CESAR ALEXANDRE FUMEY

SEIZING LANDFILLS’ POTENTIAL FOR ENERGY AND FUEL PRODUCTION

IN BRAZIL

Graduation work presented at Escola Politécnica da Universidade de São Paulo for the accomplishment of the “Diploma de Engenheiro de Produçao”

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RESUMO

Com o aumento dos problemas ecológicos e da consciência ecológica, a gestão de resíduos está recebendo mais atenção, e com razão. Dependendo do país, a forma como o resíduo é considerado e tratado pode ser extremamente diferente. Para as economias em desenvolvimento, a gestão de resíduos é uma preocupação frequentemente secundária e é deixado do lado. Isso leva a sistemas ineficientes, que têm pouca consideração pela sustentabilidade ou pelas possibilidades oferecidas pelas tecnologias atuais.

O presente estudo visa oferecer soluções economicamente viáveis de valorização de resíduos, adaptadas à atual economia e regulamentação brasileira. Será realizada uma avaliação das principais tecnologias existentes de valorização de resíduos no mundo. Esse conhecimento será então aplicado ao caso específico de um aterro sanitário na região de São Paulo. O objetivo é oferecer soluções de valorização que tratariam uma parte do que esse aterro recebe e transformá-lo em combustível ou energia. Para propor as soluções mais adaptadas, será realizado um estudo de campo no aterro, com o objetivo de caracterizar os resíduos recebidos com maior potencial de valorização. As soluções serão então analisadas financeiramente, para avaliar a sua viabilidade nos olhos de investidores privados.

Espera-se que estas soluções sejam financeiramente interessantes para o investimento privado, sem depender de futuros incentivos governamentais, como existem em outros países desenvolvidos. Eles seriam um primeiro passo para a valorização dos resíduos a serem aterrados no país e poderiam servir de exemplo para o resto do sistema brasileiro de gerenciamento de resíduos. As soluções oferecidas são consideradas viáveis e estão prontas para serem avaliadas por investidores privados. O objetivo é que eles constituam um ponto de partida para um sistema sustentável de gestão de resíduos no Brasil.

Palavras chaves: Gestão de Resíduos, Valorização de Resíduos, Sustentabilidade, Caracterização de Resíduo.

ABSTRACT

With the rise of ecological problems and ecological awareness, waste management is getting more attention, and justifiably so. Depending on the country, the way waste is considered and treated can be extremely different. For growing economies, waste management is often a secondary concern, and is disregarded for too long. This leads to inefficient systems, that have little regard for sustainability or possibilities offered by the current known technologies.

The present study aims to offer economically viable waste valorization solutions, adapted to the current Brazilian economy and regulation. An evaluation of the main existing waste valorization technologies in the world will be conducted. This knowledge will then be applied to the specific case of a landfill in the region of São Paulo. The goal is to offer valorization solutions that would treat a part of what that landfill receives, and turn it into combustible or energy. To propose the most adapted solutions, a field study will be conducted on the landfill, with the goal of characterizing the received waste with the highest potential for valorization. The solutions will then be financially analyzed, to gage their viability in the eyes of private investors.

These solutions are expected to be financially interesting for private investment, without having to rely on future governmental incentives, as they exist in many developed countries. They would be a first step towards the valorization of to-be-landfilled waste in the country, and could serve as an example for the rest of the Brazilian waste management system. The offered solutions are judged as viable, and are ready to be evaluated by private investors. The goal being that they constitute a stepping stone towards a sustainable waste management system in Brazil.

Keywords: Waste Management, Waste Valorization, Sustainability, Waste characterization

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

ADEME Agence De l’Environement et de la Maîtrise de l’Energie (French environment and energy management agency)

CDR Combustível Derivado de Resíduo (portuguese for RDF)

CGR Central de Gerenciamento de Residuos (portuguese for Landfill)

CAPEX Capital Expenditure

HCV Higher Calorific Value

IRR Internal Rate of Return

ISWA International Solid Waste Association

LCV Lower Calorific Value

MSW Municipal Solid Waste

OPEX Operational Expenditure

PCI Poder Calorifico Inferior (portuguese for LCV)

PNRS Política Nacional do Resíduo Solido (Brazilian national solid waste politic)

RDF Residue Derived Fuel

RSU Resíduo Solido Urbano (portuguese for MSW)

UNEP United Nations Environment Program

WACC Weighted Average Cost of Capital

TABLE OF CONTENT

1 INTRODUCTION

1.1 ENVIRONMENTAL CONTEXT

Waste Management is a growingly concerning issue, as societies consume more and we become more aware of waste's environmental dangers. Treating the waste we produce and reducing its stocked amount is one of biggest ecological challenges our society is facing. It cannot be forgotten that the consequences of the environmental problems of today will fall eventually onto the next generations. We have to act as if the well-being of these future generations was a public good, and thus require collective and organized actions by the society to be taken care of (May, Lustosa, & da Vinha, 2010).

Companies have to find a way to actively help global sustainability, and put sustainability as a competitive criterion when evaluating projects. The more a company includes sustainability as a strategic focal point, the more positive ecological impact it can have. But in practice, what first pushes the development of environmental projects is usually the law. Having to comply laws on sustainability, or expecting future restrictive laws is usually what motivates sustainable projects. But if the law isn't moving fast enough, motivation has to come from within the companies, and viable business opportunities have to be searched for (Amato Neto, 2011).

One of the main environmental problems that our society is facing is waste management. And the Brazilian law is still relatively lax on the waste treatment questions, when compared to the laws of the most advanced countries on this subject. As such, any means and initiative available for waste reduction is good to take, and the more financially profitable the easier it can be implemented by private or public entities without having to wait for the law change.

In the meantime, the global need and research for green energy is increasing quickly too, and one can wonder how we could link the two.

When learning about waste management, especially how it is done in developing countries, one of the first thoughts that comes to mind is: untapped potential. And the easiest way to make use of this potential is energy and fuel production.

Being in the middle of such currently relevant problematics should offer the kind of traction that is needed for technology development, and research of new businesses. Motivation should be high for the Government, for the polluting industries, and for the waste management companies. But the political and economic realities are not always as theory would suggest, and this is also true in Brazil's case.

The goal that should be strived for is a form of industrial symbiosis, which is an important component of the circular economy theory (Amato Neto, 2018). Industrial symbiosis happens when the waste from a process serves as raw material for another process, instead of being discarded. Considering the daily life of a city as the base process, treating the waste generated and re-injecting it into other processes would be a great step towards turning that city more sustainable and making it a circular economy: if the waste is reused, there is no more output in the system. A circular economy being an economic system without inputs and outputs, working mainly on the reuse of the material it holds.

1.2 OBJECTIVES OF THE WORK

In this context, our objective is to find economically viable sustainability projects, that make use of to-be-landfilled waste in order to produce green fuel or green energy in Brazil. That would allow for waste reduction, which is a step towards closed-loop economy, while keeping the solution viable on its own. Meaning that private investors would not have to wait for governmental laws and incentives to be created.

But making energy or fuel from waste is not simple. Various technologies exist, but none are perfect. They are all relatively young and have their flaws and difficulties associated.

We will start with an overview of how solid waste management is conducted in the world and in brazil. This will let us see the different existing possibilities for waste valorisation. From recycling to combustibles, this work aims to determine which might be the more adapted to Brazil. For this study, financial, technological, environmental and political aspects will be evaluated.

Once the history, feasibility and potential of each technology has been evaluated, the results will be applied to a practical case: the landfill **XSP,** in the region of São Paulo. Having learned about the possible valorisation technologies available, the goal will be to determine which is more adapted to this particular case. For this purpose, preliminary studies and field studies will be conducted, and the results analysed. These conclusions aim to help Saturn, the company I have interned in from September 2018 to July 2019, and the owner of the CGR landfill, conduct the most adapted project.

Finally, with the experience acquired on this particular project and through academic research, we will try to assess the future of waste valorisation in Brazil: which technologies have the brightest future, what could have a big impact on the market, and what could open opportunities for waste valorisation to develop faster in the country.

2 WASTE MANAGEMENT IN THE WORLD

2.1 THE CURRENT GLOBAL WASTE PRODUCTION

As of 2015, around 2 billion tonnes of municipal solid waste (MSW) are produced each year. And if we include commercial, industrial, construction and demolition waste, this number goes up around 7 to 10 billion tonnes per annum (Wilson, 2015).

The nature of this waste mostly depends on the average income of the population producing the waste. As such, low income countries will have very different waste composition compared to high income countries. The approximate distribution is as follows:

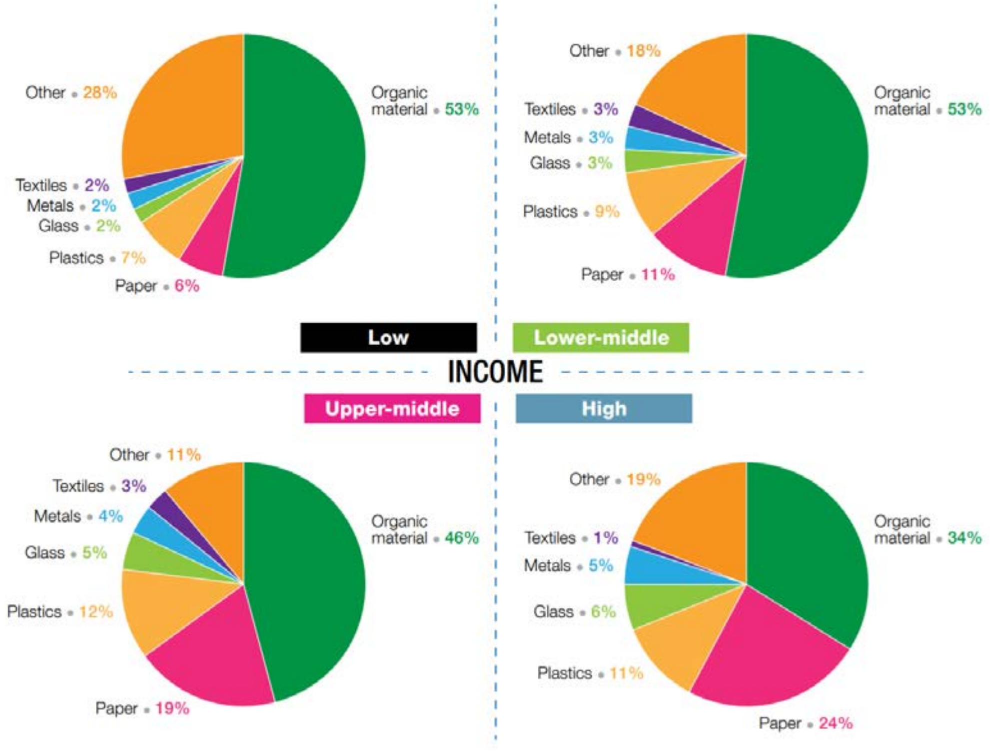
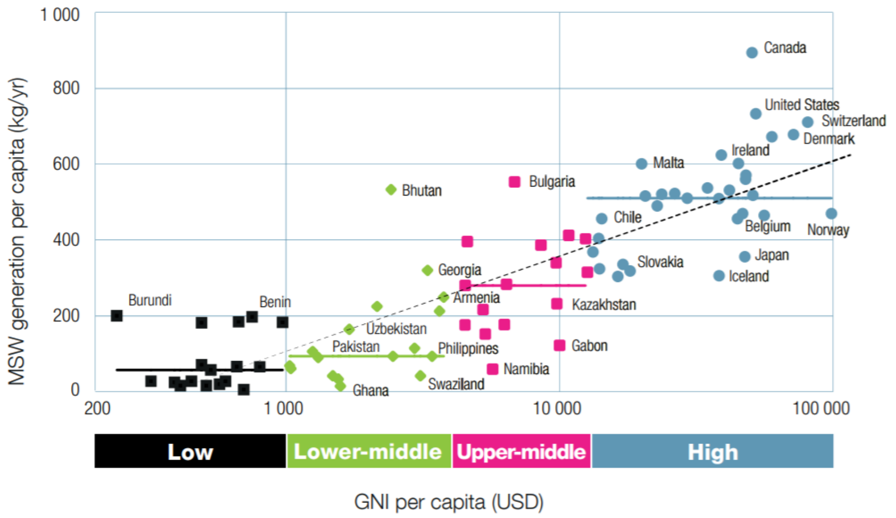


Figure 1 Waste sources based on a country's income (Wilson, 2015)

With this repartition we can see that the main evolution is that the organic portion reduces when income increases, and the glass/plastic/paper portions take its place.

But the truth here is not that the population in developing countries produces more organic waste than they do in developed countries. It's mostly that a person in an high income country produces way more glass/plastic/paper waste, and around the same amount of organic waste. And this can be seen on the following graphic:



Notes: Based on data from 82 countries using the latest available data within the period 2005-2010. For 12 countries, the latest available data was older than 2005.

Regression: y = 109.67ln(x) – 651.45, R^2 = 0.72

Data sources: EMC's Master Country Database (n.p., 2014) using primarily data from the EU, OECD and World Bank; Lawless (2014), Waste Atlas: Recycling and resource recovery around the world (Unpublished master's thesis). University of Leeds, Leeds, UK. Both were prepared for the GWMO (see Annex B, under Waste databases).

Figure 2 Waste generation per capita, according to the country's Gross National Income (GNI) per capita (Wilson, 2015)

As we can see by comparing the two graphics, a country like the US produces around 4 times as much waste per capita as a country like Benin. So even with Figure 1's percentages, a US citizen will produce twice as much organic waste as a Benin citizen, on average.

But the population trends are very much in favour of these low to upper middle countries:

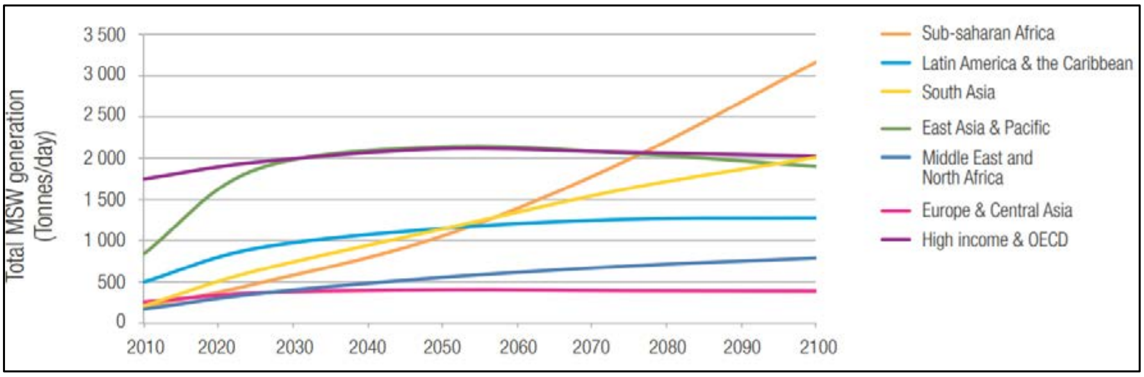


Figure 3 Total MSW generation prevision (Wilson, 2015)

Africa, Asia and Latin America are set to increase a lot their MSW generation in the next 10 years. This means that waste treatment in these regions cannot be discarded as secondary due to its smaller size, because it is far behind in terms of coverage and quality and will become a major issue soon, if it isn't already.

The coverage of controlled waste management is as such, as of 2014:

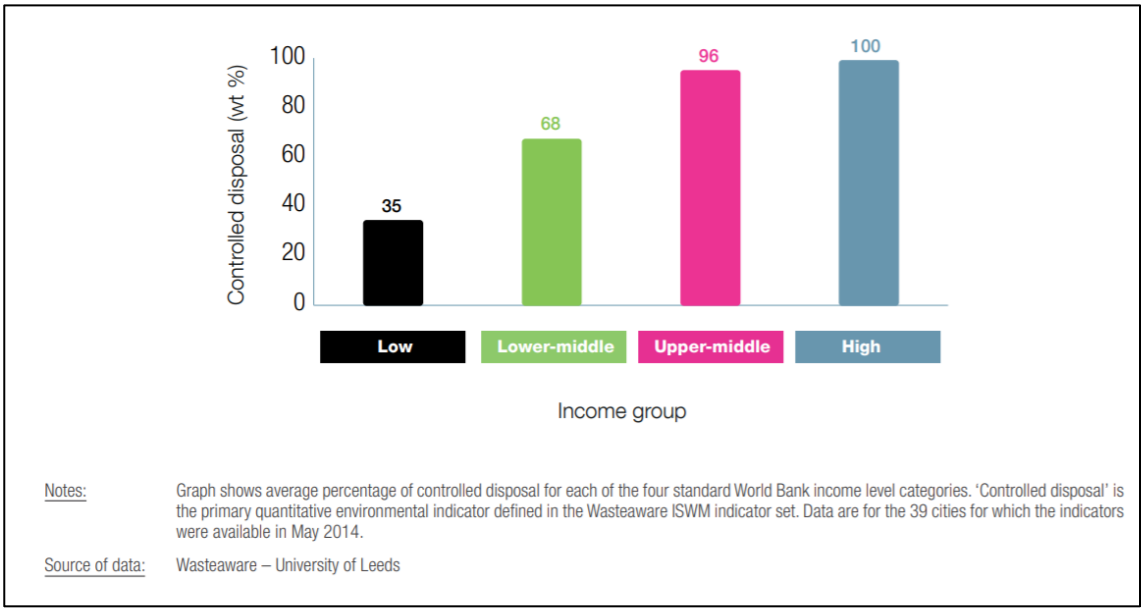


Figure 4 Controlled waste disposal rate, according to income (Wilson, 2015)

Before talking about treating the waste, countries should first focus on controlling their waste disposal system, and getting them as close to 100% as possible. As any non-controlled waste cannot even hope to be treated appropriately.

But controlling the disposal doesn't mean treating the waste the best way possible. There are various levels to waste treatment, classified as such:

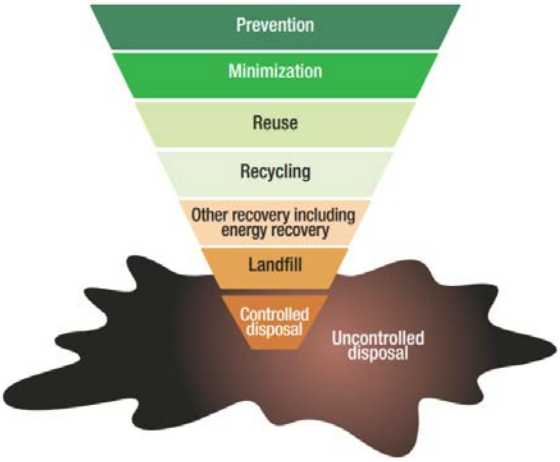


Figure 5 Waste treatment pyramid (Wilson, 2015)

As we can see, it all starts with controlled collection of the waste. Eliminating uncontrolled disposal is a priority for protecting the environment. But it's a full process to climb up to the top of the pyramid, and a country starting near the bottom should think on going up 1 echelon at a time, rather than attempting to skip phases with an unprepared system.

2.2 RECYCLING

Recycling may help conserve resources and reduces waste quantities, but as we can see on the **figure 5**, it's already quite a way up on the pyramid. And that is because to have high recycling rates, the materials have to be separated well and kept clean. Only high-income countries have significantly increased their rates over the past 30 years, and mainly thanks to legislative and economic instruments. These kinds of measures might take too much of a toll on a developing country's economy.

Though, in lower-income countries the informal sector (such as catadores in Brazil) is often achieving recycling rates of 20 to 30% for MSW (Wilson, 2015). But these numbers are highly imprecise and hard to evaluate, due to the nature of the uncontrolled recuperation.

The gap in official recycling between the biggest recyclers and the worst ones is quite striking:

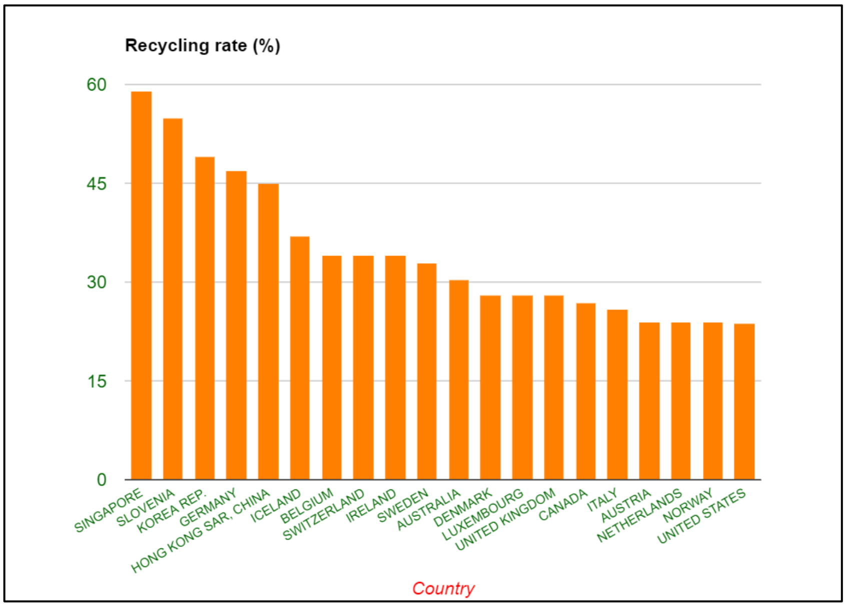


Figure 6 Top 20 countries in official SW recycling rate (Waste Atlas, 2014)

These graphics show that all the top recyclers are first world countries, while Latin America shows up at the bottom of the bottom twenty. Brazil is listed at 1% of official solid waste recycling, while the top 20 countries are listed at an average of over 30%.

This gap will be hard to close, as recycling is the most complicated type of waste treatment to implement. It needs awareness from the population, public communication campaigns, and a countrywide recycling chain to be organised. One of the biggest issues for recycling in developing countries is the lack of Public Incentives (Hettiarachchi, Ryu, Caucci, & Silva, (2018). Public involvement doesn't just happen overnight, and nearly all countries in the top 20 have used money-related incentives to kick-start recycling: taxes, benefits, and other types of retributions. And that budget usually isn't a priority in developing economies.

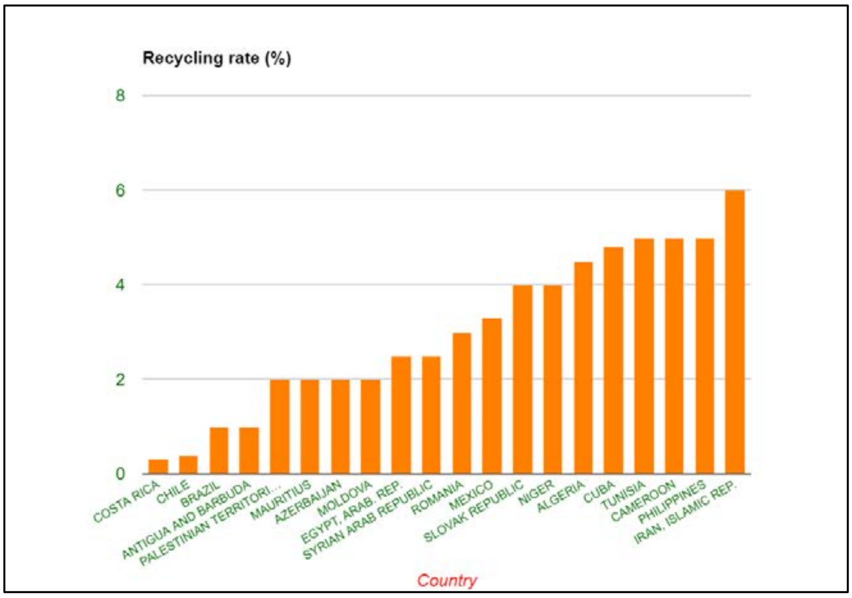


Figure 7 Bottom 20 countries in official SW recycling rate (Waste Atlas, 2014)

2.3 INCINERATION

Incineration of waste has been very much used in the past decades, in Europe, Japan and the US mostly. It's a straight forward technique, that uses direct combustion of waste in the presence of excess air to recover the energy content of the waste. This energy can be then used for Electricity or for Heat and Electricity. The efficiency of these plants goes up to 30% for electricity only, and up to 90% for Heat and Electricity (Wilson, 2015), which is extremely high for an energy recuperation technology.

This high efficiency explains the investment that was put in incineration, as we can see in the following graphic:

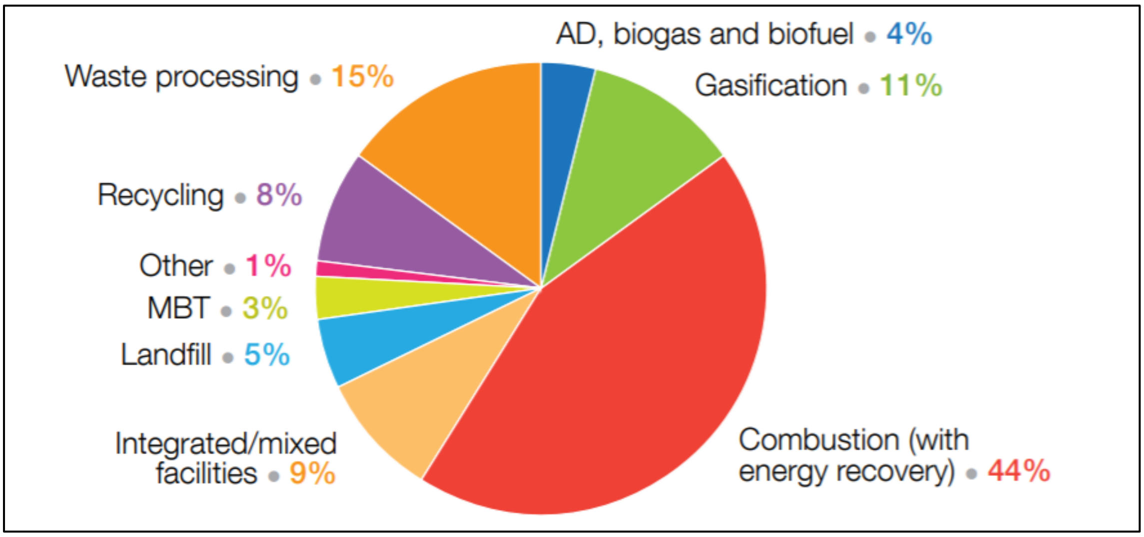


Figure 8 Most used waste treatment techniques in the world (Wilson, 2015)

With a 90% efficiency, it then seems quite obvious that a heat an electricity plant would be the best choice, but there has to have a need for that heat right around the plant. Exchanging heat on long distances is extremely difficult, and becomes inefficient after just a few kilometres.

The problem is that a large part of the developing countries is located in hotter climates, and don't necessarily have the need for that heat, largely reducing the benefits of this technology.

Additionally, as we will see in Brazil's case in the third part of this work, badly conducted and controlled waste incineration can lead to environmental tragedies. This also explains the limited use of incineration in countries that don't necessarily have the right process control agencies.

2.4 COMPOST

Compost is already widespread and simple to make, as it is just a controlled aerobic decomposition of organic waste. The problem being that it is usable for only a small portion of the organic waste, as the waste needs to be clean in order to make good compost. Industrial compost also competes with household sized productions, made by houses and farms to sustain their own needs.

Thus, the demand is quite low and turns industrial sized compost factories hardly profitable. A better separation of organic waste in developing countries would make it a lot more interesting, especially since they usually have a high portion of their waste organic.

2.5 BIOGAS

Tightly linked to landfills, this technology aims to recuperate the gas produced by organic wastes inside a landfill and turning it into usable biogas through various treatments.

As a landfill will naturally produce gas that has to be taken out in order to maintain the landfill safe from explosions, biogas production is an easy way to couple security and revenue.

Landfills are most used in developing countries, and biogas has largely participated on the funding of those landfills, under the Clean Development Mechanism of the Kyoto Protocol, as they produce carbon credits to be sold and finance the landfill's investment.

The technology is very interesting for landfill using countries, but knowledge needs to be wider spread in order for it to make a bigger impact. Its production has been steadily growing in the last two decades, as we can see in the following graphic:

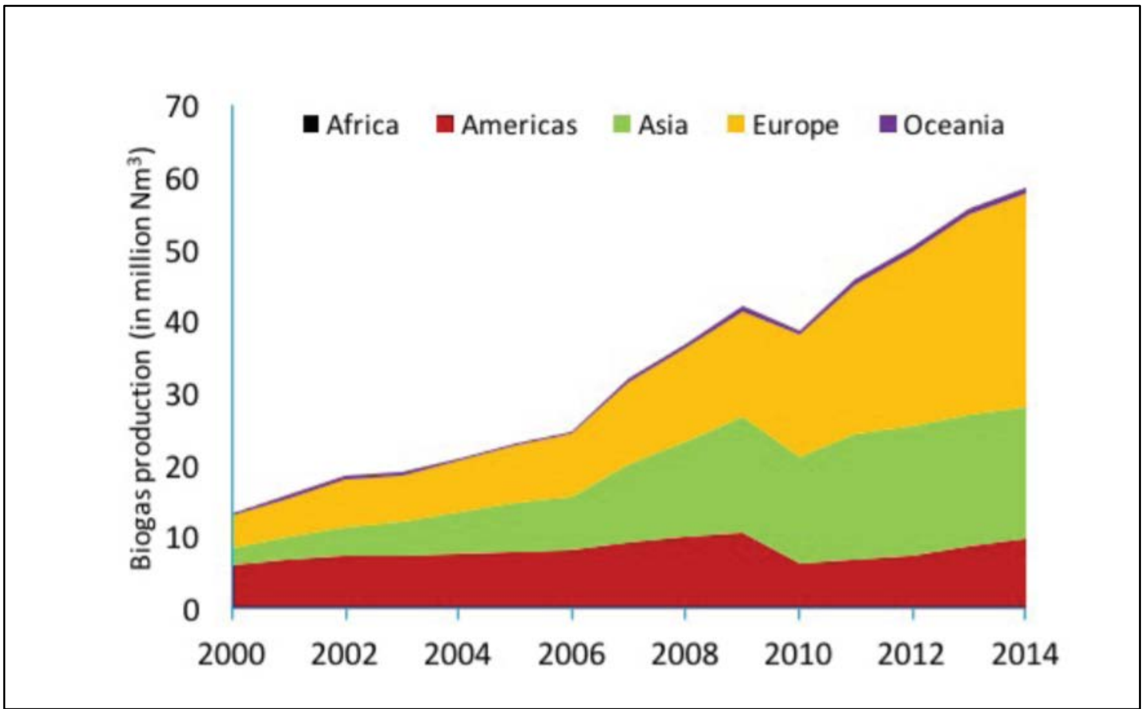


Figure 9 Evolution of the global biogas production (Kummamuru, 2017)

Biogas production should, in a few years, be used in most landfills as it is a very clean and profitable solution that works as a complement to landfills.

2.6 RESIDUE DERIVED FUEL

Using various mechanical and biological treatments, municipal solid waste can be turned into combustible of varying quality for different types of usage. The waste with the highest calorific potential is separated from the rest through a testing line and crushed into a homogeneous product, suited for industrial combustion.

This technology reduces quite drastically the amount of waste that would have to be stocked in landfills (by about 30%), without reducing its biogas production, as it doesn't use any organic waste. It's thus well suited to be combined with biogas production, in countries using lots of landfills. But the technology is still very new, and very little performance results have been published. Its market is just appearing, as polluting industries like cement producers are starting to look to replace coal in their process with green fuels, in order to reduce their carbon footprint.

The process has quite a few quality issues to resolve, inherent to the waste: a somewhat unpredictable base material has to be turned into a stable product. The technology has a lot of potential but offers few insurances to investors, as factories are only starting to appear.

3 CURRENT STATE IN BRAZIL

3.1 RECYCLING, COMPOST AND INCINERATION

As most developing countries, Brazil has had other priorities than ecology in the last few decades. The focus was more on developing the economy and reducing inequalities, rather than taking care of its environment: deforestation, pollution and such actually help the economy on the short term, whereas ecology is a long-term investment.

Recycling in Brazil suffers from a lack of a recycling culture in the population, and in its infrastructures. The process is on the way, but still in its very beginning. Therefore, the actual numbers of recycling in brasil are very low. Without a clear plan to implement widespread recycling in the coming years, the waste valorization solutions we will consider have to take into account that the domestic waste is unsorted. Thus, the plastics, metals and other easily recoverable materials are mixed and tainted with organics. Some solutions then become hard to turn viable. The cost of cleaning these materials overshadows the potential selling revenue (except for metal, which is already being recuperated).

Compost is another possibility for waste recovery, but the mixed nature of Brazilian waste again poses a problem. Compost made from organic waste that contains contaminants like batteries, chemicals and such will likely be of very low quality. It will thus have a low market value and its production will hardly be beneficial. And as said in paragraph 2.4, even if Brazil has very prominent agriculture, these businesses often have the means to produce a higher quality compost made from their own waste (animal droppings, cane and eucalyptus fibres, etc).

Incineration on the other hand could have a very high potential, but has a history of suffering many difficulties in brazil. The national politic concerning solid waste (PNRS – Politica Nacional dos Residuos Solidos) states that all brazilian solid waste shall be treated as much as possible, through recycling, selective recuperation, re-use, compost **and energy recuperation**, which mostly means incineration (Instituição da PNRS, 2010). But the fact is that incineration represents an extremely small portion of Brazil’s waste treatment: as of 2008, 0.61% of Brazil’s municipalities had an incineration plant (IBGE, 2008).

This can be explained by the fact that the public view, and consequently the politics’ general view on incineration is very negative. Multiple environmental problems have been caused by the technology in foreign countries. In case of a lack of control, or poor maintenance of the plants, the process has showed that it can turn into an environmental hasard. Which explains its bad public image. The political arguments generally given against it are that incineration is not a sustainable solution because it does not contribute to change, consumption patters, create jobs and involve the population in waste management (Jacobi & Besen, 2011).

Either way, all signs point to incineration being far away from taking over Brazil's waste treatment system.

3.2 BIOGAS

Biogas production from waste is still a developing technology in the country, but it is very promising. The technology is already widely used with sugarcane bagasse and cattle waste, and is expending in the waste business. The PNRS, which is pushing for the disappearing of uncontrolled dumps in favour of organised landfills is helping biogas production in a big way. The implementation of a biogas technology on a well-maintained landfill is relatively simple, and easily profitable (Mathias & Mathias, 2015). The biogas produced can be used to directly supply the landfill in energy, or sold on the open market.

The reason why biogas from waste is only developing is mainly that the date limit for the disappearing of uncontrolled dumps (in which it is unsafe to install any energy plant) has been pushed back year after year. Initially planned for 2014, it now goes up to 2021 (as of 2018) (Lopes & al, 2018). Because dumps were not illegal up until 2014, well controlled landfills are fairly recent, and still in the process of installing a Biogas treatment area.

As time passes, biogas production should become a staple of valorisation as a complement of landfills. Though it is important to note that because it depends on landfills, biogas is just a way to valorise more a technology that is adapted to today's problems, but that is not sustainable in the long run.

3.3 RESIDUE DERIVED FUEL

The RDF technology is very new in Brazil. The first official regulation on RDF in Brazil appeared in the form of a resolution, by the *Secretaria do Meio Ambiente do Estado de São Paulo* (resolution SMA n°38, 2017). Which means it only regulates the use of RDF in the state of São Paulo. And to this day (may 2019), no country-wide regulation exists.

Due to the very recent nature of this regulation, very few RDF plants have had the time to open. The national leader in RDF production for now is ESTRE, a Brazilian waste management company. But even as the leader of the market, their production is limited as they have only one - fairly big - plant (entry capacity of ~400 000tons of waste per year) (ESTRE, n.d.).

The demand for RDF in the country is way above what is being produced right now. The main reason being that big cement companies, such as Votorantim Cimentos, have taken international agreements on green energy use. And one of the main energy replacement cement producers make is switching the usual coke from coal used in clinker ovens for RDF.

As of 2018, Brazil ranks 6^{th} in the world in cement production, with 104.5 Mt/year (Edwards, 2017). As such, the need for replacement green energy is very high, while the current national production is very low.

But even if the demand is very real, there aren’t any guarantees yet that producing RDF in Brazil can be a lucrative activity. The difficulty of production, the unevenness of the waste to be transformed in RDF could result in a high production cost. And the cement industry will not pay any price to get their hands on local RDF. The price has to be competitive with coke and imported RDF.

Germany is the country that uses the most RDF in its cement plants: 62% as of 2014 (Ciceri & Martignon, 2015). But they manage to do so because their waste management system is excellent and allows them to produce an RDF of high and consistent quality. If Brazilian RDF isn’t consistent and of good-enough quality, it will not find its market, as cement factories won’t be able to use very much of it.

4 CASE STUDY: VALORISATION POSSIBILITES AT THE CGR SP LANDFILL

The landfill XSP is one of the biggest landfills in São Paulo’s area. It is run by the company Saturn.

For now, none of the waste that arrives is undergoing any valorization process: it all goes into the landfill, whatever the content. The waste comes by truck, and all trucks discharge their loads at the top of the landfill. Once enough waste has been discharged and compacted, all the open-air waste is covered with a consolidating layer made of stone and dirt. Another level of waste is then discharged on top of the last layer, and so on. The result is a multi-layered waste mount, as seen in the figure below:

Figure 10 The XSP Landfill

In order to make the most of the waste they receive, Saturn is looking for valorization solutions to implement on their landfills. A project for biogas recuperation is already ongoing at the CGR SP, but other means of valorization might be interesting on this site. And that is the main project I have worked on as an intern for Saturn (since September 2018).

1.1. FLUX STUDY

The first step towards finding valorisation opportunities in a landfill is knowing what you receive. That seems obvious and simple, but it is easier said than done when you are talking about waste. Municipalities and companies pay by the ton of sent waste. They have to announce the nature of the waste they send, but there is no real control over the trucks' load being discharged in the landfill. The only operational control that exists is a chemical security test at the trucks' entry, in case the waste could potentially qualify as dangerous.

Of course, the trucks are weighted. But the information of what percentage of the load is wood and what percentage is rubble is not precise. Even when it is given by the sender, it cannot be trusted at it is never verified when arriving on site.

So, we have to get that information. But screening all of the waste coming at the landfill is impossible: it receives around 5500 tons of waste per day. Plus, doing a large-scale study on all existing fluxes would greatly impair the functioning of the landfill for the time of the study. The trucks' waiting lines would most likely get very problematic, and the city's waste treatment contracts will not allow long delays, as they pay truck drivers by the hour.

The scope has to be reduced. Even if the content of the trucks is uncertain, some fluxes are bound to be more interesting for valorisation than others.

4.1.1 PRELIMINARY FIELD VERIFICATION

To choose which streams to study, we first have to understand what kinds of waste arrive at the landfill. São Paulo's waste collection system is divided in two main groups:

- Household waste collection, that picks up the classic household waste bags and bins produced by houses, condos, and small businesses (restaurants, shops, etc).
- And non-household waste collection. This part of the collection is less obvious, but three main sources have been defined:
    - street sweeping,
    - cleaning of illegal unloading (which is a common practice in São Paulo),
    - Recovery of the EcoPontos' refused waste. The EcoPontos are areas for regular disposal of construction waste, demolition waste, bulky waste, and recyclable waste of small generators. They were installed to reduce illegal unloading, and

there are 102 in the city of São Paulo as of March 2019 (Website of the municipality of São Paulo, 2019).

The household fluxes were knowingly ignored, because they are composed of small material generally stocked in plastic bags, and mixed with a high percentage of organics. The high organic content and high humidity makes it hard to valorise into combustible, and more adapted for biogas production, which already exists on the landfill.

The landfill's team had noticed that some of the non-household waste trucks were unloading reasonably clean waste with a high wood-content. With that idea in mind, a preliminary verification was conducted by the landfill's team, in February 2018. This study took as a base the landfill's 2017 (as seen in APPENDIX 1) scale report, which lists the waste weights received for each public and private flux, as well as the announced nature of the waste (when disclosed). The goal was to confirm the personnel's sentiment that some of the incoming waste streams were holding high wood and potentially plastic content, with near to no organics mixed in.

The "methodology" of this verification was very simple: trucks from the biggest non-household municipal fluxes were to be checked by simple eye-test to get an idea of their composition. Six trucks from the three the biggest public fluxes were unloaded and checked. For the rest of this study, these fluxes will be named stream n°1, stream n°2 and stream n°3.

4.1.1.1 RESULTS OF THE PRELIMINARY VERIFICATION:

- Stream n°1: the average estimation, on 6 truckloads, was 70% wood, 14% plastics, 9% branches and leaves. The rest is a mix of sofa, mattresses, cardboard, etc:

Figure 11 Extract of the photographic report – Stream n°1

- Stream n°2: the average estimation was 56% wood, 22% plastics, 17% cardboard and 4% mattress.

Figure 12 Extract of the photographic report – Stream n°2

- Stream n°3: the average estimation was 65% plastic bags containing household waste, 25% cardboard, and 10% of organic and rubble mix.

Figure 13 Extract of the photographic report – Stream n°3

It is important to note that these are all estimations, eye-tests. These numbers own no methodological value, they are just an eye-test evaluation. As a matter of fact, the photographic reports are more telling than the estimations made by the landfill's team. The only value of this pre-verification is to give directions on which fluxes to conduct a real study on.

According to what we can see on the photographic reports, two of the three waste streams seem very interesting. Both stream n°1 and stream n°2 seem to consistently be composed of a majority of wood, which is quite easily recoverable.

As for stream n°3, the yellow bags we can see on figure 13 most likely hold household-type waste. As said previously, household waste is a more difficult waste to valorise a than recuperation wood is.

Moreover, streams n°1 and 2 are the two biggest non-household waste streams, representing respectively 18% and 22% of the total waste received by the landfill.

Considering all this, a proper characterisation study focusing on stream n°1 and stream n°2 seems like the best option. The goal being to have a numbered, representative study of the composition of these two streams. Only after this will we have a reliable idea of their potential for valorisation.

4.1.2 FIELD STUDY

4.1.2.1 DISCUSSION ON METHODOLOGY

The focus of this study is to determine the average composition of waste streams n°1 and n°2. But waste is a highly heterogenous material, and characterizing a waste stream is far from simple. Numerous methods are used around the world to characterize waste. The method used for a given study generally depends on the country's own norms. Taboada-Gonzalez et al. (2011), in their characterization of waste in rural communities in Mexico use as a base the Mexican norm NMX-AA-15-1985 (1992), which states that up to 250 bags of solid waste can be characterized by sampling only 50kg of waste using a quartering method, after having homogenised the waste by mixing it with shovels. Quartering is a common statistical method used in characterization studies of all kinds. Its goal is to reduce the quantity to be tested, by first homogenising the product, then forming a cone, cutting away the top of the cone, dividing the flattened cone in 4 parts and then keeping only one of these parts. Here is a schematic representation of quartering, to help its understanding:

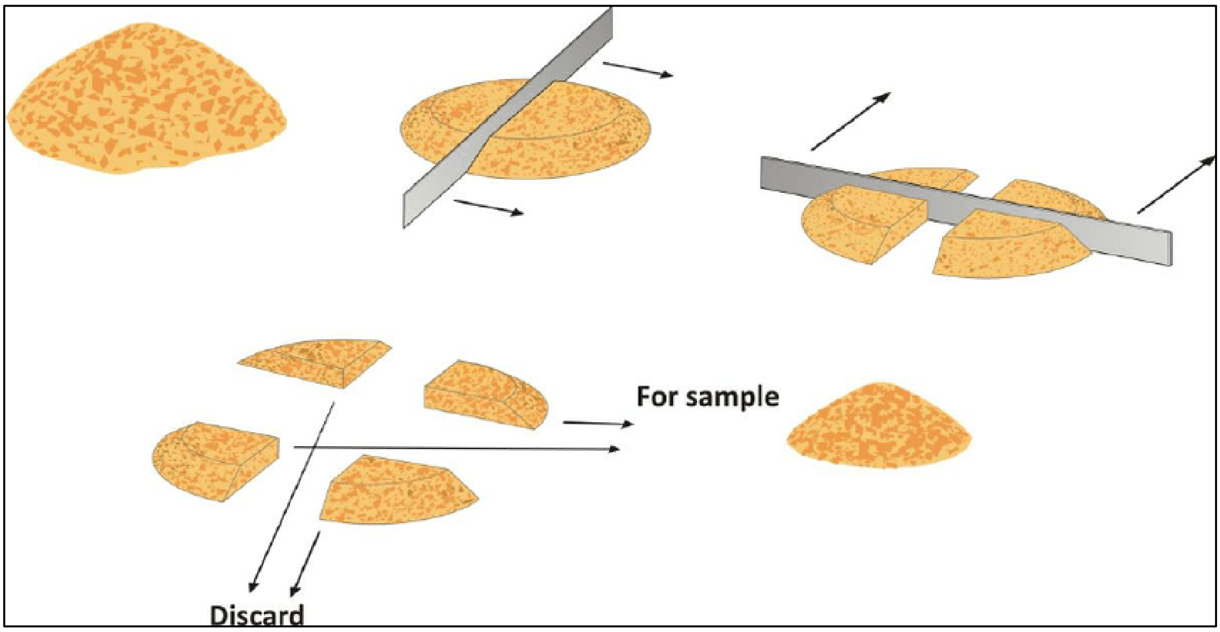


Figure 14 Reducing a sample size by quartering

In the Mexican norm, this method is used to reduce a sample of up to 250 bags of solid waste until its weight is one quartering away from dropping below 50kg. These 50kg are then classified into waste categories as per another norm (NMX-AA-19, 1992), and 10kg of the discarded waste is taken for laboratory testing to determine the residue's hazard class, according to its chemical composition. In those norms, the statistical reliability of the study isn't treated, as this is the sufficient minimum in the eyes of Mexican law.

The Brazilian norm ABNT NBR 10007 (2004), that governs solid waste sampling, is very similar. It also rules that homogenising and quartering has to be used to sample a pile of waste, and shows the exact technique to be employed. But it doesn't state any maximum or minimum quantities that can be sampled with this technique, nor how much waste has to be found in the final sample. It states that for heterogenous waste that cannot be characterized by a lone sample, the local federal body that takes care of environmental preservation (CETESB in the case of São Paulo) will choose the method to be applied and the number of samplings to be made for an official study.

The goals of these characterization norms are mainly to gage the dangerousness of a waste stream, and mainly focus on the chemical composition of the waste. The overall quantities assessment is most likely unreliable because of the small total sampling size and the lack of a statistical control frame. But having a robust statistical control on waste is extremely hard, as the material is highly heterogenous and random, with often unclear sources.

Methodology in waste characterization is still very much dependent on who carries out the study and why. As stated in CARADEME (2014), the French governmental guide on waste characterisation, the **sampling plan has to be adapted to the objectives of the study, the specificity of the site, the waste streams tested and the answers needed to take decisions**. These decisions can be of different nature: re-directing a waste stream to a more appropriate disposal site, changing a waste stream's classification, or investing in a treatment plant for that waste stream.

4.1.2.2 METHODOLOGY USED FOR THE STUDY

The conclusion of this methodology overview on waste characterization is that the best methodology will be the one that is the most adapted to our objective and specificities. In our case, the study as for main objective to determine if investing in a valorisation plant to treat streams n°1 and n°2 is worth it.

The main factor in these streams value for valorisation processes will be their macro composition. In other words, what percentage of these streams has a high valorisation value, what percentage has a medium valorisation value, and what percentage has a low valorisation value. Thanks to the preliminary verification, we can organise the categories that will be used for the study, based on which main waste types are expected to be found in waste streams n°1 and 2:

- Recovered Plastics: have a very high calorific power, and high value as a stand-alone product. Very high valorisation value.
- Recovery wood: has an interesting calorific power, and good value as a stand-alone product. Good valorisation value.
- Green waste (branches, leaves, etc.): medium to low calorific power, can be included in small quantities in RDF production.
- Sofas and mattresses: medium calorific value but potentially dangerous to put in industrial processes (may damage the machines), low valorisation value.
- Organic waste and Rubble: little to no calorific power, very low valorisation value.

A more precise classification is not necessary for the conclusions that want to be drawn out of the study. Eventually, chemical tests will have to be carried out, to know if a combustible produced from these waste streams complies with the governmental composition and emission limits of said combustible type. But at this point of the project, the type of combustible is not yet determined. Laboratory testing will thus be kept for future studies.

In order to get this macro composition, different methods are possible. As we have seen, for household waste the usual composition tests consist of homogenizing the waste load by mixing it, then quartering it to obtain a smaller sample, easier to classify. This sample (generally between 50kg and 200kg of waste) then goes through different screenings, as shown in the CARADEME (2014) guide. First, the waste is separated by size, for example <20mm, between 20 and 40mm, between 40 and 80mm, between 80 and 120mm, and >120mm. To do this, screening tables or rotating screeners can be used. Then each size category is sorted per waste type, usually by hand.

This method works for household waste because it usually contains a lot of organics, which are smaller than the rest. Separating those organics is interesting because they are humid wastes, with very low calorific power.

But in our case here, this way of testing doesn't suit. There seems to be very few to no organics in the loads, and the average size of the waste looks to be big and random in shape, with varied wood panels, small beams, concrete blocks and other potentially big waste pieces. This size range makes it very hard to homogenise even a lone truckload without an additional treatment (mechanical grinding for example). But that treatment would require a machine which cost is simply too high for a characterization study.

Though, not having organics and having big sized wastes also has advantages:

- The waste streams n°1 and 2 are much cleaner than household waste stream, and can thus be processed faster using classic security equipment.
- Having big sized waste pieces means that, with mechanical help (a backhoe for example) large quantities of waste can be classified in little time.

A specificity of this study is also that it would have to be carried out on a running landfill. This means that the study set up must be well thought to minimize its impact on the day to day functioning of the landfill. But is also implies that various means could be used for relatively low cost, as the landfill could offer various resources:

- A truck scale, to weight the entering and the sorted waste.

- Metallic dumpsters, to stock the sorted waste in. Their size ranging from $3m^3$ to $30m^3$.
- A roll-on truck with its driver, to transport the dumpsters.
- A maintenance garage, to repair potential problems on the trucks and machines.
- Equipment for the entire team (EPIs, talkie-walkies, clothing, tools)

Knowing these, Saturn's direction and I decided that a quantitative study with a simple separation method would be the most adapted to our case. That means sorting the biggest amount of waste possible with the given resources, on a given time span. The goal being to see the sorting results stabilize along the study, as we can thus obtain the weightings during the course of the study with very little delay.

That time span is an important factor. Deferent periods can possibly have an influence on the content of the waste trucks: content might be different along the day, along the week, or even depend on the season (winter or summer). Unfortunately, a quantitative study on waste this big requires the rental of a backhoe, and that cost is too high for Saturn if it has to be rented on and off for multiple weeks along the year. To limit costs, a cap was set concerning the duration of the study: **two weeks of effective sorting per waste stream**, with the trucks being deviated at random times along the day. That means that the daily and weekly periodicities were accounted for, but not the seasonal effect.

The initial objective was set on sorting **20 truck-loads per waste stream**. That means that the sorting team will have to sort and weight an average of **two truck-loads per day**. In order to fulfil the expectations of efficiency, 3 operators were contracted to help me conduct this study, as well as a backhoe with its trained driver. Both the operators and the backhoe were contracted for one and a half month, as it was expected that the day to day operations of the landfill would sometimes impair the course of the study.

To start off, the sorting area had to be elected and set up. A free area on top of the landfill was chosen, right next to the normal unloading point of the waste trucks. It gave a lot of space, while allowing the trucks to follow the route they normally take up until the last moment. Thanks to the director of the landfill, we knew this space would only be allocated for waste disposal around 4 months later, which was more than enough time to safely conduct the study. Now the exact plan of action, thought of between my manager, the director of the landfill and me was the following:

First, the chosen area is delimitated, and the unloading area is designated with signalling (the same that is used for the normal unloading spots, which respects Saturn's security norms). That area will be signalled to the drivers along the road. Empty dumpsters are to be aligned near the unloading area, ready to stock the sorted waste.

Whenever a truckload is needed, the manager (me) calls the scale. When the next truck to be studied arrives at the entry, the scale's team will call back, informing both the road operators (that indicate the path to take for the truck drivers) and the manager that a truck is coming. They also communicate the plate number, company and colour of the truck, so that it is easily recognized by all parties. The truck is then weighted at the scale, deviated to the sorting area by road operators, and received by the manager awaiting at the sorting area.

The truck is then unloaded, and the waste scattered with the help of the backhoe to help the operators discern the different waste types. The waste is then divided in the 5 macro types discussed above:

- Recovery Wood
- Recovered Plastics
- Sofas and mattresses
- Branches and leaves (green waste)
- Rubble and organics

Each dumpster is dedicated to one type only. Once one or preferably two dumpsters of the same type are full, they get onto the roll-on truck. This truck goes right to the scale to be weighted full, goes back up the landfill to be unloaded, and gets to the scale again to be weighted empty. The difference between the two weightings giving the amount of this particular type of waste that was just sorted.

The roll-on truck can then come back to the sorting area, deposit the empty dumpsters and take new full-ones to the scale.

4.1.2.3 ACTUAL UNWINDING OF THE FIELD STUDY

The study started on October 24th 2018, with the sorting of stream n°1.

To start everything off, a security formation was given to the entire team (the 3 operators, the backhoe driver and me) by the landfill’s head of security. EPI’s were distributed: Glasses, helmets, reflective vests, security shoes and ear plugs are mandatory on the landfill.

4.1.2.3.1 SOLVING THE INITIAL PROBLEMS

After a few days of sorting, some learnings were quickly made:

- At the start, some operators were directly throwing the waste they were sorting into the dumpsters, by hand, while others were loading the backhoe’s shovel. That means that they had to walk from the unloading area, up to the dumpsters, charged with sometimes heavy loads (such as wood planks). That made the process slow and tiring. It was found that having the operators focus on loading the backhoe’s shovel, and then having the backhoe unload into the dumpsters and come back was more efficient and safer. The process being as shown in the following photos:

Figure 15 Photo of an operator loading the backhoe's shovel in the sorting area

Figure 16 Photo of the backhoe unloading into the dumpsters

- Initially, the dumpsters were disposed in an arc around the sorting area, as to minimize the distance between the sorting area and each dumpster. But made the backhoe and the roll-on truck have much more manoeuvring to do. As the first week went by, rain started to fall, turning the dirt-floor into mud and making manoeuvres that much more difficult. The trucks started to get stuck in the mud, having to be helped out by the landfill's steamrollers.

  This prompted a change in dumpster disposition: they were put in a straight line, as can be seen in the following photos:

Figure 17 Photo of the final disposition of the dumpsters, as seen from the front

Figure 18 Photo of the final disposition of the dumpsters, as seen from the back

And as the loading of these dumpsters wasn't done by hand anymore, but only with the backhoe, adding a little distance between the sorting area and the dumpsters didn't significantly slow down the process.

4.1.2.3.2 IDENTIFYING AND RESOLVING THE BOTTLENECKS

Once these issues were resolved, my main focus was to better the efficiency of the process as a whole. To do this, I had to identify the steps that took more times than the others, and that forced the whole process to wait for them to be completed. These are the bottlenecks, preventing you from accelerating.

1. The first one was the waiting time between the arrival of trucks in the afternoon. If trucks from stream n°1 were arriving during the entire day at the landfill, their arrival was much more concentrated towards the morning: the scale welcomed a such truck every 5 to 10 minutes in the morning, while there could be up to 2 hours of waiting for the next truck in the afternoon.

That led to the operators not having any waste to sort in the end of the afternoon and also early in the morning, as they arrived two hours before me in the morning and had to wait for me to call for trucks to be deviated to the loading area.

To solve this, more trucks were called for in the morning. Overcharging the sorting area for a while, but allowing the operators to work non-stop up to the following morning. This would also be more representative of the average daily composition of the trucks.

2. Once this problem was solved, it became apparent that the weighting of the dumpsters was the next bottleneck. The waste was being sorted faster that it was being taken to the scale and back to the landfill. To equilibrate, one of the operators to help on the roll-on truck at all times.

   As can be seen on Figure 18, chains had to be placed onto the dumpsters for them to be loaded on and off the truck. Sending an operator to help allowed the diver to focus on managing the driving and hydraulic pumps that activate the truck’s articulations.

   Even though this sped up the process, that weighting step stayed a problem throughout the study because of the simple fact that the scale was far away from the sorting area. With priority over the others trucks, 15 minutes were needed to get to the scale, 15 to go back up and empty the dumpsters into the landfill, 15 more to return to the scale empty, and 15 minutes again to come back to the sorting area. This made for an hour of incompressible transportation time, that could only be solved by either moving the sorting area, or adding another truck into the operation. Neither of which could be done, because of limited resources.

Figure 19 Photo of the loaded roll-on truck

3. As we will see in the next part, wood was predominant in terms of weight in the results of this study, and even more in terms of volume as it is usually lighter than the other materials. This led to the dumpsters filling up with more and more wood, and around a week in, all dumpsters got full because 4 were used for the 4 other types, and all the rest was used for wood. So, operators had to wait for wood dumpsters to be weighted before being able to sort again.

   During the first week, more and more dumpsters were aligned to alleviate the issue, until a maximum (due to space) of 12 were aligned. As wood dumpsters kept filling up, a solution was found: the trucks company owned by Saturn could provide a $30m^3$ dumpster to replace one of the $5m^3$ ones, as can be seen below. This allowed us to put near to all of the wood in that new dumpster, and have a way more fluid turnover on the other dumpsters and other waste types to be weighted.

   And even this one would eventually get filled twice, as seen in the following photos:

Figure 20 Photo of the 30m3 dumpster

Figure 21 Photo of the 30m3 dumpster's content when filled

4.1.2.3.3 TIME COURSE OF THE STUDY

The first part of the study, focused on stream n°1, ended after the two weeks limit, on November 9th. Fifteen trucks were sorted instead of the twenty planned. This delay being due to the problems listed above, that were mostly resolved during these two first weeks.

The second part of the study, focused on stream n°2, started only on December 3rd. The 4 weeks of layoff being due to a lack of roll-on trucks available from Saturn's transport company during that span. Though, this part of the study went much faster, due to the experience accumulated and changes made, as explained above. Eighteen trucks were sorted in ten days, the study coming to an end on December 13th. I decided to stop the study one day early, as the total weight sorted for this stream had already far exceeded that of the first stream, and the results had long since stabilized.

4.1.2.4 RESULTS

4.1.2.4.1 STREAM N°1

As said above, fifteen trucks from this source were sorted, for a total of 64 176kg of sorted waste. The day to day listing of the weightings is as seen below:

Weighting order	Day (dd/mm)	Hour	Waste type (Wood, Plastics,, Sofas and mattresses, branches and leaves, Rubble and organics)	Weighting (in kg)
1	24-oct	15h10	Wood	870
2	25-oct	10h00	Branches and leaves	1360
3	25-oct	12h10	Wood	810
4	26-oct	16h00	Branches and leaves	3250
5	26-oct	14h30	Wood	1540
6	26-oct	11h00	Sofa	320
7	26-oct	16h00	Sofa	250
8	29-oct	11h30	Rubble and organics	1970
9	29-oct	8h40	Wood	1910
10	29-oct	14h30	Wood	1490
11	29-oct	16h00	Wood	940
12	31-oct	10h00	Rubble and organics	3980
13	31-oct	14h00	Wood	1566
14	31-oct	14h30	Wood	1920
15	31-oct	15h30	Wood	1200
16	31-oct	15h15	Plastics	710
17	31-oct	8h30	Sofa	460
18	05-nov	15h00	Wood	1580
19	05-nov	16h00	Wood	1270
20	05-nov	17h30	Wood	2830
21	05-nov	19h50	Wood	1440
22	06-nov	8h00	Wood	450
23	07-nov	10h30	Branches and leaves	3120
24	07-nov	17h10	Rubble and organics	2900
25	07-nov	17h50	Rubble and organics	2120
26	07-nov	11h50	Wood	1240
27	07-nov	19h20	Wood	930
28	07-nov	19h50	Wood	1640
29	08-nov	16h20	Rubble and organics	4760
30	08-nov	17h30	Wood	430
31	09-nov	10h40	Wood	1740
32	09-nov	12h30	Wood	
33	09-nov	16h00	Rubble and organics	4230

34	09-nov	8h15	Rubble and organics	2640
35	30-nov	16h10	Branches and leaves	2270
36	30-nov	18h00	Plastics	10
37	30-nov	17h30	Sofa	340
38	30-nov	18h30	Wood	1090
39	12-déc	14h45	Wood	490
40	12-déc	15h50	Branches and leaves	730
41	13-déc	9h20	Wood	470
42	13-déc	13h30	Wood	910

Table 1 Weightings for stream n°1

This gives us the following totals:

Total	64176kg
Wood	28756kg
Rubble and organics	22600kg
Branches and leaves	10730kg
Sofas and mattresses	1370kg
Plastics	720kg

Table 2 Total weightings of stream n°1 by waste type

To analyse these results, the clearest representation is the following:

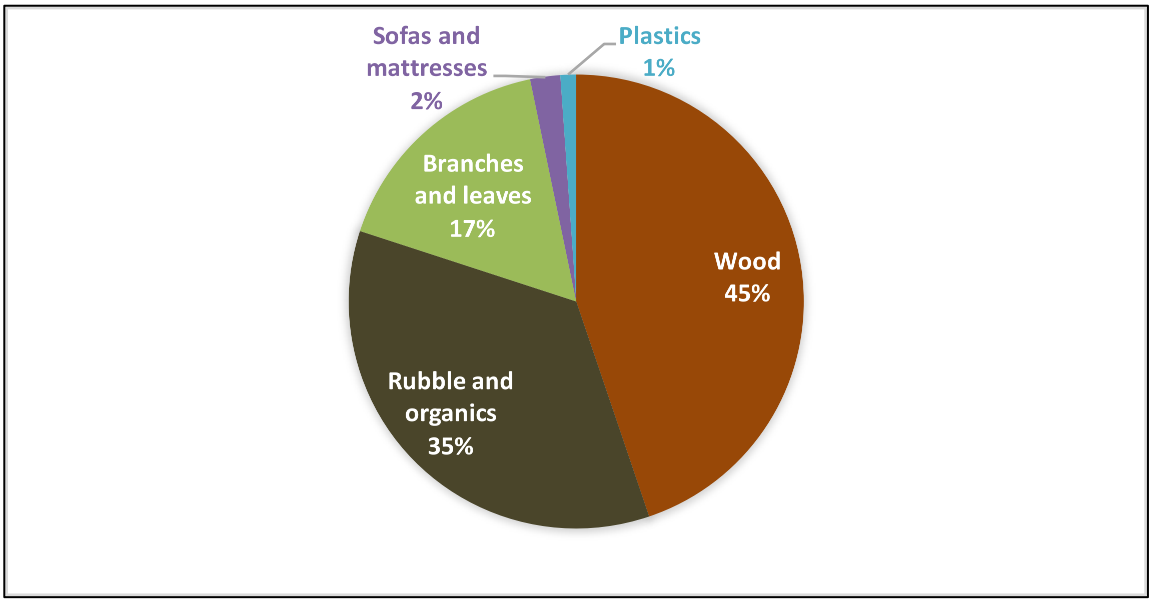


Figure 22 Waste type composition of stream n°1

As we can see, wood is predominant in this waste stream, with 45% of all sorted content being recovery wood. This is very uncommon for an untreated waste stream, and means it has high valorisation potential. Part of the “Branches and leaves” category, an estimate 50% in terms of weight, can also be qualified as wood, only highly humid. The humidity makes it hard to turn into a combustible, but it could come as a complement in case the rest of the recovery wood is dry enough.

The “Sofas and mattresses” category isn’t present enough to justify a dismantlement unit, as such a unit would be needed in order to valorise this material’s components. Indeed, sofas and mattresses are often composed of metallic parts (springs for example), wood, foam, fabric and possibly plastic. These parts are quite hard to separate, and can impair the functioning of a production line if they get into a line dedicated to one only one of these components. Typically, springs and foam have a high chance of disrupting the functioning of a wood pulper.

There isn’t enough plastic to justify the installation of a plastic screening system in a potential valorisation unit. This plastic also being dirty, the recuperation cost would far outweigh any revenue it could generate.

The “Rubble and organics” category is set to go back into the landfill, as there isn’t any known valorisation technology that makes efficient use of rubble, and the organic part will participate in the landfill’s biogas production.

To conclude, this waste stream has a very high valorisation potential because of its high wood content. This is explained by the source of this waste stream, which is São Paulo’s **EcoPontos.** These EcoPontos are waste collection points in the city, were people are supposed to bring their waste that doesn’t fit in bags. That means a lot of furniture. Not to forget that this furniture is recovery wood and usually contains paints, resins, and other chemical treatments, that makes it less easy to use than regular wood. It is still interesting, and we will discuss in the following part of the study which valorisation techniques are the most adapted to this stream.

4.1.2.4.2 STREAM N°2

From this source, 18 trucks were sorted, for a total of 96940kg of sorted waste. The day to day listing of the weightings is as seen below:

Order	Date (dd/mm)	Hour	Waste type (Wood, Plastics, Sofas and mattresses, branches and leaves, Rubble and organics)	Weighting (em kg)
1	03-déc	9h30	Wood	750
2	03-déc	7h45	Wood	2020
3	04-déc	10h00	Plastics	320
4	04-déc	11h15	Rubble	7520
5	04-déc	14h00	Rubble	7610
6	03-déc	10h50	Rubble	7870
7	03-déc	15h20	Rubble	7280
8	03-déc	14h00	Rubble	5440
9	05-déc	11h30	Wood	1090
10	05-déc	14h45	Sofa	460
11	05-déc	16h00	Plastics	250
12	06-déc	15h00	Rubble	6760
13	10-déc	15h30	Rubble	6130
14	10-déc	9h30	Rubble	6800
15	10-déc	8h15	Rubble	7890
16	10-déc	14h00	Cardboard	470
17	10-déc	11h00	Sofa	1090
18	11-déc	9h40	Rubble	4800
19	11-déc	14h30	Wood	480
20	11-déc	13h30	Plastics	40
21	11-déc	11h00	Rubble	6160
22	12-déc	12h45	Wood	3660
23	12-déc	10h30	Rubble	3050
24	12-déc	9h00	Sofa	210
25	12-déc	8h00	Rubble	5010
26	13-déc	10h30	Plastics	30
27	11-déc	16h15	Rubble	3750

Table 3 Weighting list for stream n°2

The “Branches and leaves” category was replaced with a “Cardboard” category, due to the lack of green waste found in this stream.

This gives us the following totals:

Total	96940Kg
Wood	8000kg
Rubble and organics	86070kg
Sofas and mattresses	1760kg
Plastics	640kg
Cardboard	470kg

Table 4 Total weightings of stream n°2 by waste type

Let's analyse the following composition percentages of this waste stream:

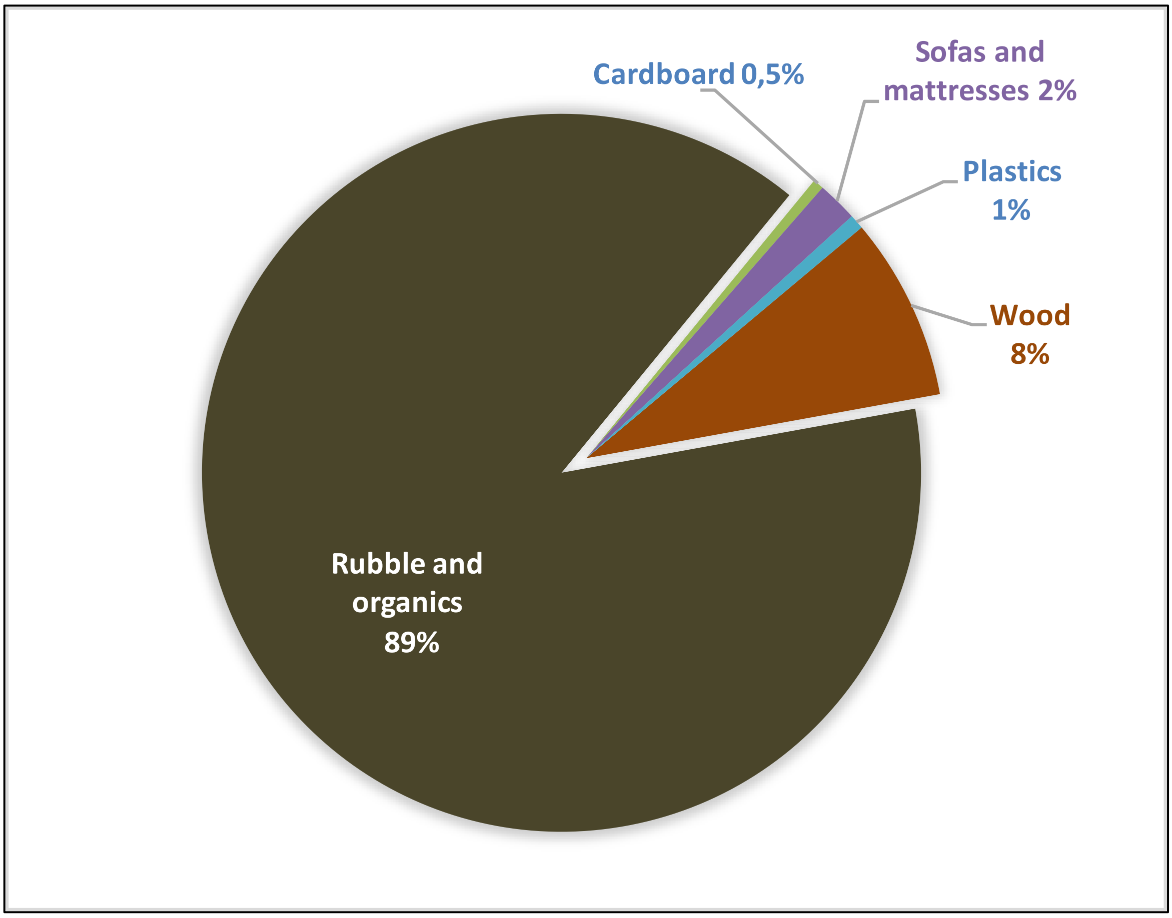


Figure 23 Waste type composition of stream n°2

As we can see, the “Rubble and organics” category is overwhelmingly present in this waste stream. This is highly disappointing when compared to the results of the preliminary verification, in which this stream was judged as very similar to stream n°1. Near to all of this category, in this stream, was rubble and not organics.

The difference with the preliminary verification can be explained by the fact that some wood is nearly always covering the rubble, thus making it hard to detect by eye-test. Furthermore, the density difference between wood and rubble is significative, so a 50/50 proportion of wood/rubble in terms of volume can easily turn into a 20/80 proportion in terms of weight.

With all that said, it seems clear that the small percentages of cardboard, plastics, sofas and mattresses, and even the 8% of wood will not cover for the cost that would be having to treat near to 90% of rubble.

Compared to the waste stream coming from São Paulo’s EcoPontos, this one has way less potential for valorisation purposes. We will thus focus on the valorisation possibilities only for stream n°1 in the next part of this study.

4.1.2.5 CRITICAL ANALYSIS OF THE RESULTS

First, he initial goal of twenty trucks sorted per stream was not quite achieved: 15 trucks were sorted for stream n°1 and 18 for stream n°2. Though, as expected by Saturn and me, the results were stabilizing after approximately the 10^{th} truck for each stream. This stabilization was enough for Saturn to judge the study as reliable and worthy of making decisions upon its results.

Still, it is important to highlight the sources of inaccuracy that this study held. First, the human error factor is high, with the sorting team possibly putting the wrong type of waste in the bins by error. This should be mitigated by the total quantity of waste treated. Secondly, the uncertainty concerning a possible seasonality of the two waste streams, which could not be mitigated. It will only be evaluated if another similar study is eventually conducted on the same streams during at least winter.

4.2 VALORISATION POSSIBILITIES

Now that we have clear results on the macro composition of these fluxes, let's determine the more adapted valorisation solution. As said above, we will focus on stream n°1, coming from São Paulo's EcoPontos.

These discussions were made with the support of an expert from the company Mercury. Mercury is the supplier for the future plant's machines. Their experience in creating waste treatment factories helped greatly in evaluating each solution.

4.2.1 RDF PRODUCTION

Residue Derived Fuel was the initial valorisation solution that was thought at the beginning of the project. That is because if incineration isn't possible, as in Brazil's case, production of RDF is the main existing technology to valorise mixed household waste. For when it is already mixed, this type of waste becomes extremely hard to recycle or sort precisely.

Though, as we have seen in part 4.1, the waste stream studied here is not mixed household waste. It comes mainly from São Paulo's EcoPontos. It's the part these places cannot recycle or sell easily. And instead of organics, it is mainly composed of wood, branches and leaves, rubble, and a little bit of plastic. But that doesn't make this waste stream misfit for RDF production, on the contrary.

It is hard to find public efficiency figures of existing valorisation factories. But per Mercury's and Saturn's knowledge of existing RDF factories, the usual conversion rate of **household waste into RDF is around 30%** in the best of cases. Now, let's evaluate the conversion rate into RDF that this waste stream would have.

4.2.1.1 EVALUATION OF THE QUALITY OF AN RDF

The most important parameter to consider in a residue derived fuel is its **calorific power**. The **main measurement** used to characterize calorific power in this sector is **a material's Lower Calorific Value**, or LCV (called Poder Calorífico Inferior, or PCI in Portuguese).

To get this Lower Calorific Value, the first step is to calculate the Higher Calorific Value (HCV), which is determined by the quantity of heat produced during the combustion of the material, up until all the products of combustion are back to the original pre-combustion temperature, and all vapor produced is condensed back into liquid state. Then, subtracting the heat of vaporization of the water produced during combustion gives you the LCV. Basically, LCV assumes that the heat used to vaporize the water is not recovered in the process, and this is usually true in cement burners, where the vapor escapes into the atmosphere during combustion. That is why LCV is more accurate than HCV for this process.

For the moment in Brazil, there are two distinct classes of RDF that cement producers ask for. The first, higher quality class, is to be used in their main burner. The second, lower quality class, is destined to be used in their precalcinator. The main difference between these two classes is the calorific power, or LCV, due to the fact that the main burner requires higher temperatures to function. Let's take the Brazilian cement company VOTORANTIM's 2015 specifications for RDF in Brazil as a base for our evaluation (full specification sheet disponible in APPENDIX 2):

Class	1: RDF for the Main Burner	2: RDF for the Precalcinator
LCV (in Kcal/Kg)	>=4000	>=3600

Table 5 HCV specifications according to the RDF's quality class

Now let's estimate the potential LCV of the RDF that is possible to produce with our waste stream. To produce RDF, the principle is to remove the low calorific power waste from the waste stream, while keeping as much of high calorific power part as possible. Among the waste types present in our stream, are considered as interesting for RDF the following waste types:

Waste type	LCV (in Kcal/Kg)
Unrecycled plastics	8530 (Tsiamis & Castaldi, 2016)
Dry wood (~15% of moisture)	3820 (Trossero, Nogueira, Etherington & Flood, 2001)
Moist wood (~40% of moisture)	2390 (Trossero, Nogueira, Etherington & Flood, 2001)

Table 6 High calorific power waste types and their HCV

All of the "wood" category from part 4.1.2.3 is considered as dry wood, and according to Mercury we could recover approximately 95% of it through the industrial process. Branches being moist wood, the "branches and leaves" category can also be interesting for RDF. But as leaves and branches are smaller and more volatile, only 50% of this category is expected to be recovered through the industrial process. As for the wood category, 95% of the plastics are expected to be recovered. The "Sofas and mattresses" category will not be recovered, as the size of these trash is dangerous for the machines. The "Rubble and organics" category will not be recovered either, due to having a negligible calorific power. To resume:

Category	Initial presence in waste stream	Recovery rate	LCV (in Kcal/Kg)
Plastics	1%	95%	8530
wood	45%	95%	3820
Branches and leaves	17%	50%	2390
Total recovered as RDF	-	52,2%	3672,86398

Table 7 Total recovery rate and calorific value

Even if it would be ecologically beneficial, adding more low-calorific power waste to the RDF mix would make it dangerously close to the 3600Kcal/Kg limit of the class 2 RDF. Thus, with this technology we can expect to recover a maximum of 52,2% of the total waste quantity in stream n°1 as RDF. The calorific value of this RDF, an LCV of 3672Kcal/Kg, is enough to classify it as acceptable as a class 2 RDF for cement producers.

4.2.1.2 ECONOMIC VIABILITY OF THE PROJECT

Now that we know the quality and quantity of RDF that can be produced from this waste stream, the next step is to evaluate the real economic viability of opening an RDF plant on this landfill.

To do this, we will calculate the Internal Rate of Return (IRR) of the project. The IRR is the discount rate that makes the net present value (NPV) of a project zero. In other words, the IRR represents the rate of growth that the project is expected to generate for the company. For the project to be profitable to the company, the IRR has to be higher than the company's cost of capital. This cost of capital (or WACC) is situated between 5 and 20% for most international companies. The IRR is one of the most commonly used criteria for the financial evaluation of future projects. Its formula is the following:

$$0 = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{(1+IRR)^3} + \ldots + \frac{CF_n}{(1+IRR)^n}$$

Or

$$0 = NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+IRR)^n}$$

Where:
CF_0 = Initial Investment / Outlay
$CF_1, CF_2, CF_3 \ldots CF_n$ = Cash flows
n = Each Period
N = Holding Period
NPV = Net Present Value
IRR = Internal Rate of Return

To calculate the project's IRR, we thus need estimates of the main parameters: the initial investment, the holding period, and the cash flows.

The holding period (or time the factory is planned on working) is fixed by Saturn to 35 years, starting in 2020 and ending in 2055.

The cash flows depend mainly on a few parameters: he cost of the initial investment (CAPEX), the cost of operation of the plant (OPEX), the quantity of RDF produced and the selling price of the RDF.

4.2.1.2.1 EVALUATION OF THE CAPEX

The landfill currently receives approximately 350 000 tons waste from stream n°1 per year. But it is expected to lose around 40% of its receiving after a redistribution of São Paulo's municipal waste, that will happen mid-2019. Thus, the expected amount of waste to treat has been set to 200 000 tons.

To evaluate the CAPEX, two quotations have been asked from Saturn's suppliers:

- Mercury, the RDF specialist, was asked or a quotation on the cost of machines, services and other equipment needed for an RDF factory capable of processing 200 000 tons of waste per year.
- Mars, a Brazilian construction company, was asked for a quotation on the cost of all construction work: the main production building, the storage shed, the administration building, road work and earthwork.

A contingency of 10% was taken as a safety net on all CAPEX costs. Here is the resume of these quotations:

	Price (in BRL)
EQUIPMENTS	**R$ 19 512 613**
Sub-total machines	R$ 15 990 979
Sub-total services	R$ 2 321 634
Wheel loader	R$ 600 000
Backhoe loader	R$ 600 000
INFRASTRUCTURE	**R$ 10 482 947**
Main production building	R$ 4 713 718
Storage shed	R$ 4 659 202
Administration	R$ 830 028
Road work and parking	R$ 280 000
Earthwork	R$ 1 400 000
Contingency 10%	R$ 3 139 556
Total CAPEX	**R$ 34 535 116**

Table 8 CAPEX quotations

4.2.1.2.2 EVALUATION OF THE OPEX

To help establish the OPEX of the factory, Mercury shared its experience on opening RDF factories. They helped establish the average use of combustibles per ton of waste processed, the different costs of maintenance per ton of waste processed, and the number of people necessary to run the factory. The detail of these calculations can be found in APPENDIX 3, and here is the resume of the OPEX, with at the end the cost of Operation & Maintenance per ton of waste treated by the factory:

OPEX anual	**TOTAL**	**15 643 002**
Fixed Costs		**3 227 780**
	HR with charges	1 445 025
	Licensing	202 176
	Saturn's tax	1 491 048
	Insurances	89 531
	Others	-
Variable costs		**10 393 462**
	HR with charges	1 405 100
	Light maintenance	909 792
	Auxiliary combustibles	50 544
	Eletricity	909 792
	Cooling water	-
	Sanitary water	-
	Slag Quench	-
	Rejected waste	7 118 233
	Others	-
Maintenance cost		**2 021 760**
O&M - cost (BRL/ton of waste)		**77,37**

Table 9 OPEX evaluation Resume

4.2.1.2.3 IRR CALCULATION

The current price for class 2 RDF in Brazil is estimated around 60R$/ton, though there is no public RDF market yet. The total amount of RDF produced depends on the amount of waste treated by the future plant, which has been fixed to 200 000 tons. We also have the conversion rate of waste to RDF calculated in Table 7, of 52,2%.

All this information, along with the Holding period, CAPEX and OPEX calculations are enough to fill Saturn's model for project evaluation. This model takes into account the depreciation and amortisation of equipment and maintenance, Saturn's prevision for currency fluctuations, and the Brazilian taxes on companies and revenues. The full cash flow results can be found in APPENDIX 4.

Here is the resume of these main parameters, and the resulting IRR calculated through Saturn's model:

Total waste treated (annually)	**200 000 tons**
Conversion rate (waste to RDF)	52,2%
Selling price	60R$/ton
CAPEX	34,5 Million Reais
OPEX	77,3R$/ton
Resulting IRR	23,7%

Table 10 Financial Summary of the RDF project

With an Internal Rate of Return of 23,7%, this project is most likely financially viable and interesting to invest in, but might not meet some companies' investment threshold. And itt still holds some risks: the distribution of public waste can change rapidly, depending on new politicians and new politics. Also, the price and demand for RDF is uncertain, as its market in Brazil very new. All in all, this project holds uncertainties but also promise, and can be a profitable investment for companies willing to take moderate risks for new and ecological projects.

4.2.2 RECYCLED WOOD CHIPS PRODUCTION

Having a very high wood content in a waste stream destined for landfilling is very rare. Plus, the wood present usually is dirty with organic matter, so picking it off to sell as recycled wood fuel normally isn’t an option.

But in stream n°1 there is very little organic matter. If the rubble and the organics were mixed in the same category for the field study, it is because none of the two has an interesting calorific value. But the observations of the field study showed that near to all of this “Rubble and organics” category was in fact rubble. Furthermore, the wood content is overwhelming when compared to the plastics and “branches and leaves” categories.

After a discussion with the supplier Mercury, it was determined that with a very similar industrial process to the RDF’s, it was possible to recover just the wood, with again a 95% conversion rate. And the wood market is a well-established one, with clients potentially interested in recycled wood. In fact, recycled woodchips have a higher LCV than regular woodchips, due to having lower humidity percentage: wood with 15% humidity has an LCV of ~3800Kcal/Kg, while wood with 35% humidity (which is common for regular woodchips) holds an LCV of around 3000Kcak/kg (Martin, 2015). This makes up for the dirt and heterogeneity of the material. As for the RDF, it is also expected to recover 50% of the “Branches and leaves” category as humid wood. That would increase substantially the recovery rate, without erasing the LCV advantage of the material when compared to classic wood chips.

Currently, the vapor industry in Brazil already uses up to 20% of recycled wood in their boilers, as it has a positive ecological impact and improves the efficiency of the boilers by allowing them to rise to higher temperatures. And this vapor-production market that uses wood-boilers is expending, so the market for recycled wood is real, and market prices are fairly high: around 100R$/ton in the state of São Paulo as of early 2019.

According to the supplier Mercury, the wood-content was so high in the previously studied RDF (98% wood and 2% plastic), that producing nearly pure would only require minor alterations to the machines settings, so that they also take out the 1% of plastic held in stream n°1. That means that the CAPEX and OPEX previously calculated stay exatly the same for this project as they were for the RDF project. The principal differences being the disappearing of the small plastic fraction and the clients the product will be sold to.

This selling price of 100R$/ton, a conversion rate of 51% (95% recovery of the 45% of wood and 50% of the "Branches and Leaves" present in the waste stream), and the same costs of capital and production were then put into Saturn's financial model for project evaluation. The full cash flow results can be found in APPENDIX 5, and here is the resume of these main parameters, and the resulting IRR calculated through Saturn's model:

Total waste treated (annually)	200 000 tons
Conversion rate (waste to RDF)	51%
Selling price	100R$/ton
CAPEX	34,5 Million Reais
OPEX	77,3R$/ton
Resulting IRR	30,77%

Table 11 Financial Summary of the recovered wood project

As we can see, the IRR of this project is much higher than that of the RDF project. Plus, the market for recycled wood chips is already well established and expending. The main downside when compared to the RDF project is the discarding of the plastic fraction in the waste stream. But since it represents only 1% of the total waste in this stream, having a more profitable and financially safer project makes this project the more interesting of the two.

Concerning this project, the main risks to consider for the future are: a drop in gas prices, which would lower the interest of using wood-boilers instead of gas-boilers; new politics with harsh regulation against the use of recovery wood; new recycling chains in the municipality, that could take away the wood content of the waste stream before it reaches the landfill.

Though, none of the aforementioned risks are currently in discussion in the state of São Paulo. Thus, this project can be considered profitable, safe, and with excellent ecological impact in the short and middle term. If at some point in the future, the wood-content is indeed taken out of the waste stream before it reaches the landfill, there is still a backup possibility: as the processes are very similar, it is possible to turn that recycled woodchips plant into an RDF plant running on household waste. The return would be much lower, but the investment would at least not be lost.

5 PROJECTION FOR FUTURE VALORISATION POTENTIAL IN BRASIL

5.1 WHAT TO EXTRAPOLATE FROM THE CASE STUDY?

This field study characterized a quite peculiar kind of waste stream. But even though this waste stream, coming from EcoPontos, isn't common, it is not unique. Cities like Salvador and Belo Horizonte also started a process of installing EcoPontos. Depending on the quantity of waste their EcoPontos process, we now know that installing a wood recovery plant may be very interesting. First from an ecological stand point: half of what cannot be recycled by the EcoPontos can be valorised instead of landfilled. Secondly, we just showed that with enough quantity, that kind of project can be profitable, and can really interest private investment.

Now, in the current state of things, most of the municipal waste streams aren't as the one that has been studied in part 4.2. In house-hold waste, the wood-content is usually very low, so a woodchip valorisation is out of the question. Now, according the supplier Mercury, regular household waste streams have approximately a 28% conversion rate into RDF. To have an idea of the financial viability of RDF production on such a stream, we can run the Business Model that we used in part 4, keeping the other parameters of the project equal, to simplify. That gives us:

Total waste treated (annually)	**200 000 tons**
Conversion rate (waste to RDF)	28%
Selling price	60R$/ton
CAPEX	~35 Million Reais
OPEX	~50R$/ton
Resulting IRR	11,2%

Table 12 Financial Summary of a household waste-to-RDF project

With an IRR of only 11,2%, it is unlikely that private companies will take the risk of making such an investment if they are not bound to by law. But while not appealing, that IRR doesn't mean such projects are money sinkholes. Municipalities with an important budget and focus towards ecology could still decide to make that investment. Reducing the waste production by nearly 30% is still very ecologically interesting.

5.2 WHAT COULD INCENTIVIZE WASTE VALORISATION IN THE FUTURE?

Unfortunately, ecology-driven public investment is still rare. Finding ways to make ecological projects interesting to private investors is, for now, the main solution. Still, this study showed me that a lot of subjects could be worked on to help valorisation projects develop in Brazil. Let’s discuss the most interesting points to work on, the ones that could open doors in the near future for a more efficient waste valorisation system:

- National laws on public waste treatment**:** If RDF production projects on household waste are not particularly interesting to invest in for private companies, a solution could be to legally constrain companies into valorising waste. Municipalities pay for waste management by publishing public contracts, and the company that makes the best offer gets paid to treat the waste. A simple way to jump-start valorisation processes in the country would be to **force private waste treatment offers to include a valorisation process**. Modifying the national regulation on waste treatment offers in that sense would be a big step towards the generalisation of valorisation processes.

- Forcing big polluters to use green fuels: We have seen that the whole RDF market exists mainly because of cement producers. The cement industry is one of the world’s most polluting industry. As such, they have taken vows, notably at the Paris Agreement signed in 2016, to reduce their use of fossil fuels. Unfortunately, these agreements do not come with any financial backlash if they are not respected. So if the price of the RDF in a certain country doesn’t suit the local cement producers, they can decide to just not use RDF. A financial backlash for using only coal in their ovens instead of coal + RDF would mean **having leverage over cement companies to make the RDF prices rise to the point of profitability for the RDF producer**. Thus, incentivising private investment in waste valorisation projects.
- Refine the RDF production process: Another way to make RDF production more interesting to private investors would be to reduce its cost of production. RDF production is still a young technology, with a lot of room for improvement. **Research**

projects aiming to make the production process more efficient could be real game changers. Reducing the investment needed to produce RDF would open the technology to local producers, and possibly even municipalities themselves.

- Improving waste separation at the source: One of the biggest issues in the production process of RDF is the heterogeneity of the base material. Countries like Germany manage to produce a higher quality RDF, that consequently sells better, because their waste is sorted at the source. Knowing what you are going to treat is what allows for efficient treatment processes. Implementing a working waste separation chain from the source means that the population has to actively sort its own waste as much as possible. This takes time, money and energy from the government, usually with the use of **communication campaigns and the implementation of a fining system** to incentivize behavioural changes. And of course, a waste treatment supply chain that treats differently the sorted waste streams.

- Generalizing the EcoPontos system: The solution presented above is a very demanding one, that usually takes decades to be fully implemented. In the meantime, a good starting point would be to **generalize the EcoPontos system to the entire country, and make communication campaigns to increase its use**. As we have seen through this work, waste coming from the EcoPontos is sufficiently sorted to have profitable valorisation processes treat it. It represents a small percentage of the total waste produced in the municipalities, but it would be a first step towards educating the population on waste management, and a solid stepping stone for the implementation of generalised valorisation processes in the country.

5.3 CONCLUSION

The goal of this study was to find valorisation possibilities for the waste currently entering Brazilian landfills. It was motivated by ecological goals, such as limiting the landfilling of potentially valuable waste, and producing green energy and fuels. It ultimately led to a project proposal that has been duly evaluated and is financially viable. With more experience of the functioning of landfills, this study could have been conducted more efficiently, and possibly have covered more waste fluxes.

Still, thanks to this study, a valorisation project has been launched, that is both ecologically impactful and economically profitable. With it, around 100 000 tons of waste could be turned into green fuel instead of being landfilled every year. It is a first step towards valorising to-be-landfilled waste, and thus a first step towards a more circular economy. Of course, it still represents a small portion of the waste going to landfills (5% for this specific landfill), but to eventually reach a goal of circular economy the process of cutting outputs has to start somewhere. All outputs cannot be cut at once, and this solutions represents a simple and efficient way of starting to reduce the global unused outputs of the current economy.

It also serves to show private companies that such processes can really be interesting to invest in. Its results can also serve as a first evaluation for waste streams around the world that are similar to the ones studied here.

With that said, many topics remain available for further work. Household waste is the main existing type of landfilled waste, and it has not been evaluated in this work. A study on this specific waste type and its valorisation possibilities could prove fruitful. Also, juridical and cultural questions have been assessed as important to work on, for the positive impact they could have on waste valorisation in the future.

In a broader sense, this study can be a stepping stone for waste valorisation projects to develop in countries with a high landfilling index, that lack a waste-valorisation culture and juridical environment and are looking for a starting point to get into it.

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APPENDIXES

6.1 APPENDIX 1. 2017 ANNUAL SCALE REPORT OF THE CGR SP LANDFILL

All entries are showed as a percentage of the total yearly entry, as the exact numbers cannot be disclosed.

	Público	
Classificação	**Tipos de Resíduos**	**Peso (Tonelada)**
Inerte	entulho manual boca de lobo	0,6%
Inerte	rejeito.	2,9%
Inerte	entulho manual córregos	4,6%
Inerte	entulho mecanizado	6,8%
Inerte	entulho mecaniza do piscinão	9,4%
Inerte	entulho manual	1,2%
Inerte	resíduos equipesolo	3,2%
Não Inertes	poda	1,8%
Não Inertes	varrição	8,3%
Não Inertes	resíduo equipe	18,0%
Não Inertes	domiciliares	11,5%
Não Inertes	orgânicos	1,0%
	Total	69,5%

Privado		
Classificação	**Tipos de Resíduos**	**Peso (Tonelada)**
Inerte	resíduos - borra de fosfato	0,0001%
Inerte	resíduos - borra de tinta	0,0003%
Inerte	resíduos - borra de retífica	0,0003%
Inerte	resíduos - lama filtro prensa clore cálcio	0,0005%
Inerte	resíduos - borra de maçarico	0,0006%
Inerte	resíduos-cosméticos venc. Improp. P/ com.	0,0010%
Inerte	resíduos - borra de solda	0,0018%
Inerte	resíduos - borra de oxicorte	0,0023%
Inerte	resíduos - borra de sabão	0,0043%
Inerte	resíduos - borra de magnésio	0,0051%
Inerte	resíduos - torta de filtro prensa	0,0122%
Inerte	resíduos - ácidos graxos	0,0161%
Inerte	resíduos - pavimento asfáltico	0,0000%
Inerte	resíduos - areia de lavagem de veículos	0,0003%
Inerte	resíduos - isolante térmico	0,0004%
Inerte	Resíduo semissólido do setor produtivo d - tanques	0,0008%

Inerte	resíduos - pó de jateamento	0,0008%
Inerte	resíduos - vidro	0,0009%
Inerte	resíduos - entulho sujo	0,0020%
Inerte	resíduos - pó de oxido de alumínio	0,0022%
Inerte	resíduos - lã de rocha	0,0023%
Inerte	resíduos - areia de jateamento	0,0027%
Inerte	Resíduos de minerais não metálicos	0,0035%
Inerte	resíduos - produtos de cerâmica	0,0042%
Inerte	resíduos - areia de ete	0,0048%
Inerte	resíduos- gesso	0,0078%
Inerte	Areia e cimento proven. Da fabricação de argamassa	0,0080%
Inerte	resíduos - rescaldo de incêndio	0,0090%
Inerte	resíduos - de granalha	0,0091%
Inerte	Sucata de metais ferrosos	0,0094%
Inerte	resíduos - negro de fumo	0,0104%
Inerte	resíduos - lixo do leito do rio tiete	0,0120%
Inerte	resíduos - de refugo de produção	0,0135%
Inerte	resíduos - carbonato de cálcio c/ cal	0,0151%
Inerte	resíduos - entulho/leroy	0,0188%
Inerte	Resíduos de filtração	0,0213%
Inerte	Escoria de fundição de ferro e aço	0,0232%
Inerte	resíduos - pó de ferro	0,0304%
Inerte	Resíduos de refratários e mat. Cerâmicos	0,0562%
Inerte	Resíduos de varrição de fábricas	0,0757%
Inerte	Resíduos separado da sucata metálica	0,0849%
Inerte	Resid serv. Saúde trat. Por proc. De autoclavagem	0,0977%
Inerte	resíduos - de disco	0,0990%
Inerte	resíduos - pó de filtro de manga	0,1850%
Inerte	Escoria de fundição de alumínio	0,2220%
Inerte	resíduos - entulho/Mercedes	0,3311%
Inerte	Areia de fundição	0,5437%
Inerte	Resíduos da limpeza de canaletas	1,6477%
Inerte	resíduos - entulho	1,7828%
Inerte	resíduos - solo classe ii a	8,9048%
Não Inertes	resíduos - resíduos de branches and leaves	0,0015%
Não Inertes	Resíduos de papel e papelão	0,0185%
Não Inertes	Resíduos de Wood	0,0283%
Não Inertes	resíduos - poda de arvore	0,1069%
Não Inertes	resíduos - manta de ramassor	0,1115%
Não Inertes	resíduos - camada vegetal	0,5465%
Não Inertes	resíduos-cinzas de ciclone do lav. De gases	0,0024%
Não Inertes	Cinzas de incineração dos resid. Hosp. Serv. Saúde	0,0084%
Não Inertes	resíduos - cinzas de caldeira	0,0087%
Não Inertes	Resíduos comerciais	0,4204%
Não Inertes	resíduos - comerciais	15,5643%
Não Inertes	Resíduos de caixa de gordura	0,0002%

Não Inertes	Resíduos de fundo do tanque de silicato	0,0005%
Não Inertes	Res. pastoso star contem substancia não toxica	0,0012%
Não Inertes	Lodo de estação de tratamento de efluentes	0,0082%
Não Inertes	Resíduos de pasta de cálcio	0,0230%
Não Inertes	Res. Sólido star contendo substancias não tox.	0,0239%
Não Inertes	resíduos - lodo de ETA	0,0380%
Não Inertes	resíduos - lodo de ete	0,1365%
Não Inertes	Resíduos de materiais têxteis	0,2869%
Não Inertes	resíduos - fezes de animais	0,0001%
Não Inertes	resíduos - ração imprróprio para consumo	0,0024%
Não Inertes	resíduos - pão improprio p/ consumo	0,0086%
Não Inertes	resíduos - lixo comum/ res. Alimentar	0,0431%
Não Inertes	Lixo de restaurante	0,0458%
Não Inertes	resíduos - casca de coco	0,0786%
Não Inertes	resíduos - alimentos improp. P/ consumo	0,1815%
Não Inertes	resíduos - orgânicos	1,7651%
Não Inertes	resíduos - epi não contaminados	0,0000%
Não Inertes	resíduos - resina de poliéster	0,0010%
Não Inertes	resíduos - lixa	0,0011%
Não Inertes	resíduos - aparas de poliuretano	0,0050%
Não Inertes	resíduos - lona de freio	0,0057%
Não Inertes	resíduos - papel de etiqueta	0,0067%
Não Inertes	resíduos - de eva	0,0085%
Não Inertes	resíduos - fibra de vidro	0,0094%
Não Inertes	resíduos - espuma	0,0150%
Não Inertes	resíduos - isopor	0,0489%
Não Inertes	resíduos - lã de vidro	0,0560%
Não Inertes	Resíduos de borracha	0,0720%
Não Inertes	Resíduos de plásticos polimerizados	0,1763%
	Total	**34,1546%**

6.2 APPENDIX 2. VOTORANTIM'S SPECIFICATIONS FOR RDF QUALITY

ESPECIFICAÇÕES PARA RECEBIMENTO E CONTROLE DE CDR
Revisão MAR/2015

Votorantim Cimentos

	Parâmetros	Unidade		CDR Queimador Principal		CDR Pré-Calcinador
	Poder Calorífico Superior (PCS)	kcal/kg	≥	5.000	≥	4.500
	Umidade	%		5,0 - 20,0	≤	20,0
☼	Cinzas [Sólidos Totais, em Res. Líquidos]	%		15	≤	20,0
	S	%	≤	1,2	≤	1,2
☼	Cloretos (Cl^-)	%	≤	0,5	≤	0,5
	Fluoretos (F^-)	%	≤	0,3	≤	0,3
	P_2O_5	%	≤	2,0	≤	2,0
	Tamanho máximo de Partícula – 2D	mm	≤	25,0		–
	Tamanho máximo de Partícula – 3D	mm	≤	15,0	≤	50,0
	Granulometria – Passante P-50 mm	%		100,0		100,0
	Ponto de Fulgor	°C	≥	80,0	≥	80,0
	Poder Calorífico Inferior (PCI)	kcal/kg	≥	4.000	≥	3.600
	Cádmio (Cd)	mg/kg		–		–
☼	Mercúrio (Hg)	mg/kg	≤	10,0	≤	10,0
	Tálio (Tl)	mg/kg		–		–
☼	Soma Grupo I (Cd + Hg + Tl)	mg/kg	≤	100,0	≤	100,0
	Arsênio (As)	mg/kg		–		–
	Cobalto (Co)	mg/kg		–		–
	Níquel (Ni)	mg/kg		–		–
	Selênio (Se)	mg/kg	≤	100	≤	100
	Telúrio (Te)	mg/kg		–		–
☼	Soma Grupo II (As+ Co+ Ni+ Se+ Te)	mg/kg	≤	1.500	≤	1.500
	Antimônio (Sb)	mg/kg		–		–
	Cromo (Cr)	mg/kg	≤	3.000	≤	3.000
	Estanho (Sn)	mg/kg		–		–
☼	Chumbo (Pb)	mg/kg	≤	3.000	≤	3.000
	Vanádio (V)	mg/kg		–		–
☼	Soma Grupo III (Sb + Cr + Sn + Pb+ V)	mg/kg	≤	5.800	≤	5.800
	Bário (Ba)	mg/kg	≤	3.000	≤	3.000
	Cobre (Cu) **	mg/kg	≤	3.000	≤	3.000
	Manganês (Mn)	mg/kg	≤	10.000	≤	10.000
	Cianetos (CN^-)	mg/kg	≤	100	≤	100
	Zinco (Zn) **	mg/kg	≤	3.000	≤	3.000
	Berílio (Be)	mg/kg	≤	100	≤	100
☼	Fe_2O_3	%	≤	15,0	≤	15,0
	Resíduos Radioativos	–		Ausentes		Ausentes
	Resíduos de Serviços de Saúde	–		Ausentes		Ausentes
☼	PCB's (bifenil policlorados e similares)	mg/kg	≤	50	≤	50
☼	Pesticidas	–		Ausentes*		Ausentes *
	Explosivos	–		Ausentes		Ausentes
	Benzeno	mg/kg	≤	5.000	≤	5.000
	SVOC – Compostos Orgânicos Semi Voláteis	mg/kg	≤	2.000	≤	2.000
	PAH – Hidrocarbonetos Aromáticos Policlíclicos ***	mg/kg	≤	1.500	≤	1.500
☼	TOC – Total de Carbono Orgânico	mg/kg		–		–
☼	THC – Total de Hidrocarbonetos	mg/kg		–		–
☼	Critério de Aceitação					

* Limite de Detecção ≤ 100 µg
** Limitado aos resultados do Teste de Queima
*** PAH analisados (mínimo)

01. Benzo[a]anthracene
02. Benzo[b]fluoranthene
03. Benzo[k]fluoranthene
04. Benzo[a]pyrene
05. Chrysene
06. Dibenzo[a,h]anthrancene
07. Indeno[c,d]pyrene
08. Acenaphthene
09. Acenaphthylene
10. Anthracene
11. Benzo[g,h,i]perylene
12. Fluoranthene
13. Fluorene
14. Naphthalene
15. Phenanthrene
16. Pyrene

6.3 APPENDIX 3. TOTAL OPEX EVALUATION

		Unit / Mg MSW	Unit / Mg MSW	R$/Unit	US$/Unit	Consumption / Production (Unit /a)	TOTAL (BRL/a)
1. AUXILIARY FUELS	Natural Gas (Auxiliary burners)	Nm3	0	1,2	0,32	0	0,00
	Gas-Oil (Mobile Equipment & Genset)	l (liter)	0,1	2,5	0,66	20 218	50 544,00
						TOTAL	50 544,00
2. ELECTRICITY		kWh	15,0	0,3	0,08	3 032 640	909 792,00
3. REAGENTS	Urea solution (32.5%)	Kg	0,0	0,40	0,11	0	0,00
	Hydrated lime	Kg	0,0	0,40	0,11	0	0,00
	Activated carbon	Kg	0,0	3,36	0,88	0	0,00
						TOTAL	0
4. PROCESS WATER	FGC Cooling water	l (liter)	0,0	0,0028	0,0007	0	0,00
	Slag Quench	l (liter)	0,0	0,0028	0,0007	0	0,00
	Sanitary Water	l (liter)	0,0	0,0028	0,0007	0	0,00
	Clean & Hose down	l (liter)	0,0	0,0028	0,0007	0	0,00
	TOTAL (l/Mg MSW)					0	0
5. DEMINERALIZED WATER	Demineralized Water	l (liter)	0,0	0,0079	0,0021	0	0,00
6. RESIDUES & EFFLUENTS	Organic waste to Landfill	t	0,00	80,00	21,05	0	0,00
	Inert waste to Lanfdfill	t	0,44	80,0	21,05	88 957	7 116 595,20
	Sanitary Water	m3	0,00	2,5	0,66	655	1 638,00
						TOTAL	7 118 233

		Unit $		Unit $/Mg MSW	US$/Mg MSW	Treated MSW (Mg MSW/a)	TOTAL (BRL/a)
7. OTHER OPERATIONAL COSTS	Other costs	R$	Licensing, HSE, ...	1,0	0,263	202 176	202 176,00
8. MAINTENANCE COSTS	Heavy Maintenance (EM+CW)	R$		10,0	2,63	202 176	2 021 760,00
	Light Maintenance & Consumables (Oil, Grease, small material)	R$		4,5	1,18	202 176	909 792,00
							2 931 552,00

Waste Treatment Capacity		
Lines	nbr	1
Waste treatment capacity per line	t/h	45
Plant Availability	%	90,0%
Working time	h/y	4992
Annual waste treatment capacity	**t/a**	**202 176**

Steam production	
Steam Production (t/h)	
Steam Production (t/ano)	

Currency Rate Exchange		
Currency Rate Exchange	4,40	R$/€Eur
	3,80	R$/USD

6.4 APPENDIX 4. TOTAL CASH FLOW OF THE RDF PLANT PROJECT

RETURN RATIOS	CALCULAR	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Simplified Free Cash Flow		(21 685)	(10 325)	13 047	11 001	11 443	11 912	12 401	12 910	13 439	13 991	14 565	15 159	15 776	16 419	17 088	17 784	18 509	19 262
Unlevered Tax @ Local marginal Income Tax Rate		-	(1 476)	(3 400)	(3 458)	(3 559)	(3 665)	(3 775)	(3 889)	(4 008)	(4 132)	(4 262)	(5 232)	(5 370)	(5 598)	(5 835)	(6 082)	(6 339)	(6 606)
Unlevered Free Cash Flow after theoretical tax on EBIT		**(21 685)**	**(11 801)**	**9 647**	**7 543**	**7 883**	**8 247**	**8 626**	**9 020**	**9 431**	**9 858**	**10 303**	**9 927**	**10 406**	**10 821**	**11 253**	**11 702**	**12 170**	**12 656**
Project IRR	**23,74%**							6,5%	11,1%	14,2%	16,5%	18,2%	19,3%	20,3%	20,9%	21,5%	21,9%	22,3%	22,6%
Project NPV at WACC	**15 805**	(21 685)	(31 754)	(24 731)	(20 046)	(15 867)	(12 138)	(8 809)	(5 839)	(3 190)	(827)	1 280	3 012	4 562	5 936	7 156	8 238	9 199	10 051
Cumulative Free Cash Flows		(21 685)	(33 486)	(23 839)	(16 296)	(8 413)	(166)	8 460	17 481	26 912	36 770	47 073	57 000	67 406	78 227	89 480	101 182	113 352	126 008
Simple Cash Flow Payback	5,0							5,0											
Discounted Cash Flow Payback	**9,5**											9,5							

RETURN RATIOS	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055
Simplified Free Cash Flow	20 047	20 863	21 712	22 595	23 513	24 469	25 464	26 499	27 576	28 697	29 864	31 077	32 341	33 655	35 024	36 446	21 686	-
Unlevered Tax @ Local marginal Income Tax Rate	(6 884)	(7 173)	(7 474)	(8 008)	(8 333)	(8 672)	(9 025)	(9 391)	(9 773)	(10 171)	(10 584)	(11 014)	(11 462)	(11 928)	(12 413)	(13 193)	(4 489)	-
Unlevered Free Cash Flow after theoretical tax on EBIT	**13 163**	**13 690**	**14 238**	**14 587**	**15 180**	**15 797**	**16 439**	**17 107**	**17 803**	**18 526**	**19 280**	**20 063**	**20 879**	**21 728**	**22 611**	**23 253**	**17 197**	**-**
Project IRR	22,8%	23,0%	23,1%	23,2%	23,3%	23,4%	23,5%	23,5%	23,6%	23,6%	23,6%	23,7%	23,7%	23,7%	23,7%	23,7%	23,7%	23,7%
Project NPV at WACC	10 807	11 478	12 074	12 594	13 057	13 467	13 832	14 155	14 442	14 698	14 924	15 125	15 304	15 462	15 603	15 727	15 805	15 805
Cumulative Free Cash Flows	139 171	152 861	167 099	181 686	196 866	212 663	229 102	246 209	264 012	282 538	301 818	321 881	342 760	364 488	387 099	410 351	427 548	-
Simple Cash Flow Payback																		
Discounted Cash Flow Payback																		

6.5 APPENDIX 5. TOTAL CASH FLOW OF THE RECYCLED WOOD CHIPS PROJECT

RETURN RATIOS	CALCULAR	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Simplified Free Cash Flow		(21 685)	(8 447)	17 137	15 239	15 851	16 500	17 175	17 878	18 610	19 371	20 164	20 985	21 840	22 729	23 655	24 618	25 620
Unlevered Tax @ Local marginal Income Tax Rate		-	(2 268)	(4 796)	(4 905)	(5 065)	(5 232)	(5 405)	(5 586)	(5 774)	(5 970)	(6 174)	(7 222)	(7 441)	(7 753)	(8 078)	(8 416)	(8 767)
Unlevered Free Cash Flow after theoretical tax on EBIT		**(21 685)**	**(10 715)**	**12 341**	**10 334**	**10 786**	**11 268**	**11 770**	**12 292**	**12 836**	**13 401**	**13 990**	**13 764**	**14 399**	**14 976**	**15 577**	**16 202**	**16 853**
Project IRR	**30,77%**					1,2%	11,0%	17,1%	21,1%	23,8%	25,6%	27,0%	27,9%	28,6%	29,1%	29,5%	29,8%	30,0%
Project NPV at WACC	**33 792**	(21 685)	(30 828)	(21 843)	(15 424)	(9 707)	(4 611)	(69)	3 977	7 583	10 795	13 657	16 058	18 202	20 105	21 793	23 292	24 622
Cumulative Free Cash Flows		(21 685)	(32 400)	(20 059)	(9 725)	1 061	12 329	24 099	36 391	49 227	62 628	76 619	90 382	104 781	119 757	135 334	151 536	168 388
Simple Cash Flow Payback	3,9					3,9												
Discounted Cash Flow Payback	**6,0**								6,0									

RETURN RATIOS	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055
Simplified Free Cash Flow	26 663	27 748	28 877	30 052	31 274	32 545	33 868	35 245	36 678	38 169	39 720	41 335	43 015	44 764	46 583	48 477	50 446	29 246	-
Unlevered Tax @ Local marginal Income Tax Rate	(9 133)	(9 514)	(9 910)	(10 322)	(10 972)	(11 418)	(11 882)	(12 365)	(12 868)	(13 391)	(13 935)	(14 502)	(15 091)	(15 705)	(16 343)	(17 007)	(17 975)	(6 515)	-
Unlevered Free Cash Flow after theoretical tax on EBIT	**17 530**	**18 234**	**18 967**	**19 730**	**20 302**	**21 127**	**21 986**	**22 880**	**23 810**	**24 778**	**25 785**	**26 833**	**27 924**	**29 059**	**30 240**	**31 470**	**32 472**	**22 731**	**-**
Project IRR	30,2%	30,3%	30,4%	30,5%	30,5%	30,6%	30,6%	30,7%	30,7%	30,7%	30,7%	30,7%	30,7%	30,8%	30,8%	30,8%	30,8%	30,8%	30,8%
Project NPV at WACC	25 802	26 850	27 779	28 605	29 329	29 972	30 544	31 051	31 501	31 901	32 256	32 571	32 851	33 100	33 321	33 517	33 689	33 792	33 792
Cumulative Free Cash Flows	185 918	204 152	223 119	242 849	263 151	284 278	306 264	329 144	352 954	377 732	403 517	430 350	458 274	487 333	517 573	549 043	581 515	604 246	-
Simple Cash Flow Payback																			
Discounted Cash Flow Payback																			