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Economic Viability for a Large-Scale Model of Municipal Solid Waste Treatment in the Most Important Brazilian Economic Region

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ABSTRACT

Despite the National Policy for Solid Waste (PNRS) in 2010, nothing has changed to the waste disposal in Brazil. Planned to reach 100% of all Municipal Solid Waste (MSW) collected and treated in landfills by Aug. 2nd, 2014, until nowadays, 42% of this total remains in dumps. Even the most important national economic region treating its urban waste in landfills, what it has is no more than 4% of recycling and its landfills reaching the exhaustion. Building other ones is getting harder year by year, due to water reservoirs around the region, high freight costs, waste disposal and the severe control of emissions associated to its logistics.

This article comes to break the paradigm of investment and profitability proposing an alternative to the land-use, achieving higher rates of recovering. The economic viability, carried out through well-known financial variables and Monte Carlo analysis, has taken in account proven local waste characteristics and market prices. Even considered a proposal highly intensive in capital and people, the revenues from the sales would be enough to guarantee viability of 100% equity with IRR of 33.7% and ROI of 24.5% per year within confidence of 99%.

Keywords: *Solid Waste, Sorting, Recycling, Waste-To-Energy, Metropolitan Region Of São Paulo, Energy Recovering.*

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GRAPHICAL ABSTRACT

IN	PROCESS FLOW					OUT
		Process	**Fraction**	**"Raw Materials"**	**Fraction**	**PRODUCTS/SERVICE**
MSW	100%	*Biological*	43%	Organic	43%	Fertilizer
		Mechanical (Recycling)	24%	Paper	8%	Recyclables
				Plastic	8%	
				Metal	1%	
				Glass	1%	
				Other (e.g., electronics)	6%	
		WtE	33%	Dirty plastics	24%	Electricity
				Textile, dirty papers, city cleaning	9%	
		Urban Waste Service				Treatment
TOTAL	100%	**All Processes**	100%	**All Recyclables**	100%	**All Revenues**

ECONOMIC ANALYSIS SUMMARY

VARIABLE	100% EQUITY	80% LOCAL FUNDING
IRR	33.7%	116.3
NPV	R$ 10.8 (USD 4.3) billion	R$ 13.4 (USD 5.8) billion
PAYBACK	6.6 years	6.9 years
ROI	24.5% per year	22.9% per year
ROE	24.5% per year	95.3% per year

Summary: Economics from a Large-Scale model of Municipal Solid Waste in the Metropolitan Region of São Paulo

STATEMENT OF NOVELTY

The statement of novelty comes from the proposal of an integrated large-scale model of treatment (or Mechanical-Biological Treatment with Waste-to-Energy facilities) offering waste treatment service, recyclables (plastic, metal, paper, and glass), an organic compost (fertilizer) and electricity to the most important economic region of Brazil, a recognized developing country where urban waste treatment is neglected.

An alternative to the landfills, the study intends to increment Brazilian researches for the integration of solutions to treat the urban waste as a way to reach the ideal circular economy.

CHAPTER ONE

INTRODUCTION

The Metropolitan Region of São Paulo (MRSP) is the biggest wealth generation center in Brazil. This macro-region holds a large part of the national private capital with the most important industrial complexes, commercial and financial headquarters installed and responsible for the Brazilian economic activity. It represents 56% of São Paulo state´s GDP, 20% of Brazil´s one and its GDP per capita is 1.7 times bigger than country´s one, by the Brazilian Institute of Geography and Statistics (IBGE, 2013) and São Paulo State Foundation for Statistics (SEADE, 2011).

Directly associated with value and income generation, the amount of Municipal Solid Waste (MSW) is equally high in this Brazilian region. The MRSP has São Paulo city, the capital of São Paulo state, with 11 million people, considered the largest of Brazil and one of the largest worldwide urban agglomerations. With 39 cities, this region produces 21.4 thousand metric tons per day or annually 7.7 million metric tons of MSW in 2013. This amount corresponds to 10% of all Brazilian's MSW, and only São Paulo city contributes with 62.5% at MRSP (ABRELPE, 2014; IBGE, 2013).

The absence of an Integrated Municipal Waste Management (IMWM) is one of the factors responsible for hindering the coordination of an integrated action between municipalities, and that is why environmental and financial costs are too high in this region. As for the household garbage collection in the urban area, only five municipalities have less than 90% coverage in the MRSP. On disposal, approximately half of the total municipalities have their wastes in landfills, and the other half in controlled landfills (**Figure A *1***), what partially attends the Brazilian National Policy for Solid Waste (PNRS) (BRASIL, 2011; FUNASA, 2010).

In the MRSP, as well as in the city of São Paulo, the average of urban waste generation per capita is 2 lbs (about 1 kg) per day. The greater differential between MRSP and other Brazilian macro-regions, concerning waste disposal, is the dumps' eradication. The number of municipalities who disposal their wastes in landfills out their limits increased from 23 in 2005 to 32 in 2009 (JACOBI and BESEN, 2011).

In 2010, 29 cities from MRSP (74.4%) had a selective collection, but only seven of them had 100% urban area coverage. In 28 of them, recyclable collectors worked organized in cooperatives subsidized by the governments. With 2,206 collectors, this selective collection covered 28 municipalities with 1,045 people in São Paulo city and 1,161 ones shared with the other 27 cities (**Figure A *2***). However, these cooperatives have shown low efficiency, because 70 to 80% of all recyclables collected are still coming from the informal collectors working under precarious conditions in the streets of the cities (BESEN et al., 2014; JACOBI and BESEN, 2011).

In a financial point of view, São Paulo's selective collection has cost R$ 192 (or USD 79) per metric ton, or the equivalent to R$ 8.3 million (or USD 3.4 million) per year. This cost represented a little bit more than 1% expended in 2013 (R$ 725 million or USD 298 million) to collect, transport and dispose of MSW in landfills and dumps, but it was twice higher than the conventional process (CEMPRE, 2013).

Most recent information from São Paulo's Municipal Secretary of Services presents 31 collectors' cooperatives working in the city with 3.2 thousand collectors, and despite having 10% as an agreed target, no more than 4% of the MSW is recovered (CEMPRE, 2013; JACOBI and BESEN, 2011). Other important information comes from the infrastructure available to the selective collection. Only 7% of the waste collection fleet, working under contract in São Paulo, is available to support the selective collection. This inefficient selective collection and its low coverage in São Paulo causes economic losses estimated at R$ 749 million (or USD 308 million) per year. More than 1 million ton of paper, plastic, metal, and glass are discarded and transported to landfills and dumps, instead of sorted and sold to return to the production chains (BIZZOTTO, 2010).

Less waste recovered means to reduce the landfills lifetime in the region with too many restrictions to build new ones. More than 50% of the RMSP is under environmental protection due to water reservoirs. Programs for reducing the traffic and gas emissions in the transportation, high freight costs and disposal far from the point of waste generation are main reasons that make difficult to build new disposal areas (CETESB, 2014).

This MRSP's scenario shown above is common in the world. Authors, such as ZHANG (ZHANG et al., 2010) and RUOFEI (RUOFEI and SIBEI, 2010), report about sharp population growth in China and its residues' generation without appropriate treatment. The solution to the problem, as well as the majority articles found to developing countries, is to replicate well-succeed European cases, especially Danishes MSWM's models. This task seems to be simple and trivial if it was not by the fact Denmark's GDP is three times bigger than MRSP's one, and five times higher than Brazilian's one. It's one of the six European nations, which has at least 90% of its MSW destined to save and generate energy through a selective collection to recycle metals, glass, paper and plastic, organic composting and incinerating waste to produce electricity and steam for heating. In these developed countries, there is an awareness culture of environmental impact miigation based on conscious consumption through the 3Rs (Reduce, Reuse and

Recycle). There is a clear understanding which waste is a public health problem, and due to this, governments do not save investments to get solutions, avoiding land-use, mainly because, in most of the cases, there is not its availability in Europe.

Most recent articles are coming with a new approach: procedures and technologies should complement each other to improve the sustainability on waste treatment, mainly when the focus is to reach economic viability and mitigation of environmental impacts. CIMPAN (CIMPAN and WENZEL, 2013) presents in his study that it is possible to get an expressive reduction of CO_2 emissions and high net profits, in comparison with landfills, when applying the WtE process after the MBT one. The explanation comes from an improved Refuse-Derived Fuel (RDF) with a higher Lower Calorific Value (LCV). Due to only "clean" recyclables (metal, plastic, paper, and glass) and all wet portion (organics) are sorted, what remains is a mass with enough "dirty" plastic and paper which are not feasible to be cleaned and commercialized.

A combination of technologies is also suggested by HAM (HAM and LEE, 2017) in his Korean article for sustainable solid waste management. The author calls attention to the efficiency's improvement when associating technologies and, emphasizes that less amount of waste to be burn reduces WtE facility's scale, what is extremely important to let the business model less capital intensive and more viable.

WHEELER, from the Waste Management Magazine and KHALID, have written scientific texts where both reinforced the importance of the technologies' complementarity and called attention to the potential of energy generation if considered anaerobic digestion in the MBT (KHALID et al., 2011; WHEELER, 2006). The author WHEELER has estimated up to 15% of the UK's energy demand could be supplied by its biological anaerobic digestion. The same magazine published in 2013 a text informing a proposed £ 240 million small-scale waste facility is featuring MBT+WtE with 245 thousand metric tons per year (or about 0.5% of the annual production of waste) and 14 MW of capacity (WEKA, 2013). By the same authors, the urban waste anaerobic bio-digestion is not very common on the industrial scale except when considering wastewater treatment. That is because the MSW presents low-efficiency anaerobic digestion and business economic viability when compared with bio-digestion of sewage sludge, agriculture, and livestock residues. The heterogeneous composition of the urban organic waste and the presence of stabilizers and acidulants retard the anaerobic bio-digestion in the reactors. So, the best way to get methane from MSW anaerobic digestion is still in landfills where waste amount, degradation and pressure build-up are the matters of space and time.

Some Brazilian works and authors do not present an integration of existing technologies for MSW treatment in the light of sustainability. SANTOS (SANTOS, 2011) discusses landfills and incinerators, LIMA (LIMA, 2012) describes technological alternatives to several regions in the country, and even VIEIRA (VIEIRA, 2011), writes about electricity considering all the urban waste, but neglecting mechanical recycling and composting. Furthermore, they do not make an economic viability evaluation of introducing expensive and more efficient technologies, such as Waste-to-Energy (WtE), applied in the poorest or developing countries.

CHAPTER TWO

OBJECTIVE

This article aims to present the economic viability and risk analysis of an integrated large-scale model of MSW treatment at MRSP.

CHAPTER THREE
MATERIALS AND METHODS

3.1. BUSINESS MODEL

The proposed model is a Mechanical-Biological Treatment with Waste-to-Energy (MBT+WtE) facilities at MRSP. These facilities would supply the economy with the waste treatment service, recyclables (metal, plastic, glass, and paper), an organic compost (bio-fertilizer) and electricity (**Figure 1**). The article is not considering the potential revenues from energy generation through anaerobic digestion and the steam from the WtE facilities.

The well-succeed practice of MSW treatment with energy generation in too many countries in Europe, especially in Germany, MBT+WtE is the state-of-the-art technology regarding controlled emission and land-use mitigation, as mentioned in last COP 21 (CHRISTENSEN et al., 2015). There, facilities receive materials from the recyclables collection and separate them to reintroduction in the market, reducing demand for more “virgin” materials and energy. Organics are aerated and well-drained to produce fertilizers because biogas through anaerobic digestion in reactors is not viable yet, as already explained.

The remaining waste, or RDF (Refuse-Derived Fuel), burns under high temperatures in closed systems where gases are washed, filtered and submitted to long periods of residence enough to break chemical components. Ashes are the particulate by-products obtained by the incineration. Both ashes and gases must attend legislation requirements described in **Table C1**.

Brazil has local legislation that guides residues thermal treatment. The Resolution CONAMA No.316/2002, which defines procedures and criteria for treating them thermally, is too comprehensive as American and European legislation who allow WtE facilities to operate their countries (CONAMA, 2002). As seen in the table above, assumed a technology well-established in any mentioned regions, risks for health and environmental seem to be under control and attending the Brazilian resolution. However, due to security reasons, it should be considered technologies which can meet a more restrictive standard, such as the European one which is more rigorous with emissions and control procedures.

Initially, only depleted mines of minerals (e.g., coal) received ashes to fill them and reduce the environmental impact caused by the mining, but nowadays cement and pavements are receiving them, and other applications are under development (LYNN et al., 2016).

3.2. WASTE GRAVIMETRY, PROCESSES, AND PRODUCTS

The gravimetric composition assumed to MRSP's MSW is the one used by Municipal Environmental Sanitation Service of Santo André (SEMASA), a department of a social and economic representative city from MRSP (SEMASA, 2008). Even being a data from 2008, it fits with the Brazilian Institute for Applied Economic Research (IPEA, 2012), research performed four years later that showed MRSP's waste composition in detail.

In **Table 1** are summarized and broken-down the weight fractions of waste, where will be processed and what products and service the MBT+WtE model will produce.

Fractions of the 21 thousand metric tons per day of waste treated in each process are in **Table C2** and **Table C3**. The information about the mass amount fractioned in "wet" and "dry" portions was as an idea of how much is possible to recover from a simple sorting. Without any additional process (washing and drying), recyclers would buy recyclables (metal, plastic, glass, and paper) compacted and into bales. Organics, the fraction extremely wet in the waste, would be to produce bio-fertilizer. Other waste contents also considered wet, but in fact recognized as dirty, are fuel to the burning process.

Note the important waste recovery rate of 67% potentially achieved, considering organic composting and recycling. In a scenario of average waste composition with 61% of organics, MIEZAH (MIEZAH et al., 2015) estimates 76% of rate recovery in Ghana. It would be a remarkable level in comparison with the 10% sought by São Paulo, and not achieved by now, or with the insignificant 2% performed nowadays in Brazil, by the Brazilian Association of Waste Companies (ABRELPE, 2014). Besides that, this would be a rate compared to the developed European countries, according to European Environmental Agency's (EEA) data (EEA, 2014).

3.3. POTENTIAL REVENUES, ASSETS, AND INVESTMENT

Annual revenues from sales of products and service calculated assuming market prices (**Table 2**), Lower Calorific Value (LCV) references (**Table C4**), and the average LCV of the waste in the MRSP (**Table C5**).

Especially talking about WtE facilities, technical configuration #3 (**Table 3**) and electricity fee were used to calculate their revenues. This assumption is reasonable due to the previous sorting of "wet" and "dry" fractions which improves the LCV to highest levels, as suggested by BOSMANS (BOSMANS et al., 2013) when discussing benefits of combining Waste-to-Products (WtP) and Waste-to-Energy (WtE) technologies.

The economic analysis follows considering CNIM's WtE technology that has more than 150 years of experience in more than 15 countries and 2,800 employees. With 160 plants working all over the world and treating 24 million tons per year, this company presents a technology with the best relation between investment and RDF's treatment capacity of USD 86 per metric ton in 10 years. Studies from The World Bank's procedures (BANK, 2000) and FEAM (FEAM, 2012), a Brazilian State Environmental Foundation, and NIXXON (NIXXON et al., 2013) ratified that.

Considering an average exchange of R$ 2.34 per USD in 2013's Brazilian Exchange, the estimated investment to attend MRSP is R$ 4.5 billion (or USD 1.9 billion) (BACEN, 2018). The market recommends units with 600 metric tons per day of capacity because of technical issues (units' availability and maintenance). Due to this, the MRSP should have 12 units well distributed to treat 33% of its waste daily as shown in **Table 4** compiled from

Figure B *1*. São Paulo, the biggest city at MRSP, covered by 7 MBT+WtE facilities. Other five ones would be covering the rest of the metropolitan region, shown as regions purple, red, yellow, green and blue.

Based on CNIM and past articles considering MBT+WtE facilities, also mentioned by DEMIRBAS (DEMIRBAS, 2011), the total investment assumed to have all 12 facilities serving the MRSP in 2013 would be R$ 5.8 billion (or USD 2.5 billion), or 1.3 times of what is required to have only WtE facilities.

This article is not considering an MBT with gasification, but only assets to sort recyclables (conveyors and compactors), dryers and blowers to aerobic compounding. In case of gasification's MBT assets, the factor 1.3 must increase to 4.

3.4. FIXED, VARIABLE EXPENSES AND CAPITAL COST

Operational and Maintenance (O&M) costs for MSW's treatment are between USD 50 and 110 per metric ton, based on the previous study, fulfilling rigorous best practices of production and emissions' control (BANK, 2000; FEAM, 2012; NIXXON et al., 2013).

All facilities would use some resources from the economy, such as public (gas, water, urban cleaning) and maintenance services, especially when a WtE asset needs to meet sustainable aspects as discussed by JAMASB (JAMASB and NEPAL, 2010). MBT+WtE facilities normally produce 8% of ashes (relative to the weight amount burnt) as a by-product, normally disposed of in abandoned mines or used in pavements. Maintenance and overhauling are also eventually required to keep the facilities working properly. Therefore, it takes in this study 1.5% and 6% of the annual gross income to by-product disposal and maintenance, respectively, as mentioned by The World Bank and EPE reports (BANK, 2000; EPE; MME, 2018).

Other import operational assumption to the MBT+WtE model is the number of jobs. Following what is recommended by FERRI, when considering collectors to select materials manually, it is strongly recommended to use one collector picking up 730 metric tons of waste per year (FERRI et al., 2014). This parameter sounds reasonable if considered the estimated mass balance in **Table 1**. Taking into account this assumption, each collector would set-aside 43% of organics (313.9 mt per year) to dry and 33% of dirty materials (240.9 mt per year) to burn. Recyclables would be 8% of paper (58 mt per year), 8% of plastic (58 mt per year), 1% of metal (i.e. aluminum) (7.3 mt per year), 1% of glass (7.3 mt per year) and 6% of other (i.e. electronics) (43.8 mt per year). In comparison with a petrochemical production efficiency of plastics, the operation is more than 34 times smaller. So, in this article will be accounted 10,678 workers, including those to operate the WtE process. Besides that, the payroll considers two minimum wages per worker including labor costs and benefits, meeting Consolidated Labor Laws (CLT) in Brazil (see **Table D1**) (BRASIL, 1943).

This formal remuneration represents twice more of what people can get from the informal collection in cooperatives at São Paulo city, based on the Brazilian Association for Business Commitment to Recycling information (CEMPRE, 2013).

Table 5 presents labor costs, operation expenses, sectorial contributions, taxes and assets accounts followed with local market practices.

The Law No. 9,991/2000 requires 1% of the net operating income (NOI) for electricity generation ventures (DEPUTADOS, 2000). However, this article adopted The World Bank’s recommendation based on 0.5% of the total investment, or the equivalent to 1.55% of the NOI (BANK, 2000).

The National Agency for Electrical Energy (ANEEL) gives exemption to Distribution (TUSD) and Transmission (TUST) fees since the auction for an alternative source of energy in 2007 (ANEEL, 2007). Generation plants based on biomass, including MSW, with power capacity between 30 and 50 MW are eligible by the ANEEL’s Resolution No. 482/2012 in its Article 3 and paragraphs III and IV (ANEEL, 2012).

Capital for civil engineering, machines for treating recyclables and organics, filters, particulates and gas washers are in CAPEX provisioned as 0.5% of the investment, as recommended by The World Bank (BANK, 2000).

In the case of funding, the National Bank of Economic and Social Development (BNDES), a Brazilian federal bank has a credit line for Environmental Sanitation and Water Resources. This line has an annual TLP (Brazilian Long-Term Interest Rate), 1% of BNDES's premium and more 1% accounted as risk, covering 80% of the investment done by entrepreneurs (private and public players) (BNDES, 2018).

3.5. FINANCIAL ANALYSIS AND LEVEL OF CONFIDENCE

All economic viability was taking into account a cash flow period of 20 years, aligned to the period of municipal concession given to an entrepreneur, and a depreciation of 10 years.

Revenues, Expenses (Fixed and Variable) and Financial costs were broken-down to understand where strengths and weak points of the financial analysis would be for the year 2013.

This study used Monte Carlo Method to measure the risk through the confidence calculated by the simulation using 10,000 random scenarios. Based on almost 20 years' series of input variables (prices for products and service, exchange, investment, amount of waste, and more), these scenarios allowed to calculate other 10,000 decision output variables (NPV, IRR, PAYBACK, ROI and ROE). All available records of these variables are in **Table 6** and assumed as a normal distribution.

Taking into account historical moments of crises in the USA and Europe, where the technology is well-used, is reasonable to consider an investment range of +/- 10% based on the original budget of R$ 5.8 billion (or USD 2.5 billion) calculated to 2013.

Concerning waste generation rate, based on ABRELPE and CETESB's (Brazilian Environmental Sanitation Technology Company) data, last ten years represented a growth of more than 40% in the amount, or +3,5% per year (ABRELPE, 2014; CETESB, 2014).

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CHAPTER FOUR
RESULTS AND DISCUSSIONS

Considering potential revenues through the MBT+WtE model to the year 2013, 58% of them would be from sales of recoverable materials (metal, plastic, paper, glass, and bio-fertilizer). Electricity would represent 25% and 17% coming from the service of MSW treatment provided to the cities at MRSP (see **Figure 2**).

Plastic and bio-fertilizer would represent 48% and 20% of the total amount of recoverable' revenues.

Attending the entire MRSP with 12 units, the model considers 504 MW of installed capacity and would generate 4.5 TWh of electricity in 2013. This amount of energy would be equivalent to 25% of the thermoelectric supply for the State of São Paulo, or 2% for the Brazilian territory. All public lighting demand in the State of São Paulo would have the electricity produced and sold by MBT+WtE facilities at MRSP (SEMESP, 2014).

The waste recycling rate would rise from the current 4% to up 24%, or considering organic composting; the waste recovery rate could reach 67%.

The assumptions of operational and financial costs in the model would consume 56% of gross revenue, resulting in 44% pocket margin (see **Figure 3**). In absolute value, this margin would be, in 2013, 26% of the total budget invested in the MRSP.

Operational costs would take 25% from gross revenue, where fixed costs (or expenses) would be 94% of the total, and HR component is the most important representing 66% from it (see **Figure 4a**). On the other hand, more than 10.6 thousand formal jobs created at MRSP.

Financial costs demanding 31% of gross revenue would have tax payment as the heaviest variable, or 62% of their total (see **Figure 4b**).

The risk analysis was performed using 10,000 aleatory scenarios, built with records from the last ten years. Considering a confidence interval of 99% (means only 50 lower and higher values discarded from 10,000 ones), the variables IRR, NPV, PAYBACK and ROI using cash flows of 20 years would be as shown in **Figure 5a**, **Figure 5b**, **Figure 5c** and **Figure 5d** as a normal distribution with 99% of confidence interval (mean ± 3 standard deviations).

In average, IRR calculated would be 33.7% per year for the cash flow of 20 years considering constant currency. Negative and positive scenarios, based on records from the last twenty years, would give 16.5% as the lowest IRR, and 50.9% as the highest one (**Figure 5a**). Considering the average hurdle rate of 6.2%, the calculated average IRR would be 5.4 times higher than it.

Value generation, assumed here as NPV, would present average value of R$ 10.8 (or USD 4.3) billion, or 68% higher than the worst scenario of investment mentioned in **Table 6**. Taking into account negative and positive historical scenarios, the model would create a minimum of R$ 2.1 (or USD 0.9) billion, almost 36% of the average amount of investment, and 334% for a maximum NPV of R$ 19.4 (or USD 7.8) billion (see **Figure 5b**).

Analyzing the payback, the average time to pay the investment under conditions assumed in this study would be 6.6 years (**Figure 5c**). For the best and worst scenarios, the range calculated would be from 4.4 to 8.8 years.

The proposal presents an average ROI (Return of Investment) of 24.5% per year (see **Figure 5d**). However, even considering the lowest possible value of 7.9% per year, it would be higher than the highest hurdle rate of 7.5%.

Assuming 2013´s market records, just to a cross-check, the model would delivery an IRR of 32.6%, NPV of R$ 12.9 (or USD 5.5) billion, and a payback of 5.5 years, fitting perfectly within the confidence interval. However, if the entrepreneurs decide to get BNDES’s funding for sanitary ventures, the IRR could reach 116,3%. The value generation (NPV) would be R$ 13.4 (or USD 5.8) billion, and a payback of 6.9 years. ROI would be 22.9% in both cases but considering maximum BNDES funding of 80%; the ROE (Return on Equity) would be 95,8% per year to the investors (see **Table 7**).

It is possible to find some initiatives of landfills generating electricity with gas, but their references to the economic viability are pretty difficult to access in Brazil. ABREU and PICANÇO presented in their researches economic viabilities to landfills with gas recovering considering market fees (waste disposal service), prices (electricity) and efficiency on gas recovering and conversion to energy. By them, landfills with gas recovering presents IRR in a range from 16% to 36% and an ROI from 2 to 5% (ABREU, 2009; PICANÇO et al., 2011).

Once more it is important to emphasize that this work does not seek to demonstrate the financial and economic viability of the WtE facility. As pointed out in other studies, such as the FEAM or EPE, if considered only WtE units to treat the MSW, there are not encouraged conditions to propose an alternative to the landfills (EPE; MME, 2008; FEAM, 2012). The reasons are multiples, such as high investment, poor waste (low LCV and high humidity) and an energy market without encouraging prices. Here, as seen in articles already mentioned, the WtE technology (or other expensive existing technology) would be part of an integrated high-scale line for MSW treatment. The most important for reaching the economic viability would come from the sales of recoverable materials, such as plastic, fertilizer, paper, metal (mainly aluminum) and glass, and from the waste treatment service supplied by the MBT+WtE model to the municipalities. Using an RDF with an LCV improved by the MBT, the WtE facilities would be smaller and more efficient what would close the portfolio with their electricity revenues.

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CHAPTER FIVE
CONCLUSIONS

Based on assumptions described in this article, it is economically viable to have MBT+WtE facilities in the MRSP treating 100% of its waste with 99% of confidence. As shown, 12 facilities, attending 39 cities would be profitable enough to be an alternative to the landfills in the metropolitan region.

Perfectly meeting the Brazilian PNRS' (National Policy for Solid Waste) requirements of having 100% of the waste recovered through logistic reverse and recycling, the proposal would help the policy to work as planned (BRASIL, 2011). However, the model proposed only works if some premises will not change, and to assure them; it is important to review the current policy. It should consider other technologies of waste treatment, besides the landfills, and suggest incentives for them, as explored by DEMIRBAS (DEMIRBAS, 2011) in his article. The service of waste treatment (or disposal) must always be a cost to the cities and revenue for the sanitary projects, whatever the circumstance. Recovered materials, such as recycled plastic, paper, glass, and bio-fertilizer, should have tax incentives to promote their usage and protect them against the predatory competition of “virgin” commodities. Also, all waste-based electricity should have a special fee because renewable sources of energy still depend on expensive energy production, gas, and particulate emissions control technologies.

Even a model considering expensive technologies are liable to attend metropolitan regions like São Paulo. Recycling and extracting as much as possible of organics from the waste, reduce the capital intensity when investing in WtE units. Smaller units are necessary to produce electricity with more efficiency, and best values come from sales of service and products. In the case shown in this article, the model presents economic viability (e.g., IRR= 33.7% and ROE=24.5% per year) that would not be an obstacle to change the status quo of dumps, landfills and low engagement on recycling. By the way, this viability can be better (e.g., IRR=116.3%, ROI=22.9% per year and ROE=95.5% per year) with lines of financial credits with substantial interest rates. A good example is the National Bank of Economic and Social Development (BNDES), a Brazilian federal bank has a credit line for Environmental Sanitation and Water Resources with low-interest rates with a minimum 20% of investor’s equity.

Breaking the paradigms of economic viability and negative social impacts, reducing the electricity demand with less carbon release, hopefully, this article contributes to improving the PNRS. It is essential to consider in it more technologies to manage the municipal waste, due to several different area characteristics, to increase the coverage of the policy’s compromises, and to attract more investors and entrepreneurs.

As already detailed, domestic waste anaerobic digestion is not typical on an industrial scale as well as agriculture and livestock ones. Its residues composition with too many preservatives, demanding activation (e.g., use of degradation promoters) to accelerate the process of degradation and gas production, and assets too capital intensive, are still considered barriers to overcome. That explains why it is more common to aerate and dry it to produce organic fertilizer.

In an upcoming article, this study will challenge the same model but consider MBT's facilities with gasification by anaerobic digestion to the MRSP's scenario. Producing methane (CH_4), the model could consider a considerable increment of electricity and revenue, as recently published by HADIDI in his research for Saudi Arabia (HADIDI and OMER, 2017).

DECLARATIONS

– AVAILABILITY OF DATA AND MATERIAL

Materials and data availability at UNICAMP Bibliographic Repository (http://repositorio.unicamp.br/handle/REPOSIP/333323).

– COMPETING INTERESTS

There are no competing interests affecting this article developed in a public institution of scientific researches.

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– AUTHORS' CONTRIBUTIONS

Through this article, the author intends to promote more discussions about alternatives to treat urban waste and its potential to save and produce energy with notorious benefits to the Brazilian society and environment.

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– AUTHOR’S INFORMATION

A Brazilian researcher with 23 years of experience dedicated to study economic viability and impacts of materials, composites, sources of energy and recycling to the society and environment.

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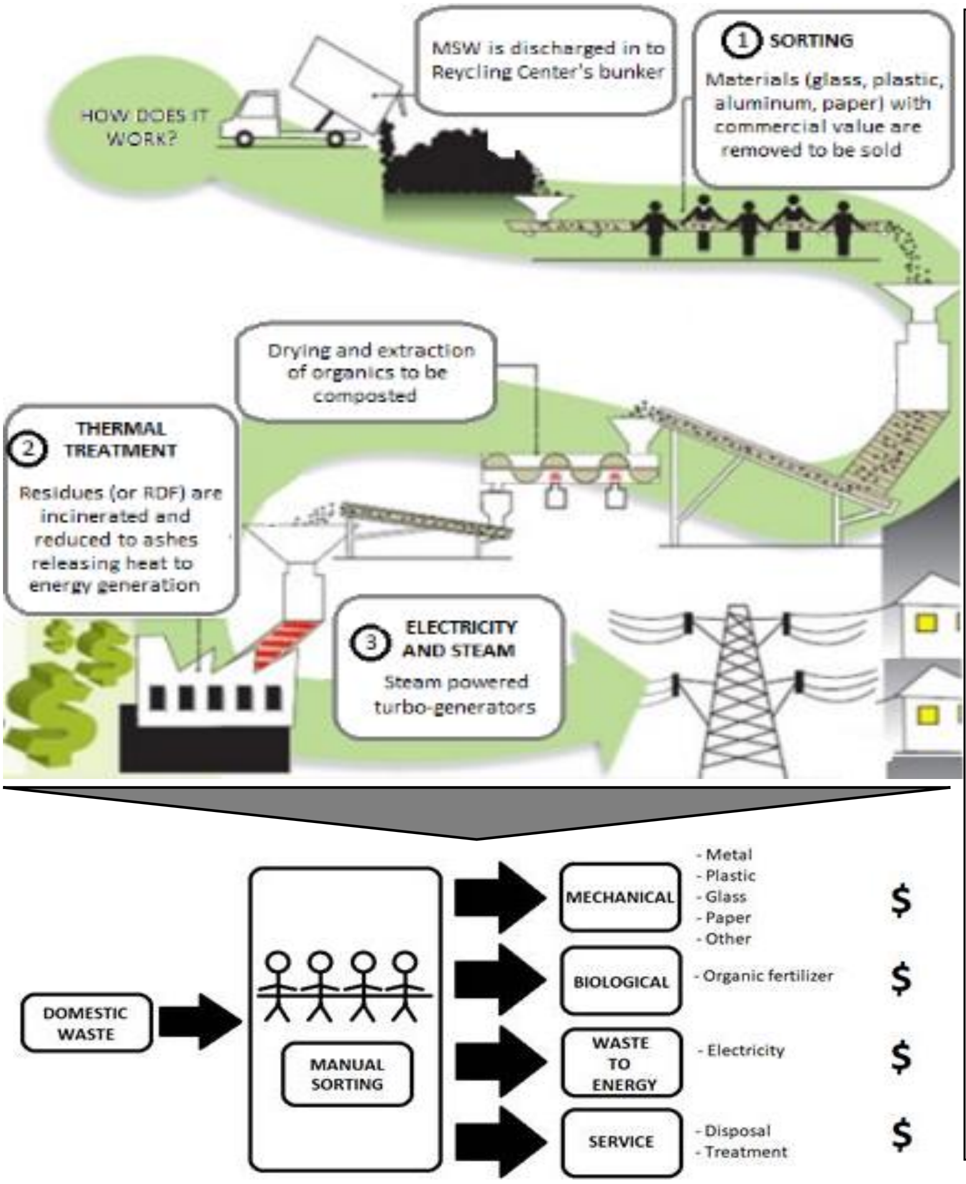

IMPORTANT ASSUMPTIONS:

- Sorting phase done by workers formally contracted;
- Sorting phase may be an alternative to cooperatives of recyclables (where not available), or work in partnership with them;
- Operation must consider all requirements of safety and health at work;
- Previous segregation done by society would be better to improve the efficiency and work conditions; and
- Technical capacitation is a must to sort and to operate WtE assets.

Source: Author´s p

Figure 1. Integrated waste recovering plant, or MBT+WtE facility

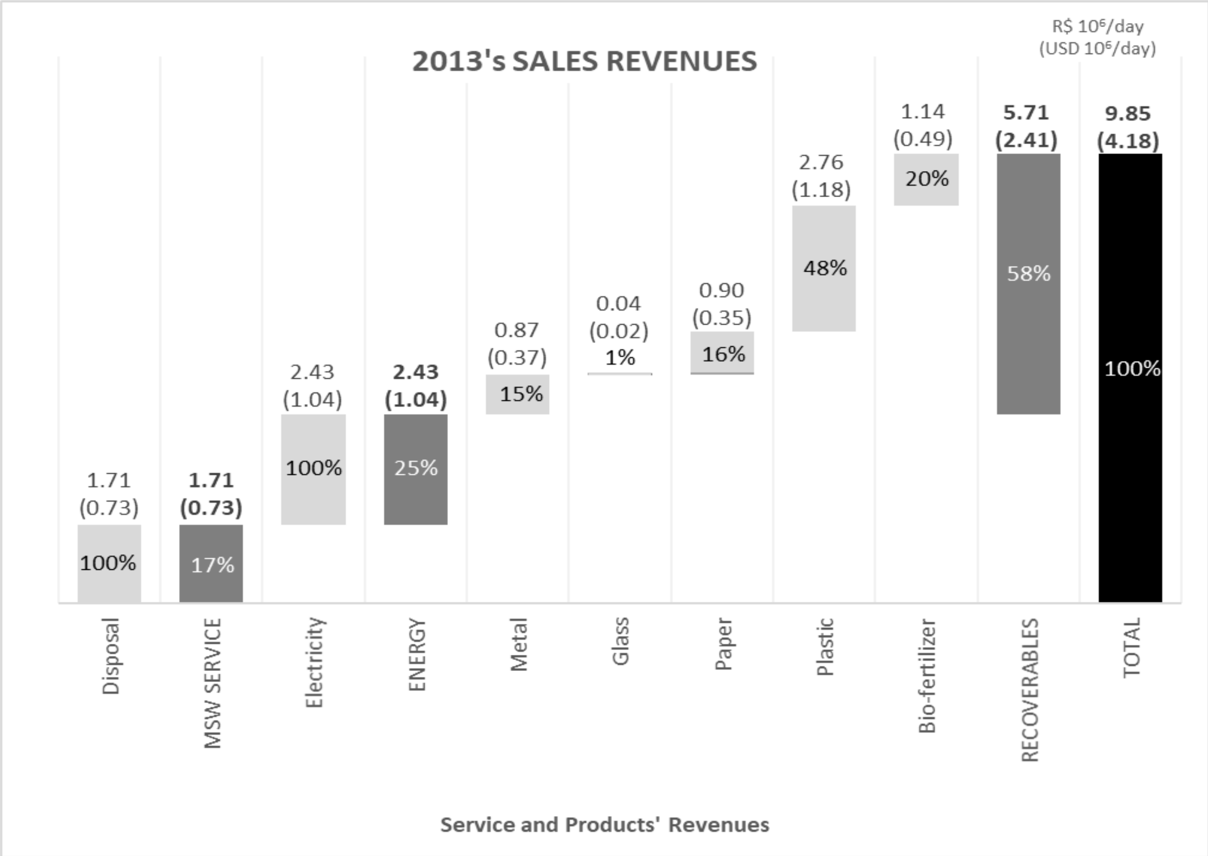

Figure 2. Potential sales revenues

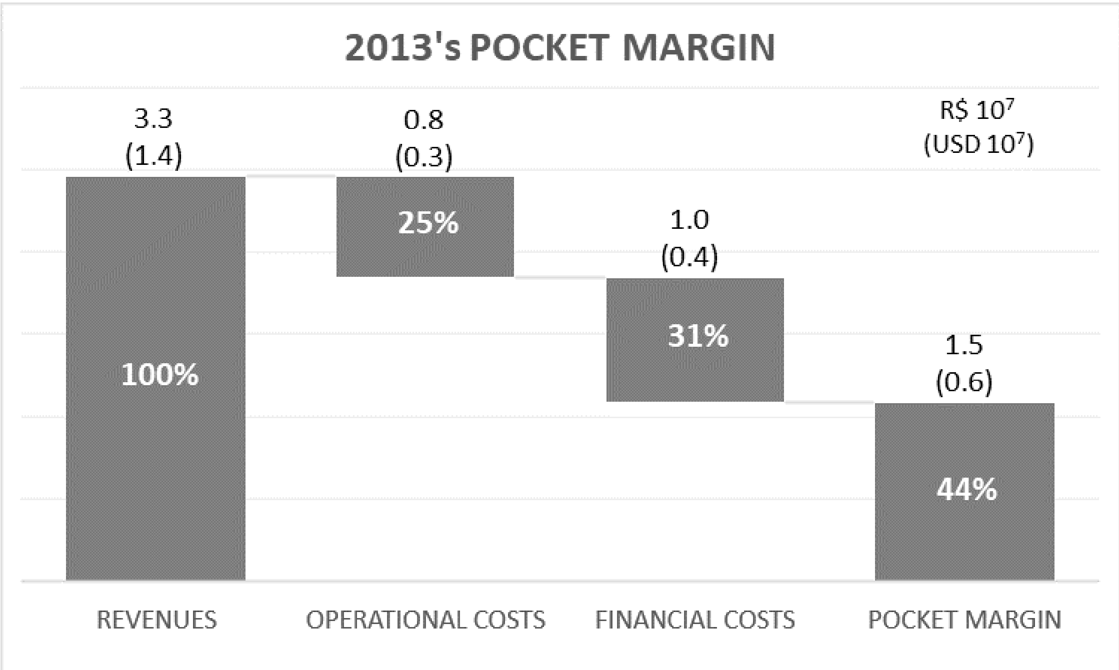

Figure 3. Pocket margin

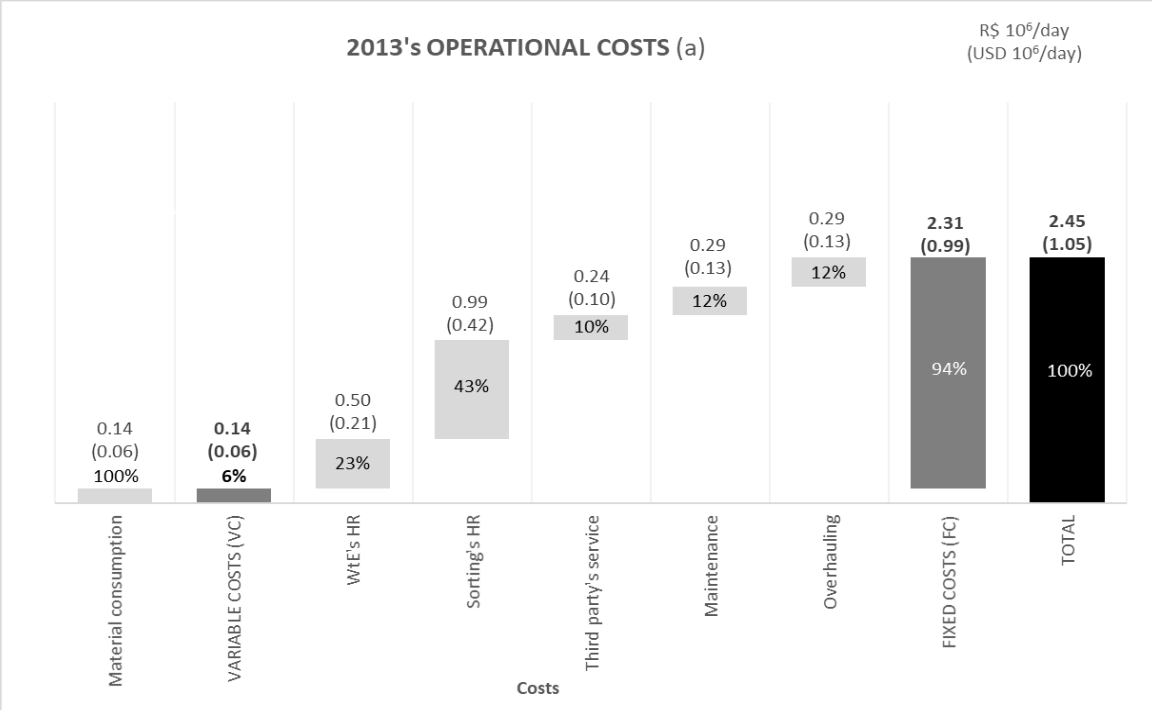

Figure 4a. Breakdown – Operational costs

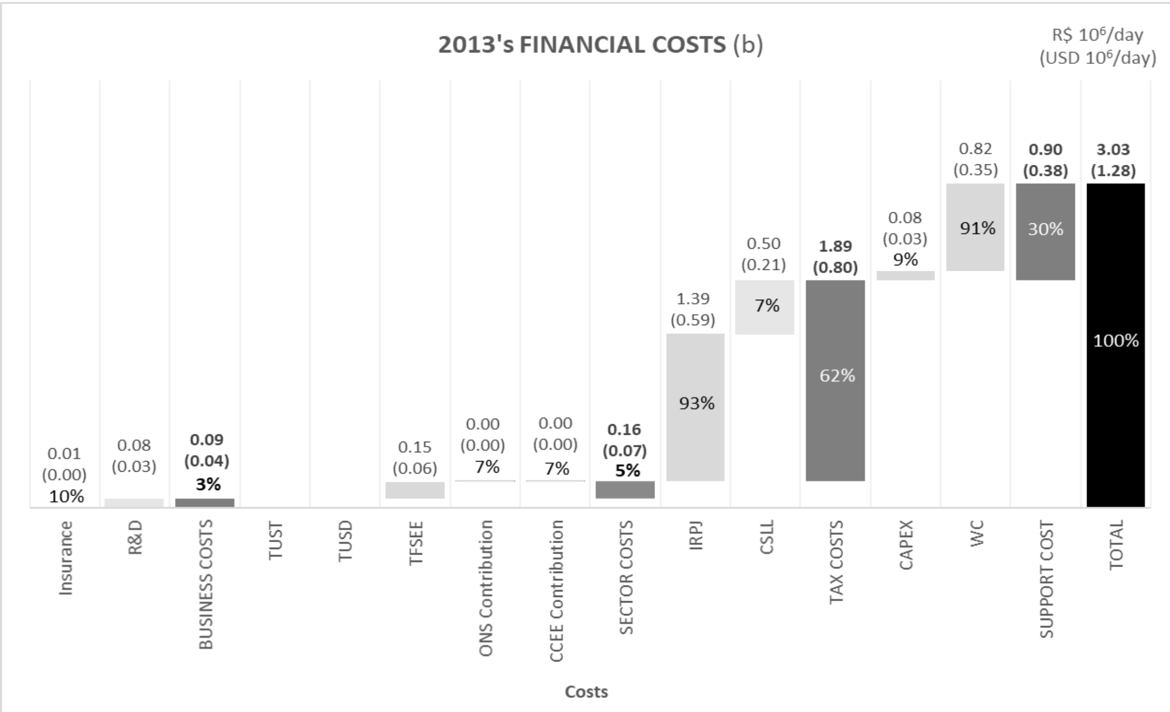

Figure 4b. Breakdown – Financial costs

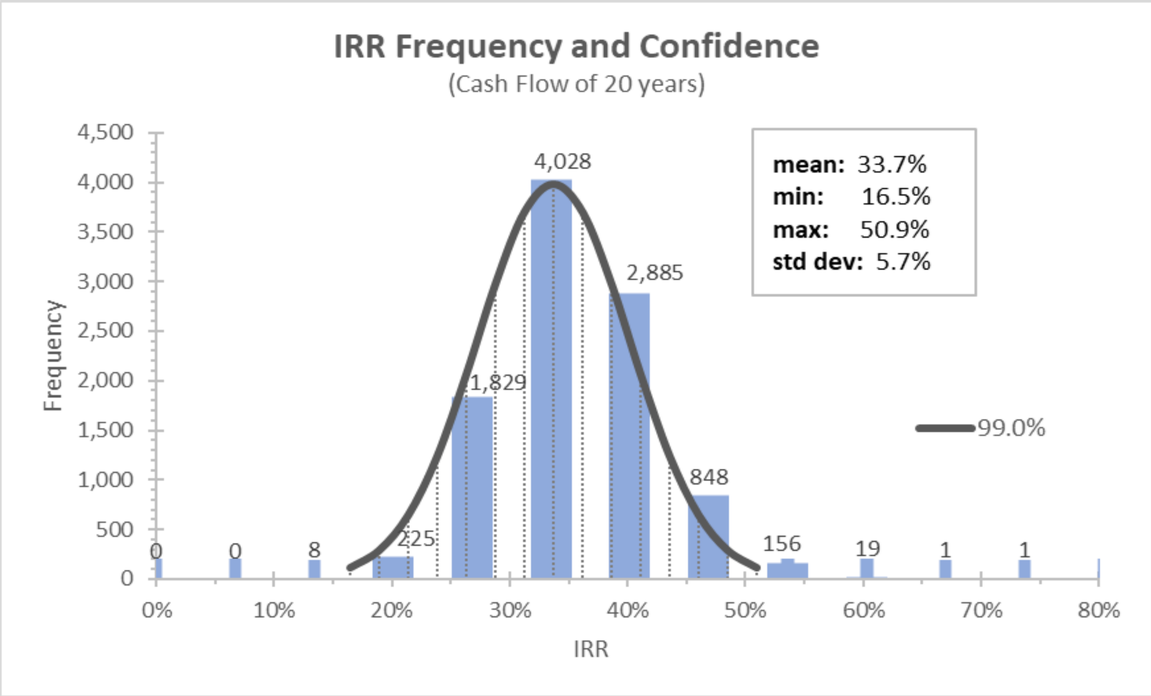

Figure 5a. IRR analysis with a 99% confidence level

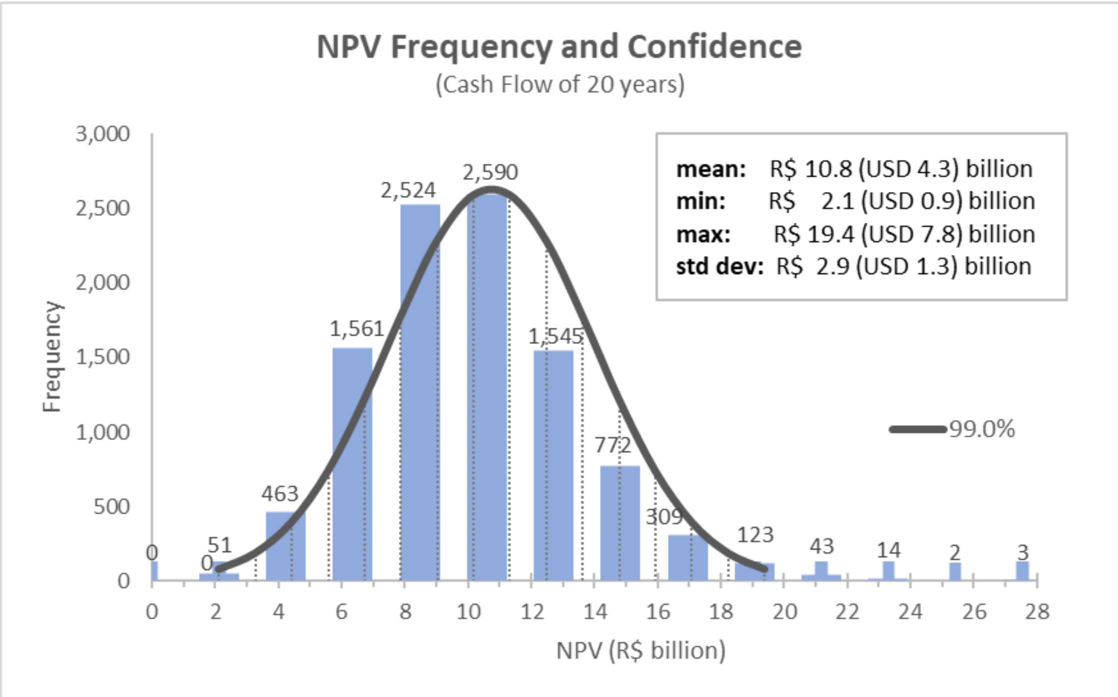

Figure 5b. NPV analysis with a 99% confidence level

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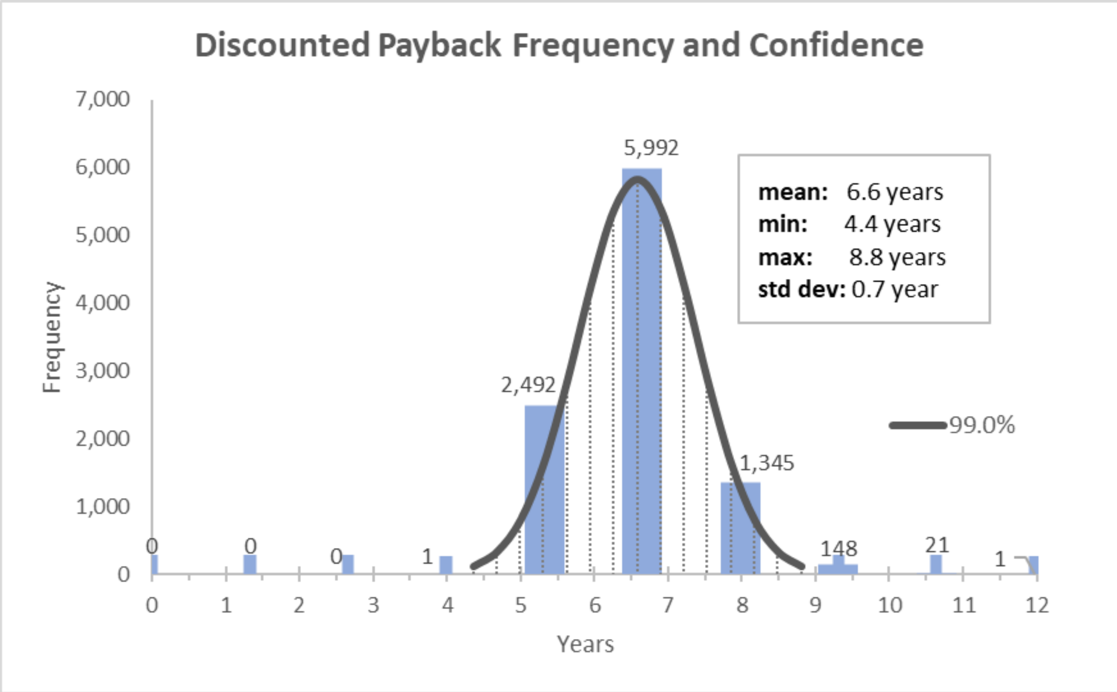

Figure 5c. Payback analysis with a 99% confidence level

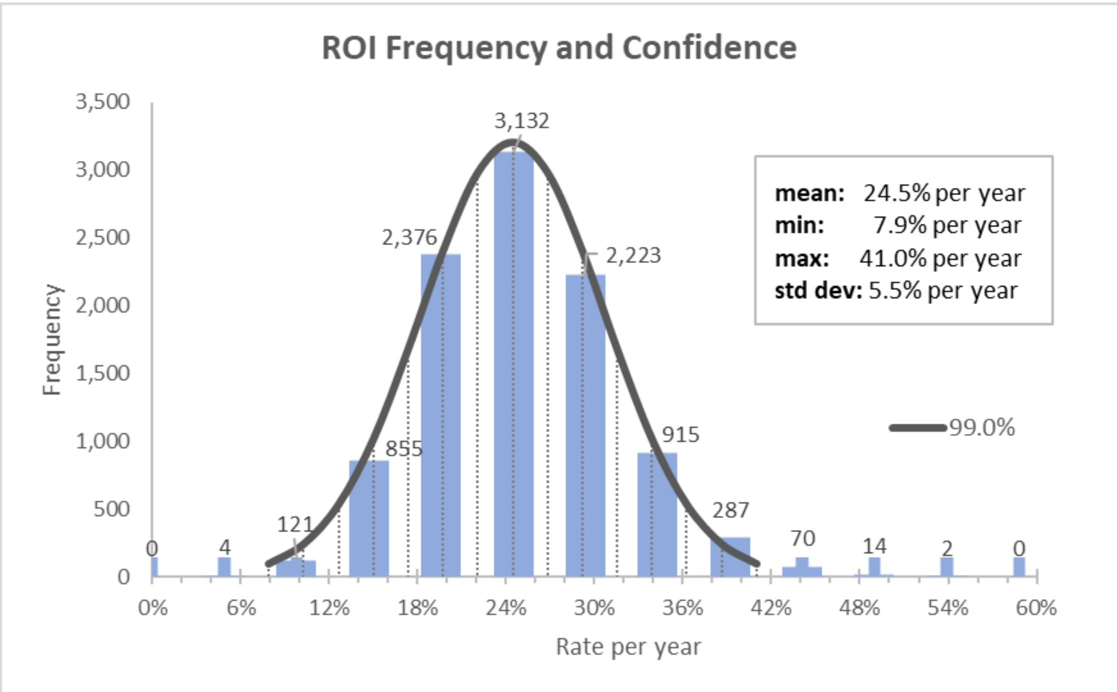

Figure 5d. ROI analysis with a 99% confidence level

Table 1. Estimated mass balance

IN	PROCESS FLOW					OUT
		Process	**Fraction**	**"Raw Materials"**	**Fraction**	**PRODUCTS/SERVICE**
MSW	100%	*Biological*	43%	Organic	43%	Fertilizer
		Mechanical (Recycling)	24%	Paper	8%	Recyclables
				Plastic	8%	
				Metal	1%	
				Glass	1%	
				Other (e.g., electronics)	6%	
		WtE	33%	Dirty plastics	24%	Electricity
				Textile, dirty papers, city cleaning	9%	
		Urban Waste Service				Treatment
TOTAL	100%	**All Processes**	100%	**All Recyclables**	100%	**All Revenues**

Source: Compilation from **Table C2**, **Table C3** and **Table C4**

Table 2. References to prices and fees for sales revenues

<table>
<tr><th>REVENUE</th><th>ORIGIN</th><th colspan="4">2013’s MARKET PRICES</th><th colspan="2">PRICE´S RANGE FROM 2000 TO 2016</th><th>REFERENCES</th></tr>
<tr><td>MSW disposal</td><td>Service</td><td>80</td><td rowspan="6">R$ per metric ton</td><td>34</td><td rowspan="6">USD per metric ton</td><td>35 – 150</td><td rowspan="6">R$ per metric ton</td><td>(ABRELPE, 2014)
(CETESB, 2014)</td></tr>
<tr><td rowspan="5">Recyclables</td><td>Metal</td><td>2,800</td><td>1,197</td><td>1,300 – 3,300</td><td rowspan="5">(CEMPRE, 2013)</td></tr>
<tr><td>Glass</td><td>180</td><td>77</td><td>162 – 198</td></tr>
<tr><td>Paper</td><td>510</td><td>218</td><td>150 – 510</td></tr>
<tr><td>Plastic</td><td>1,700</td><td>726</td><td>600 – 2,200</td></tr>
<tr><td>Fertilizer</td><td>125</td><td>53</td><td>100 – 150</td></tr>
<tr><td>Energy</td><td>Electricity</td><td>197</td><td>R$ per metric ton</td><td>84</td><td>USD per MWh</td><td>90 – 430</td><td>R$ per metric ton</td><td>Aneel 2007 e 2013</td></tr>
</table>

Source: Author’s elaboration based on market references

Table 3. Configurations and specs for WtE units

Config.	**Waste Capacity** (m ton/day)	**Min. LCV** (kcal/kg)	**Installed Capacity** (MW)	**Operation** (h/year)	**Electricity Potential** (MWh)	**Electricity Efficiency**
#1	600	1,200	10	8,000	80,000	29%
#2	600	3,200	26	8,000	208,000	28%
#3	**600**	**5,200**	**42**	**8,000**	**336,000**	**28%**
#4	600	6,600	60	8,000	480,000	31%

Source: CNIM spec and configurations (CNIM, 2018)

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Table 4. Proposed distributions of MBT+WtE facilities at MRSP in 2013

REGION	**QTY** (m ton/day)	**MBT** (m ton/day)	**WtE** (m ton/day)	**NR OF UNITS (600 m t)**	**% CAPACITY**	**ESTIMATED INVESTMENT** R$ (USD) billion
Purple	928	622	306	2	86%	0.9 (0.4)
Red	455	305	150			
Yellow	1,762	1,180	581			
Green	2,714	1,819	896	3	100%	1.5 (0.6)
Blue	2,698	1,808	890			
Gray	12,800	8,576	4,224	7	100%	3.4 (1.5)
TOTAL	**21,357**	**14,309**	**7,048**	**12**	**98%**	5.8 (2.5)

Source: Compilation from

Figure B *1*

Table 5. The breakdown of operational costs

OPERATIONAL EXPENSES · VC – Variable cost · FC – Fixed cost	**VALUE DESCRIPTION**		**UNIT**	**REFERENCES**
WTE's human resource (CF)	Investment amount	3.1	**%**	(BANK, 2000)
Material consumption (VC)		0.9		
Third party's service (FC)		1.5		
Maintenance (FC)		1.8		
Overhauling (FC)		1.8		
Sorting's human resource (FC)	1 labor per 730 metric ton per year of MSW	46 (20)	R$/metric ton year * (USD/metric ton year)	(FERRI et al., 2014)
OTHER OPERATIONAL	**VALUE DESCRIPTION**		**REFERENCES**	
Minimum wage's range	R$ 240 – R$ 937		(BRASIL, 2017)	
Insurance	0.06% x Investment		(BANK, 2000)	
R&D	0.5% x Investment			

TUSD (Distribution fee)	-	CCEE – Renewable Energy (ANEEL, 2007)
TUST (Distribution fee)	-	
TFSEE (sector's service rate)	R$ 470.63 per installed kW	(ANEEL, 2013)
ONS's contribution (sector's rate)	R$ 0.1/MWh	Sector's rate (ANEEL, 2007)
CCEE's contribution (sector's rate)	R$ 0.1/MWh	
Depreciation	10 years	Market practice (BNDES, 2018)
IRPJ (income tax)	25% x Profit	Brazilian's income tax (RFB, 2018)
CSSL (social contribution)	9% x Profit	
CAPEX	5% x Investment	(BANK, 2000)
OTHER FINANCIAL	**VALUE DESCRIPTION**	**REFERENCES**
Exchange (USD/R$)	0.82 – 4.17	(BACEN, 2018)
WACC (TJLP+RISK+BNDES)	7% – 13%	(BNDES, 2018)

(*) Considering remuneration of two 2014's minimum wage plus CLT's costs and benefits

Source: Author's elaboration based on market references (BRASIL, 2017, 1943; MTE, 2018)

Table 6. References to calculate 10,000 scenarios of decision

PARAMETERS	**Min** (x-3σ)	**Max** (x+3σ)	**Mean** (x)	**Std dev** (σ)	**References**
Investment (R$ billion)	5.3	6.4	5.8	0.2	(CNIM, 2018)
Exchange (R$/USD)	0.82	4.17	2.50	0.56	(BACEN, 2018)
Amount of Waste (k metric ton per day)	15.2	21.4	18.3	1.0	(ABRELPE, 2016)
Destination Fee (R$ per metric ton)	35	120	77	14	
Metal scrap (R$ per metric ton)	1,300	3,300	2,300	333	
Glass scrap (R$ per metric ton)	162	198	180	6	
Paper scrap (R$ per metric ton)	150	510	330	60	
Plastic scrap (R$ per metric ton)	600	2,200	1,400	267	
Organic fertilizer (R$ per metric ton)	100	150	125	8	
Electricity (R$ per MWh)	90	430	260	57	(MME, 2016)
Minimum Wage (R$ per month)	240	954	597	119	(BRASIL, 2017)
Annual Interest rate for funding (%)	6.8	9.5	8.2	0.4	(BNDES, 2018)
Annual TLP (former TJLP) (%)	4.8	7.5	6.2	0.4	(BNDES, 2018)

Source: Author's elaboration based on the market's references from 2000 to 2018

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Table 7. Comparison of equity versus funding (20 year's cash flow)

VARIABLE	100% EQUITY	80% of BNDES's FUNDING
IRR	33.7%	116.3
NPV	R$ 10.8 (USD 4.3) billion	R$ 13.4 (USD 5.8) billion
PAYBACK	6.6 years	6.9 years
ROI	24.5% per year	22.9% per year
ROE	24.5% per year	95.3% per year

APPENDIX A. Current MSW organization at MRSP

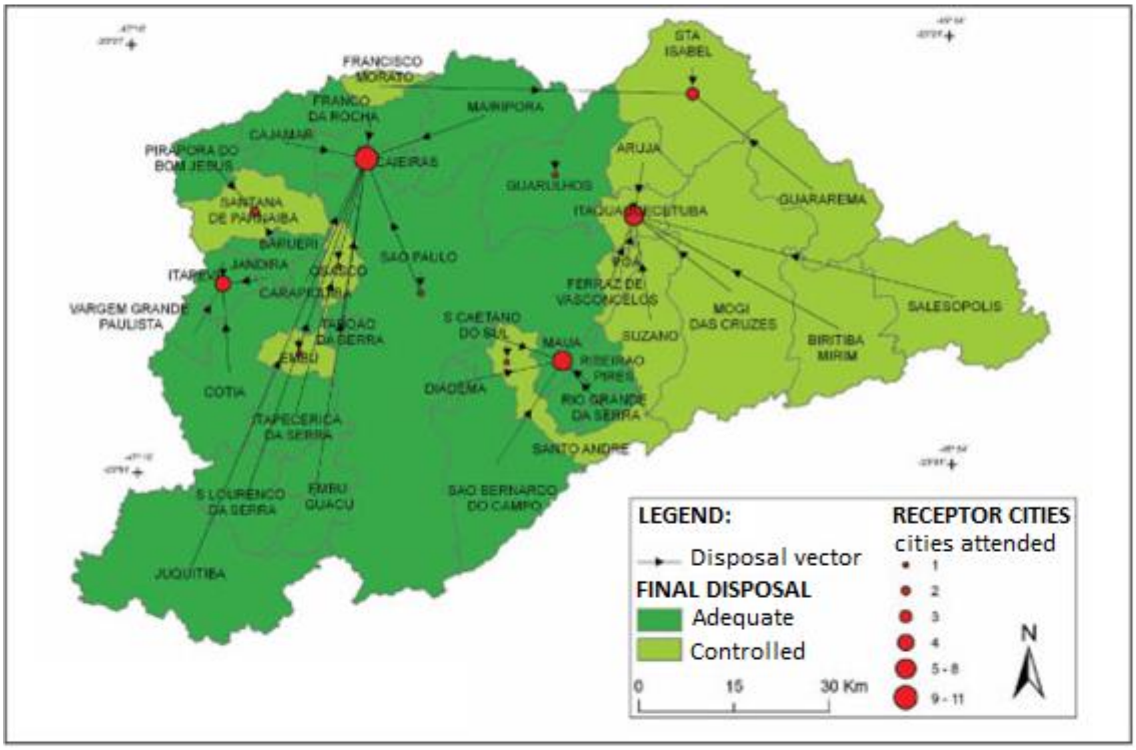

Figure A 1. MSW disposal´s map at MRSP adapted from JACOBI (JACOBI and BESEN, 2011) – *colored*

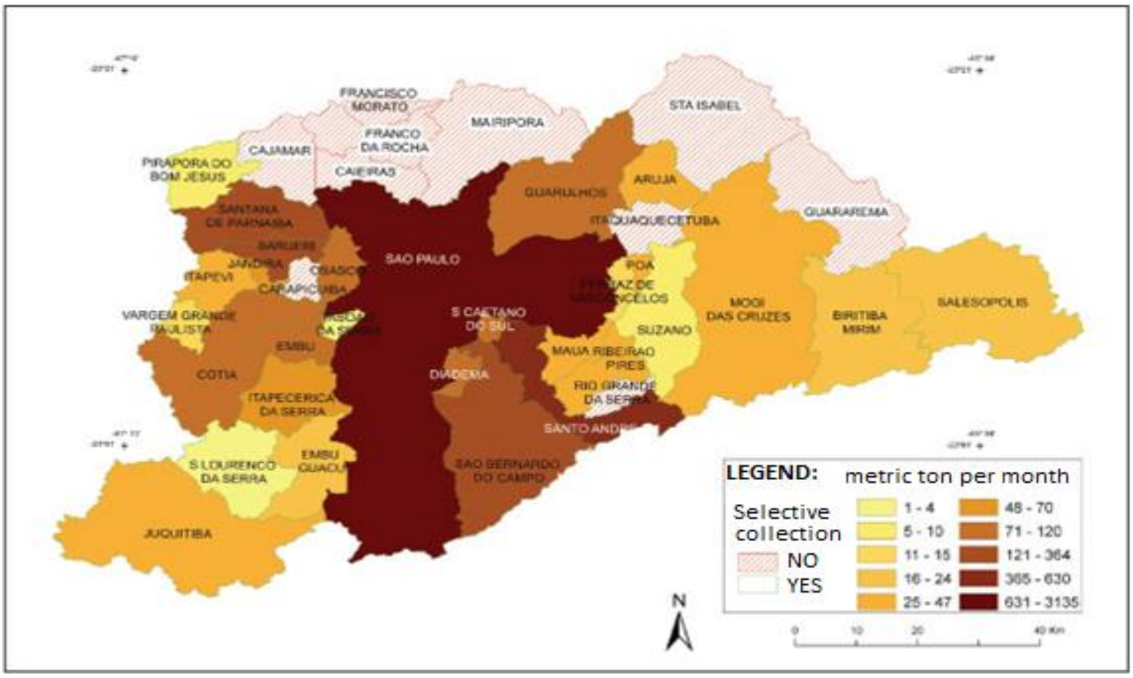

Figure A 2. Selective collection's map at MRSP adapted from JACOBI (JACOBI and BESEN, 2011) - *colored*

APPENDIX B. Proposed locations for MBT+WtE units at MRSP

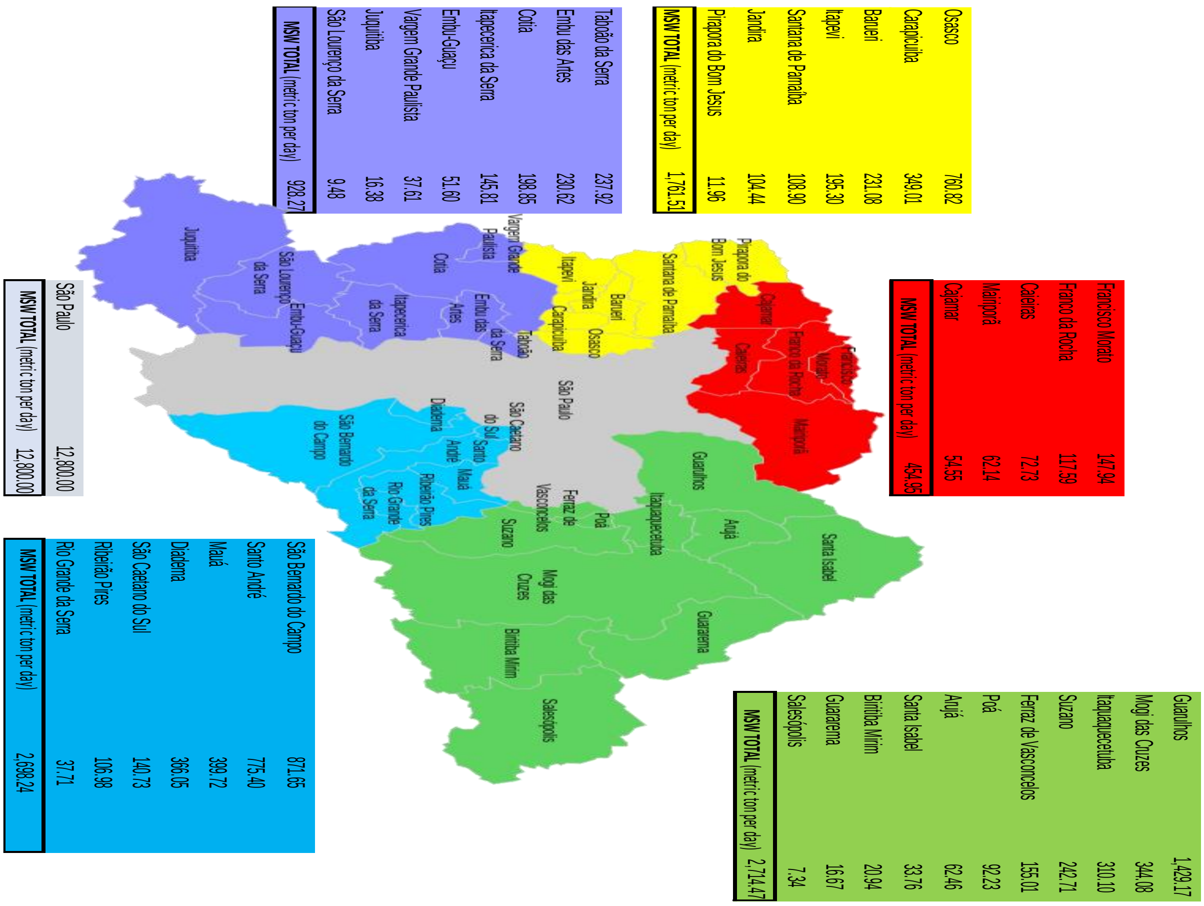

Figure B 1. Distribution of MSW at MRSP in 2013 - *colored*
Source: Author's draft based on CETESB's data (CETESB, 2014)

APPENDIX C. MSW´s gravimetric composition at MRSP

Table C1. Standards for Systems of Residues' Thermal Treatment

RESTRICTIONS	CONAMA 316/2002 (mg/Nm³)	US-EPA (mg/Nm³)	EU-2000/76/EPC (mg/Nm³)
Particulate material	70	11	10
Cl_2	n.d.	n.d.	10
HCl	80	29	10
HF	5	n.d.	1
SO_2	280	63	50
NO_x	560	264	200
CO (ppm)	100	45	50
Heavy Metals Class I (e.g. Cd)	0.28	n.d.	0.05
Heavy Metals Class II (e.g. Hg)	0.28	0.06	0.05
Heavy Metals Class III (e.g. Pb)	6.2	n.d.	n.d.
Dioxins and furans (ng/Nm³)	0.1 - 0.5	0.14	0.1

Source: Compilation from CONAMA (CONAMA, 2002), EPA (US EPA, 2016) and European Standard (EPC, 2000)

Table C2. Gravimetric composition to the MSW at MRSP

MATERIAL	WET	DRY
	76%	24%
	GRAVIMETRY (%)	
Aluminum	0.46	1.2
Rubber	0.12	1.22
Styrofoam	0.27	0.21
Natural wood	0.71	0.07
Processed wood	0.13	0
Metal	0.58	1.59
Paper	4.97	16.14
Cardboard	2.58	10.71
PET bottles	0.77	1.88
Various plastic	1.11	4.05

PP bags, vessels, and packages	0.86	1.15
PE bags, vessels, and packages	28.73	24.39
Fabric	3.82	4.68
Tetrapack® packages	1.18	3.79
Glass	0.47	2.82
Organics	49.9	19.7
Other (e.g., lamps, batteries, electronic)	3.34	6.4
MSW's TOTAL COMPOSITION (%)	**100.00**	**100.00**

Source: Author's estimate based on SEMASA and IPEA's data (IPEA, 2012; SEMASA, 2008)

Table C3. Potential sorting of the MSW at MRSP

MRSP's MSW TOTAL (metric ton per day)	21,357.44	
	WTE	**SORTING**
	33%	67%
	7,153.29	14,204.15
	MATERIALS	
Aluminum	0.00	136.18
Rubber	19.48	62.53
Styrofoam	43.83	10.76
Natural wood	115.24	3.59
Processed wood	21.10	0.00
Metal	0.00	175.64
Paper	806.71	827.30
Cardboard	418.78	548.97
PET bottles	124.98	96.36
Various plastic	180.17	207.59
PP bags, vessels, and packages	139.59	58.95
PE bags, vessels and packages	4,663.35	1,250.18
Fabric	620.05	239.89
Tetrapack® packages	0.00	385.80
Glass	0.00	220.84
Organics	0.00	9,109.37
Other (lamps, batteries, electronics…)	0.00	870.19

(*) Considered wet by WTE heating and aerobic process

Source: Author's potential estimate based on **Table C2**.

Table C4. Lower calorific values for wet components in the MSW

MATERIAL	**Humidity** (%)	**LCV** (kcal per kg)
Organic	66	712
Plastics	17	8,193
Paper or cardboard	21	2,729
Fabric or leather	36	1,921
Wood	25	2,490
Rubber	5	8,633

Source: The World Bank, FEAM, and NIXXON (BANK, 2000; FEAM, 2012; NIXXON et al., 2013)

Table C5. The energetic potential for the RDF

MSW's COMPONENT	**FRACTION**		
	33% 7,153.29		
	QTY (m ton per day)	**Composition** (%)	**LCV** (kcal per kg)
Aluminum	0.00	0.00%	0.00
Rubber	19.48	0.27%	23.51
Styrofoam	43.83	0.61%	50.20
Natural wood	115.24	1.61%	40.12
Processed wood	21.10	0.29%	7.35
Metal	0.00	0.00%	0.00
Paper	806.71	11.28%	307.76
Cardboard	418.78	5.85%	159.76
PET bottles	124.98	1.75%	143.15
Various plastic	180.17	2.52%	206.36
PP bags, vessels and packages	139.59	1.95%	159.88
PE bags, vessels and packages	4,663.35	65.19%	5,341.16
Fabric	620.05	8.67%	166.51
Tetrapack® packages	0.00	0.00%	0.00
Glass	0.00	0.00%	0.00
Organics	0.00	0.00%	0.00
Other (lamps, batteries, electronics…)	0.00	0.00%	0.00
MRSP's MSW TOTAL	7,153.29	100.00%	6,605.75

Source: Author's potential estimate based on **Table C3** and **Table C4Error! Reference source not found.**

APPENDIX D. Human resources´ expenses

Table D1. The breakdown of monthly expenses with HR

TYPE OF EXPENSE	REFERENCE	VALUE
Sorting salary	2014 national's minimum wage (R$ 724 or USD 309)	R$ 1,448.00
		USD 618.80
Transport voucher	R$ 10 (USD 4.30) per day	R$ 220.00
		USD 94.02
Transport voucher discount	6% of employee's salary	-R$ 86.88
		-USD 37.13
Meal voucher	R$ 15 (USD 6.41) per day	R$ 330.00
		USD 141.03
Healthcare	Market offer	R$ 150.00
		USD 64.10
Another benefit	-	R$ 0.00
		USD 0.00
13th salary provisioning	CLT (BRASIL, 1943)	R$ 120.67
		USD 51.57
Vacation provisioning	CLT	R$ 120.67
		USD 51.57
1/3 of vacation provisioning	CLT	R$ 40.22
		USD 17.19
FGTS (Service fund)	CLT	R$ 115.84
		USD 49.50
FGTS (13th salary plus vacation) provisioning	CLT	R$ 22.52
		USD 9.62
INSS (Social security)	20.00%	R$ 289.60
		USD 123.76
INSS (13th salary plus vacation) provisioning	CLT	R$ 56.31
		USD 24.06
Employee cost	**R$ 2,826.95**	
	USD 1,208.10	
Factor (Employee cost/salary)	**1.95**	

Source: Author's compilations and calculations