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Technological Innovation in Biomass Energy for the Sustainable Growth of Textile Industry

Leonel Jorge Ribeiro Nunes [1,2,*], Radu Godina [3] and João Carlos de Oliveira Matias [1,2]

1. DEGEIT—Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, 3810-193 Aveiro, Portugal; jmatias@ua.pt
2. GOVCOPP—Research Unit on Governance, Competitiveness and Public Policies, University of Aveiro, 3810-193 Aveiro, Portugal
3. Research and Development Unit in Mechanical and Industrial Engineering (UNIDEMI), Department of Mechanical and Industrial Engineering, Faculty of Science and Technology (FCT), New University of Lisbon, 2829-516 Caparica, Portugal; rd@ubi.pt

* Correspondence: leonelnunes@ua.pt; Tel.: +351-232-446-600

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Abstract: The growing increase in world energy consumption favors the search for renewable energy sources. One of the existing options for the growth and sustainable development of such types of sources is through the use of biomass as an input. The employment of biomass as solid fuel is widely studied and is no longer a novelty nor presents any difficulty from the technical point of view. It presents, however, logistic obstacles, thus not allowing their direct dissemination in every organization that is willing to replace it as an energy source. Use of biomass can be rewarding due to the fact that it can bring significant economic gains attained due to the steadiness of the biomass price in Portugal. However, the price may rise as predicted in the coming years, although it will be a gradual rising. The main goal of this study was to analyze whether biomass in the case of the Portuguese textile industry can be a viable alternative that separates the possibility of sustainable growth from the lack of competitiveness due to high energy costs. The study showed that biomass can be a reliable, sustainable and permanent energy alternative to more traditional energy sources such as propane gas, naphtha and natural gas for the textile industry. At the same time, it can bring savings of 35% in energy costs related to steam generation. Also, with new technology systems related to the Internet of Things, a better on-time aware of needs, energy production and logistic chain information will be possible.

Keywords: energy from biomass; textile industrial sector; alternative energy; SWOT analysis; energy costs; Internet of Things

1. Introduction

The energy sector, with particular emphasis on renewable energy, has witnessed an increased interest of scientific research on the production of energy for the manufacturing industry, particularly in the form of thermal energy [1]. Global demand for increased energy efficiency, partly driven by climate changes, but mainly by a relentless pursuit of lower energy costs, has influenced and motivated the introduction of a holistic perspective in the analysis of thermal systems. Supported by the Internet of Things (IoT), the development of new concepts and tools for the intelligent management of energy systems, with particular emphasis on thermal systems, has become one of the most pressing current demands [2].

Biomass is considered a renewable energy source that could decidedly support the mitigation of climate change [3–5] and can be used in the production of energy from processes such as the combustion of organic material produced and accumulated in an ecosystem [6]. It can be distinguished from different energy sources with considerable energy potential: wood (and waste), agricultural waste, solid municipal waste, animal waste, food waste, aquatic plants and algae [7]. Compared with fossil fuels such as petroleum products, these wastes generate fewer greenhouse gas emissions [8]. Therefore, biomass is considered a sustainable type of energy [9–11]. Energy security is an element of significant evidence and is crucial for the sustainable economic growth of every country [12]. As indicated by the European Commission, the goal is to reduce the greenhouse gas (GHG) emissions in the EU-27 by at least 80% in 2050 when compared to the emissions in 1990 [13,14]. Also, worldwide energy necessities could double in 2050, largely due to the quick development of emerging nations [15]. A different study confirms a similar tendency, with a rise of approximately 50% of energetic needs by 2030, of which as much as 70% are part of India, China and other emerging nations [16–18].

Although biomass is less utilized than hydro and wind energy for the production of electricity in Portugal, it has the advantage of being able to be stored and used only when demand justifies it. Thus, in this way, although biomass is commonly dependent on the growth, production of wastes and agriculture, therefore, it can be highly impacted on by the weather, production rate and economic parameters, which could lead to raw material shortage, it allows a constant supply, unlike other renewable energy sources that are intermittent and dependent on the atmospheric conditions in the case of wind and the level of water in dams in the case of water, making the production of energy through these sources dependent and uncertain [19].

As a result, one of the solutions to reduce Portugal's energy dependence from the exterior is to replace the use of fossil fuels, one of the most promising alternatives being biomass, which includes forest, agricultural residues, and all biodegradable organic waste originating from man and animals. This energy source is very flexible and can be used in its pure form or processed to produce biofuels. According to Eurostat [20,21], the energy produced from biomass and solid biofuels sources in Portugal in the last 10 years shows a significant decline in consumption between the years 2009 and 2012, as can be seen in Figure 1. This decrease is due mainly to the exportation of biomass products, mainly in the form of wood pellets, to northern Europe, instead of national use due to the higher prices paid by such countries.

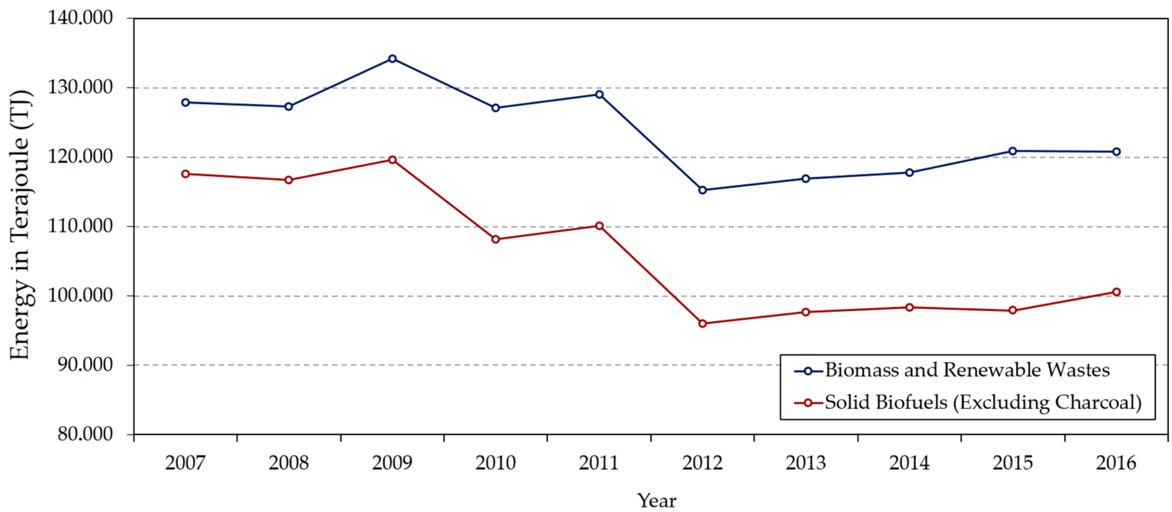

Figure 1. The energy produced from biomass and solid biofuels sources in Portugal from 2007 to 2016.

This new perspective on the use of biomass is also due to the discovery of this type of energy by industries. Large companies that produce their own energy are replacing the fossil fuels that moved their plants through alternative sources. Among the main benefits is achieving the emissions reduction targets [22]. Biomass has started to become a more attractive source thanks to the advancement of its processing technology. With the improvement of the equipment used in combustion, the efficiency of the process has increased. One of the main challenges of the industry is to make the most of biomass, since the conditions of humidity and conservation of waste have a direct impact on the generation of energy [23].

The main objective of this work is to research into the energy efficiency management and logistics associated with the use of biomass as a source of thermal energy in the Portuguese textile industry, since the increasing consumption of this energy will require the creation of information networks and data analysis that will support decision making, contributing to the development of the collective awareness systems.

This work is organized as follows. In Section 2, the literature review is performed. In Section 3, the energy sources used in Portugal by the textile dye Industry are addressed. A comparison between biomass and fuels of fossil origin is made in Section 3. In Section 4, a SWOT analysis of the use of biomass energy in the textile industry is made. Finally, the results are analyzed in Section 4, and conclusions are drawn in Section 5.

2. State-of-The-Art

The textile industry is considered one of the most complex industries due to the variety of processes, machinery and components used throughout the process, as well as all types of fibres and yarns, production methods, finishing, preparation, dyeing and coating, amongst others which are also important. The number of enterprises that are part and are operating in this industry in Portugal can be seen in Figure 2, where the turnover in millions of euros that these enterprises generate when combined can also be observed [24]. Energy is one of the main components of this industry, and consequently, energy consumption costs are especially high during a period of high price volatility. One of the main interests of the stakeholders of this industry is energy efficiency.

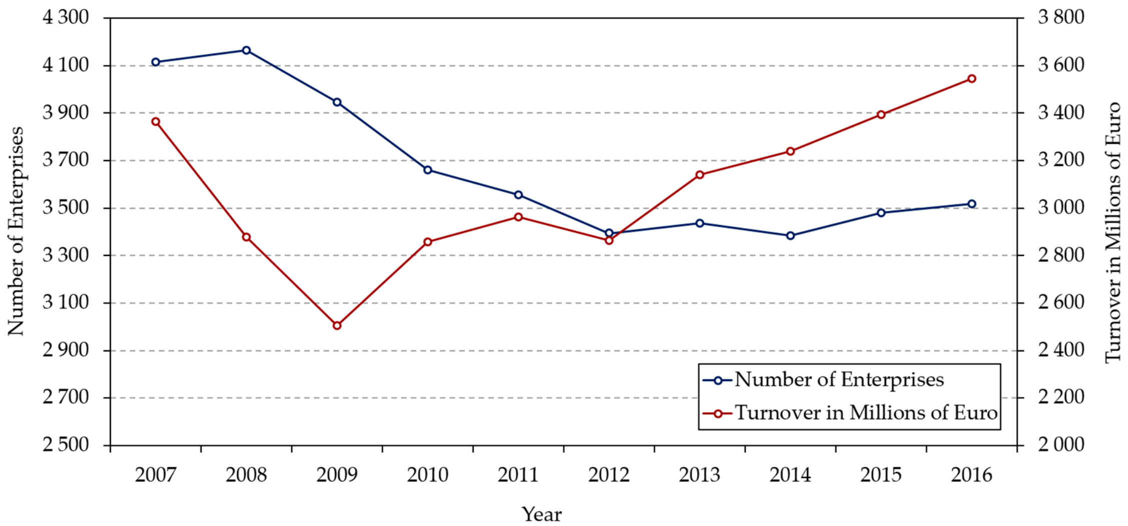

Figure 2. Number of Portuguese enterprises operating in the textile industry vs the turnover in millions of euro.

The textile industry is considered a significant element of the global economy, which suffered profound changes in the last few decades due to the technological advancements that followed during the same years [25]. This industry, in Portugal, is up against difficult competitive challenges, and the reason is elevated costs of production, which in turn are provoked by increasing costs of energy as a part of the European energy cost trend [26]. However, this industry has been resilient, as represented in Figure 3, where it can be seen that the turnover has been steadily increasing since the 2007–2008 financial crisis [24]. However, this industry is responsible for a substantial share of energy consumption, as can be observed in Figure 4 [24]. The textile industry is known for being very diverse, with several distinct production processes. However, within this industry, the textile dyeing sector is recognized as a considerable energy consumer, since its manufacturing process requires a substantial quantity of steam for it to operate properly [27].

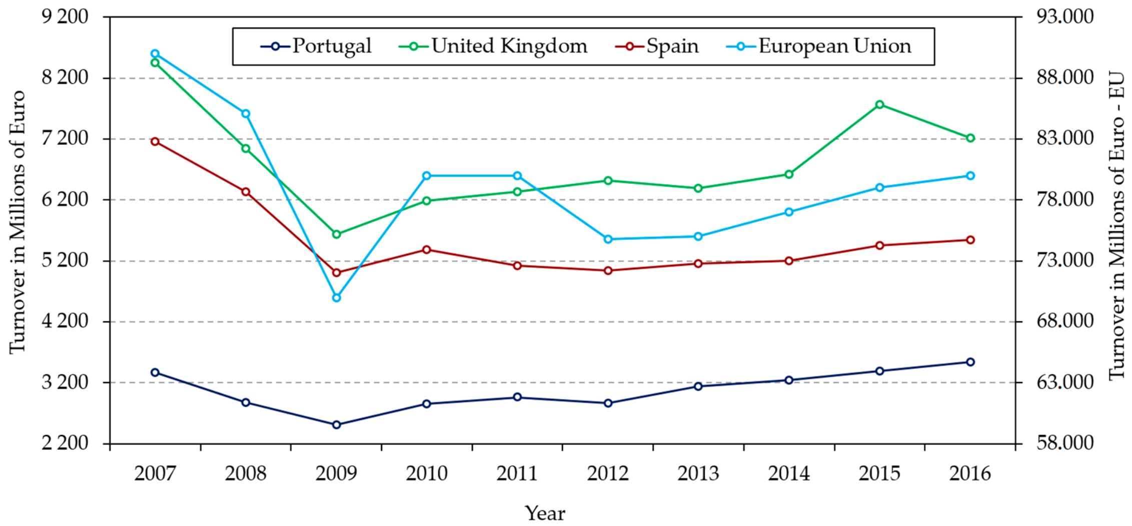

Figure 3. The turnover of the textile industry in EU, Portugal, United Kingdom and Spain.

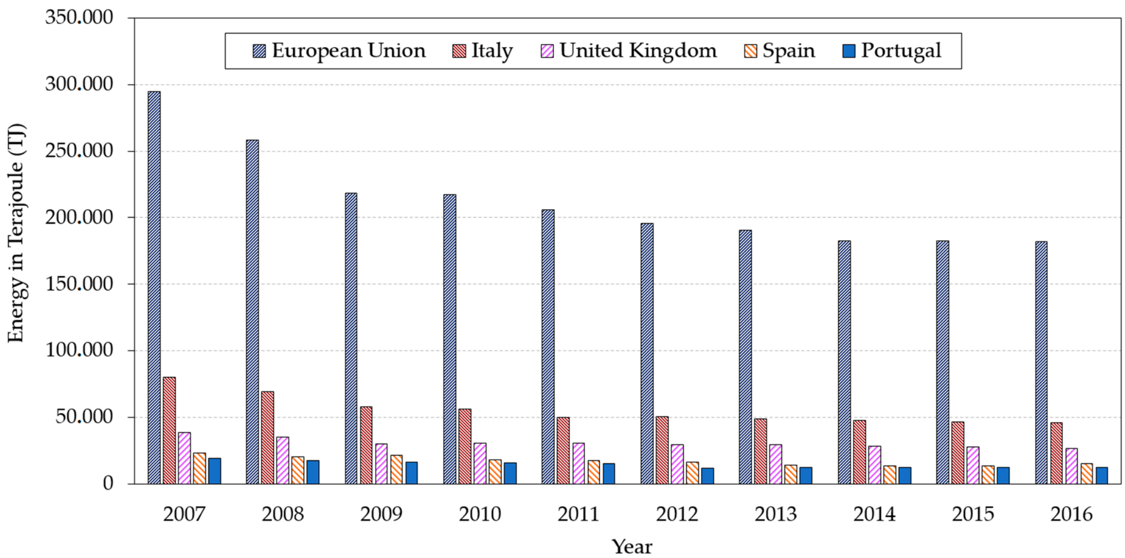

Figure 4. The energy consumed by the textile industry in EU, Portugal, United Kingdom and Spain.

The Portuguese textile dyeing industry relies mostly on natural gas as fuel. However, in some instances, the use of naphtha and propane gas still occurs, not by the choice of prices being more competitive, but due to logistical obstacles or due to a lack of access to the natural gas supply chain [4]. The price of utilising steam boilers for steam production, usually at 10 bar and at 90 °C, makes up as much as 60% of the textile dyeing industry's energy costs. Therefore, the opportunity to use biomass as an alternative energy source brings many advantages for this industry [28,29].

Researchers have been steadily increasing their focus and attention on the use of biomass in the textile industry. A study focusing on the analysis of the energy mix profile and energy efficiency of the Brazilian dairy industry is presented in Reference [30], in which, biomass sources for thermal energy generation are addressed. In Reference [4], the environmental and economic benefits of utilising textile waste for thermal energy generation are investigated and a comparative economic assessment with distinct fuels is made. A study of biomass employment as an energetic substitute for the textile dyeing industry of Portugal is made in Reference [25]; however, a more detailed consumption of steam production in m^3 is lacking.

A decrease of the adsorbed dyes' volume by utilizing the aerobically-activated sludge process in the discharged sludge originating from an industrial textile wastewater treatment plant is proposed in Reference [31]. By selecting a performant biomass, the authors argue that microorganisms are capable of generating an adjusted conglomerate capable of lowering toxic dye molecules. In the author's analyses, the energy footprints of the textile industry, namely textile manufacturing, utilization, and recycling stages [32]. In Reference [33], the potential of future energy saving of the textile industry of China is predicted by analysing the energy substitution effect of technological progress through the use of a macroeconomics approach while the authors in Reference [34] conducted a comprehensive study and analysis of the GHG emissions in the textile industry of China and then assessed the nature of the emission. The results showed that coal was the main source of GHG emissions. Since biomass pellets or torrefied biomass pellets are a direct replacement of coal, here lies an opportunity to significantly decrease the emissions of the textile industry. Authors in Reference [35] also identified potential cost-effective opportunities to improve the energy use and energy efficiency in this industry. Also, in Reference [36], such types of opportunities and potential are discussed, and the author identifies the compressor, steam boiler and lighting as the elements taking a substantial slice of the overall energy consumption. Finally, the assessment and the capability of a photovoltaic/thermal-energy system of cogeneration equipped with a storage device applicable to the textile industry is proposed in Reference [37].

3. Materials and Methods

The textile dyeing industry operating in Portugal has a significant share of the Portuguese economic activity, which translates into having substantial importance. The major industrial units and organizations are all situated in and around the proximate regions of Vale do Cávado and Vale do Ave, located in the north of Portugal. Thus, for this paper, these industrial units were selected, specifically in the municipalities of Barcelos, Famalicão and Fafe, and the city of Guimarães, which are the areas were the Portuguese textile industry is mostly concentrated and which have been operating for more than 150 years [27,38].

The textile industry in Portugal suffered a steep decline a few years ago, as can be deduced from Figure 2, a period during which many industrial units closed doors. In the aftermath of the 2007–2008 financial crisis, many other organizations suffered profound changes and drastically reduced their workforce with the purpose of keeping the operation active and trying to survive [25]. Several of the abovementioned industrial units were willing to modernise through the implementation of distinct and original requalification policies and procedures for their production processes. Thus, these industrial units implemented several measures with the purpose of achieving a higher energy efficiency, which also meant reducing the production costs and liberating more income for other more urgent expenses [39].

Three types of fuel in steam boilers were used: natural gas, propane gas and naphtha; they can be observed in Figure 5. The last two are mainly used in smaller units without direct access to the natural gas distribution grid.

Not even one industrial unit considered in this study was employing biomass for their energetic input. Thus, an opportunity arose to assess the use of this source in this industry. The steam boilers that were most frequently met in the sought industrial units are usually equipped with capacities of steam generation between 8 and 12 ton/h at 10 bar pressure, as can be observed in Figure 6.

A modern biomass boiler (for pellets, chips, wood briquettes and wood residues) represents an ecological and convenient solution, alternatively or by integration, of traditional heating systems for fossil fuels. The transition from fossil fuels to biomass also means altering and upgrading the equipment, as can be observed in Figure 7, where the first steam boiler in a textile dyeing industry was assembled. This can frequently be very challenging to accomplish due to logistical and spatial order obstacles. This happens mainly due to the fact that these units have been operating unaltered for decades and are occupying obsolete facilities. These installations have been established to satisfy the production needs of that period. Thus, in facilities adapted for biomass, they must have space for storage and for the filter system, as can be observed in Figures 8 and 9, respectively.

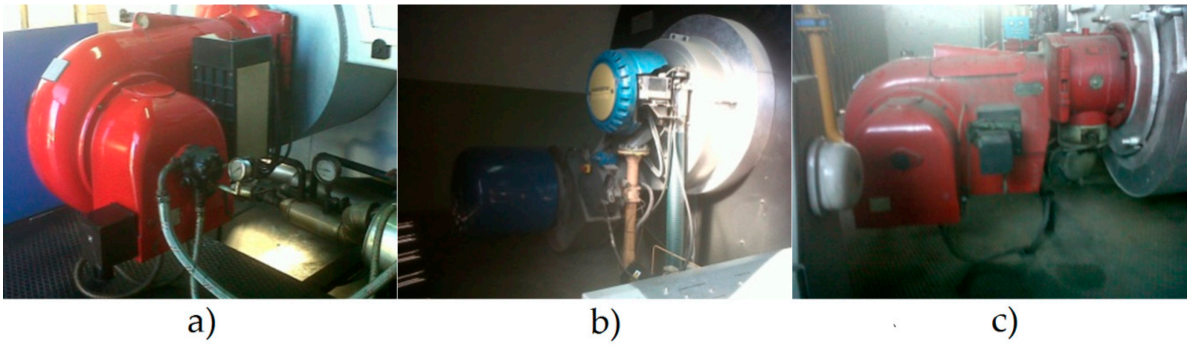

Figure 5. Example of (**a**) naphtha, (**b**) propane gas and (**c**) natural gas burners connected to steam boilers.

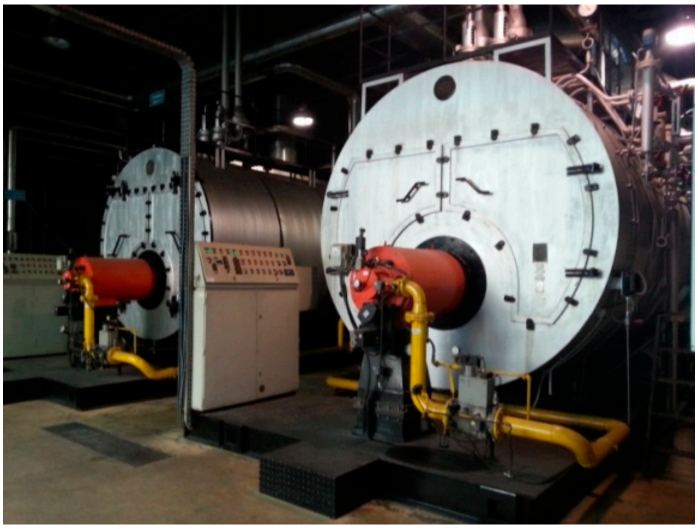

Figure 6. An example of a steam boiler that produces 10 tonnes per-hour of steam.

Figure 7. Example of a biomass burner in a steam boiler of a textile production plant.

(**a**) (**b**)

Figure 8. Biomass warehouse (**a**) with a burner automatic feeding system (**b**).

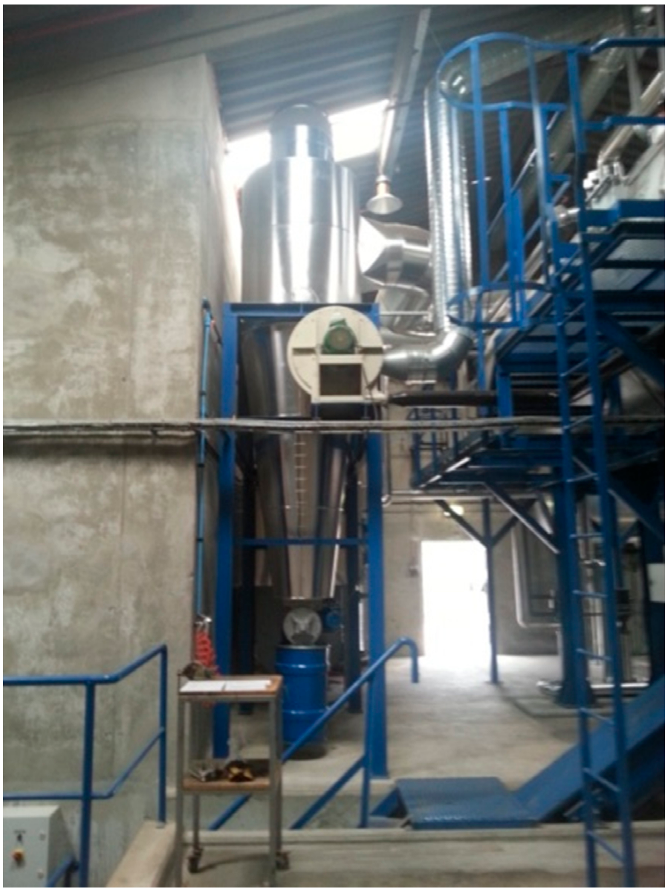

Figure 9. Biomass steam boiler filtering system.

4. Results and Discussion

By being utilised as a substitute fuel to fossil fuels, the biomass can support the reduction of GHG emissions [40]. However, every biofuel positively impacts the environment. The production of biomass and transportation techniques could have a negative effect on the environment as well as in certain areas of the world the production of biofuel threatens agricultural crops [41].

Natural gas is the most utilized fuel in steam boilers while propane gas and naphtha are only used as a last resort in cases when the natural gas is not readily available. Thus, in this paper, is only made reference to natural gas and biomass comparing.

Previous consumption data from the top 10 textile dyeing industrial units in the regions of Vale do Cávado and Vale do Ave were gathered and compiled by the authors, thus presenting in Table 1 the average of the annual consumptions for the year 2016, assuming that of the energy total amounts calculated, only 60% is related to the production of steam. For the comparative study, woodchips of pine wood were used as biomass form, which is considered to be a product containing particles with an average moisture content of 40%, a size around 40 × 40 × 20 mm and a lower heating value (LHV) of 3.50 kWh [42], which is in opposition to natural gas that has a LHV of 9.16 kWh [43].

Table 1. Natural Gas Consumption of the top 10 textile dyeing industrial units in 2016.

	Monthly Average Values	Annual Average Values
Consumption of steam production in m^3 (60% of the entire consumption)	175.000 m^3	1.925.000 m^3
Consumption of steam production in kWh (60% of the entire consumption)	2.250.000 kWh	24.750.000 kWh
Steam production costs (60% of the entire consumption)	75.000 €	825.000 €
The cost of kWh	0.034 €/kWh	

Thus, in order to achieve a similar result, it is required to consume a monthly mass of around 645,000 kg of woodchips, which is overall 7,095,000 kg per year, as can be observed in Table 2. In this study, a yearly reference value of 11 months was utilized, due to the reason that August is usually vacation month and is used for maintenance. The 11-month year was used as the reference for the present calculations, the highest quotation accessed from several local suppliers of pine woodchips, and that was 75 €/t. All values used are presented free of VAT.

Table 2. Biomass (woodchips) consumption—estimated annual average values.

	Monthly Average Values	Annual Average Values
Consumption of steam production in m^3 (60% of the entire consumption)	645.000 kg	7.095.000 kg
Consumption of steam production in kWh (60% of the entire consumption)	2.250.000 kWh	24.750.000 kWh
Steam production costs (60% of the entire consumption)	48.375 €	532.125 €
The cost of kWh	0.024 €/kWh	

By comparing the annual steam production costs of the natural Gas and biomass, using pine woodchips, it is possible to asses from the results that real savings in energy costs for steam production of about 35% can be achieved, as can be observed in Table 3.

Table 3. Yearly savings if biomass is chosen instead of natural gas.

	Natural Gas	Biomass (Pine Woodchips)
Annual kWh consumption for steam production	24.750.000 kWh	
Annual steam production costs	825.000 €	532.125 €
Annual total savings	±35%	

The SWOT analysis, as can be observed in Table 4, is a technique capable of identifying weaknesses, strengths, threats and opportunities for a given goal. In the current study, employing biomass as a different and more sustainable energy source for the textile industry helps achieve an optimized operational strategy [44]. As can be observed, the use of IoT technologies in monitoring energetic consumption and logistic control of solid fuel's supply is identified as a potential opportunity.

Table 4. Employing Biomass Energy in Textile Industry—a SWOT Analysis.

Strengths	Weaknesses
• Energy efficiency. • The rise in competitiveness achieved by reducing the energy costs. • The rise of textile-dependent industries and suppliers, meaning job creation. • An important role in decreasing the imports of natural gas, coal, etc.	• Biomass logistics and supply. • The necessity for initial investment. • Spaces adaptation for the updated equipment. • Recurrent price variation and certain physical traits of the biomass. • Absence of a clear successful example that could validate biomass as an alternative.
Opportunities	**Threats**
• Positive impact in the economic development of the region. • Opportunity to implement a resource preservation policy. • Increase the use of autochthone energy resources. • Development and modernization of the forest management and industry. • Use of IoT technologies in monitoring energetic consumption and logistic control of solid fuels supply.	• Difficult to penetrate into the energy market. • Lack of a steady national policy that could promote sustainable exploitation of renewable energy in industry. • Doubt of decision makers regarding the potential of biomass.

Among the different sources of renewable energy, the importance of Biomass stands out. There is wide use of Biomass in energy production, namely Biomass Energy Forestry and Biomass Residual Forest (surplus exploitation). The biomass sector for energy purposes has been undergoing strong development, with an increase in the production of electricity at the Portuguese national level. By looking at Table 4, it is possible to assess the general outline of the energy mix of the textile dyeing industry in Portugal and its potential to grow and develop, since it is an important sector for the entire Portuguese economy and currently is going through a very difficult period as a result of very high costs of production, which in turn is caused mainly by the ever-rising energy taxes and costs.

Because it is a renewable resource, the utilization of biomass as the most important source for the production of steam encourages the textile industry to consume an autochthone energy source, thus reducing the dependence on imported energy of Portugal, while additionally being more environmentally friendly.

Regardless of all the aforementioned listed benefits, replacing fossil fuels is not an easy task, since it requires high investing efforts in order to upgrade the current equipment used in this industry, or replace it entirely. However, replacing the equipment is not enough, significant changes of the entire supply chain need to occur and how to store the biomass must be investigated into.

One of the most significant benefits that the use of biomass could bring is the incentive for improved economic development of rural areas through job creation, thus decreasing the rural exodus and strengthening the local industry.

However, despite the benefits achieved in this study, the substitution of conventional fossil fuels is not a sure bet, since it requires substantial investments for upgrading the existing equipment or replacing it entirely. Such a transition will also signify a transformation in the entire process of storage, movement and supply chain of biomass. Yet, this transition could be strengthened by employing IoT. Thus, as soon as great service-based, distributed energy infrastructure with IoT is implemented, it will be possible to develop innovative cost-effective concepts that could empower the textile industry with more efficient capabilities and tools to solve old problems. However, in order for this technology to be successfully implemented, several challenges have to be overcome through research and real test bed implementation.

5. Conclusions

The Portuguese textile industry is of great importance for the country's exports and economy. However, in this industry, it has been reported that the energy consumption reaches up to 60% of the total production cost. The aim of this study was to explore the potential of energy efficiency management and logistics associated with the use of biomass as a source of thermal energy in the Portuguese textile industry. Given that the increasing consumption of this type of energy source will require the creation of information networks and data analysis that will support decision making, the study performed in this paper showed that Biomass could be a reliable, sustainable and permanent substitute for fossil fuels for the textile industry. Thus, it could make the energy consumed at the industrial units more cost-effective, which is detrimental to other more traditional energy sources such as propane gas, naphtha and natural gas. Such a transition could bring substantial savings by the order of 35% in energy costs related to steam generation, which is essential to the industrial process, thus increasing the overall competitiveness of this industrial sector.

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