Economic and environmental benefits of using textile waste for the production of thermal energy

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Abstract

There is a growing demand for alternative forms of energy that could firstly replace fossil fuels, with the environmental advantages resulting therefrom, but that could be as well economically more beneficial by allowing companies to obtain competitive advantages from the aforementioned alternative forms of energy. In this sense, the use of waste to produce thermal energy is presented as an alternative worthy of study. In this paper, an analysis is made of the use of waste from the textile industry, more precisely cotton waste, which is used as a renewable resource for the production of thermal energy. After the characterization of the waste, the energetic potential is determined comparatively to other fuels such as woodchips and wood pellets. A comparative economic assessment with other fuels is carried out. The obtained results show that the cotton briquettes have a heating value of 16.80MJ/kg and a cost of 0.006 €/kWh when used as fuel. This predicts an annual reduction in fuel cost of 80, 75 and 70% when compared with fuel-oil, wood pellets and wood chips, respectively. Thus, the use of cotton waste could be a viable alternative, economically and environmentally, to produce thermal energy.

Keywords: energy waste; textile waste; cotton waste; energy recovery; renewable resource; economic analysis.

1. Introduction

Modern society demands the eager pursuit of new energy sources that can meet the growing demand for energy, both for domestic and industrial use. The industrial sector, which operates in a globalised world where competition arises from different fronts, is investing considerable time and money in the development of energy solutions that might enable a reduction in production costs and thus increase competitiveness. This search stems mainly from the difficulty of reducing operating costs related to labour or raw materials under current market conditions (Smith and Ball, 2012; Bornschlegl et al., 2016; Eustathios Sainidis and Andrew Robson, 2016; Esen et al., 2006, 2007a; Esen and Yuksel, 2013; Esen et al., 2007b).

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Awareness of the environmental and sustainability matters should be in the interest of every enterprise in the present economical and social circumstances. Thus, by still aiming to satisfy the demand companies should also increase their responsibility of the surrounding natural environment where they operate. Academics in the research community argue that environmental progress improves the operational, economic, and organizational performance. Therefore, in some cases, progress in the environmental sphere resulted in cost reduction through a more efficient use of the available resources thus, leading to sale and profit increases (Hänninen and Karjaluoto, 2017).

The textile manufacturing process produces a significant amount of solid waste, typically the biological and primary sludge obtained from the treatment systems of wastewater and residues of the cotton textile industry from originated during the weaving manufacturing process. The overall composition of the textile sludge can show a significant variation. Simply put, besides the expected heavy metals and dyes it typically comprises a substantial amount of organic matter, phosphorus, nitrogen, and micronutrients. This type of sludge can be incinerated or can be utilized in agriculture. In addition, it can also be dried in order to be utilized a type of process such as energy creation through combustion, further contributing to the minimization of environmental impacts and assuring a sustainable operation (Avelar et al., 2016).

As a direct result of the Great Recession, labour costs in Portugal have reached a level which can hardly fall any lower, while the purchase of raw materials, regulated by the markets and outside suppliers, follows the natural law of supply and demand and is thus not open to a large margin of manoeuvre (Alkaya and Demirer, 2014; J. Zambujal‐Oliveira and Miguel Faria e Castro, 2011).

Portugal is strongly dependent on energy sources associated with the use of fossil fuels, namely oil, coal and natural gas. As a result, the country is almost totally reliant on the outside world, raising issues regarding security of supply and energy price volatility, as regulated by variations in global markets. Analysing the variation in energy consumption in Portugal for the last few years, reveals a decrease in the consumption of oil and coal and an increase in the consumption of natural gas, largely related to the conversion of combined-cycle power stations. A clear increasing trend can also be observed regarding the use of energy derived from renewable resources, with water and wind power in particular contributing significantly to the reduction in fossil energy sources (Fernandes and Ferreira, 2014). The use of energy sources of fossil origin remains very significant, representing 82% of total primary energy consumption in Portugal.

In terms of renewable energy sources, the predominant source is wind power, which is mainly used to produce electrical energy. Biomass and waste remain poorly exploited, mainly used to produce electrical energy and considerably less for heat production, as can be seen in Table 1.

'See Table 1 at the end of the manuscript'

The industrial sector is a major consumer of not only electrical energy – mainly for the operation of industrial equipment – but also of thermal energy for the production of heat (steam or thermofluid boilers) essential to different productive processes. This is the main reason why many companies have decided to invest in the installation of cogeneration units producing both electricity and heat, with their clear advantages in economies of scale and resource optimisation. However, the vast majority of industrial units have neither the financial capacity nor size to justify the deployment of a cogeneration unit and thus the latter are not a solution that can be applied indiscriminately (Nunes et al., 2015).

A more frequent scenario is the need for more efficient heat production, which is the case for the vast majority of textile companies – mainly those associated with finishing and dyeing – and also for the agri-food and leather industries (Nunes et al., 2013a). In these cases, a range of alternative solutions have already been sought, mainly aimed at finding fuels that could replace those traditionally used, in particular heavy fuel oil and natural gas (van der Veen and Kasmire, 2015).

Is here that biomass and other associated products may be increasingly employed for heat production in the form of steam or thermofluid. This trend has encouraged the internal trade of wood pellets, as well as increasing demand for other forms of biomass such as waste (Nunes et al., 2014). Figure 1 shows the fitting of a steam production unit using wood pellets as fuel. Recent studies focusing on the textile dyeing industries of northern Portugal have revealed that energy costs in this important industrial sector could be reduced by up to 27% if wood chips or 18% if wood pellets are used as an alternative fuel to natural gas. However, due to its ease of use, particularly in respect of its supply, the latter continues to be the preferred form of fuel (Nunes et al., 2013a, 2015).

'See Fig. 1 at the end of the manuscript'

The Portuguese natural gas network does not cover the country in a uniform way, with many areas, even some of those adjacent to main urban centres, remaining without access. As a result, a considerable number of companies are forced to rely on fuel oil.

Figure 2 shows the changing price of heavy fuel oil in Portugal in recent years. This is a relatively expensive fuel whose supply is more complex logistically than natural gas, with storage necessarily adjacent to the point of use, and which is also more harmful to the environment, especially with regard to emissions. Therefore, all industrial units capable of making the change to natural gas have done so. Natural gas is also more advantageous from the point of view of cost per kWh used, as demonstrated by the graph shown in Figure 3.

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Besides the rising price of fuel-oil, such type of boilers has associated to them certain problems related to leaks and spills in the burners (which were evident in all units visited during the preparation of the present study), as well as the need for large-dimension storage structures that require significant maintenance costs.

The present study focuses on the production of thermal energy from the use of wastes from the textile industry, based on a technical characterization of the fuel produced with textile waste and economic analysis of energy costs comparatively to the most used fuels and also with other forms of alternative fuels such as woodchips and wood pellets. The study is based on a case study, which analysed the fuel consumption in steam production. This fuel produced with waste from the textile industry, was produced and consumed at the company, not having transportation costs. The analysis of the problems in a real context is provided, demonstrating their applicability and the validation of concepts (Stake, 1995; Yin, 2009).

2. The textile sector in Portugal

The Portuguese textile industry is well established and despite the serious crisis that it is currently experiencing is still one of the most important industrial sectors in the country, playing a major role in terms of employment and in the Portuguese economy. The sector is mature, fragmented and subject to periodic mismatches between supply and demand, with its performance strongly conditioned by fluctuations in global economic activity (Pickles et al., 2015).

The liberalisation of the global textile trade, together with the consolidation of the position of Asian countries in the European market, has served only to aggravate the difficulties that this sector has been experiencing in recent years, which have affected not only Portugal but also the whole sector at the European level. The future of the sector is thus increasingly affected by factors such as R&D, innovation, design, the pursuit of excellence, quality, distribution and logistics, as well as by the internationalisation of its products, especially those that contain high levels of differentiation (Eckhardt and Poletti, 2016). The textile sector thus requires strengthening, with companies encouraged to focus on elements contributing the most in terms of added value and competitiveness (Carreira and Lopes, 2015).

Increasing globalisation and the opening of the EU market to Asian economies, together with the associated difficulty of achieving good levels of competitiveness with the latter's low production costs and the appreciation of the euro against the US dollar, have resulted in impacts of various kinds on the world economy to which Portugal is also not immune (Litsios and Pilbeam, 2017; Pomfret, 2014). One of these impacts is the decrease in the number of firms in the sector, mainly due to the relocation of foreign companies with production units in Portugal, but also of national companies either moving their production to other countries in order to benefit from advantages in the cost of production, or closing as they cannot survive in an increasingly more demanding market. Associated with the continuous reduction in firm numbers and the resizing of others due to the new market conditions, employment in the sector has also decreased (Turker and Altuntas, 2014).

The Vale do Ave, which is home to the highest number of textile companies in the north of Portugal, has about 150 years of textile manufacture tradition and habituation to an industrial model that has involved, directly or indirectly, the majority of its population (Neffke et al., 2011). Indeed, the textiles industry is the region's main source of employment.

The European textiles industry employs some 2.2 million workers, with more than 100 thousand companies and a turnover of 198 billion euros. However, in addition to the so-called "traditional" socio-economic challenges facing the industry, other new ones, particularly those related to working conditions and the environment, are becoming increasingly significant (Nunes et al., 2013b). In Portugal this sector employs more than 134,000 workers, with more than 11,766 companies and a turnover of more than 5,800 million euros according to data collected with ATP – Associação Têxtil e Vestuário de Portugal ("ATP - Associação Têxtil e Vestuário de Portugal," n.d.).

One of the main environmental problems facing the textiles industry is the generation of significant quantities of waste from the various stages of production. This waste requires management and proper treatment in order to mitigate its impact on both environmental and public health.

Generally, the textile production chain begins with wiring, passes through intermediate stages of weaving/knitting, dyeing and stamping, and ends with finishing – the latter comprising a range of operations which provide comfort, durability and other product-specific properties. Throughout this set of processes of transformation from fibre (i.e. the basic raw material) to finished product (MacCarthy and Jayarathne, 2012), residues are generated in the form of textile dust and waste solids. Normally the solid waste can be recycled as textile materials within the industry, or else is deposited in landfill (Marechal et al., 2012).

However, landfill is becoming increasingly expensive and land is limited, prompting the search for alternative solutions involving the recovery of either the material or the energy content of the waste (Ruiz-Torres et al., 2013).

Energy is of vital importance to any economy, being one of the fundamental components responsible for the development of modern society; as such, its performance and responsibility can also be monitored in environmental terms. Although energy provides personal comfort and mobility and is essential for the production of most industrial and commercial wealth, its production and consumption put on the environment considerable pressure, including contributing to climate change, destroying ecosystems, tarnishing the built environment and adversely affecting human health (Tozlu et al., 2016).

3. Energy recovery of waste textiles

Until very recently, the majority of solid waste in Portugal was deposited in landfills, because this was considered the most practical and simple way to deal with it. However, factors such as the reduced life of landfill sites and a greater awareness of the negative effects of landfill waste on the environment and public health, have meant that the use of such sites is increasingly limited and are becoming more expensive and as such is no longer the most desirable solution (Arafat et al., 2015).

The current growing interest in the use of waste as a source of energy stems not only from the environmental motivation of reducing landfill, leachate formation and greenhouse gas emissions, but also the preservation of fossil fuels aimed at increasing the life of available energy reserves (Rajaeifar et al., 2015). The simultaneous increase in energy demand and the difficulty of energy production due to the scarcity of fossil fuels has prompted the identification of new possible sources of energy, including the recycling of materials for thermal use (University, 2003; Zabaniotou and Andreou, 2010).

Waste and refuse materials frequently contain significant quantities of the valuable resources (matter and energy) that were originally used in the production process, with landfill thus representing a wasted energy source. Indeed, such materials are often produced using fossil fuels that could be saved if the latter are replaced by waste itself. Waste essentially constitutes a renewable resource that can be used for the production of heat and/or electricity (Merrild et al., 2012), since it is generated continuously with human activity and can replace raw materials and energy of a non-renewable nature. Energy recovery from waste that cannot be recycled economically is also a fundamental part of both the waste management process as well as sustainable energy policy (Nigam and Singh, 2011).

Several methods are available for the recovery of energy from waste, including the construction of facilities specially designed for this purpose, new power and energy units based on advanced technologies (gasification, torrefaction, pyrolysis), as well as the conversion of industrial ovens, cogeneration installations and existing power stations to burn waste or waste fuels (Demirbas, 2011). For example, the pyrolysis of mixtures of residues and forwarding of gases produced for a gas turbine is able to produce energy with an efficiency greater than 30% (Fan et al., 2011).

The co-combustion of waste with a significant calorific value via industrial processes can replace part of the quantity of fossil fuels (Feng et al., 2015). Studies performed using textile wastes, especially cotton waste, in an incinerator oven and a small-scale circulating fluidised bed have shown that despite the fact that the chemical composition of these residues can vary, they generally have a high energy potential that makes them suitable for co-combustion with coal, although combustion efficiency slightly decreases with an increase in the fraction of waste (Ortolano et al., 2014). In contrast, and despite having a high energy content, textile waste burned alone in a fixed bed oven showed very low combustion efficiency due essentially to an uneven spread of ignition (Clancy et al., 2015; Fischer and Pascucci, 2017; Franco, 2017; Singh et al., 2017; Zhou et al., 2017).

To achieve a more controllable and efficient combustion, textile waste can be burned in conjunction with other materials of high calorific value. A range of co-combustion tests involving mixtures of various compositions have revealed that the co-combustion of waste residues can be improved when burnt together with a material with a similar ignition point (Singh and Gollner, 2015).

4. Materials and methods

Part of the waste produced in the textile industry, in particular in the areas of spinning and weaving, can be forwarded to recycled wire production units, where they are subjected to a process of fibre recovery. However, the remaining percentage of materials that cannot be reused is in the great majority of cases compressed and stored or simply sent to landfill. Figure 4 shows an example of a waste compression unit and bale storage section.

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Such bales are essentially composed of remnants of cotton fibres and polyester threads that for reasons of colour, size and contamination cannot be used for the production of recycled wire, as well as small-dimension fibres retrieved by aspiration systems during industrial textile production processes.

Since it is generally comprised of naturally low-density materials, a given quantity of textile waste has a considerable volume, further increasing its landfill costs. For this reason, the densification of these materials (at the same location in which the waste was produced) into a form that optimises energy recovery has several advantages, in particular:

- Eliminates costs related to landfill, including transport and deposition rates;
- Not sending low-density high-volume materials to landfills increases the latter's life;
- Reduces operating costs, since compression is performed only with the objective of minimising transport and storage costs prior to sending to landfill;
- Reduces costs when used with other fuels for the production of heat.

The compression of residues to form briquettes, as presented in Figure 5, enables direct energy recovery in a furnace originally prepared for biomass. Only the feed auger must be altered, due to the dimensions of the briquettes being slightly larger than that of other fuels derived from biomass, such as wood chips.

Such types of briquettes can be stored in large bags, which are subsequently deposited in a tank supplying the furnace of a boiler, as displayed in Figure 6.

'See Figure 5 at the end of the manuscript'

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Sample briquettes were collected and submitted to laboratory characterisation in order to determine their properties, including analysis of the following parameters: High Heating Value (HHV), Low Heating Value (LHV), % oxygen, % hydrogen, % carbon, % nitrogen, volatile content, % ash, % moisture and % fixed carbon. During a period of one month (21 working days) one briquette was collected per day. After, all the 21 briquettes were ground and mixed, being rebriquetted again and was randomly selected the quantity necessary to perform all the laboratory tests. This procedure was thought to allow a better representativeness of the material to be characterized.

The determination of Heating Value (High and Low) was achieved using a Calorimeter PARR and following EN14918. Oxygen, hydrogen, carbon and nitrogen content were determined using a LECO Elemental CHN Analyser and according EN15104. Ash, moisture and fixed carbon content were determined using a thermogravimetric analysis (TGA) equipment (ELTRA THERMOSTEP) according EN15148 for volatile content and EN14775 for ash content.

5. Results and discussion

Several previous studies address the issue of the use of alternative fuels to natural gas and naphtha, especially wood pellets and wood chips (Nunes et al., 2013b). In these studies, the authors demonstrate the feasibility of using these fuels, especially from an economic point of view. Regarding the use of other fuels, such as those addressed in this study, are only occasional and very recent references. In these recent studies, the residues characterized consist of mixtures of different types of waste, particularly sludge from wastewater treatment plants and textile waste (Avelar et al., 2016).

The results obtained from this characterization analysis are presented in Table 2.

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As is evident from Table 2, the tested textile residue briquettes represent a very interesting potential fuel, with their LHV very close to that of wood pellets and their ash content of 0.52% being very low. The latter is particularly significant as it means problems associated with excessive deposition of ash in the furnace will be less likely to occur.

A factor that also deserves to be mentioned is the low moisture content that such residues normally present, which contributes significantly to their increased net calorific value.

Based on the obtained results and assuming the use of a boiler of typical dimensions for the sector, it is possible to determine the viability of textile waste briquettes as fuel compared to other materials, in particular fuel oil, wood chips and wood pellets.

Thus, fuel consumption data for a boiler with a thermal power of 1,542 MW and capable of producing 2 t/h steam at 10 bar are presented in Table 3. The simulation was carried out assuming that the unit can work 1, 2 or 3 shifts per day, with 21 working days per month and 11 working months per year.

'See Table 3 at the end of the manuscript'

Table 4 displays the market values for the year 2015 for the compared fuels. Most of these figures were collected through direct contact with suppliers, with the cost of briquette production estimated at 25 €/t, based on the electrical energy required, labour costs, other costs related to equipment wear and assuming that the material is delivered at zero cost.

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Thus, on the basis of these values and the operating conditions mentioned above, it was possible to calculate the annual cost of fuels derived from each of the analysed examples, as presented in Table 5.

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Analysis of the data reveals a significant difference in the respective costs of the fuels, on which basis alone one could justify the switch from heavy fuel oil to biomass, in addition to the beneficial local recovery of waste.

By assigning a value for the acquisition of a boiler, including the entire storage structure and fuel supply, of 275,000.00 €, the pay-back for each of the presented options was calculated, as shown in Table 6. The price assigned to the boiler and all its constituent parts was obtained by consulting with a national manufacturer.

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Analysis of Table 6 reveals that the use of textile waste briquettes offers the best return on investment due to the associated reduction of energy costs. Supplementation of the briquettes with a mixture of other biomass fuels during periods of low supply does not significantly change the period of return on investment. Thus, in this way, further contributing to the minimization of environmental impacts and assuring a sustainable operation of the facility by replacing the use of heavy fuel oil to textile waste briquettes and biomass.

6. Conclusions

In this paper the use of waste from the textile industry, more precisely cotton waste used as a renewable resource for the production of thermal energy, was analysed. After the characterization of the waste, the energetic potential was determined comparatively to other fuels such as woodchips or wood pellets. A comparative economic assessment with other fuels was made. The results have shown that the calorific value of this waste is 16.80 MJ/kg and therefore very close to other fuels such as wood pellets and wood chips. The benefits are even more apparent if the waste can be valued energetically at the place where it is produced. Thus, the economic benefits were proven to be high, because besides being available as a fuel that has a low cost, the logistics costs associated primarily to the transport of fuel to the end point of use were eliminated. All this combined showed a reduced pay-back period of the investment in equipment, since the pay-back will be 0.7 years, much lower than the 1.08 or 1.25 years if wood chips or wood pellets were to be used. The use of this fuel proved to be advantageous, particularly from an economic point of view due to the cost being significantly lower than other fuels analysed in this study. Also, environmental benefits were obtained by this solution, since waste elimination on the same location of the production proved to be advantageous by avoiding unnecessary costs by sending it to the landfill.

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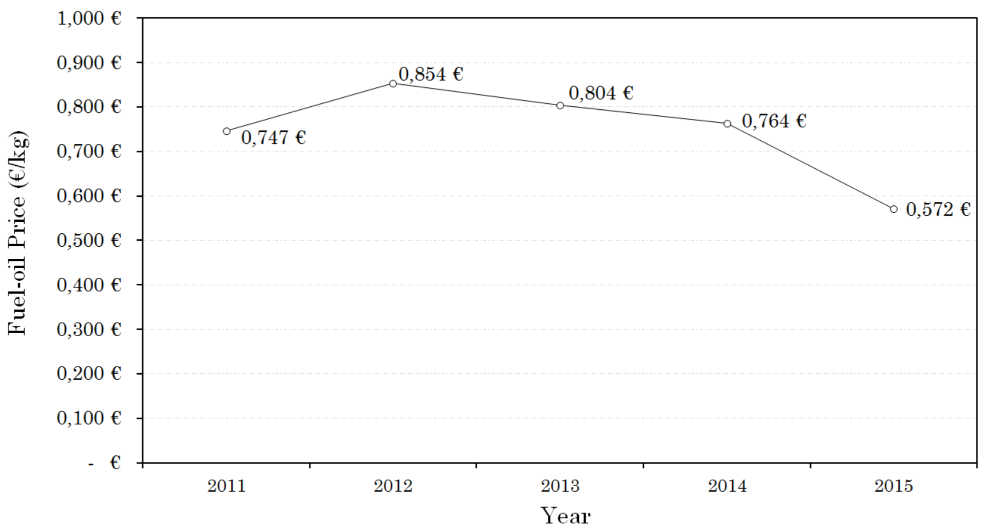

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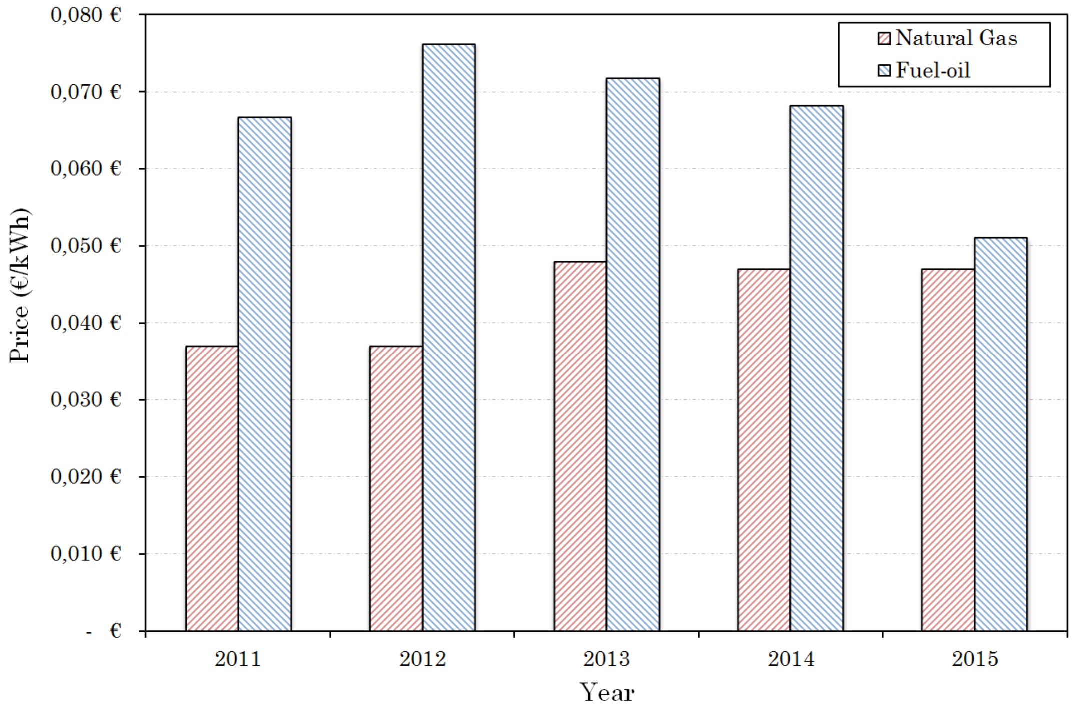

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Tables

Table 1. Monthly production of electricity from biomass and waste (*source: www.dgeg.pt*).

	Monthly production (GWh)											
	2014					2015						
	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
Biomass with cogeneration	152	142	148	143	153	145	125	135	118	134	132	138
Biomass without cogeneration	69	68	68	61	63	57	57	67	64	71	68	67
MSW	54	52	11	23	51	54	46	52	43	54	38	35
Biomass wastes	27	26	5	12	25	27	23	26	22	27	19	17

MSW – Municipal Solid Waste

Table 2. Laboratory characterisation of the analysed textile waste briquettes.

Parameter	**Result**
HHV (a.r.)	16.80 MJ/kg
LHV (a.r.)	15.50 MJ/kg
Oxygen content (d.b.)	52.80%
Carbon content (d.b.)	40.28%
Hydrogen content (d.b.)	6.01%
Nitrogen content (d.b.)	0.365%
Moisture (a.r.)	6.22%
Volatiles content (a.r.)	80.26%
Fixed carbon (d.b.)	13.86%
Ashes content (d.b.)	0.52%

HHV – High Heating Value; LHV – Low Heating Value; a.r. – as received; d.b. – dry basis

Table 3. Fuel consumption.

Fuel oil	Wood chips	Wood pellets	TW Briquettes
137.54 kg/h	616.80 kg/h	321.25 kg/h	367.14 kg/h

TW – Textile Waste

Table 4. Market values of selected fuels in Portugal for the year 2015.

	Fuel oil	Wood chips	Wood pellets	TW Briquettes
Price €/t	572	53	125	25
Price €/kg	0.572	0.053	7125	0.025
Price €/kWh	0.051	0.021	0.026	0.006

TW – Textile Waste

Table 5. Annual costs of fuels.

	Fuel oil	Wood chips	Wood pellets	TW Briquettes
1 shift	145,391 €	60,412 €	74,209 €	16,962 €
2 shifts	290,782 €	120,824 €	148,418 €	33,924 €
3 shifts	436,173 €	181,236 €	222,626 €	50,886 €

TW – Textile Waste

Table 6. Pay-back period in years.

	Wood chips	Wood pellets	TW Briquettes
1 shift	3.86	3.86	2.14
2 shifts	1.62	1.93	1.07
3 shifts	1.08	1.29	0.7

TW – Textile Waste