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Modelling hybrid thermal systems for district heating: A pilot project in wood transformation industry

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ABSTRACT

The development of modern cities promotes the emergence of metropolitan areas with industrial areas. This situation favours the development of production nuclei of industrial waste, which is susceptible to being energetically used. Biomass of forest origin is particularly interesting due to its importance as an energy resource that mitigates CO_2 emissions. The development of energy modelling methodologies is necessary to achieve cleaner production by circular economy in the world. This study aims to improve existing methods and develop new methods to characterise the energy potential of biomass from wood for thermal energy production. The methodology is based on the implementation of a model that calculates waste in terms of quantity, energy and cost while considering techno-economic and environmental restrictions. The study is developed in the Metropolitan Area of Vigo (MAV) for its wood processing industry. MAV is important for the production of manufactured and semi-manufactured products. The results suggest economic and environmental advantages with the installation of hybrid thermal generation systems to supply part of the heat demand using indigenous resources in the MAV. A total of eight district heating systems can be developed with thermal generation systems by Thermal Hybrid Units (THU).

1. Introduction

Environmental management refers to all human activities that affect the environment, regardless of their degree of impact, and is subject to existing territorial and usage regulations. The transition to a society driven by renewable energy will become an important alternative in the future. The European Union's policy on renewable energy and greenhouse gas (GHG) emissions requires that 20% of the energy consumed should be produced from renewable sources by 2020 (Da Graça Carvalho, 2012). Biomass is one of the oldest energy resources used all over the world, it represented 10% of the global primary energy supply (IEA, 2016). The development of biomass use is crucial due to its important advantages in reducing the dependence on energy and GHG emissions (Tokimatsu et al., 2017; Vandecasteele et al., 2016; Arce et al., 2015). Developing a sustainable energy industry is a mechanism that fosters economic development and employment (Watkinson et al., 2012; He et al., 2016). Several studies have evaluated the potential of biomass resources with differences in the scope of approach in Europe (Scarlat et al., 2015; Dafnomilis et al., 2017). Bioenergy systems that employ biomass can contribute to the future of an energy industry (Míguez et al., 2012). The availability of a stable supply of raw material is essential for its development and can hamper the development of energy production projects (Castillo-Villar, 2014).

More than two-thirds of Europe's population lives in urban areas (Soares et al., 2011). The development of modern cities favours the formation of metropolitan areas where waste management and air quality are significant challenges (Paredes-Sánchez et al., 2015a; Dou et al., 2018).

Regarding the lumber industry, environmental management includes all activities which are dedicated to creating a safer and healthier work environment for employees through the prevention of occupational risks. It also includes measures oriented towards reducing energy and raw material consumption as well as improving the supply conditions. Therefore, energy savings obtained from using the most efficient potential resources should be

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considered to be the result of efficient environmental management of company residues. Thus, many industrial sectors are looking for ways to integrate innovative systems to develop environmental management systems which are based on saving resources in order to make positive economic and environmental impacts (Deveci et al., 2015).

The lumber industry includes the milling and industrial preparation of wood products relating to first and second production phases. The output obtained by the first phase of wood production includes lumber and wood products like scrap wood, sawdust, by-products, etc. The second group of businesses which form part of lumber and milling industry are dedicated to the fabrication of semi-finished products. The study of the second production phase presents two problems. The first is the difficulty in separating this phase from later applications of the products, the second difficulty is that waste wood is not normally used for the manufacture of end products (ALTENER, 2002).

One characteristic of the lumber industry is the generation of large volumes of residues during the production process, which often begins before the wood arrives at the facility and continues up until the finished product is obtained. The exploitation of these residues is an essential part of the work to reduce the consumption of fossil fuels and the negative environmental impact that they have.

Circular Economy (CE) is a term that several national governments and the European Union (EU), as well as some companies around the world have started to use. The traditional linear energy flow model of extract-produce-use-dumpmate is no longer enough (Korhonen et al., 2018). In this context, the transition to a more circular economy, where the generation of waste is minimized, is an essential contribution. At the same time, it will save energy and help avoid the irreversible damages caused by traditional energy resources to improve the efficiency and environmental performance of energy-related products.

Among renewable resources, biomass is one of the main ones due to its abundance and availability. The bioeconomy provides alternatives to fossil-based products and energy, and can contribute to the circular economy (Pan et al., 2015). It will create local jobs and opportunities for social integration and cohesion (Saavedra et al., 2018).

In this context, the wood processing industry is a strategic sector in the bio-supply chain and production of wood biomass residues. Biomass has the potential to replace fossil fuels in many applications, from the generation of bioenergy (e.g., heat, electricity or biofuels) to the production of bioproducts (e.g., chemicals or other materials). Wood waste is a source of renewable energy and reduces CO_2 emissions (Kim and Song, 2014). In addition, the use of energy resources available at a plant has particular importance in the industry (Paredes-Sánchez et al., 2014). The analysis of waste management in the wood processing industry in metropolitan areas for energy purposes is important due to its potential as an environmentally sustainable fuel or raw material with currently available technology.

Most studies have considered environmental aspects (i.e., life cycle assessment studies) or bioenergy projects (i.e., techno-economic and optimisation studies) and identified barriers to bioenergy development. First, biomass feedstocks are dispersed, and therefore, the collection of significant amounts requires large areas (Ba et al., 2016; Gabrielle et al., 2014). Second, biomass has a low energy density, which produces higher transport costs to the plant (Golecha and Gan, 2016). Third, biomass requires pretreatment to reduce particle size and moisture content and improve energy density (Singh et al., 2016). Finally, seasonality and annual biomass variability require careful planning to ensure energy supply, which increases the costs and time required for proper supply chain management (Gironès et al., 2017).

Various studies have assessed the bioenergy potential and environmental sustainability with differences in scope and approach regarding the use of indicators or methodologies (Motghare et al., 2016; Cambero and Sowlati, 2014). González-García et al. (2014) analysed bioenergy production chains with different supply types of forest biomass. Yemshanov et al. (2014) noted that biomass supply costs are the major constraint to the widespread use of waste for bioenergy commercialisation. Bergeron (2016) emphasises the importance of wood processing industry waste to obtain bioenergy from by-products of the wood industry. Botard et al. (2015) suggested that the market for wood products is a key factor in determining the feasibility of biomass. Therefore, research is required to combine the criteria defined for the use of by-products from the wood industry for use in integrated bioenergy production systems.

The use of wood industry residues for solid biofuel production will allow for a sustainable exploitation project and provide a readily available energy source for the development of heating networks in the studied area. This analysis demonstrates the environmental, social and economic benefits of the exploitation of residues in hybrid energy generation systems within the European political framework established by 2020. Currently, there is an increasing tendency to use forestry industry residues either as a raw material for production or as an energy source. These applications serve to help find a viable use for these residues as well as to help protect the environment, as they reduce landfill contamination levels.

This study develops a methodology for evaluating and modelling thermal bioenergy from waste from the wood processing industry. The main aim to define this work is to provide the necessary information to evaluate the different valorisation possibilities for produced residues by businesses within the wood and furniture sectors within the territory of a circular economy. Thus, a number of different potential enhancements to and valorisations of the residues generated within these sectors will be outlined, which will not require any additional production cost on behalf of the businesses themselves, providing the possibility of creating a by-product that will in turn generate additional income.

The analysed aspects refer to both the evaluation of available resources and their use in hybrid thermal technology machines. The proposed characterisation depends on variables such as (i) waste generation parameters, (ii) resource availability factors and (iii) techno-economic aspects. The work is performed in the metropolitan area of Vigo (MAV), which is located in southern Europe, as it represents a typical location of the coastal metropolitan environment.

2. Materials and methods

2.1. Location

Currently, a large proportion of European citizens live in metropolitan areas, so there is a debate in many states about the need to find clean energy production formulas that ensure efficient and sustainable management of metropolitan areas. The configuration of metropolitan areas is characterized by the presence of a central city that begins to lose population and industrial weight in favour of the municipalities around it. The Metropolitan Area of Vigo (MAV), located in the north of Spain, follows the reference model indicated and current in developed countries (ESPON, 2011). The MAV is configured as a study area that represents a physical management space in which close to half a million people live and