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# Biomass in the generation of electricity in Portugal: A review

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ABSTRACT

The quality and composition of biomass as used in Portugal's thermal power plants is highly variable. The biomass consists mainly of residual forest biomass derived from forestry operations and wood waste from industrial processes, in particular paper and pulp industry. Its quality and composition is influenced by the presence of moisture and inert fragments, the latter being incorporated during collection or as a consequence of adherence to the biomass prior to collection. This variability presents difficulties for the thermal power plants; besides being an additional operational cost, the presence of large amounts of water and inerts in biomass used as a fuel, can result in problems related to the instability of the combustion and the accumulation of ash or rock that have to be removed and discarded. The objective of this paper is to review the main parameters that influence the quality of biomass, while analysing the current state-of-the-art power generation from the biomass sector in Portugal, as a new contribution to earlier studies.

## 1. Introduction

Energy consumption is growing rapidly worldwide, leading to a rise in atmospheric concentrations of greenhouse gases (GHG's). There is also increasing concern regarding the negative environmental impact caused by the combustion of fossil fuels, in particular of coal, oil and the latter's derivatives, with combustion processes generating combustion products such as $CO_2$ that boost climate change [1].

Since the publication of the Kyoto Protocol, which established targets for the reduction of GHG emissions, many countries and regions, including European Union, have promoted the use of renewable energy sources. As a result of this, a range of new cleaner technologies have been developed for energy production, such as wind, solar, hydro, geothermal and biomass, both for industry and transportation. The economic influence of supply and demand also had an impact, with the increase in fossil fuel prices prompting an interest in other forms of energy, including those derived from biomass. In this context, biomass as a source of renewable energy could play a fundamental role in the reduction of GHG concentrations [2–10].

In addition to assisting in the battle against climate change, the use of biomass also contributes to increasing the security of energy supply, economic growth and the creation of employment, especially in rural areas [11].

Among the various types of biomass, forestry waste plays a very important role from both an economic and environmental point of view. However, such waste is very heterogeneous and typically contains a large amount of debris (soil and rock fragments) that can enter combustion systems and interfere with the combustion process, mainly with ash production and behaviour. In addition to the accumulation of ash and particle emissions, certain intrinsic and extrinsic biomass elements may interact and cause problems such as fouling, slagging and corrosion [12].

Considering these issues, it is essential to know the origin of the selected biomass and to evaluate the latter's final quality prior to its use as fuel. Studies are therefore required aimed at characterising the biomass used in combustion systems, defining quality parameters to prevent, for example, equipment damage and the emission of pollutants into the atmosphere, as well as the low energy efficiency of many biomass combustion systems [13].

## 2. Solid biomass as fuel

In Portugal biomass is defined by Decree-Law no. 127/2013 as the set of products consisting in whole or in part of vegetable matter derived from agriculture or forestry, which can be used as fuel for the purpose of recovering its energy content, as well as certain forms of waste when used as fuel.

When the energy stored in biomass is used in a thermal power

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plant, $CO_2$ is emitted in addition to other GHGs and combustion products. However, via the process of photosynthesis, this $CO_2$ is used again and is accumulated in plants and other autotrophic organisms. Thus, the use of biomass as fuel can be considered neutral in $CO_2$ balance, contributing to alleviate the greenhouse effect and climate change [14]. However, to ensure this balance it is necessary that all emissions associated with the production, exploitation and use of biomass be compensated with the replacement of the same amount of the biomass used to grant sustainability [15].

Although biomass has the potential to play an important role in the replacement of fossil fuels for the production of thermal or electrical energy, either in dedicated biomass combustion plants or in co-firing processes with other fuels, its use has both advantages and disadvantages [16].

In terms of disadvantages, problems may arise during combustion, in particular due to the high levels of moisture, ash, Cl, K and Na that may be present in biomass. Variability in the composition of residual biomass or mixtures of biomass can also be problematic, resulting in difficulties in combustion operation and efficiency. Biomass in general exhibits a low energy density due to its reduced calorific value and density compared with coal [17]. In addition, biomass production, collection, transport and pre-treatment may involve high costs [18] and thus the use of biomass requires that regional availability should be ensured and maintained, with continuous and permanent compensation of the resources involved [19].

In terms of its benefits, biomass is a renewable energy source whose chemical energy can be converted for the production of heat or electricity. Portugal contains a high abundance of this resource and its exploitation can contribute to forest clearance and management, minimising the risk of forest fires [20]. Dedicated forestry may also involve the creation of new green areas and the use of low quality soils, at the same time that increases job creation [21]. Biomass not only has considerable potential as a source of fuel, but is also of reasonable cost in comparison to other renewables [22]. When compared to coal, biomass usually contains lower levels of ash, N and S, thus contributing to the mitigation of $CH_4$, $CO_2$, $NO_x$ and $SO_x$ emissions, but may also present higher O and H content, as well as increased levels of Ca, Mg, P, K and Cl [23].

Although the use of biomass as fuel has become increasingly attractive due to the associated low levels of pollutant emissions, when employed in industrial applications involving old and inefficient combustion systems, its use may result in higher levels of pollution [24].

Biomass can be composed of both organic and inorganic matter, with the former related to compounds containing C, H, N, S and P, and the latter related to materials of mineral or inorganic origin and including metallic elements such as Ar, Al, Fe, K, Ca, Mg and Si [25]. Several studies have revealed great variability in the chemical composition of biomass and ashes due to differences in biomass moisture content and inorganic matter percentage [26].

Previous studies have also shown that biomass can vary considerably in terms of its inorganic constituents [27]. This complexity of biomass composition varies with several factors, including the type of biomass used, the parts of the plant, the conditions in which the latter developed (i.e. climate, soil nutrients, water, pH, geographic location, pollutants), the state of plant development, how it was collected, the conditions of transport and storage, the season in which it was collected, the use of fertilisers and pesticides (which may influence biomass Cl, K, N, P and S) and the mixture of different types of biomass [28].

Biomass elemental concentrations can be classified into main, minor and trace elements. Main elements, which include C, H, N, Ca, Na and K, are those whose concentration is higher than 1%. Minor elements are typically Si, Mg, Al, S, Fe, P and Cl, which vary in concentration from between 0.1–1%, while trace elements are those with concentrations lower than 0.1% [29].

In order to ensure the quality control of forest biomass to be burned in a power plant, an evaluation of biomass moisture and a visual inspection during delivery must be carried out, since forest biomass waste can contain contaminants such as stones, sand, metal parts, glass and plastics, which if burned together with the biomass can reduce the ultimate energy yield [30].

One of the goals of biomass users is to reduce moisture and impurities, thereby significantly improving the quality of the fuel, increasing its calorific value and reducing the content of ash. The improvement of biomass quality with regard to moisture and inorganic contaminants is also aimed at reducing the costs of transport and storage, as well as ensuring the homogeneity of the fuel in order to achieve good process efficiencies and to reduce operational constraints [31].

Levels of inorganic contaminants of biological origin depend on conditions such as their quantity in different parts of the plant (roots, stem, leaves), seasonal variability (heavy rains, dry conditions) and plant growth cycles. The inorganic content in biomass may vary between 0.1–30% (always expressed in dry basis), depends on factors such as soil composition, plant type, plant age and part of the plant (for instance, leaves typically contain a greater quantity of inorganic matter than any other plant component) [32]. Whereas K, Ca, Mg, P, N are plant macronutrients, Fe, Mn, Cl, Zn are plant micronutrients. However, all of these elements may be transported and incorporated via biochemical processes in plant fluids such as xylem and phloem, and are fixed as precipitated inorganic salts incorporated within organic tissues. Si also forms part of the structure of some plants, such as cereal straw and bark [33].

Soils are mixtures of sand, clay and silt, and may be incorporated into plant biomass and thereby contribute to the presence of inorganic compounds, generating a higher ash content. During the harvesting of forest biomass waste, soil is often collected jointly with the biomass itself, while the most exposed parts of trees such as bark and leaves tend to accumulate larger quantities of soil and dust, and thus these biomass components typically contain higher levels of ash [34].

Forest biomass is also influenced by industrial environments contamination and the pollutant emissions associated to these environments. Although naturally containing few components that cause environmental problems, forest biomass may accumulate atmospheric pollutants whose combustion would generate further pollutants, such as $SO_x$, $NO_x$, HCl and particulates [35].

## 3. Biomass power plants in Portugal

According to Decree-Law no. 5/2011, dedicated biomass power plants were built across Portugal following the public tenders of 2006 promoted by the *Direcção Geral de Energia e Geologia* (DGEG), as well as other power plants (not yet in operation) with authorisation for the installation of forest biomass waste systems [36].

The main objective of the public tenders was to achieve 250 MW of electric energy from forest biomass upon the installation of 22 new power plants. Table 1 shows the installed power in Portugal during the period 2006 through to July 2015. According to the data presented by DGEG, the installed power derived from biomass, with and without cogeneration, is 474 MW, including those obtained from the use of agricultural waste, forest waste, and pulp and paper industry waste

**Table 1**
Installed power of biomass production units in Portugal.

| Installed power (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 (July) |
| 335 | 348 | 350 | 408 | 592 | 575 | 564 | 564 | 534 | 474 |