Waste-to-Energy Solutions for the Case Study of Tratolixo

(Master Thesis Extended Abstract)

Pedro Cerqueira

Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

e-mail: pedro.cerqueira@tecnico.ulisboa.pt

Abstract

This Thesis focused on a case study and had the objective of evaluating the possibility of valorisation of the refuse fraction of Tratolixo's municipal solid waste mechanical treatment unit, in the perspective of European policies, included in PERSU 2020, and the recent Circular Economy Package. The solution focused on the implementation of a Waste to energy technology with capacity for 75kt/year and suitable for the characteristics of the refuse fraction.

The selection of a technology among various combustion technologies available in the market with potential to constitute a solution to be adopted was based on three pillars: environmental, technical and economic. Environmental and economic conclusions point to gasification as the solution, but that conclusion has weaknesses, as there is a lack of LCA comparative studies and credible data on the investment associated to commercial gasification of small/medium dimension and high level of maturity. After a technical comparison of various technologies available in the market, the study points to an updraft moving bed gasification technology with efficiency of about 30%, which applied to the study case would mean an annual production of *45 GWh$_{el}$*.

Keywords: *Waste to Energy*, Municipal Solid Waste, Gasification, Municipal Solid Waste Management System, Circular Economy

1 Introduction

1.1 The waste sector in Europe, Portugal and Tratolixo's municipalities

The waste management sector is one of the six major contributors to the green house gas emissions in the European Union, being responsible for about 6% of the emissions. When the scope is restricted to Portugal, the contribution of the waste management sector is even greater, being responsible for about 10% of the emissions (Eurostat1, 2016).

Although the average Municipal Solid Waste (MSW) production in the European Union has been decreasing in the last few years, not every European country is following the trend, with countries like Germany, Denmark and some countries in Eastern Europe (Eurostat2, 2016). In fact, it is possible to establish a correlation between Gross Domestic Product (GDP) and MSW production, as well as with the selection of the waste treatment technique. The higher the GDP the higher is the MSW production and the lower is the amount of MSW being sent to landfill, i.e. the waste management companies invest in alternative waste treatments. Adding Tratolixo, the case study, to this analysis, it is clear that the region where it is inserted and its choices of waste treatment follow the European trend in waste production, except in the case of landfilling, which Tratolixo does less than most countries with similar GDP (Figure 1).

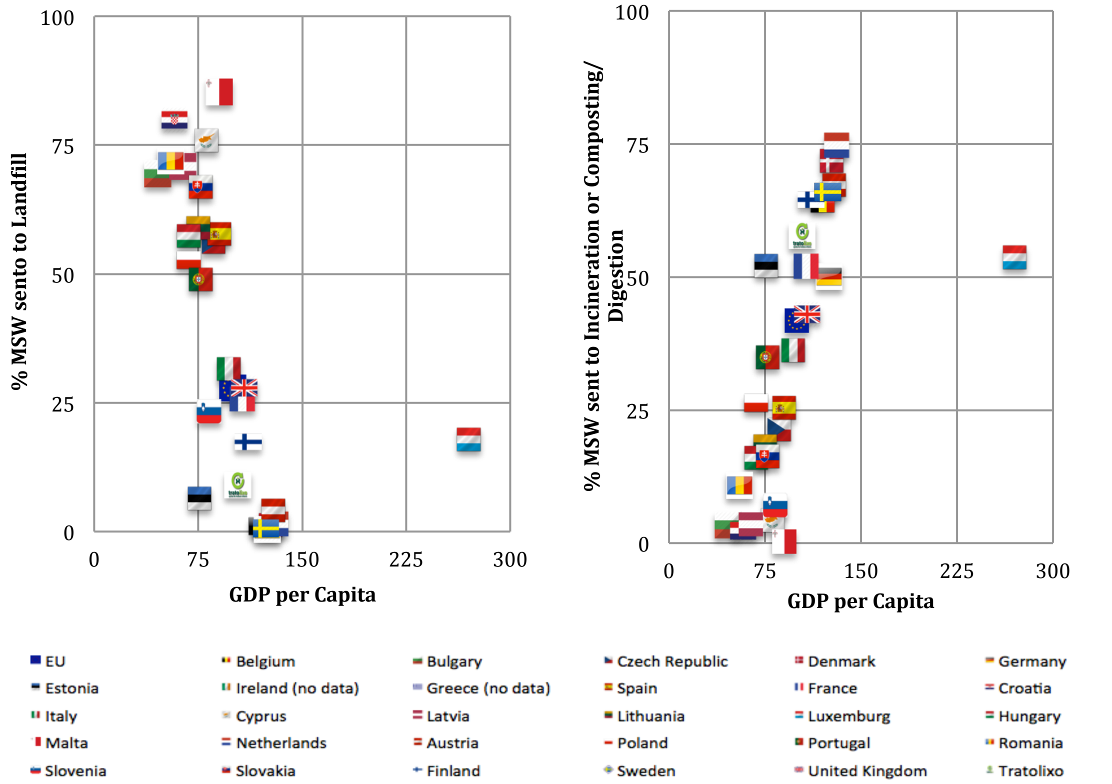

Figure 1 - Percentage of MSW sent to landfill (left graphic) and sent to other treatment facilities (right graphic) in the E.U. and at Tratolixo as a function of GDP in 2014. For Tratolixo the GDP used was that of Lisbon metropolitan area. Sources: (Eurostat2, 2016) (Tratolixo, 2014) (2014 process layout kindly released by Tratolixo on July 21 of 2017)

Regarding the sector's situation in Portugal, the last known results, from 2015, showed negative total net aggregate results of -51M€ for the waste management entities. However, looking only at the class in which Tratolixo is inserted, the results were +12M€, with Tratolixo having the third best result, among 20 companies. A direct correlation was observed between the waste management service cost and the applied tariff, but such did not happen between the tariff and the average family income in the region of each company. Comparing with the other companies of the same class, Tratolixo had the highest cost for the waste management service but also the highest tariff and contrary to most of the other companies, the higher tariff is backed by the second biggest average family income (ERSAR, 2016).

1.2 Future Perspectives According to the European Waste Policies

The European Union's policies for the waste sector are inscribed, for Portugal, in the PERSU 2020, where certain targets and objectives are established for the country and for each waste management system, with a deadline in 2020. For Tratolixo the targets were (MAOTE, 2017):

- Preparation for reuse and recycling ≥ 53%
- Biodegradable Municipal Solid Waste sent to the landfill ≤ 16%
- Separate collection of waste ≥ 49kg/year per capita

In 2016 Tratolixo had already achieved the landfilling target, with only 3% of direct landfilling of waste. The other two targets hadn't been achieved, with 34% for the preparation for reuse and recycling and 41kg/year per capita for the separate collection of waste (Tratolixo, 2017).

The recent European waste policies are object of the Circular Economy Package, which establishes new targets and objectives, this time for 2030 (European Commission1, 2015) (European Commission2, 2015):

- Preparation for reuse and recycling of municipal solid waste ≥ 65%
- Preparation for reuse and recycling of packaging waste ≥ 75%
- Municipal solid waste sent to the landfill ≤ 10%

The key concept of the Circular Economy Package is precisely Circular Economy, which stands for a change from the current linear model of resource extraction, production, use and discard to a circular model in which the products are returned back to the production cycle. An essential part of the Circular Economy strategy is Waste to Energy (WtE) technology and one of the most energy efficient technologies referred is gasification (European Commission, 2017).

1.3 Objective

The objective of this thesis is to study the possibility of valorisation of a waste stream, from a WtE perspective, for the case study of Tratolixo, bearing in mind the environmental impacts of the waste management sector and its dynamics and respecting the Circular Economy philosophy imbued in the recent European policies for the waste area.

1.4 Methodology

To achieve the proposed objective, first a data collection on the state-of-the-art of WtE technologies was made, in order to have a good knowledge of the available technology. After that the focus shifted to the market, to select models of different technologies that could have the potential to constitute a solution for the case study.

To know which type of WtE technology would better achieve the objectives, a comparison between technologies was made, with associated impacts as the deciding factor, using scientific papers based on Life Cycle Assessment. Because gasification was the one considered to be the most favourable, a more thorough study of this technology was made, with a retrospective of its evolution in the world until now and an outlook into the near future, as well as an economic analysis and a comparison of the gasification technologies selected from the market.

A characterization of Tratolixo's waste management system was made and finally an analysis of the potential of the selected gasification technologies to fit into Tratolixo's needs.

2 Waste to Energy Technologies

WtE technologies from the three families of combustion processes were considered, incineration, gasification and pyrolysis, as well as three alternative technologies that could be use online or in parallel with the previous combustion processes, torrefaction, hydrothermal treatment and biomass pyrolysis.

With the main focus on the combustion technologies, the market was searched in order to find out the options offered and to select some of them for further study. They were categorized by type, maturity, scale and input (Table 1).

2.1 Associated Impacts

Scientific papers comparing WtE technologies based on Life Cycle Assessment were used to determine which technology would be the most favourable in terms of caused and avoided impacts. Most of them preferred gasification, either by comparing various waste treatment techniques for the same MSW ((Gunamantha & Sarto, 2012), (Kumar & Samadder, 2017) e (Rajaeifar et al., 2017)) or various techniques for each individual fraction that composes a MSW ((Arafat et al., 2015)). However it is not unanimous that gasification has the best balance between caused and avoided impacts, with some papers suggesting otherwise ((Fernández-González et al., 2017) e (Arena et al., 2015)).

2.2 Gasification

2.2.1 Gasification in the World

In 2014 there were 2 378 in GTC Worldwide Gasification Database, with 862 of them being planned facilities, which shows the growth trend of this technology (Chris Higman, 2014). That is also noticeable by observing the evolution of installed capacity in the world, which shows great growth from 1970 until now and that if the facilities currently in the construction or planning stages are successfully finished, between 2014 and 2019 the gasification capacity will almost triple (Figure 2, graphic 1).

It is interesting to observe that the gasification capacity installed is mostly concentrated in Asia/Australia, with Europe coming in third, which won't change in the near future, as the planned and in construction capacity is big in Asia/Australia and almost stagnant in Europe (Figure 2, graphic 2). The majority have the objective of producing chemicals, followed by liquid fuels, energy and finally solid fuels. The biggest growth in the near future is expected for the solid fuel and the smallest for energy (Figure 2, graphic 3). Fossil fuels are still the main feedstock for gasification, mainly coal, with biomass and waste occupying the last places, a trend that will remain in the near future, as the expected growth in coal gasification is much bigger than for any other feedstock (Figure 2, graphic 4).

Table 1 – Categorization of the technologies considered. Fonte: (Contacto com JFE) (Arena, 2012) (JFE3, 2017) (Shimakura, 10 May 2016) (Enerkem, 2014) (Enerkem4, 2017) (Valmet, 2016) (UNIDO) (Haoran et al., 2015) (Recari et al., 2017) (Biomacon2, 2015) (Contacto com Shinko Tecnos) (AlterNRG, 2016) (JFE4, 2017) (JFE, 2013) (Martin Biopower1, 2015) (Martin Biopower2, 2015)

Type	**Maturity***	**Manufacturer**	**Subtype**	**Technology**	**Scale****	***Input***
Gasification	Commercial	JFE	Updraft fixed/moving bed	JFE High-Temperature Gasifying and Direct Melting System	Medium-Large	MSW, RDF of MSW, Sewage sludge, Industrial
		Kobelco	Bubbling fluidized bed	Kobelco Fluidized Bed Gasification and Melting Furnace	Medium-Large	MSW, RDF of MSW, Sewage sludge
	Proven	Enerkem	Bubbling fluidized bed	Enerkem Bubbling Fluidized Bed Gasification	Large	RDF of MSW
		Valmet	Circulating fluidized bed	Valmet Circulating Fluidized Bed Gasification	Large	RDF/SRF of MSW, Wood
	Demonstrated	AlterNRG	Plasma gasification	Plasma Gasification Vitrification Reactor	Small-Large	MSW, RDF of MSW, Sewage sludge, ASR
Incineration	Commercial	JFE	Stoker grate	JFE Hyper 21 Stoker System	Medium-Large	MSW, RDF of MSW, Industrial
		Martin	Moving grate	Martin Reverse-Acting Grate Vario system	Medium-Large	MSW, RDF of MSW, Industrial
Others	-	Shinko Tecnos Co., LTD	Hydrothermal treatment	Shinko Tecnos Hydrothermal Treatment	-	MSW, Sewage sludge, Agricultural waste
		Biomacon	Biomass pyrolysis	Biomacon Compact Converter		Biomass
		-	Torrefaction	-		MSW, RDF/SRF of MSW, Biomass

*Commercial Maturity – Several functioning totally commercial units; Proven Maturity – At least one functioning totally commercial unit; Demonstrated Maturity – There are just non commercial functioning units or is transitioning to commercial functioning

**Small Scale ≤ 25t/day; 25t/day ≤ Medium Scale ≤ 250t/day; Large Scale ≥ 250t/day

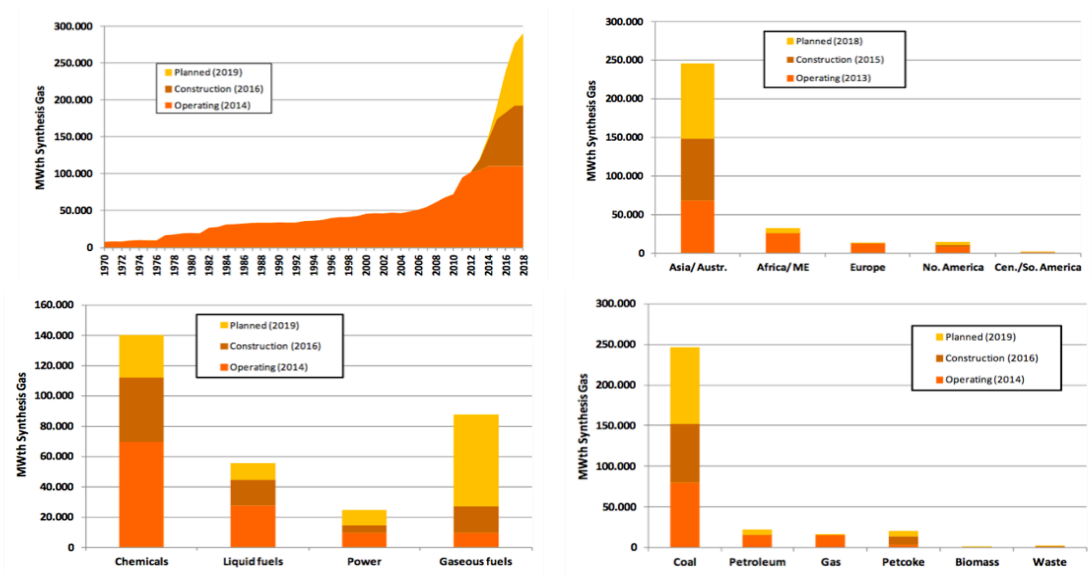

Figure 2 - Evolution of the installed gasification capacity in the world from 1970 until 2018 (graphic 1), geographic distribution of the installed capacity (graphic 2), installed capacity by application (graphic 3) and by feedstock (graphic 4), including units in the planning and construction stages. Source: (Chris Higman, 2014)

2.2.2 Economics

Studies found gasification to be the most economically viable option. Fernández-González et al. (2017) compared various scenarios with different waste treatment techniques, making the balance between the cost (capital and operation) of each of them and the income they would produce and found that the scenario that included gasification was the most viable. Lavaee, (2013) also compared four waste treatment techniques (landfill, incineration, conventional gasification and plasma gasification), using as criteria the capital and operation costs and income produced (tipping fee, energy sold and government sources), and found the two gasification technologies to be the most profitable, with plasma gasification taking the first spot.

The typical structure of the costs of WtE facilities is presented on Table 2.

Regarding the costs and income generated by actual gasification units, there was no willingness from the manufactures to provide such data on their technologies or operating units and there were few scientific papers with such studies for MSW gasification.

Table 2 – Typical distribution costs in a WtE unit. Source: (WSP, 2013)

Capital Costs (%)	
Thermal processing equipment	40
Energy production equipment	10
Flue gas cleaning system	15
Building and civil works	25
Miscellaneous	10
Operation Costs (%)	
Labour and administration	25-30
Maintenance	35-40
Utilities and Supplies	20
Residues management and disposal	20

3 Case Study

Tratolixo is a waste management company for the municipalities of Sintra, Oeiras, Cascais and Mafra. Its waste management system is composed of: collection of MSW (one transfer station, three eco centres and a network of separate collection stations), material valorisation (separate collection paper/cardboard sorting central), mechanical treatment (MT) in the solid waste treatment industrial centre, organic valorisation (anaerobic digestion central (ADC) and the Trajouce centre of energetic valorisation of landfill biogas), landfilling (one landfill in exploration and one sealed landfill) and two water treatment stations, one for landfill leachate and another for industrial waste water.

In 2016 Tratolixo received about 415 916t of waste, of various typologies, distributing them among the its various facilities. In the mechanical treatment entered 145 938t, mainly undifferentiated but also 1 474t of refuse from paper/cardboard sorting. 2,17% of the input was sent to recycling, 47,51% was the organic fraction, sent to anaerobic digestion and the remaining 50,32% was the refuse, sent to incineration and landfill. The target fraction of this thesis is precisely this refuse fraction, which in 2016 totalled 73 431t (Tratolixo, 2017). The refuse fraction's composition can be observed in Figure 3. It has a water content of about 48,8% (Tratolixo, 2011), an ash content between 11,8% and 20,1%, a chlorine content between 0,54% and 1,2% and a LHV between 7,3MJ/kg and 13,1MJ/kg (Laboratório de Análises AVE, 2014).

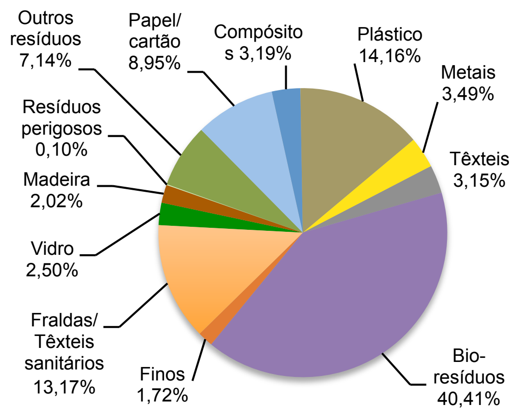

Figure 3 – Average physical characteristics of the refuse fraction from Trajouce MT unit, which totalled 73 431t in 2016. Source: (Tratolixo, 2011)

3.1 Refuse Fraction's Gasification Potential

To know if the refuse fraction would fit directly, with some pre-treatment or not at all into the requirements of the gasification technologies considered, a comparison between its characteristics and those of the technologies was made, Table 3.

Table 3 - Characteristics of the gasification technologies considered. Sources: (Arena, 2012), (Contacto com JFE), (Valmet, 2014), (Lahti Energia1, 2017), (Lahti energia3, 2017), (Valmet, 2017), (Shimakura, 10 May 2016), (Westinghouse Plasma Corporation, 2014), (AlterNRG2, 2016), (Westinghouse Plasma Corportation)

Type of gasification/ technology	**Particle size (mm)**	**Water content (%)**	**Ash content d.b. (%)**	**Calorific power (MJ/kg)**
Updraft fixed/moving bed gasification	<100	<50	<15	
JFE High-Temperature Gasifying and Melting System	<600	N.L.	N.L.	LHV<24
Circulating fluidized bed gasification	<100	<55	<25	
Valmet Circulating Fluidized Bed Gasification	*20-40 (RDF/SRF)	*<30	*<15	*18<LHV
Bubbling fluidized bed gasification	< 150	<55	<25	
Kobelco Fluidized Bed Gasification and Melting Furnace	<400		N.L.	
Enerkem Waste to Biofuels Process	*50 (fluff)	*20-25		
Plasma gasification	N.L.	N.L.	N.L.	
AlterNRG Plasma Gasification Vitrification Reactor	150	<25	N.L.	9.3<HHV <14

Compatible with the refuse fraction without pre-treatment? Yes / No

*Values referring to actual units

4 Conclusions

Studies indicated that from all of the WtE technologies considered, gasification was the most favorable by environmental and economic standards. These results should, however, be taken cautiously, because most of the literature available on the subject of economic and associated impacts of WtE technologies is still not very extensive and not always explain the characteristics of the processes being compared. There is also a lack of studies comparing technologies from different manufacturers.

Looking at the technical requirements of the gasification technologies considered, there wasn't any that would be impossible to apply to the case study. However, some of them could require pre-treatment.

For instance, Enerkem, AlterNRG and Valmet's technologies would require pre-treatment to decrease particle size and water content. Valmet's technology would also need the calorific power of the refuse fraction to increase, by pre-treatment or mixing with another feedstock. Note for the fact that most of Enerkem, AlterNRG and Valmet's data is from actual units, meaning that their requirements are those of the units and not necessarily those of the technology, so there could the possibility of adapting some of the requirements to the characteristics of the refuse fraction.

JFE and Kobelco's technologies were more flexible, stating that their processes wouldn't need pre-treatment if the particle size of the refuse wouldn't surpass 600mm and 400mm respectively. In the case of Kobelco's technology, there was no data on water content and calorific power limits, but the data on the general process of bubbling fluidized bed gasification refers to a water content limit of 55%, which is compatible with the waste stream.

Being a pillar of the decision process, the lack of economic data available on the manufacturers' technologies made it impossible to ascertain which would be more favourable for the case study and if it would be worth it to implement one of the alternative technologies that could work online or in parallel with the gasification.

Future works could focus on the weaknesses mentioned, such as the availability of economic data from the manufacturers' technologies and improving the impact assessment and economic studies on WtE technologies with more data on the technologies being compared and more technologies of the same type of process being compared.

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