A Guidebook for Sustainable Waste Management in Latin America

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Economic development and growth of urban population in Latin America have resulted in the generation of an increasing amount of municipal solid waste (MSW) that is surpassing the existing capacity of sanitary landfills. This situation has led local and national governments to evaluate alternative options for diverting MSW from landfills. Waste-to-energy (WTE) become the preferred choice for managing post-recycling wastes in many E.U. countries, Japan, several cities in the U.S., and increasingly in China. However, the high investment cost of this technology, and also the need for better information and communication with the population regarding the environmental impacts of WTE, have impeded the development of WTE in Latin America. The objective of the Earth Engineering Center Guidebook, discussed in this paper was to introduce the reader to the current state of knowledge and application of various waste management methods and present three preliminary feasibility studies of advancing waste management in three Latin America cities: Valparaiso (Chile) Toluca (Mexico), and Buenos Aires (Argentina). Only the first two case studies are discussed in this paper. All three cases are described in detail in the EEC Guidebook, which is available to the public on the web. It is hoped that the data and information derived in this study will enable policymakers and MSW managers in Latin America to make better-informed decisions regarding the feasibility of including thermal treatment of MSW in their plans for advancing sustainable waste management.

1. Introduction

Economic development and rapid growth of urban population have resulted in the generation of enormous quantities of municipal solid waste (MSW) that cannot, any longer, be disposed of in the makeshift landfills of yesteryear. This has led the E.U., U.S. and other developed nations to adopt the so-called *hierarchy of waste management* that gives priority to waste reduction, recycling, composting and waste-to-energy (WTE) over landfilling. Sanitary landfills protect surface and groundwater and reduce greenhouse gas (GHG) emissions to the atmosphere so they are preferable to non-regulated landfills. However, it has been estimated that only twenty percent of the global landfills are sanitary [5, 15, 23].

Sustainable waste management is a critical part of sustainable development and it has become increasingly important in the urban environmental agenda of cities and nations in the Latin America and Caribbean region (Latin America). Although considerable effort have been directed towards increasing recycling rates, i.e., the recovery of materials from MSW, international experience has shown that after all feasible recycling has been done, there remains a large fraction of solid waste that must be treated thermally to recover its energy content [5, 23, 24].

At the request of Inter-American Development Bank, the Earth Engineering Center compiled a 275-page waste management Guidebook that is now available on the web. This publication included the results of three case studies of what may be the first WTE plants in Argentina, Chile, and Mexico. These studies followed the methodology proposed in the Guidebook for planning and executing an improved waste management system that includes formal and informal recycling and waste-to-energy [5]. This paper presents the two of the three case studies in Toluca Mexico and Valparaiso Chile.

2. Planning for and building a WTE plant

WTE plants require a large investment and should be as low-risk as possible. The methodology and required steps for planning and building an energy recovery from wastes plant are based on the application of a widely proven technology: Combustion of as-received MSW on a moving grate with energy recovery (Figure 1). The applicability of the implementation is very important, especially for the costs side. The incineration investment costs are between 500 - 1.000 USD/ton of waste (and up to 2.000 USD/ton for small scale plants as indicated in a World Bank study [23]), thus resulting in capital charges for MSW processed ranging from 50-100 USD/ton. The operating costs are 20-60 USD per ton per ton and must be added to the investment cost. Subtracting the revenue from the sale of electricity produced (estimated at USD forty to seventy per ton of MSW), results in a net cost of the municipality that is substantially higher than the average cost of landfilling in Latin America which is less than 30 USD/ton [5, 23, 24].

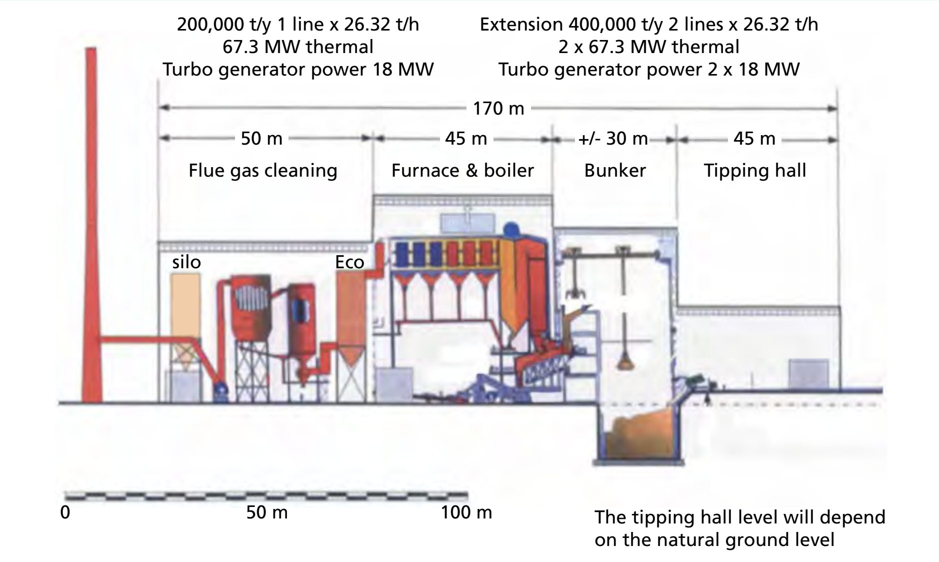

Figure 1: Layout elevation view of a grate combustion WTE (Earth Engineering Center)

Source: Themelis, N.J.; Diaz Barriga, M.E.; Estevez, P.; Velasco, M.G.; Guidebook for the application of Waste-To-Energy technologies in Latin America and the Caribbean, EEC/IDB 2013, http://www.seas.columbia.edu/earth/wtert/pressreleases/Guidebook_WTE_v5_July25_2013.pdf

The affordability of a WTE plant is related with the willingness to pay which is usually correlated with the average income of the citizens or at least with the GDP/capita, on a purchasing power basis (PPP). The average affordability threshold used internationally lies between 0.2 to 0.5 percent of the GDP/capita. Assuming an average gate fee for a WTE plant of 50 USD/ton, corresponding to forty percent of the overall waste management cost (including collection, transportation, recycling and disposal), and per capita waste generation of 350 kilogram per year, WTE plants will be more affordable in areas, where the GDP is over 10,500 USD/capita [5].

International experience has shown that economies of scale dictate that in order for a WTE plant to be viable should have a high capacity, and a lower heating value (LHV) above 6 MJ/kg. The costs of the WTE plans for various capacities in the form of gate fees (including both financing and operating costs) are extremely high for capacities lower than 300 kton per year, according to a study by DEFRA 2013 [6]. The same study shows that the cost benefits of increasing facility scale begin to reduce above 400 ktn per year. Based on the above it is concluded that the WTE plants capacities should not be below 150 to 200 ktn per year in order to be financially feasible [5, 6, 15, 23, 24].

Another important consideration is the composition and LHV of the MSW in a particular region. The high organic content, which usually appears in lower GDP/capita regions generally means very dense waste, high moisture content and reduced heating values, as opposed to relatively light waste with low organic content in the higher income countries.

This aspect should also be taken into account, when deciding on the possibility to develop WTE plants as it has negative impacts on the WTE plant economics. The waste collection should be well organized and waste pretreatment would increase the calorific value of the waste that will enter the WTE plants. In this way, the financial performance of the WTE plant may be significantly improved [5, 6, 15, 23].

The energy produced and utilized is a very critical parameter. The WTE plant produces electricity that requires electricity grid able to transfer the produced energy; otherwise, the implementation of a very expensive WTE plant cannot be justified. If the utilization of electricity is combined with the utilization of the thermal energy produced, then the energy absorption becomes even higher. Considering the fact that district heating networks are not common in Latin America and Caribbean countries, the only end users of the heat may be heat-consuming industries. Therefore, it is preferable for the WTE plants to be close to industrial areas in order to increase the opportunity of absorption of the heat produced [6, 15, 23].

3. Waste management in Latin America

According to the latest data, 79 percent of the Latin America population lives in cities. There are 51 cities with over one million inhabitants, 14 of them in Brazil. There are four megacities (Mexico City, Sao Paulo, Rio de Janeiro, Buenos Aires and Lima) with populations of several million. From 2002 to 2010, the urban population increased by nearly 63 million and the per capita GDP by 23 percent. Urban areas are a symbiosis of extreme wealth and extreme poverty, while allowing for the rise of a new middle class. It is estimated that by 2050, the Latin America population will increase by forty percent to over 650 million [9, 25].

A characteristic of waste management in Latin America population is the informal recycling sector. The catadores in Brazil, the pepenadores in Mexico, and the cartoneros in Argentina are examples of this sector that reduces the amount of MSW landfilled. The Inter-American Development Bank (IDB) has estimated that this sector engages somewhere between 500,000 and 3.8 million people. An important characteristic of the informal sector is its hostile attitude against any potential change that may affect their jobs. It is therefore important for any new WTE plan to include means by which the existing informal recycling can be included in the plan [9, 24].

Despite the potential threat to water supplies, nearly 50 percent of the waste generated in LA is disposed of in non-regulated landfills. MSW generation is related directly to economic development. Empirical evidence has shown [5] that a 1 percent increase in the gross domestic product per capita creates a 0.69 percent increase in waste generation. An example of this is Brazil, where in 2010 there was a six percent increase in MSW generation [9, 24, 25]. Another important factor for WTE in LA is that the demand for electricity by 2030 is projected to increase to 2,500 TWh, up from about 1,150 TWh in 2008 [9, 25]. This would require an estimated investment of 430 USD billion. Some of which could be used toward WTE electricity, part of which qualifies as renewable energy [24].

4. Case studies

The case studies to be discussed in this paper are Valparaiso Region, Chile and city of Toluca, Mexico. The thermal treatment technology selected was combustion on a moving grate because it is the most widely used WTE technology. The case studies developed the kind of information needed for all such projects, including quality and quantity of MSW, current status of MSW management system, projected capital and operating costs, sources of revenue, and calculations of the net present value (NPV) and internal rate of return (IRR).

4.1. Valparaiso, Chile

Chile is an emerging economy with a population of 17 million and a per capita income of about 12,000 USD in current dollars and 15,000 USD, in terms of purchasing power parity (PPP). Chile is one of the world's most open economies and its total foreign trade accounts for 67 percent of its GDP. Chile has experienced tremendous economic growth in the last 25 years, vastly improving the standard of living of its population. As usual, this growth was coupled to the increase of significant and uncontrolled amounts of waste, creating many environmental and social costs that need to be addressed. The solid waste management system of most regions of Chile is clearly unsustainable and faces important political, geographical, and environmental challenges. Therefore, there is an urgent need to investigate new solid waste management technologies such as WTE. In a *sustainable development* approach, wastes are considered as a resource for recovery of materials and energy and not simply as a disposal problem [9, 24, 25].

In Chile, municipalities are responsible for the collection, transport and final disposal of MSW. Most municipalities contract waste management services out to the private sector by bidding openly for the collection and disposal services. The rest have their own collection system and disposal facilities, which in many cases are very inefficient. Each municipality acts independently and negotiates its own price; consequently there is no fixed price for this service, and the municipalities charge citizens for the collection and disposal waste costs through a *property tax*. There is a pressing need to solve sanitary problems related to improper waste disposal across the country. Only the capital city of Santiago, where 100 percent of collected waste goes to modern sanitary landfills, and a few regional urban centers have modern sanitary landfills [12, 13, 21, 24].

The Valparaiso region was selected based on evaluation of selected facts that this region presents. The Valparaiso Region has the third largest urban population in Chile and is a tourist destination; therefore, it generates a large amount of MSW. Most of the waste disposal facilities of the Valparaiso Region have reached near full capacity; in contrast, Santiago has three sanitary landfills of an expected lifetime of over two decades. The national government is developing policies to decentralize the Metropolitan Region and prioritize the development of infrastructure projects at the Regions. Valparaiso is the gateway to the sea for metropolitan Santiago and is a historical city, designated as Heritage City of Humanity by the U.N. If the first WTE plant in Chile were to be constructed in the Valparaiso Region, it could influence other Regions of Chile to develop and implement modern solid waste management solutions [12, 13, 21, 24].

The city of Valparaiso houses the National Congress and is designated as a UNESCO World Heritage Site. It is one of the country's most important seaports and an increasingly vital cultural center. The population of Valparaiso, with the neighboring resort city of Vina del Mar and surrounding seaside resorts such as Renaca Concon, San Antonio and Quintero, is nearly doubled during the summer and holiday months of December, January and February. The main economic activities of Valparaiso are tourism, culture, transport, manufacturing industries and food production. The Valparaiso Region is host to agricultural lands, wine producers, as well as industrial activity such as copper mining and cement [9,12,13, 21,24].

4.2. Waste generation and management in the Valparaiso region

According to the most recent census (2006) the population of Valparaiso Region was 1.9 million [21]. The MSW generated in 2009 was 1,600 tons per day, i.e. about 584,000 tons annually [3,12]. There is one sanitary landfill, ten regulated landfills, and four non-regulated open dumps that represent about 10 percent of the MSW disposed in the region. There are no transfer stations in the region and very little recycling [3,13]. There are several municipalities in this region but this study concentrated on seven adjoining municipalities, Valparaiso, Vina del Mar, Concon, Quilpue, Villa Alemana, Quillota, and Quintero. These municipalities have a total population of 1,013,493 persons and produce 379,513 t per year or 1,134 t per day of MSW. The Municipality of Valparaiso and Vina del Mar represent 56 percent of the total population of Valparaiso Region. The MSW generation is growing at 1.8 percent annually and it is estimated to reach 155,000 tons in Vina del Mar and 121,000 tons per year in the Municipality of Valparaiso [3]. The solid wastes brought into Valparaiso by cruise ships are considered *foreign waste* (by law) and must be transported and disposed of in a Santiago landfill [13].

The WTE energy generation and revenue depend on the calorific value of the waste. Table 1 shows the average composition of the Valparaiso and Vina del Mar MSW in 2001, as there no official updated characterization [8,24].

Table 1: Composition and heating value of Valparaiso MSW

MSW component	Characterization of Valparaiso MSW (2001) %	Material (Tchobanoglous Handbook) MJ/kg	Contribution to heating value of MSW MJ/kg
Organic waste	63.6	4.6	2.9
Paper and cardboard	11.7	15.6	1.8
Plastics	11.7	32.4	3.8
Textiles	4.4	18.4	0.8
Glass	4.1	0	0
Metal	3.9	0	0
Other	0.6	4.0	0.02
Total	100.0		9.4

Source: Grupo de Residuos Solidos, P.U.C.V., „Caracterizacion de RSU para Valparaiso“. Report provided by Esteban Alves, Stericycle, Valparaiso

The calorific value of 9.38 MJ/kg, from the 2001 study [8], is low in relation to those obtained by EEC for Buenos Aires, Toluca and Montevideo. In view of the economic development of Chile in the first decade of the 21st century, it is expected that the current heating value is somewhat higher. Recycling in the Valparaiso Region is informal and minimal. The local government estimates it to be as little as 2 percent. The main waste management method is landfilling, consisting of El Molle landfill, Villa Alemana municipality controlled, non-sanitary landfill and San Pedro non-sanitary landfill [8,24].

El Molle is the main landfill in the region, with private management, is in operation since 2001, and occupies an area of 943.6 hectares. It is expected to reach full capacity in 2028 and only one cell opend in 2013 as a sanitary landfill. It receives about 357,000 tons (1,000 tons per day) of solid wastes annually from the municipalities of Valparaiso, Vina del Mar, Quilpue, Concon, La Ligua, Olmue and Limache (total population of 872,000 inhabitants in 2009). Of this amount, 837 tons per day is MSW from the municipalities and 163 tons per day commercial waste from private firms. The facility collects and flares an estimated 15 tons per day of methane and El Molle gets carbon credits for reducing methane emission to the atmosphere. The final density of the landfilled MSW is 0.9 ton/m^3. The average gate fee is 14 USD per ton landfilled [3,19,24].

There are two more sites for waste disposal in the area, the Villa Alemana municipality controlled, non-sanitary landfill owned and operated by the municipality, and the San Pedro non-sanitary landifill, privately operated. The Villa Alemana landfill is in operation since 1994 and covers an area of ten hectares was expected to reach final official capacity in the year 2010, but still receives approximately 23,000 tons of waste per year (63 tpd) from a population of about 116,000. The gate fee is only 6 USD per ton. The San Pedro Open Dump, is located in the Commune of Quillota and it has been in operation since 1996 and covers an area of ten hectares. It was projected to reach final capacity in the year 2007, but still receives the waste of the municipalities of Quillota, Calera, Hijuelas, La Cruz and Nogales, 38,000 tons of waste per year (103 tpd) from a population of about 194,000. The gate fee is 8 USD per ton [3,13,19,24].

4.3 Proposed WTE facility for Valparaiso

The case study for Valparaiso proposed that the first WTE plant in Chile be of nominal capacity of 42 tons per hour i.e., 336,000 tons per year (90 percent availability, i.e. 8,000 hours per year). The plant would consist of two lines, each of nominal capacity of 21 tons per hour. The LHV of the Valparaiso MSW was estimated to be 9.4 MJ/kg (Table 1). Therefore, the net electricity production in a plant of 1,000 tons per day capacity is estimated at 540 kWh per ton, or 182 GWh per year. The proposed site is in the El Molle, the nearest site to Valparaiso and Vina del Mar, the most populous municipalities in Valparaiso Region. El Molle is an operating landfill with all environmental and other permits approved. Proximity to main roads and accesses is granted, providing strategic and economic reasons. Additionally, it is operated by a private company, which is interested in developing methods that reduce environmental impacts [24].

The cost estimation for the proposed WTE plant was based on recently built facilities in Europe and the U.S.. There, the WTE plants are designed with a high quality grate combustion furnace, empty vertical passes and a vertical boiler followed by a semi-dry flue gas cleaning and a 75 m stack. All concentrations are referenced to 11 percent O_2 dry gas basis at 0 °C and 1 atm. Therefore, these estimates do not take into account all the local conditions, and are also subject to many varying factors such as the price of steel and the labor cost. Hence, they are considered to be within a plus or minus 30 percent accuracy. The site needed for the development of the facility was estimated roughly at five hectares (50,000 m^2). The cost per square meter at El Molle is about 13 USD. Table 2 shows the estimated capital and operating cost, assuming a personnel of 43 people, and that the bottom and fly ash will be combined and disposed of at El Molle landfill [13, 21, 24].

Parameter	**Units**	
Number of lines		**2**
CAPITAL COST		
Site preparation, access, landscaping	million USD	14
Buildings, stack	million USD	46
Grate, boiler, air supply, ash handling, electrical and mechanical systems	million USD	94
Turbine generator	million USD	23
Air pollution control system	million USD	23
Contingency	million USD	23
Land	million USD	2
Estimated total capital cost	million USD	225
Estimated capital cost	USD/ annual ton of capacity	670
OPERATING COST		
Ash disposal (USD3.75/ton)	million USD	1.3
Chemicals (USD4/ton)	million USD	1.3
GasCleaning (USD8/ton)	million USD	2.7
Maintenance (USD15.6/ton)	million USD	5.2
Miscellaneous (USD2/ton)	million USD	0.7
Personnel, 43 employees	million USD	1.2
Subtotal	million USD	12.4
Contingency (5%)	million USD	0.6
Subtotal	million USD	13.0
Insurance (0.6%)	million USD	0.1
Estimated operating cost	million USD	13.1
Estimated operating cost	USD/ton capacity	39.0

Table 2:

Capital and operating cost estimate

Table 3 summarizes the projected revenues that define the gate fee. The current gate fee charged in El Molle is 22.8 USD per ton for 16.3 percent of the industrial waste from private companies disposed of, and 12 USD per ton for the 83.7 percent of the MSW of the municipalities, resulting in an average of 14 USD per ton.

Collection costs are assumed to remain constant. However, considering the present high cost of MSW collection at Valparaiso and Vina del Mar, indicates that the collection system should be streamlined alongside with the construction of the WTE [13,19,21,24].

Table 3: Potential revenues for the WTE plant

Parameter	Unit	Value
Electricity Production annually,	MWh	182,000
Electricity sold at Spot Price (prices in 2009 varying between 68 USD and 163 USD ,average 105.91 USD, in 2010 between 116 USD and 163 USD, average 137.17 USD	USD per MWh	
Price under Power Purchase Agreement (PPA) 2011 prices: 80-110 USD; projected for WTE plant: 90 USD	million USD	16.4
Carbon Credits A factor of 0.6 tons CO_2/MWh was used, as provided by the United Nations Framework Convention for Climate Change (UNFCC)	tons CO_2 credits	109,200
Sales of metals recovered at assumed 50 % metal recovery	million USD	1.3

4.4. Toluca, Mexico

Mexico has a land area of 1.96 million km^2, a population of 112 million inhabitants (2010), and a population growth rate of 1.8 percent (2005-2010) [20]. The country is divided into 31 states plus the Federal District (Mexico City) and each state is divided into municipalities. The GDP of Mexico is 1.57 trillion USD (2010 est.) [4], the 12th highest in the world, and the highest in Latin America. The per capita GDP is 13,900 USD (2010 estimate on basis of purchasing power parity) [4]. Each municipality is responsible for its waste management, including, collection, transportation, treatment and final disposal of solid wastes. Most of the municipalities manage these services directly, while a few do it through municipal autonomous companies or private companies [16]. Citizens in Mexico do not pay directly for waste management; municipal governments are responsible for funding these services through real estate and other taxes. Therefore, the available funding may not be sufficient to provide quality services. An estimated 66 percent of the MSW is disposed in sanitary landfills, twelve percent in regulated landfills, twelve percent in non-regulated waste dumps, six percent is burnt in open-air and four percent is discarded on land and waters [1]. In the metropolitan zones, where 56 percent of the population of Mexico lives, 77 to 96 percent of the collected MSW is disposed of on either sanitary or regulated landfills; in semi-urban areas this fraction ranges from 29 percent to 34 percent, while in rural areas less than three percent is disposed of properly [2, 18].

The Toluca region was selected because it is a medium-sized city, which is more representative of small cities in Latin America and is located about 70 km east of Mexico City. It is an industrial city with companies that can provide high calorific value waste and possibly use some of the exhaust steam of the WTE plant. Toluca is the capital of the State of Mexico, the state with the highest MSW generation in the country. Toluca has a population 0.82 million inhabitants and is the capital of the State of Mexico, the most populous state in the country (fourteen million). Some of the most important Mexican industries can be found there, such as textiles, automobiles, beverages, and pharmaceuticals.

4.5. Waste generation and management in the Toluca region

The General Direction of Public Services and Environment of Toluca Municipality collects and transports 510 tons per day, at a cost of 39 USD per ton of MSW. The reported disposal cost at the San Antonio la Isla landfill is 12.7 USD per ton. The generation per capita of MSW in Toluca has tripled from 0.11 to 0.36 tons per capita in the last fifty years and amounted to 295,000 tons in 2009. Table 4 shows the composition of MSW in 2010 [22]. The lower heating value (LHV) for Toluca MSW is estimated at 10.4 MJ/kg (Table 4) [24]. This is near the middle of the range of calorific values of WTE plants operating in Europe and North America (7 MJ to 14 MJ/kg).

An estimated 186,000 tons [14] of MSW are collected annually in Toluca. This represents only 63 percent of the total MSW generated in Toluca; the remaining is discarded in non-regulated landfills. Residues are still not separated at the source, even though the 2007 Biodiversity Code states that citizens in the State of Mexico must separate their residues into organic and inorganic streams. There are no waste transfer stations (WTS) in Toluca. All collected waste is transported to the final disposition sites when the collection route is completed, or the truck is filled up. The MSW collected by the municipality is disposed in two sanitary landfills. Nearly one half is disposed at the San Antonio la Isla (SALI) landfill that is located about 17 kilometers from the center of Toluca and serves the northern part of the city; the other half of the MSW, collected from the southern part of the city, is disposed at the Zinacantepec landfill, 15 km away from the center. Both of these landfills collect and flare some of the landfill gas. Regarding the gate fees, the Toluca Municipality pays an average fee of about 13 USD per ton [14, 22, 24].

Table 4: Composition of Toluca MSW (2010) and heating value

Material	**Percentage** MSW %	**Material (Tchobanoglous Handbook)** MJ/kg	**Contribution to calorific value of MSW** MJ/kg MSW
Food waste	50	4.6	2.3
Paper and cardboard	19	15.6	3.0
Wood	6	15.4	0.9
Plastics	10	32.4	3.2
Textiles	4	18.4	0.7
Glass	2	0	0
Metals	2	0	0
Other	7	4.0	0.3
Total	100		10.4

Source: Toluca General Direction of Public Services and Environment, 2010.

As in the rest of Mexico, informal collection plays an important role in recycling in Toluca and amounts to about eight percent of the MSW generated. It is very common to see people going from house to house offering to buy or cart away all kinds of paper, cardboard, metal, and other materials. Also, in order to promote recycling by the citizens, the Toluca municipal authorities have created twelve *collection centers* located at different convenience stores and neighborhoods that accept paper, glass, plastic, metal, aluminum, batteries, wood, etc. For every kilogram of recycled material, citizens receive, in exchange, coupons called *Ecos*. The Ecos have a monetary value and can be used to purchase some basic products such as rice, beans, detergents, etc [10, 11, 14, 17, 22, 24, 26].

There are some composting sites that serve Toluca, such as the one at the San Antonio la Isla landfill. There, green wastes are shredded and composted aerobically. Approximately two tons of wastes per day are processed, generating about 500 kg of a compost product that is used for soil conditioning. In the second sanitary landfill that serves Toluca, Zinacantepec, it was stated that they had tried to compost mixed MSW but it was not possible to produce a usable compost product from household mixed wastes [11, 24, 26]

4.6. Proposed WTE plant for Toluca, Mexico

As mentioned earlier, the current generation of MSW in Toluca is about 300,000 tons per year and is projected to increase to 400,000 tons by 2015. The idea is to start with a relatively low cost plant and also allow room for increased recycling. The WTE plant size selected for the Toluca case is a single line of twenty tons per hour capacity, or 160,000 tons per year. Based on the experience that will be gained from this one-line plant, a second line may be added in the future, doubling capacity to 320,000 tons per year [24, 26].

The net electricity production is estimated at 0.6 MWh per ton MSW, or 96 GWh per year and 12 MW of base load electricity to the grid. The most suitable site for the Toluca WTE is next to *San Antonio la Isla* sanitary landfill, that currently serves Toluca. It is estimated that the WTE facility would occupy approximately four hectares of San Antonio la Isla land property. This estimate includes a Materials Recovery Facility and a Visitors Center that would educate the public regarding recycling and energy recovery from MSW [24, 26].

As in the Chile case study, the cost estimates for Toluca were based on recently built facilities in Europe and the U.S. where the WTE plant is provided with grate combustion high quality furnace, boiler, and state-of-the-art Air Pollution Control system. These estimates did not take into account local conditions and are subject to many factors, such as the price of steel. Hence, they are considered to be within a plus or minus thirty percent accuracy. The facility will need approximately of 40,000m^2 land at a cost of 22 USD per m^2 approximately, for land around *San Antonio la Isla* sanitary landfill. Table 5 presents the capital and operating costs of the proposed WTE plant, assuming a personnel of forty people and combining bottom and fly ash for use as daily cover at San Antonio la Isla landfill [24, 26].

The possible revenues that will define the gate fee are summarized in Table 6 [7, 24]. The current gate fee charged in San Antonio la Isla is 13 USD per ton. Collection costs are assumed to remain constant. The results of an economic analysis that considered the most optimistic prices for revenues, showed that even with a fifty percent public grant, the gate fee of the WTE facility would have to be at least twice the gate fee currently paid in San Antonio la Isla landfill [24].

Parameter	Units	
Number of lines		**1**
CAPITAL COST		
Site preparation, access, landscaping	million USD	6
Buildings, stack	million USD	33
Grate, boiler, air supply, ash handling, electrical and mechanical systems	million USD	38
Turbine generator	million USD	16
Air pollution control system	million USD	10
Contingency	million USD	16
Land	million USD	1
Estimated total capital cost	million USD	120
Estimated capital cost	USD/ annual ton of capacity	750
OPERATING COST		
Ash disposal (USD3.75/ton)	million USD	0.60
Chemicals (USD4/ton)	million USD	0.64
GasCleaning (USD8/ton)	million USD	1.28
Maintenance (USD15.6/ton)	million USD	3.38
Miscellaneous (USD2/ton)	million USD	0.32
Personnel, 40 employees	million USD	0.98
Subtotal	million USD	7.19
Contingency (5%)	million USD	0.36
Subtotal	million USD	7.55
Insurance (0.6%)	million USD	0.05
Estimated operating cost	million USD	7.60
Estimated operating cost	USD/ton capacity	47.50

Table 5:

Capital and operating cost estimate

Table 6: Estimated revenues for the WTE plant

Parameter	Unit	Value
Gate fees 13 USD per ton	million USD	2
Electricity Production annually	GWh	96
Electricity sold 62 USD/MWh delivered, the revenue from the sale of electricity is estimated of 5.95 million USD or 37.2 USD per ton of MSW	million USD	5.95
Electricity sold with carbon reduction incentives at a price of USD 69.5/MWh (62 USD/MWh + 7.5 USD/MWh) and 77 USD/MWh (62 USD/MWh +15 USD/MWh). The revenues would be 41.7 USD - 46.2 USD per ton of MSW	million USD per year	6.67 to 7.39
Metal revenues at assumed 50 % metal recovery	USD per year	149,000

5. Conclusions

The main conclusion from these case studies is that considering the gate fees for landfilling in Latin America, the WTE alternative will only be economically feasible if government support is provided. For example, for the WTE project in Chile to break-even after twenty years operation and at a five percent IRR, the required gate fee would be of 38 USD/tn. Additionally, it is concluded that to have an affordable gate fee for the WTE project, it is necessary to have a very high plant availability. This is connected to the quality and quantity of the MSW provided to the plant, i.e. the WTE solution must consider the collection and transportation rates and the robustness of the overall solid waste management system.

The Valparaiso Region is considered to offer the most likely site for locating the first modern WTE facility in Chile, because of the urgent need to solve its current solid waste management. The best option for the Valparaiso Region WTE facility is to be located at El Molle, where most of the required environmental permits have been already approved. El Molle is the largest waste disposal facility in the Region and receives the MSW of the cities of Valparaiso and Vina del Mar, with already settled waste disposal contracts. Collaboration with the company that is now operating this landfill would be advantageous in developing the WTE project and the company has expressed their interest in this Project. Unfortunately, despite all its environmental advantages, the financial analysis presented in this report has shown that, at current gate fees and energy prices in Chile, WTE is not yet economically feasible unless electricity is sold at spot price. Moreover, the gate fee would need to be at least 38 USD per ton, 24 USD per ton higher than the current landfill gate fee, for the project to break even operationally under the base scenario. On the basis of international experience, it is estimated that implementation of a truly sanitary landfill in the Valparaiso Region would require a gate fee of at least 30 USD per ton MSW; such a gate fee would make the proposed WTE economically competitive with sanitary landfilling. Policies related to the increment of the green energy percentage in the Chilean energy mix and legal bindings from the inclusion of Chile in OECD countries will reduce this gap and may enhance an effort for building a WTE in Chile.

Toluca in Mexico could be highly benefited by implementing WTE as it has been reported that there are no remaining landfill sites. It is recommended to use a well-proven technology, such as grate combustion, due to the lack of WTE experience. Due to its closeness to Mexico City, Toluca is a good site for installing the first WTE in Mexico. For this study, the chosen location for the facility was next to one of the two sanitary landfills where Toluca disposes its waste: San Antonio la Isla. However, even with the numerous advantages, environmental benefits and the necessity of replacing landfills in Mexico, the financial analysis has shown that the gate fee of the WTE facility would have to be increased substantially in order for the project to be feasible, which implies that WTE is not competitive with landfilling in Mexico. This is mainly due to the Latin America´s economic and public policy strategies that align the legal framework, for example in electricity prices, with the economic factors of electricity generated from renewable sources. The only realistic scenario under which the plant could be built is if it is publicly owned and the government builds it as a showcase to advance the nation in waste management, despite the fact that in the short term it will be costlier than sanitary landfilling. Finally, based on the current MSW management situation in Toluca, where informal and formal recycling has been estimated to be less than ten percent, it is very important to plan for increasing the current recycling rate by means of collection of source-separated recyclables, in parallel with the WTE plant implementation.

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