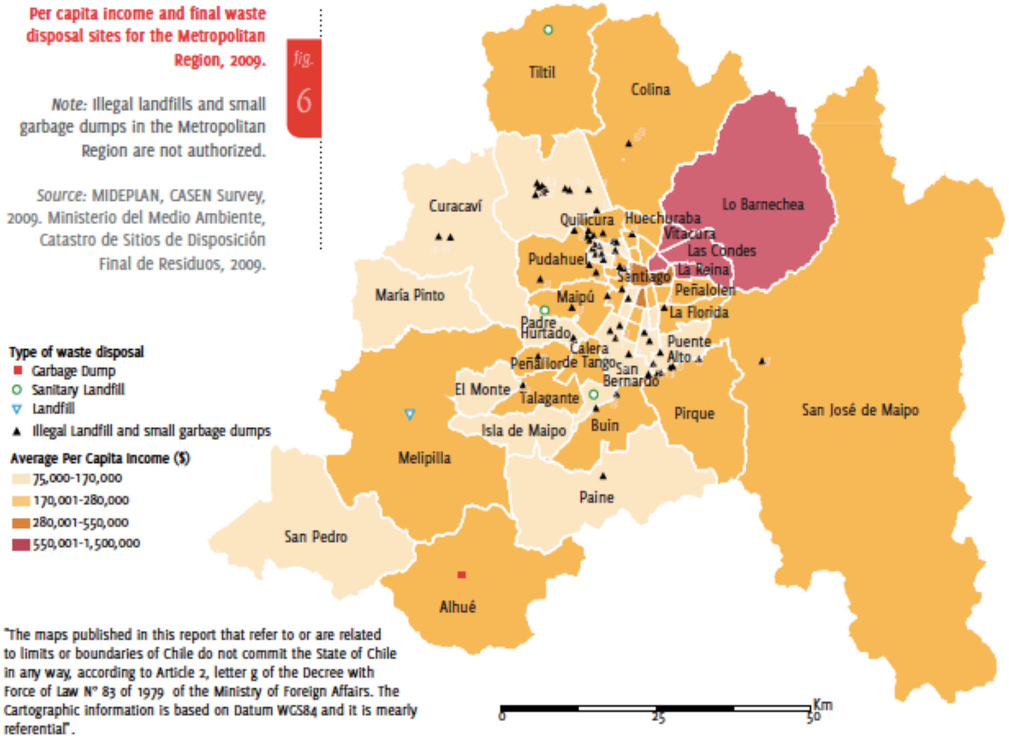


Figure 4. Per capita income and final waste disposal sites for the Metropolitan Region MMA (2009)

1.3 Status of recycling

Chile does not have incentives to reduce and reuse, and the recycling industry is not well-developed. Some municipalities charge their inhabitants for waste services, but about 80% of households in Chile are exempt from such charges. Since the costs of disposal in privately-operated landfills decrease with the volume of waste, there is no incentive to reduce landfilled waste. According the OECD Environmental Performance Review of Chile, 80% of municipalities do not have a waste management plan, and resources are insufficient to run adequate waste management programs (OECD, 2016).

In June 2016, a new Framework Law on the Management of Waste came into force, called Extended Producer Responsibility (EPR) (Law 20,920, 2016). EPR aims to make producers responsible for their environmental impact throughout the product chain, from design to end-of-life of the product. This framework reduces landfilling, increases recycling rates, and alleviates the liability of municipalities and taxpayers of final disposal (OECD, 2016).

In Europe, this system was implemented in the 90s; however, some experts say that Chile is not prepared to introduce this approach yet, since very strict monitoring and controls are required, as well as developed markets for recyclable materials and a competitive cost structure (MMA, 2016). Chile has set the goal of increasing the recycling rate from 10% to over 30%. The MMA will also establish targets to recover products such as lubricant oils, electronics, packaging, batteries, and tires.

Even considering a most ambitious recycling scenario of 40%, there would be at least 1.7 million tons of post-recycled MSW available in the entire Metropolitan Region that could become fuel for a WTE in Santiago, as noted in Figure 5.

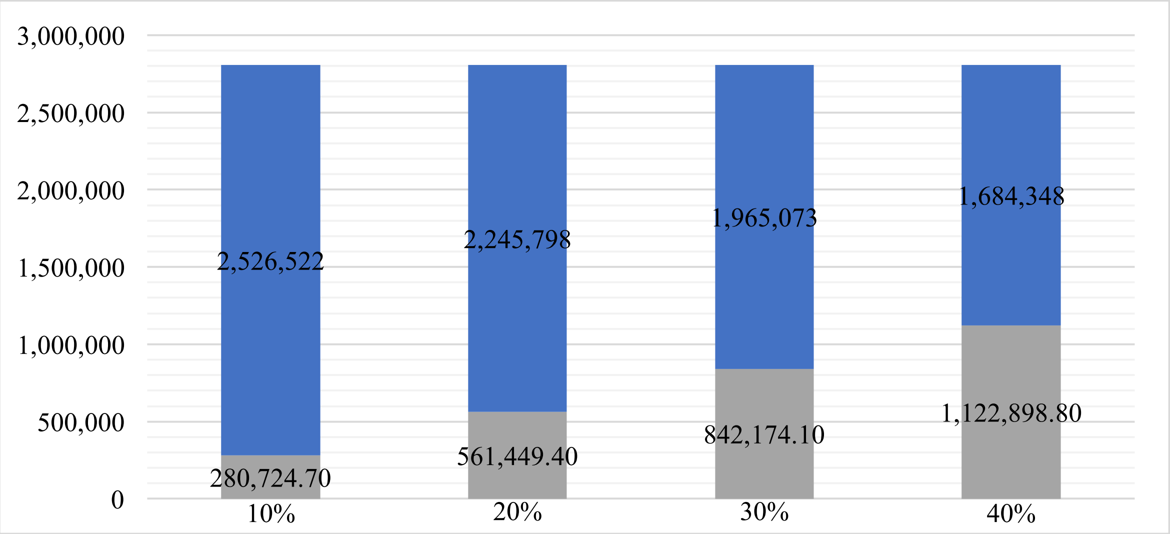


Figure 5. Availability of Post-Recycled MSW in the Metropolitan Region versus Recycling Targets

2. The Energy Sector in Chile

2.1 Current status of energy generation in Chile

The main electrical systems in Chile are the Central Interconnected System (SIC- Sistema Interconectado Central) and the Large Northern Interconnected System (SING- Sistema Interconectado del Norte Grande), which represent 99% of the total installed capacity in the country. The Aysén and Magallanes electric systems are much smaller and have several non-interconnected subsystems due to geographical isolation, which makes it very expensive to interconnect with the SIC (Central Energía, 2015).

The SIC grid supplies power to central Chile, the most densely-populated region. This system has an installed capacity of 15.2 GW (20 GW is the combined installed capacity of SIC-SING) and a total load of 52.9 TWh (72 TWh is the total combined load for SIC-SING). Currently, 51% of the installed capacity is due to thermal power plants (mainly coal, natural gas and oil), 40% hydro, 5% wind and 4% solar (CDEC SIC, 2016).

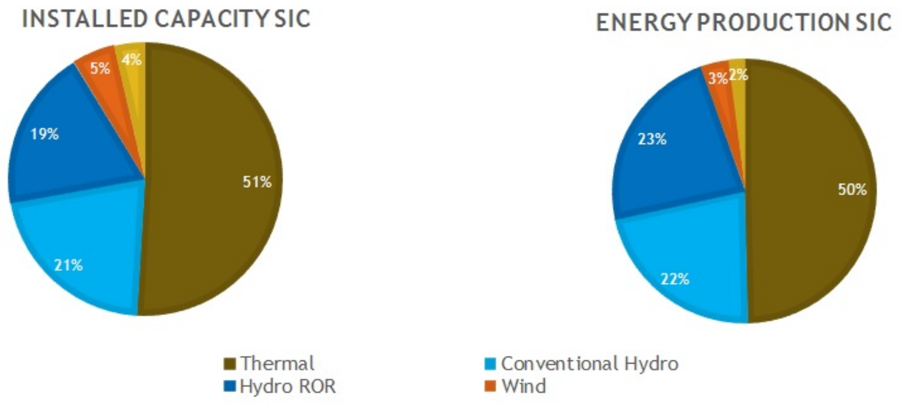


Figure 6. Installed Capacity and Energy Production SIC by technology
CDEC-SIC (2016)

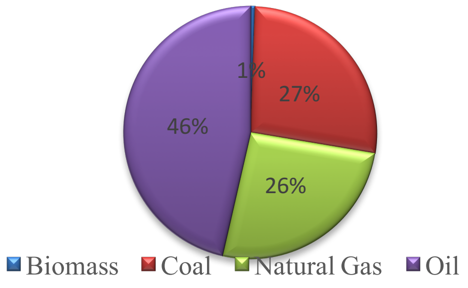


Figure 7. Thermal electricity by type of fuel
CDEC-SIC (2016)

2.2 Chile’s contribution towards the Climate Agreement in Paris 2015

According to the United Nations Framework Convention on Climate Change (UNFCC), each Party of the Paris Agreement shall prepare, communicate, and maintain domestic mitigation measures with the aim of achieving the objective of the contributions. The Intended Nationally Determined Contribution (INDC) of Chile was published in September 2015 as an expression of interest to address climate change.

The INDC is committed to a quantified reduction of 30% of GHGs emissions by 2030, relative to 2007, and by 45% if international support is received. Energy is one of the priority sectors for mitigation in Chile, including both generation and distribution of electricity. Transportation, industry, mining, and buildings are other major fossil fuel consuming sectors (UNFCCC,2016).

The Energy Agenda 2014 includes targets such as: 30% reduction in the marginal costs of electricity by 2018, 20% of the energy matrix consisting of non-conventional renewable energies by 2025, a 20% reduction in the energy consumption forecast by 2025, and the design of a long-term energy development strategy (Ministry of Energy, 2014).

2.3 Incentives for the production of energy from non-conventional sources

The Ministry of the Environment of Chile does neither directly fund, nor confer subsidies to, environmentally friendly projects. However, this institution manages the *Environmental Protection* fund (FPA), established under the law N 19,300. This aims to support citizen initiatives, and provides total or partial funding to projects whose goals are to: protect the environment, promote sustainable development, preserve nature, or conserve the environment (MMA, 2016).

The Chilean Economic Development Agency (CORFO) provides support for innovation and marketing activities related to technologies that partially satisfy the energy demand of an entity or industry through non-conventional energy sources. The fund co-finances 50% of the capital investment of a project, up to $750,000 (CORFO, 2016).

In addition, the 2014 tax reform includes a tax on emissions of local air pollutants and CO_2 from large stationary sources. This tax aims to promote clean energy sources and discourage contaminating activities, such as electricity generation from fossil fuels. The tax rate of $5 per ton of CO_2 is relatively low compared with most other OECD members, and is expected to increase progressively (OECD, 2016).

For the purposes of this study, subsidies from the government will not be considered, which means that 100% of the project will be privately owned.

2.4 Waste-to-Energy versus Garbage Incinerators

The United States Environmental Protection Agency (EPA) developed the non-hazardous materials and waste management hierarchy, which ranks waste management strategies from the most to the least environmentally preferred. The hierarchy places emphasis on reducing, reusing, and recycling as key to sustainable materials management, followed by energy recovery, with disposal at the tip of the pyramid (EPA, 2015).

Energy recovery from waste is the conversion of non-recyclable waste materials into usable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolysis, anaerobic digestion and landfill gas recovery. This process is often called Waste to Energy (WTE) (EPA,2016).

Waste incineration is an uncontrolled process of combustion without energy recovery - an obsolete technique to reduce the volume of waste requiring disposal. On the other hand, modern Waste-to-Energy facilities generate more than 14 billion kWh of renewable electricity worldwide; using fuel that otherwise would be buried. According to the Energy Recovery Council, some of the benefits of this technology in the three areas of the sustainability are:

- Net reductions of greenhouse gas emissions for every ton of MSW processed. The World Economic Forum, the EPA, the European Union, and the IPCC all view WTE as a mechanism to mitigate climate change. It is estimated that every ton of MSW processed by WTE facilities reduces 1 ton of CO_2-e.
- The electricity generation of 1 MWh in WTE facilities emits less CO2 than burning fossil fuels, including natural gas (EPA,2016).
- WTE pollution control systems have become so advanced that the most common and dangerous toxins once produced have been almost completely eliminated.
- Encourages the development of recycling markets for ferrous and non-ferrous metals that would otherwise have been buried in landfills.
- Recycling and WTE are complementary. For example, Germany, the Netherlands, Austria, Belgium, and Sweden have the highest recycling rates in Europe and have reduced their dependence on landfills to 1 percent or below of waste disposal.
- The WTE sector is comprised of well-paying jobs, prioritizes local employment, and employs a highly-trained workforce dedicated to health and safety.
- WTE can be located near the center of waste generation, thereby reducing the costs of the waste transportation.

3. Cost-Benefit Analysis for a Waste-to-Energy Plant in Santiago

3.1 Description of the project

This project aims to assess the viability of the usage of post-recycled materials as a source of energy for a Waste-to-Energy plant, which is the only proven alternative to landfilling, as implied by the waste management hierarchy.

Table 1 presents the results of two previous case studies of energy recovery in Chile, the first developed 10 years ago for Santiago (Estevez, 2006), and the second, a case study of Valparaiso in 2013 (Themelis et al., 2013). The Earth Engineering Center of Columbia University has identified a less costly technology than those traditionally used, while a greater capacity of generation allows taking advantage of the economies of scale.

Table 1. Comparison between different cost-benefit analyses of WTE plants in Chile

Category	**Santiago 2006**[1]	**Valparaíso 2013**[2]	**2016**[3]
Municipalities	La Florida/Puente Alto	Valparaíso/Viña del Mar	Metropolitan Region
Population (habitants)	1 million	1 million	7.2 million
MSW generated (ton/year)	288,000	379,513	2.9 million
Installed Capacity (tons/year)	330,000	336,000	1,000,000
Calorific value MSW (MJ/kg)	9.5	9.4	8.73
Electricity production (kWh/ton)	600	540	650
Gate fee ($US/ton)	14	14	18
Area (m2)	60,000	50,000	100,000
Land cost ($US/m2)	34	13	53
Capital cost ($US/ton of installed capacity)	260	670	300
Operating costs ($US/ton of installed capacity)	16	39	12
Electricity price ($US/MWh)	75.4	90-207	50

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[1] The study considers an exchange rate of CLP/USD = 530

[2] Calorific value based on data from 2001. It is assumed a PPA contract, which is substantially lower than the electricity spot price, but constant along the time.

[3] This study considers an average currency exchange rate of CLP/USD = 677 (Dec 2016).

3.1.1 Technology

There are several combustion technologies that have been developed for energy recovery from MSW. About 80% of the WTE capacity in the world is based on the "grate combustion" technology, because its simplicity of operation. Providers of grate combustion furnaces guarantee over 8,000 hours of operation in a year, that is, over 90% plant availability (Themelis et al., 2013).

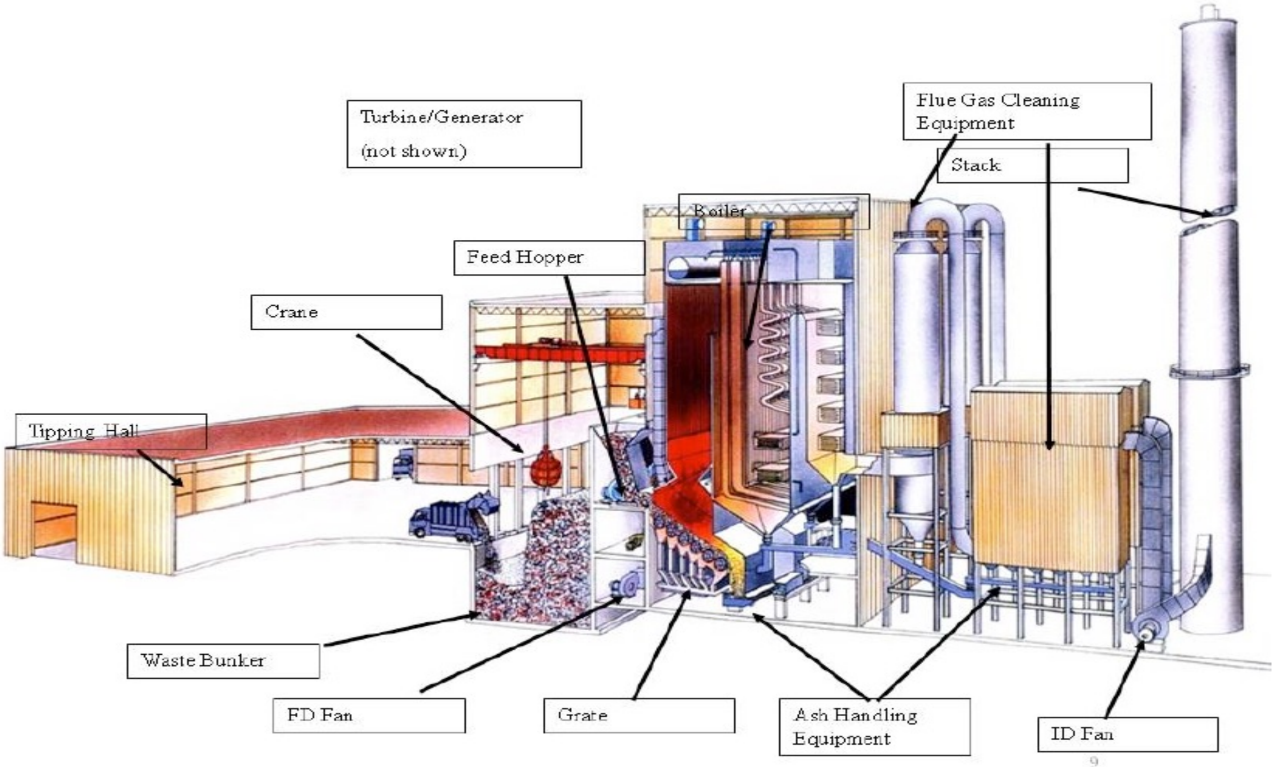

Figure 8. Parts of a WTE grate combustion plant
Earth Engineering Center, Columbia University (2013)

In the moving grate WTE, the solid waste is discharged from the collection vehicles into the waste bunker in a fully enclosed building. The cranes load the solids into the feed hopper, and a ram feeder moves the wastes onto the moving grate. Primary combustion air passes from below the grate underneath the burning solids and flow through the waste bed into the freeboard zone above the bed. Secondary and tertiary air injection ports are used to ensure complete combustion of the gas phase components volatilized from the solid waste (WSP Group, 2013). The heat contained in the combustion gases is transferred, through the water-cooled furnace water wall and super heater tubes, to the high-pressure steam that drives the turbine generator.

3.1.2 Thermal Energy in MSW components

According to the Official Environment Status Report in Chile, the main component in the waste stream is food waste, followed by plastics and miscellaneous, based on data of 2009 (MMA, 2011). The calorific value of the MSW is calculated based on the waste composition and the heating value of each component.

Compared with the waste composition in 2006, the calorific value of MSW in Santiago has decreased from 9.49 MJ/kg to 8.73 MJ/kg mainly because a higher amount of miscellaneous in the waste stream, which constitutes a low contribution to the overall heating value. Compared with the waste composition in Valparaíso, even though that city has a higher amount of food waste, the presence of 1.7% more of paper and 1.4% of textiles are significant to increase the heating value of the waste stream.

Table 2. Calorific Value of MSW in Chile from different studies

		Composition (%)		
Material	**Heating Value (kJ/kg)**	**Santiago (2006)**	**Valparaíso (2013)**	**Santiago (2016)**
Food waste	4647	49.31	63.6	48
Yard waste	6506	4.83		
Plastic	32531	10.43	11.7	11
Paper	16730	10.02	11.7	10
Cardboard	16266	3.3		
Beverage and milk boxes	15800	0.72		
Rubber and leather	21387	0.11		
Textiles	17445	2.01	4.4	3
Glass	0	3.51	4.1	7
Metal	0	1.59	3.9	3
Wood	18590	0.71		
Ashes and other fines	6970	4.07		
Miscellaneous	4000	9.39	0.6	18
Total		100	100	100
Heating Value (MJ/kg)		9.49	9.51	8.73

Solid Waste Engineering, P. Vesilind, W. Worrell, D. Reinhart

3.1.3 Capacity and potential energy generation

Considering that there is at least 1.7 million tons of post-recycled MSW available in the entire Metropolitan Region that may become a source of energy for a WTE in Santiago, it is proposed a 3-line facility, able to process 3,000 tons of MSW per day (1 million tons/year). From the 13 WTE plants of this characteristics in the world, 61% are concentrated in Japan, 15% China, and the remaining in France and South Korea (Themelis et al., 2013).

The energy balance, assuming a calorific value of 8.73 MJ/kg (2.42 MWh/ton), is presented in the Table below.

Table 3. Energy balance of proposed WTE plant

Energy Input (MWh/ton of waste)		Energy lost or consumed (MWh/ton of waste)		Remaining Energy (MWh/ton of waste)	
Energy in waste	2.42	Heat losses in furnace, ash and stack gases (10%)	0.24	Energy exported to the grid	0.56
		Turbine losses (70%)	1.53		
		Plant consumption (15%)	0.10		
Total	2.42	Total	1.87	Total	0.56

Therefore, the potential energy generation of this WTE will be 556 GWh of net electricity to the grid, and an installed capacity of 69.5 MW. The mass balance, assuming that 20% of the mass input is bottom ash and 5% fly ash, is presented in Table 4.

Table 4. Mass balance of proposed WTE plant

Mass input (tons)		Mass consumed during combustion (tons)		Remaining mass (tons)	
Waste	1,000,000	Mass consumed during combustion (75%)	750,000	Bottom ash	200,000
				Fly Ash	50,000
Total	1,000,000	Total	750,000	Total	250,000

The bottom ash produced during the waste combustion can be treated using various techniques to recover ferrous and non-ferrous metals. In addition, using a wet process, sand and grit can be used for the production of sand-lime bricks and concrete. Fly ash can be used in asphalt concrete as well (WSP Group, 2013).

3.1.4 Site location

According to Article 7.2.3.3 of the Regulatory Plan Ordinance of the Metropolitan Region of Santiago (PRMS), the Thermal Treatment Plants for Household Solid Waste, may be located only in Zones of Productive Activities and/or Industrial Areas, at least 50 meters from residential neighborhoods from the outside perimeter of the plant.

In addition, it is allowed to be emplaced outside the Metropolitan Urban Area, complying with the technical - urbanistic provisions established for Landfills in Article 7.2.3.2. of the same Ordinance.

For the purposes of this study, a site will be chosen that complies with the conditions described above. This type of site should be located in sectors with greater waste generation, in order to reduce transportation costs.

The proposed boundaries to locate the plant are defined in Figure 9. In terms of land costs of areas for productive activities, the price ranges from $53 to $117 per square meter. This study will assume the minimum cost, even though the ideal scenario is to be able to build on a land granted by the government.

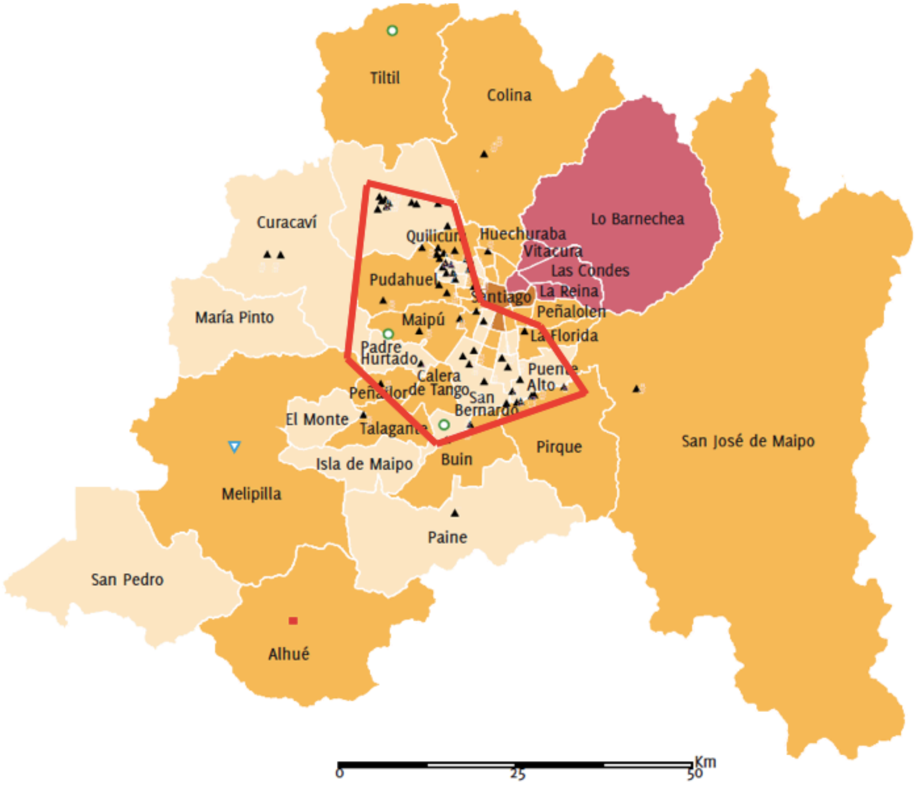

Figure 9. Proposed boundaries of WTE location

3.2 Projected WTE Plant Costs

3.2.1 Capital Costs

This item includes land plot, infrastructure (e.g. roads, buildings, air pollution control system), services, and equipment (e.g. grate, boiler, ash handling). Typically, a WTE plant may cost between $500 and $1000 per ton of annual capacity (Themelis et. al, 2013). However, plants built in China in the last ten years are less costly than the above numbers (Figure 10).

The capital cost assumed for this study is $300/ton, using the technologies developed in China, where the average capital cost is $228/ton, as shown in Figure 10 below.

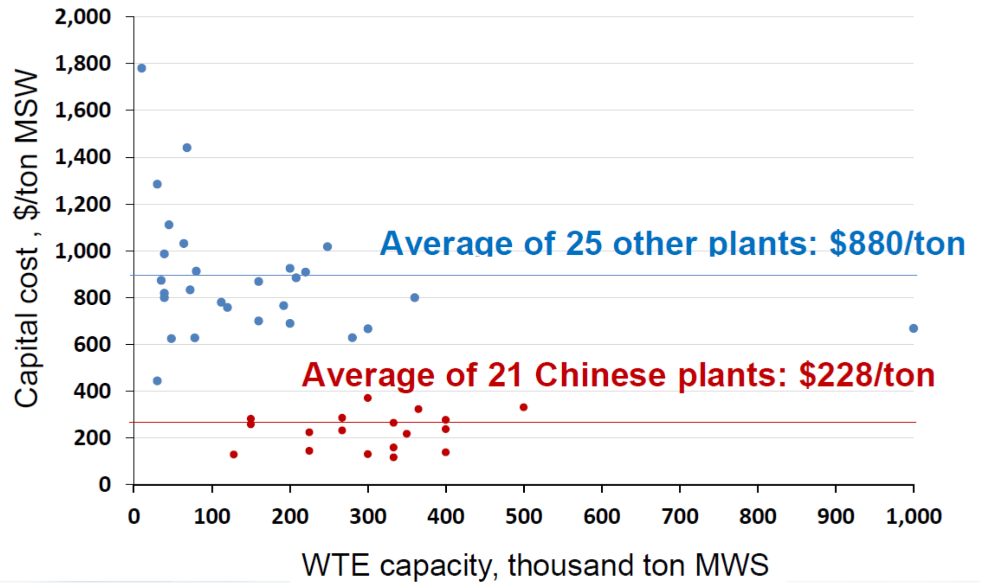

Figure 10. Capital costs of WTE plants
Earth Engineering Center, Columbia University (2015)

On the other hand, the land cost is estimated at $MM 5.3, assuming a total area of 100,000 m^2. Therefore, the total capital cost of the project will be $305,300,000.

3.2.2 Operational Costs

A facility of this size requires from 60 to 75 employees to operate the plant (Frace, 2016). Assuming 73 personnel, the breakdown of labor costs is shown in Table 5.

Table 5. Labor costs

	Number	Salary ($)
Facility manager	1	$7,385.52
Assistant manager	1	$5,908.42
Chief engineer	4	$20,679.47
Assistant engineer	4	$17,725.26
Shift supervisors	10	$14,771.05
Control room operators	8	$9,453.47
Crane operators	8	$7,090.10
Security	2	$1,181.68
Clerical Staff	10	$7,385.52
Entrance	5	$2,215.66
General workers	20	$14,771.05
Monthly labor costs		$108,567.21
Annual labor costs		$1,302,806.50

The maintenance costs comprise machinery and building maintenance. This is estimated as 3% of the investment cost per year (World Bank, 2000). Also, it will be assumed that 70% of the bottom ash (140,000 tons/year) is landfilled. The total operational costs are presented in Table 6.

Table 6. Operational Costs

Labor costs	$1,302,806
Maintenance costs	$9,000,000
Ash disposal	$2,520,000
Total operational costs	**$12,822,806**
Operational costs per ton	**$12.82**

Transportation costs are anticipated to be lower because the WTE facility is expected to be closer to the waste generation; however, for the purposes of this study it is assumed transportation costs would be comparable with the current collection system.

3.3 Projected WTE Plant Revenues

3.3.1 Gate Fees

In the Metropolitan Region, the average cost of waste disposal is $18 per ton, in a range of $12 and $45; however, the variability is very high and depends strictly on each municipality.

The average cost of waste disposal in the Municipality of La Florida is $14 per ton, which is estimated based on data provided by the Municipality, and assuming a total waste generation per capita of 0.5 tons/year (MMA, 2011).

Table 7. Costs of waste disposal in La Florida Municipality

Year	Total cost of waste disposal (CLP)	Population	Total waste generation	Cost(CLP/ton)	Cost($)/ton
2011	1,435,644,812	380,000	160,123	8,966	13
2012	1,595,899,272	383,800	182,113	8,763	13
2012	1,741,461,969	387,638	183,934	9,468	14
2014	1,889,896,392	391,514	185,773	10,173	15
2015	2,080,702,817	400,000	189,800	10,963	16

La Florida Municipality (2016)

The total costs of solid waste disposal in the Municipality of Maipú are calculated based on two companies responsible in this matter: KDM and sanitary landfill Marga-Marga. The average price has increased from $16/ton in 2013 to $17.8 in 2015.

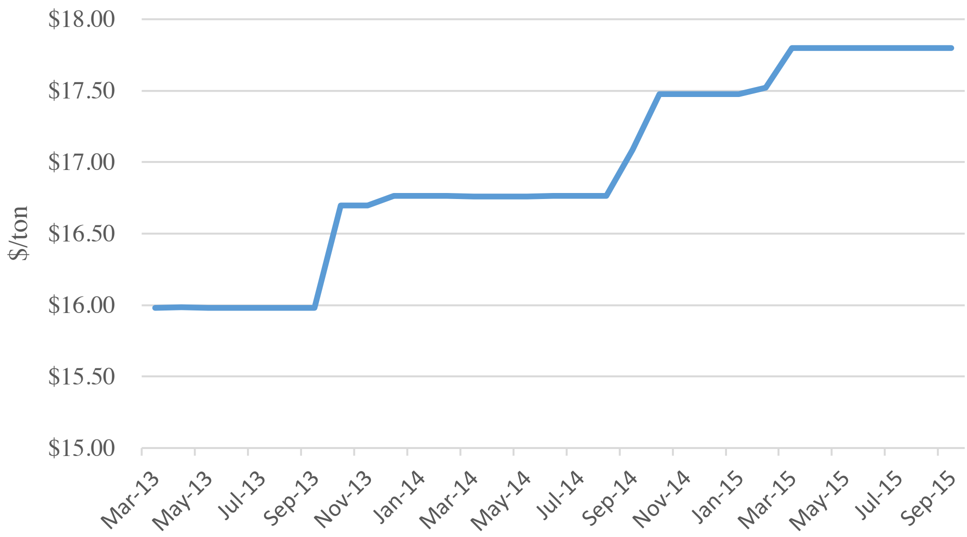

Figure 11. Total cost of solid waste disposal in Maipu
Maipu Municipality (2016)

The gate fee used for this study is \$18/ton, which each municipality will pay to the WTE plant in order to process their waste. Therefore, the annual revenue from this item would be \$MM 18.

3.3.2 Electricity Price

The average market price (PMM) of each system is determined by the average prices of the contracts reported by the generating companies to the National Energy Commission (CNE), corresponding to a four-month window, ending the third month prior to the date of publication of the PMM.

The average market price has shown high variability for the last 10 years, fluctuating between \$50 and \$130 per MWh, with an average price of \$92.3 in 2016. However, considering the goals established by the Ministry of Energy, in addition to an increase in the competitiveness of the market with the introduction of new technologies to the energy matrix, a reduction in the price of the electricity supply bids is projected. Therefore, for this study an average price of \$50 per MWh will be established.

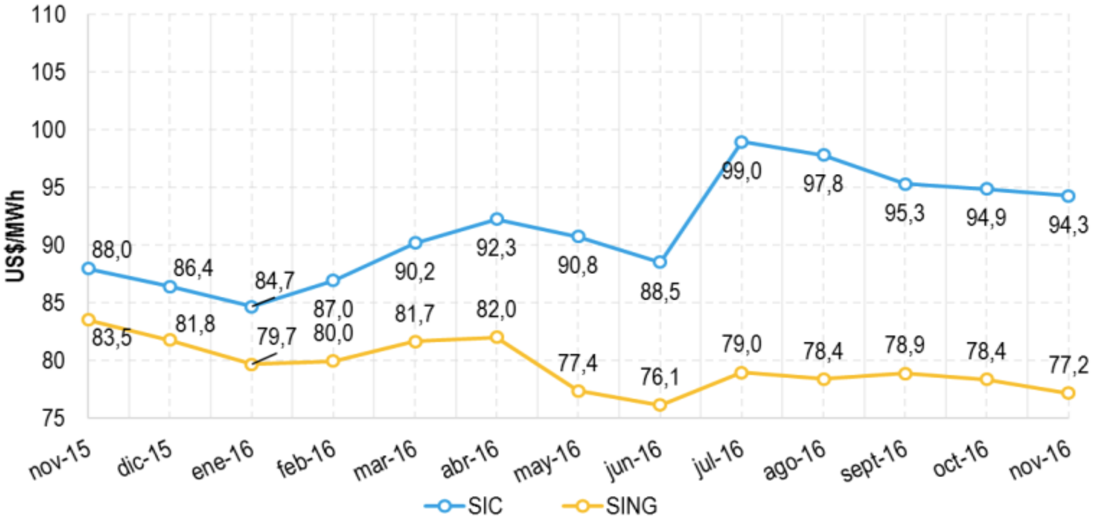

Figure 12. Average market price of SIC and SING systems
Generadoras de Chile (2016)

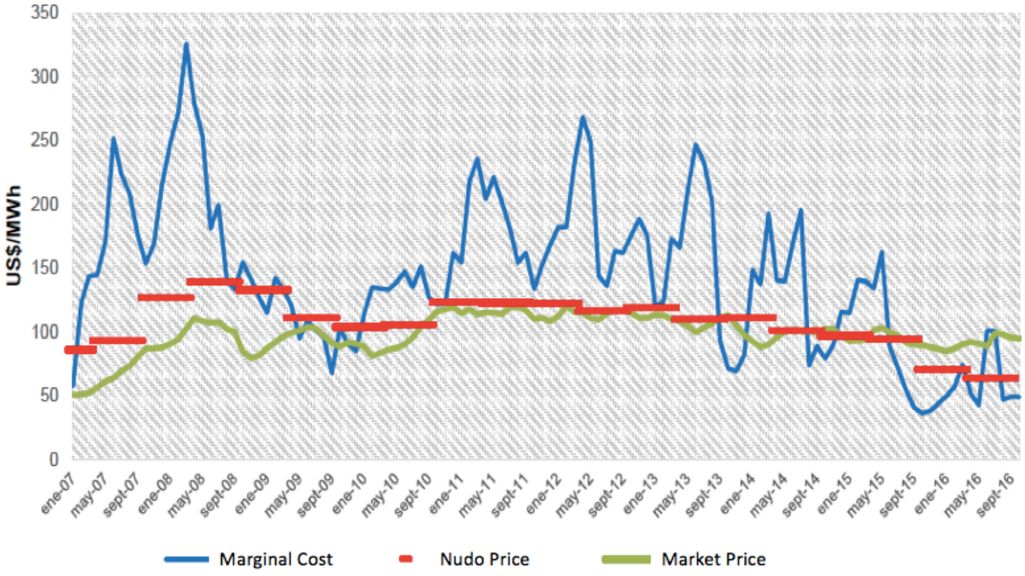

Figure 13. Average Marginal costs of SIC system
Generadoras de Chile (2016)

Since the annual electricity production of 556 GWh is assumed to be constant, the revenues from electricity would be $MM 27.8 per year.

3.3.3 Carbon Credits and Metals Recovery

The 2014 tax reform in Chile includes a tax on emissions of local air pollutants and CO_2 from large stationary sources of $5 per ton of CO2. Considering that this facility would result in the reduction of 1 million tons of CO_2 emissions per year, a revenue for carbon credits of up to U$MM 5/year is possible but not probable due to the Chilean economy's unfamiliarity with this type of reform. Metals recovery is not expected to be a major source of revenue. Therefore, for the purposes of this study, the revenues from carbon credits and metals recovery will not be considered.

4. Financial Analysis

Table 8 summarizes the financial modeling inputs of this project. Equity was assumed to constitute 20% of the investment costs, while 80% was paid with a loan at a 5% interest rate for 10 years. The payment of the loan is detailed in Table 9. The total capital expenses were considered using linear depreciation for 10 years.

Using these inputs in a financial model, the Net Present Value (NPV) of this project was calculated to be $31,891,334 with an Interest Rate of Return (IRR) of 11.76%. The details of the financial analysis are in the Appendix.

Table 8. Financial modeling inputs

TOTAL INVESTMENT ($)	305,300,000
OPERATIONAL COSTS ($/year)	12,822,806
ANNUAL PRODUCTION (MWh/ton)	0.56
ELECTRICITY PRICE ($/MWh)	50
EQUITY ($)	61,060,000
DEBT ($)	244,240,000
SUBSIDIES(%)	0
DEBT INTEREST RATE	5.00%
INFLATION	0.00%
DISCOUNT RATE	8%
INCOME TAX	27.00%

Table 9. Debt Payment

YEAR	1	2	3	4	5	6	7	8	9	10
ANNUAL DEBT PAYMENT (MM$)	-31.6	-31.6	-31.6	-31.6	-31.6	-31.6	-31.6	-31.6	-31.6	-31.6
INTEREST (MM$)	-12.2	-11.2	-10.2	-9.1	-8.0	-6.8	-5.8	-4.3	-2.9	-1.5
DEBT BALANCE (MM$)	225	204	183	161	137	112	86	59	30	0

5. Sensitivity Analysis

It was determined that this project remains profitable up to a capital cost of $337 per ton of annual capacity. In addition, analysis of NPV was conducted for different electricity prices and gate fees, and calculated break-even points of $42/MWh for electricity (Figure 13) and $13.5 per ton for gate fees, respectively (Figure 14).

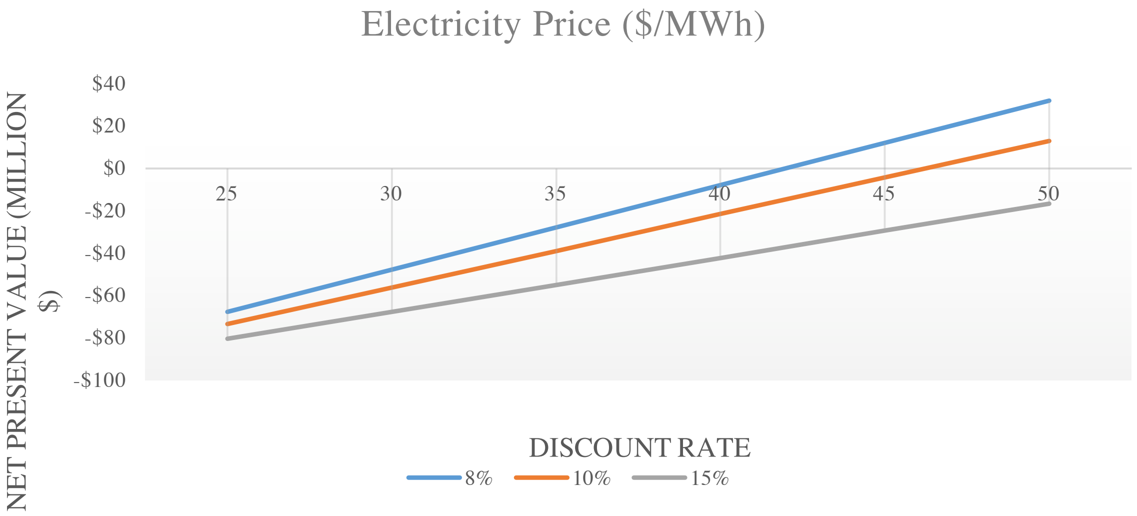

Figure 14. Net Present Value for varying price of electricity

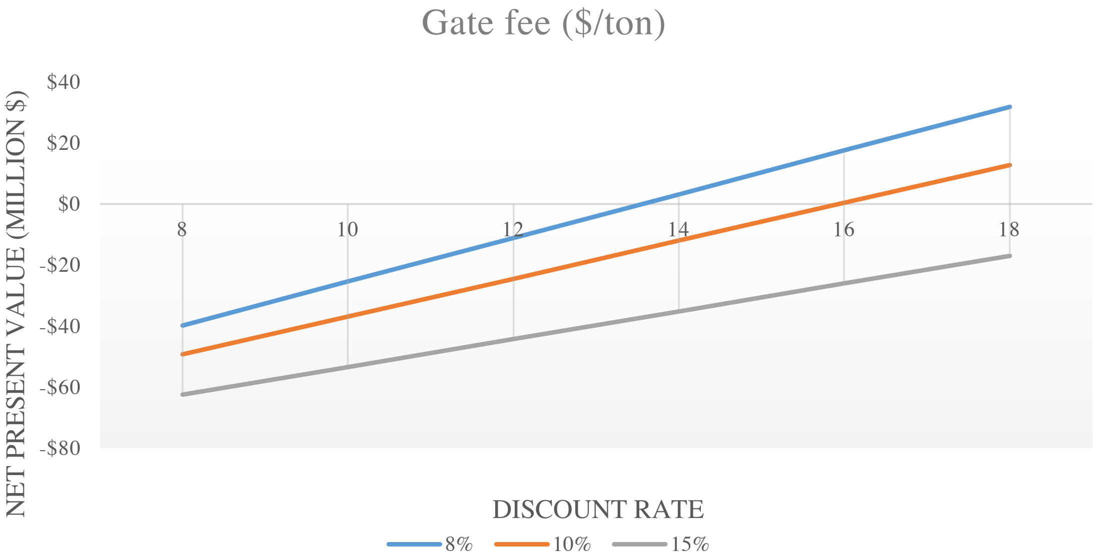

Figure 15. Net Present Value for varying gate fee

The minimum amount of waste processed per year must be 903,000 tons (Figure 15), with a minimum heating value of 7.3 MJ/kg (Figure 16) in order to make the project profitable.

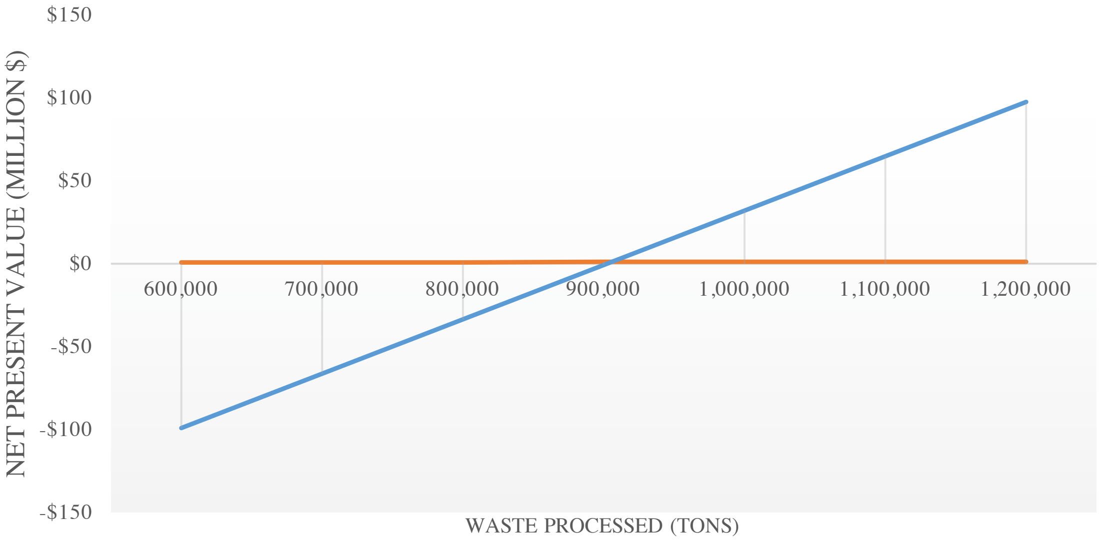

Figure 16. Net Present Value for varying waste processed

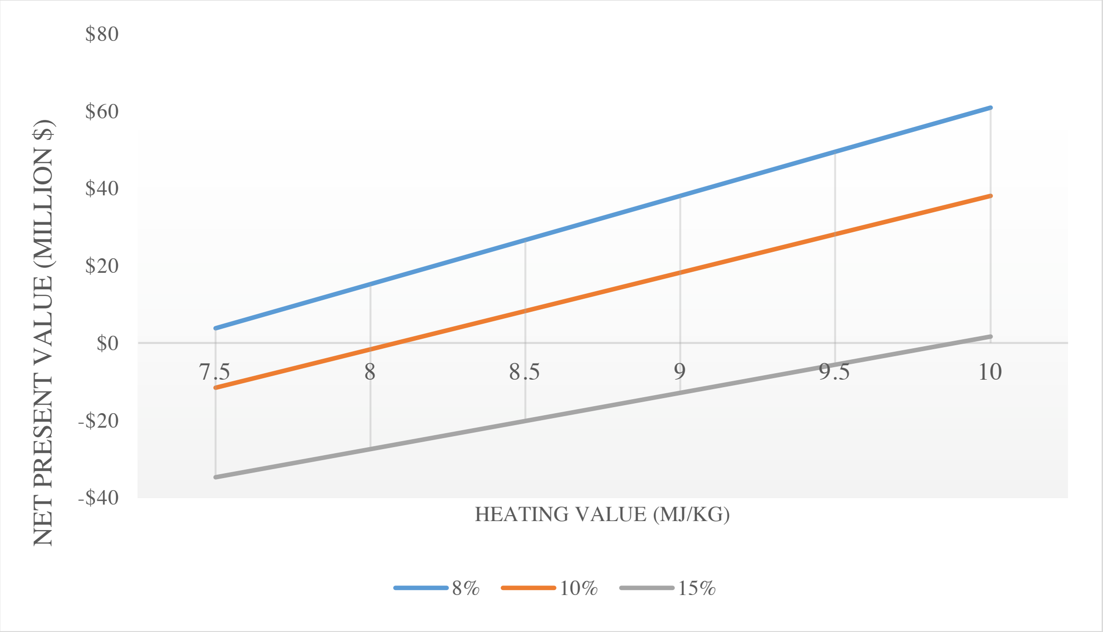

Figure 17. Net Present Value for varying heating value

6. Conclusions and Recommendations

The results of this study indicate that there has been little progress in waste management in Santiago in the last 10 years. Chile is at the bottom of OECD countries in waste treatment since the country has neither the technology nor the infrastructure for the recovery of materials and energy.

In the community there is much misinformation regarding the energy recovery technologies that are widely used in developed countries. This is unfortunate as the familiar old incinerators that were known for their high pollution and environmental impact have been replaced by modern Waste-to-Energy facilities that have very advanced pollution control systems and generate more than 14 billion kWh of renewable electricity worldwide.

The new Framework Law on the Management of Waste that entered into force in June 2016, known as Extended Producer Responsibility, aims to reduce landfilling and increase recycling rates. Based on different recycling targets, it is estimated that this proposed 3-line facility could process up to 1 million tons per year. This would reduce by 60% the waste generated in the Metropolitan Region that otherwise would be buried in landfills, assuming the most ambitious recycling scenario of 40%.

The cost-benefit analysis of building a Waste-to-Energy facility in Santiago was conducted, and the capital cost was estimated to be $305MM. This facility would be privately owned, with a capital structure of 20% equity and 80% debt, paid at a 5% interest rate for 10 years.

This project has been proven to be feasible with a NPV of $31MM and an IRR of 11.76%, based on reasonable expenses and less-than-favorable assumptions; potential profit streams such as carbon credits, metals recovery, and lower transportation costs have been ignored.

It was determined that this project remains profitable up to a capital cost of $337 per ton of annual capacity. In addition, analysis of NPV was conducted for different electricity prices and gate fees, resulting in break-even points of $42/MWh for electricity, and $13.5 per ton for gate fees, respectively. In addition, it was estimated that a minimum amount of waste processed per year of 903,000 tons is required, with a minimum heating value of 7.3 MJ/kg, in order to make the project profitable.

As for recommendations, first it is necessary to expand the culture of reuse, reduce and recycle in the society. In addition, it is imperative to inform and educate the community and policy-makers about the benefits of energy recovery technologies, and the important role that they could play in the sustainable management of waste.

Secondly, it is recommended to maintain an updated database in order to make accurate estimations regarding waste management. This information should include, among other things: amount of waste generation per municipality annually, and costs of collection, transportation and disposal. In addition, with the new initiatives, it will be essential to have a record of recycling and composting rates.

Finally, it is suggested that a more detailed study of the ideal location of this plant be made, considering several parameters crucial to its construction. As an example, a 10 hectares plot that complies with the necessary regulations, that is in the vicinity of an in-service substation, and that minimizes total transportation costs, would be optimal.

7. Appendix

Table 10. Cash flow of a Waste-to-Energy Plant in Santiago, Chile

YEAR	1	2	3	4	5	6	7	8	9	10
PLANT CAPACITY (million tons/year)	1	1	1	1	1	1	1	1	1	1
GATE FEE ($/ton)	18	18	18	18	18	18	18	18	18	18
GATE FEE REVENUES (MM$)	18	18	18	18	18	18	18	18	18	18
ANNUAL PRODUCTION (MWh)	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556
ELECTRICITY PRICE ($/MWh)	50	50	50	50	50	50	50	50	50	50
CARBON CREDITS	0	0	0	0	0	0	0	0	0	0
METALS RECOVERY	0	0	0	0	0	0	0	0	0	0
REVENUES (MM$) [1]	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**	**45.81**
OPERATIONAL COSTS (MM$) [2]	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82
EBITDA [1-2= 3]	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**
DEPRECIATION (MM$) [4]	30	30	30	30	30	30	30	30	30	30
INTEREST (MM$) [5]	12.21	11.24	10.22	9.15	8.03	6.85	5.61	4.31	2.94	1.51
PROFIT BEFORE TAXES (MM$) [3-4-5]	**-9.22**	**-8.25**	**-7.23**	**-6.16**	**-5.04**	**-3.86**	**-2.62**	**-1.32**	**0.05**	**1.48**
TAXES (MM$)	2.49	2.23	1.95	1.66	1.36	1.04	0.71	0.36	-0.01	-0.40
PROFIT AFTER TAXES (MM$)	**-6.73**	**-6.02**	**-5.28**	**-4.50**	**-3.68**	**-2.82**	**-1.91**	**-0.96**	**0.04**	**1.08**
DEPRECIATION (MM$) (+)	30	30	30	30	30	30	30	30	30	30
AMORTIZATION (MM$)	-19.4	-20.3	-21.4	-22.4	-23.0	-24.7	-26.0	-27.3	-28.69	-30.12
ANNUAL NET CAPITAL INCOME (MM$)	**3.85**	**3.59**	**3.31**	**3.02**	**2.72**	**2.40**	**2.07**	**1.71**	**1.35**	**0.96**

YEAR	11	12	13	14	15	16	17	18	19	20
PLANT CAPACITY (million tons/year)	1	1	1	1	1	1	1	1	1	1
GATE FEE ($/ton)	18	18	18	18	18	18	18	18	18	18
GATE FEE REVENUES (MM$)	18	18	18	18	18	18	18	18	18	18
ANNUAL PRODUCTION (MWh)	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556
ELECTRICITY PRICE ($/MWh)	50	50	50	50	50	50	50	50	50	50
CARBON CREDITS	0	0	0	0	0	0	0	0	0	0
METALS RECOVERY	0	0	0	0	0	0	0	0	0	0
REVENUES (MM$) [1]	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**	**45.8**
OPERATIONAL COSTS (MM$) [2]	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
EBITDA [1-2= 3]	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**	**32.9**
DEPRECIATION (MM$)(-)										
INTEREST (MM$)										
PROFIT BEFORE TAXES (MM$)	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**	**32.99**
TAXES (MM$)	-8.91	-8.91	-8.91	-8.91	-8.91	-8.91	-8.91	-8.91	-8.91	-8.91
PROFIT AFTER TAXES (MM$)	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**
DEPRECIATION (MM$) (+)	0	0	0	0	0	0	0	0	0	0
AMORTIZATION (MM$)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL NET CAPITAL INCOME (MM$)	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**	**24.08**

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