

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. © 2016 Elsevier Ltd. All rights reserved.

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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 CO₂ 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].

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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 plant, CO₂ is emitted in addition to other GHGs and combustion products. However, via the process of photosynthesis, this CO₂ is used again and is accumulated in plants and other autotrophic organisms. Thus, the use of biomass as fuel can be considered neutral in CO₂ 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 CH₄, CO₂, 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% to 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 [37].

'See Table 1 at the end of the manuscript'

The latest DGEG estimation indicates that, in Portugal, the monthly production of energy derived from biomass, with and without cogeneration, including vegetable waste, forest, and paper and pulp industry waste, is approximately 204 GWh, as presented in Table 2.

'See Table 2 at the end of the manuscript'

Until 2005, only two biomass power plants existed in Portugal that use biomass as fuel: EDP in Mortágua and Centroliva in Vila Velha de Ródão. In 2006, 15 tenders were released for the allocation of 100 MW of electric energy production from forest biomass waste. The goal of this tender release was to reach a total of 250 MW produced by dedicated forest biomass power plants, based on the addition of a further 150 MW from public interest projects. However, only two tenders were completed, with the

failure of the remainder due to various factors such as poor location, the high costs of the raw material, problems with the supply, logistics and availability of the raw material, the bureaucracy of the tendering procedures, and more recently, a lack of financing from banks. Between 2007 and 2009, five new power stations were established with a combined power of 78 MW, meaning that the total power produced from forest biomass is now more than 100 MW, still far from the original goal of 250 MW [38].

Tables 3, 4, 5 and 6 show the current status of the tenders for the construction of dedicated biomass power plants in Portugal between 2006 and 2015.

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The selection of biomass combustion technology is determined mainly by the characteristics of the fuel, environmental legislation, site location, costs, availability and performance of the necessary equipment, as well as the desired energy production (heat, electricity) [39]. Combustion technologies should be designed specifically for each type of biomass, depending on its characteristics [40].

The combustion of biomass in a fluidised bed is recognised as the most appropriate method for electricity production due to its technical characteristics, including the ability to burn fuels with higher ash and moisture contents, flexibility regarding fuel properties such as shape and size [41], as well as high efficiency and lower emissions of pollutants [42].

Fluidised bed systems contain a vertical combustion chamber, with a bed of inert material at its base. This material can be sand, limestone or dolomite and acts as a means of heat transfer. Primary air is injected via ventilators into the combustion chamber in an upward direction through a perforated bottom plate. This primary air fluidises the sand, resulting in a bed with the characteristics of a fluid, to which fuel is then added. A portion of the fuel is burned in the bed and the other part is burned in suspension above the bed, where secondary air is typically added. Under optimal operating conditions, this type of system enables complete combustion without excess air, since the mixture of air and fuel is very efficient and thus reduces the existence of unburnt material [43].

Two types of fluidised bed can be distinguished based on the speed of fluidisation: the bubbling fluidized bed (BFB) and the circulating fluidised bed (CLB) [44], with the former most common in Portugal [45]. Several authors have argued that the BFB system is more suitable for biomass due to the variation in moisture, low speed of fluidisation and high residence time of inert particles, which together provide the appropriate conditions for combustion [46].

4. Elements present in biomass and their impact on combustion

C, H and O are considered the main elements of any solid biofuel and have a direct influence on the calorific value. During combustion C and H are oxidised through exothermal reactions, forming CO₂ and H₂O and releasing its energy content [47]. On a dry basis, typical content values for C are 30-60%, for H 5-6% and for O 30-45% [48].

It is also important to assess the content of ash and inorganic material in biomass in order to ensure their adequacy for each combustion process and to prevent any operational or environmental problems. Forest biomass with a high ash or inorganic matter content may reveal a tendency toward fouling, corrosion, slagging and agglomeration on heat transfer surfaces or grates [49].

Fouling is associated with the accumulation of deposits in the walls of the heat transfer equipment, leading to a decrease in the efficiency of heat exchange [50]. Slagging and agglomeration of ash is characterised by the presence of deposits on the walls of the combustion chamber in which heat transfer via radiation is dominant. These deposits are formed due to the low melting temperatures of the ash constituents and the presence of sand [51]. Corrosion is the deterioration of the walls of the equipment and is caused by the interaction between the corrosive elements and the metal surfaces of the heat exchangers. The occurrence of any of these problems affects the proper functioning of combustion systems, reducing the time of life of the equipment and increasing maintenance costs [52]. Ash agglomeration depends on the ambient temperatures used in combustion systems and can be mitigated by using low combustion temperatures. However, such an approach can decrease the efficiency of combustion [53].

It is essential to have a low Na and K content in order to reduce the occurrence of slagging during combustion. Problems can also occur with an increase in combustion temperature, such as physical changes in ash that may provoke its complete fusion. This particular problem occurs when the ash melting

temperature is very low. Normally, woody biomass has an ash melting temperature of around 1200-1400°C, but that of some biomass types such as cereal straw is around 700-1100°C [54].

The alkali metals present in biomass are mainly associated with organic matter or occur as soluble salts. These are easily freed for the gas phase of the combustion process, forming aerosols or deposits, and can also react with the bottom ashes that contain silicates, thus favouring the formation of low melting temperature ash that constitutes the slag [55]. Mg and Ca in particular can form silicates that increase the melting temperature of ash. The reactive part of a fuel comprises mainly Na, K, Mg and Ca, but also Cl and S; Si, Al and Fe do not have very reactive properties [56]. Problems associated with fouling and corrosion can in part be avoided if the amount of alkaline compounds that are volatilised is decreased [57].

Cl, which is an important element in the formation of ash and is found in certain types of biomass, is mostly accumulated in fly ash (40-95%) or in the form of HCl [58]. Cl in the presence of alkali metals may also form salts such as KCl or NaCl and may be deposited on the walls of heat exchangers, causing corrosion of metal parts inside the boiler [59]. The reaction of Cl with alkali metals can also significantly reduce the ash melting point, causing its adhesion to surfaces and potentially the corrosion of the combustion equipment [60].

Although SiO₂ has an extremely high melting point (1700°C), in the presence of K it may form alkali silicates with a very low melting point (approximately 750°C) [61] and may form deposits on the equipment walls [62]. Concentrations of K are usually higher than 1% of biomass dry weight, with a large part being vaporised during combustion [63]. The presence of Si in the bottom ash in the fluidised bed systems is typically related to the use of SiO₂ sand in the bed, but also may be derived from tree bark. Higher levels may also be found in the bottom and fly ash of systems using forest biomass with a relatively high inert material content, mainly due its simultaneous collection with soil [64].

The combined presence of high concentrations of Na, K, Si and Ca can lead to the formation of eutectic compounds that contribute to the reduction of the ash melting point. Furthermore, the interaction of alkali metals in the presence of other elements can result in deposition on the walls of heat exchangers, causing corrosion and decreasing the efficiency of combustion [65].

Fly ashes are generally richer than bottom ash in elements inherent to the inorganic composition of biomass, such as Na, K, Ca, Mg, P, S and Cl, and may also be enriched in heavy metals either derived from the original biomass or introduced as contaminants [66].

N content may vary between 0.1-12%, S between 0.01-2.3% and Cl between 0.01-0.9% (BS) [67], although all three elements are generally found in quantities lower than 1%. In the case of N, the content of this element in woody biofuels is relatively low and thus does not have much impact on the formation of NO_x [67].

Both S and Cl play a role in equipment corrosion and the emission of atmospheric pollutants. Due to the high temperatures present in the system, elements such as S and Cl volatilise during combustion, forming salt particles due to condensation [68]. Although the influence of S is largely related to the formation of SO_2 emissions, a part remains in the ash in the form of sulphates (40-90%). A high Cl content is strongly associated with the emission of HCl, polychlorinated dibenzodioxins and polychlorinated dibenzofurans, implying the need to adopt special mitigation measures for the use of such a fuel [69].

A number of studies have demonstrated that problems associated with agglomeration, slagging, fouling and corrosion can be aggravated in the presence of P found in biomass [70], typically in the form of salts, together with higher levels of Na and lower levels of K and Ca [71]. However, further studies are required in order to identify which mechanisms contribute to the release of P during combustion, the reactions occurring between P and other ash elements, as well as the melting behaviour of P compounds [72].

Fe exists in low quantities in the majority of biomass forms, despite being an essential nutrient for plants, as is Mg. In most cases these two elements thus have little relevance in biomass-derived ash deposits [73].

5. Pollutants produced from biomass combustion

Biomass combustion can be divided into several steps whose importance varies depending on several factors, including the combustion technology implemented, fuel type and the conditions of the combustion process [74].

The main products of biomass combustion are H₂O and CO₂, combustion air and excess O₂. However, other compounds can also be formed depending on the constitution of the fuel and the conditions of combustion. Some of these compounds are air pollutants and contribute to the greenhouse effect, acid rain and other environmentally damaging processes. In addition to the compounds identified above, inorganic species present in the biomass can form ash that accumulates in the system or is released as airborne particles [75].

The more worrying impurities present in biomass include N, S, Cl, Na and K, which form pollutant emissions. Depending on the conditions of combustion, N present in the fuel can be oxidised to NO and NO₂ or N₂, while NO_x can also be formed from the N₂ present in the combustion air if both system temperature and excess of air are high. The S present in the fuel may form SO₂ or SO₃. Cl may be released as HCl, but can also contribute to the formation of chlorinated dibenzodioxins and polychlorinated dibenzofurans. Na, K, Ca and Mg may react with Cl or S, leading to the formation of deposits or aerosols containing chlorides and sulphates. Other pollutants may result from incomplete combustion, including CO, CH₄, volatile organic compounds, polycyclic aromatic hydrocarbons, particulates, NH₃, O₃ and several heavy metals in the form of aerosols or particles. Many of these pollutants are the result of occurrence of low temperatures during combustion or improper operation of the combustion system itself [76]. In Portugal, some of these pollutants are subject to regulation, with emission limits outlined in Decree-Law no. 102/2010.

As different pollutants are released during the various stages of the combustion process, it is possible to adjust process-operating conditions to optimise the combustion of biomass and thus minimise the production of unwanted pollutants [77]. However, highly efficient control of combustion conditions is required in order to prevent such emissions. For example, when using temperatures lower than 800°C, incomplete combustion may occur, producing C_xH_y compounds. If the moisture content of the fuel is higher than 50% and the combustion air is not preheated, problems may arise in terms of combustion temperature stability and combustion efficiency. The size of the fuel particles also influences the efficiency of combustion, as it is essential to have a good mix between the fuel and combustion air [78].

Nitrogen oxides are formed from the N₂ combustion gas at temperatures above 1400°C. However, as biomass combustion system temperature typically varies between 900°C and 1200°C, such systems

produce only small quantities of NO_x. As NO_x production is also sensitive to excess air, it is also possible to control the latter and thus minimise the production of NO_x [79].

Rather than taking measures for the reduction of pollutant emissions post-production, systems are often installed aimed at the removal of NO_x, SO_x and HCl from the combustion gases. The most common systems used for removal of dust are bag filters, electrostatic precipitators, scrubbers, and mechanical separators such as cyclones [80].

6. Conclusions

The presence of inorganic contaminants fundamentally depends on the origin of biomass and may have biological or detritic origin, being influenced by the environment where biomass forms were grown. Depending on several variables, such as physiological, morphological, genetic and environmental variables, the content of inorganic compounds can vary widely, and with the content of ash resulting from the combustion of different forms of biomass. Inorganic contaminants of biological origin depend of several conditions such as the amount and the location of the parts of the plant, seasonal variations and the vegetative cycle of plants. The inorganic part of a plant, expressed on a dry basis, may range between 0.1-30%, depending on several factors such as the composition of the soil where the plant has been developed, the type, age and which part of the plant was examined. The elements K, Ca, Mg, P, N are considered macronutrients to plants, and the elements Fe, Mn, Cl, Zn are micronutrients. These elements can be transported and incorporated by biochemical processes and are fixed as precipitated inorganic salts, incorporated into the organic tissue in the sap accumulated inside the cells. The Si can be a part of the structure of some plants, as in the straw and corn husks. Soil is comprised of sand, clay and silt, and when incorporated into biomass contributes to the presence of inorganic compounds, generating a large volume of ash. On the other hand, the most exposed parts of trees such as bark and leaves have a tendency to accumulate larger amounts of soil and dust, so these parts normally have higher ash content than those obtained by the combustion of only the interior of the plant parts. Contamination of forest biomass can also occur due to the influence of emissions associated with contiguous industrial environments. Biomass forest contain few components that can cause environmental problems such as S, N and Cl, which generally are in low concentrations, but can accumulated pollutants contained in the

atmosphere, and when burnt generate more pollutants such as SO_x, NO_x, HCl and particles, contributing to the formation of acid rain and aerosols.

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Tables

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 |

Table 2. Monthly production of energy from biomass.

| Monthly production (GWh) | | | | | | | | | | | |
|--------------------------|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|
| 2014 | | | | | | 2015 | | | | | |
| Aug | Set | Dec | Nov | Ten | Jan | Feb | Sea | Apr | Mai | Jun | Jul |
| 221 | 211 | 215 | 204 | 216 | 202 | 182 | 201 | 182 | 205 | 200 | 205 |

Table 3. Implemented projects currently out of tender and in operation.

| Entity | Location | Power (kW) | Biomass consumption (t/y) | Status |
|---------------------------|---------------------|---------------|------------------------------|--------------|
| EDP Produção Bioelétrica | Mortágua | 7400 | 115000 | In operation |
| Centroliva | Rodão | 6000 | 60748 | In operation |
| Central Biomassa TS Maria | Oliveira de Azeméis | 10044 | 121500 | In operation |
| Rodão Power | Rodão | 13232 | 140000 | In operation |
| EDP Produção Bioelétrica | Constância | 13020 | 140000 | In operation |
| SPCG | Setúbal | 12090 | 146000 | In operation |
| Enerplus | Aveiro | 12500 | 146000 | In operation |
| EDP Produção Bioelétrica | Figueira da Foz | 27900 | 400000 | In operation |

Table 4. Projects offered under tender in 2006.

| Entity | Location | Power (kW) | Biomass consumption (t/y) | Status |
|----------------------|-----------------|-----------------------|--------------------------------------|-------------------------|
| Probiomass | Valpaços | 11000 | 133645 | Adjudicated 2008 |
| MIESE | Braga | 10000 | 121500 | Adjudicated 2010 |
| PA Termoflorestal | Monção | 4650 | 61000 | Establishment licensing |
| Ecotator | Belmonte | 1920 | 24300 | In operation |
| MIESE | Alijó | 11000 | 133645 | Adjudicated 2009 |
| SIAF | Mangualde | 10000 | 121500 | Not adjudicated |
| Biobeiraner | Viseu | 5000 | 61000 | In project |
| Palser | Sertã | 4000 | 36500 | In operation |
| Enerwood Covilhã | Fundão | 10000 | 121500 | Adjudicated 2009 |
| Centro+Bioenergia | Sertã | 10000 | 121500 | Adjudicated 2010 |
| Enerwood | Portalegre | 10000 | 121500 | Adjudicated 2009 |
| Tecneira + Forestech | Rio Maior | 6000 | 73000 | Adjudicated 2009 |
| Tecneira + Forestech | Odemira | 3000 | 36500 | Adjudicated 2009 |

Table 5. Projects under licensing (extra tender of 2006).

| Entity | Location | Power (kW) | Biomass consumption (t/y) | Status |
|--------------------------|---------------------|-----------------------|--------------------------------------|---------------|
| EDP Produção Bioelétrica | Gondomar | 13050 | 175500 | Licensed |
| EDP Produção Bioelétrica | Mortágua | 10000 | 243000 | Licensed |
| EDP Produção Bioelétrica | Cabeceiras de Basto | 10120 | 133645 | Licensed |
| EDP Bioelétrica/Pinorval | Oleiros | 9300 | 121000 | Licensed |
| EDP Produção Bioelétrica | Monchique | 14650 | 189800 | Licensed |
| Forestech | Alcácer do Sal | 1200 | 12150 | Licensed |
| Isohidra | Anadia | 5000 | 121500 | Licensed |
| Triquímica | Sintra | 960 | 12150 | Licensed |

Table 6. Cogeneration projects.

| Entity | Location | Power (kW) | Biomass consumption (t/y) | Status |
|---------------|-----------------|-----------------------|--------------------------------------|---------------|
| Portucel | Viana | 8000 | 97500 | In operation |
| Enerpulp | Cacia | 6000 | 110370 | In operation |
| Enerpulp | Figueira da Foz | 15000 | 219960 | In operation |
| Enerpulp | Setúbal | 12000 | 168480 | In operation |
| Caima | Constância | 4000 | 54600 | In Operation |
| Celtejo | Rodão | - | - | In operation |
| Sonae | - | 5000 | 65000 | In operation |