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Review article

Energy recovery of glued wood waste – A review

E. Cesprini[a,b], G. Resente[a], V. Causin[b], T. Urso[a], R. Cavalli[a], M. Zanetti[a,*]

[a] Department of Land, Environment, Agriculture and Forestry, University of Padova, Viale dell'Università 16, 35020 Legnaro, PD, Italy
[b] Department of Chemical Sciences, University of Padova, Via Marzolo 1, 35131 Padova, Italy

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ABSTRACT

Wood waste is a material that can be upgraded from an energy point of view. The purpose of this systematic review is to analysed the energetic characterisation of glued wood waste, in view of their use in combustion plants. To assess the compatibility of glued wood wastes combustion with sustainable environmental impacts, the main studies regarding their emissions during combustion process are reported. The results of the research showed a wide distribution concerning the emissions of the main pollutants. Carbon monoxide emissions, one of the main greenhouse gases, are considerably reduced by the use of efficient plants though the presence of adhesives does not affect CO emissions. The use of nitrogen-based glues instead negatively influences the emissions related to another group of monitored pollutants, the NO_x. As far as SO_x is concerned, emissions are low, favoured both by the low percentage of sulphur in woody biomass and by the non-use of sulphur-based treatments. The quality of combustion process also influences the type of produced emissions. The incomplete combustion leads to the formation of harmful compounds to the environment and to humans. The emissions of PAHs, dioxins and PCBs are generally higher for biomass than fossil fuels, but the presence of adhesives does not affect the emissions of these compounds. This indicates that, under optimal combustion conditions and eventually by mixing glued and virgin wood waste, the wood waste containing adhesives could represent an additional source of biomass for energy production.

1. Introduction

The clear need to set a new prospective on EU energy and climate policies led to the creation of a European framework aimed at reducing greenhouse gas (GHG) emissions and at providing an optimal energy supply, analogously to the realization of a supporting and efficient market. In order to handle these objectives, EU opted primarily for a resource efficient approach. In line with this, the set targets are GHG emissions reduction, enhancing the renewable energy sector and energy saving [1].

In this context, energy utilization and consumption become of high importance considering that global energy demand, measured by Total Primary Energy Supply (TPES), raised almost 150% in the 1971–2015 period [2].

Overall the energy sector is responsible for 90% of the CO_2 global emission [3], and fossil fuel combustion stands out as the main anthropogenic cause for GHG emissions [3]. Although non-fossil energy is an emerging sector, 2015 data assessed fossil fuels an 82% share of the total primary energy supply [3].

According to the predicted CO_2 tendency, the report on global energy trends published by Enerdata (2018) [4], confirmed that the global amount of carbon dioxide in the atmosphere grew by 2.1% in 2017.

In this view a proper use of renewables could play a fundamental role, with their significant GHG mitigation potential [5]. The main indicator of renewables is the share of renewable energy sources in the gross final energy consumption. In 2016, this value equalled to 65.9 EJ, 17.9% of the total amount. Among the resources included in the renewable share, biomass reaches the highest percentage (13%), followed by hydropower (3%), solar (0.3%), wind (0.8%), geothermal (0.6%), and others 0.1% [6].

Biomass supply involves a multiplicity of feedstocks, but it can be simplified into three main sectors – forestry, agriculture and waste. TPES data show that solid biomass is dominating the biomass supply sector since 2000, reaching the 87% share in 2016 [6]. This includes 67% from fuelwood, 7% from charcoal, 6% from recovered wood, 5% from wood industry residues, 1% from forest residues and 1% from black liquor from the pulp and paper industry [7].

Woody biomass importance as a natural resource is confirmed by the increase in biomass trading, especially in the European countries where it is widely proposed as an alternative to fossil fuels [8,9].

In some contexts, traditional bioenergy is still an issue considering its effect on forest degradation and depletion of forest carbon storage [10]. Firewood and charcoal remains the dominant source of energy for heating and cooking in the rural areas of most developing countries [10]. To decrease the use of virgin wood as biofuel, recycling wood

* Corresponding author.
E-mail address: michela.zanetti@unipd.it (M. Zanetti).

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waste can have a high mitigation potential on GHG emissions [11–13]. In this context, waste wood products, coming from furniture, construction or industry, may become a very promising feedstock for combustion since a large amount of this resource remains unused for an energy purpose [13]. Nowadays there are multiple ways to implement wood waste management depending on different country policies such as: recycling for wood composites, particleboards production and biofuel production [14].

The quality of solid biofuel is regulated by the series 17225 of EN ISO standards and the origin of biomass is one of the mandatory parameters to assess their quality [15]. Chemically treated wood is included in the biomass origin list and is represented by two categories: “1.2.2 Chemically treated wood by-products, residues, fibres and wood constituents” and “1.3.2 Chemically treated used wood” [15]. Chemical treatments described in the standard include glued, painted, coated, lacquered or otherwise treated wood, as long as they do not add heavy metals or halogenated organic compounds more than in the virgin wood. Heavy metals are mainly found in paints and preservatives, whereas coatings and adhesives are typical sources of nitrogen and halogens. NO_x and SO_x, along with dioxins and volatile organic compounds, are chemical substances released by wood combustion and potentially harmful for human health and the environment [16]. Regardless, the 1.2.2 origin is included only between the characteristics of lower quality classes of pellets, briquettes and wood chips, while the 1.3.2. origin is not mentioned in the ISO standards concerning the specific biofuels. Nevertheless, a note in the ISO standards relating to wood pellets [17] and briquettes [18] says that negligible amount of grease, glue and other additives used during timber production form virgin wood are allowed if their presence does not make the chemical parameters exceed the limits set by the quality standards.

In general, there are mainly three classes with which wood waste can be grouped: untreated, lightly treated and highly treated waste. Untreated wood waste can already be used in combustion plants, meeting certain requirements defined by International standards, while highly treated wood waste with preservatives, such as copper chromium arsenic (CCA), are considered as dangerous [19]. Treated wood waste management is a complex issue, differently managed in many countries, although the ISO standards are internationally accepted [20].

If we take CHP (Compound Heat and Power) production plants as an example, some European countries such as Austria, Finland, Belgium, Denmark, Netherlands and Sweden allow the use of slightly treated wood [13,20]. On the contrary in Italy, utilizable biomass resources include only mechanically worked virgin wood according to Annexes I, IX, X in Section V of the Environmental Framework Legislative Decree No. “152/2006” [21].

To promote a better understanding of the environmental issue linked to the combustion of glued wood waste, this review aims to analyse the scientific results obtained so far on glued wood waste energy valorisation, comparing them with those of virgin wood. In particular, the goal of this study is to understand how different glue compositions influence the solid biofuel characteristics and the combustion emissions, and whether it is possible to integrate glued wood waste in standardized biofuels, in view of their energy recycling and, at the same time, enhancing their emissions reduction.

2. Systematic review

The papers concerning the comparison between the solid biofuel characteristics and the emissions from a combustion process of virgin wood and wood treated with adhesive resins have been identified by consulting Scopus and the Web of Science (WOS) databases using the following keywords: “emission”, “combustion”, “glue”, “adhesive”, “wood”, “waste”. The use of keywords returned 377 papers for Scopus and 813 for Web of Science. Logical operators such as OR or AND were used to initially decrease the number of items found. Subsequently, through a careful reading of the titles and then of the abstracts, the most relevant studies to the topic in question were selected.

The Scopus and Web of Science (WOS) search engines were also used for the bibliography concerning the new classes of wood adhesives.

The main articles cited in the studies selected by the bibliography research (Scopus and Web of Science), were included in the review bibliography, to allow a broader description of the topic. The selected articles cover a period of time from 1989 until present (2019).

The papers have been classified into two main thematic groups: (i) comparison between physico-mechanical characteristics of glued and virgin woods, and (ii) comparison between glued and virgin woods combustion process emissions. The possible use of bio-based molecules similar to the wood matrix for bio-adhesives formulation in view of an energy recovery of the glued products has also been investigated.

3. Results and discussion

3.1. Physico-mechanical characterization of biomass

The quality requirements of wood biofuels are regulated by a series of harmonized international standards [22]. Based on the type of manufacturing process, the solid wood-based biofuel are mainly divided into: firewood, wood chips, pellets, and briquettes [15]. The standards define the limits of the technical parameters for which a biomass can be considered a biofuel with low environmental impact. A regulation is assigned to each different type of wood solid biofuel: pellets [17], briquettes [18], wood chips [23], and firewood [24]. In addition to regulation just mentioned, two further solid biofuels certifications have been developed: EN Plus [25] is used to control the quality of pellet market while in Italy has been developed Biomass Plus [26] certification for checking the production chain of wood chips, briquettes and firewood. Companies that voluntarily adhere to these certifications offer customers maximum product transparency, from the raw material through the processing and characteristic of the product to the distribution of this. Depending on the type of solid biofuel, quality classes are defined by the standards in force for non-industrial use. The main classes are: A1, A2, B [15], except for the case of wood chips where the B class is split into B1 and B2 and for Biomass Plus where an additional class has been added, the A1 +. The highest quality class is A1 or A1 +, while the class with the lowest quality of biofuels is B1 or B2. Classification is made according to the origin of biomass and a number of physico-mechanical and chemical features such as: ash content, moisture, calorific value, bulk density, durability and quantity of chemical elements. The above mentioned characteristics and the limit values of each class are reported for each different type of biofuel in the European and International standards.

International legislation accepts negligible levels of chemically additives as long as the quantity of heavy metals and halogenated organic compounds does not exceed the respective limit values of virgin wood [17]. Furthermore, each country adopts European directives according to its own decrees, which may be more or less restrictive.

Tables 1 and 2 show the values of the main physical characteristics of biofuels, through which they are classified according to the International and European legislation [15]. Higher quality classes are related to a better combustion process, allowing to approach the limits imposed by the law on emissions. There are also restrictions related to the chemical composition of solid biofuel, mainly related to the presence of some heavy metals, nitrogen, chlorine and sulphur [17,18,23].

There are four main studies showing a detailed description of the physical properties of glued wood waste. The results of these studies are shown in Table 2.

The first two studies have been conducted by Moreno and Font [27,28]. The first [27] analysed furniture wood waste, while the second [28] evaluated the same samples with the addition of polyurethane foam, in order to understand how this influences the composition of briquettes and their calorific value.

The third and the fourth studies have been led by Tatanò et al. [20]