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Coal to Biomass Conversion as a Path to Sustainability: A Hypothetical Scenario at Pego Power Plant (Abrantes, Portugal)

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Abstract: Energy consumption is associated with economic growth, but it comes with a toll regarding the environment. Renewable energies can be considered substitutes for fossil fuels and may contribute to reducing the environmental degradation that the world is presently facing. With this research, we aimed to offer a broader view of the state-of-the-art in this field, particularly regarding coal and biomass. The main objective is to present a viable and sustainable solution for the coal power plants still in operation, using as a hypothetical example the Pego Power Plant, the last operating coal fueled power plant in Portugal. After the characterization of land use and energy production in Portugal, and more particularly in the Médio Tejo region, where the power plant is located, the availability of biomass was assessed and it was concluded that the volume of biomass needed to keep the Pego power plant working exclusively with biomass is much lower than the yearly growth volume of biomass in the region, which means that this transition would be viable in a sustainable way. This path is aligned with policies to fight climate change, since the use of biomass for energy is characterized by low levels of GHGs emissions when compared to coal. The risk of rural fires would be reduced, and the economic and social impact for this region would be positive.

Keywords: biomass energy; biomass waste; coal power plant; coal to biomass conversion; decarbonization

1. Introduction

Energy is very important for the growth of any organization and country, as the majority of the actions carried out involve energy consumption, whether renewable or fossil [1]. Thus, since energy consumption is associated with economic growth, renewable energies are substitutes for fossil fuels, and may contribute to reducing the environmental degradation that the world is presently facing [2]. According to Baz et al. (2021), the increasing consumption of polluting energies is generating situations that are difficult to solve, and that are directly causing health and environmental problems [3]. Over the years, several studies tried to understand the relationship between energy consumption and economic growth. Some examples can be found in the works presented by Shaari et al. (2013), Park and Yoo (2014), or even by Žiković and Vlahinic-Dizdarević (2011) [4–6]. Unfortunately, as stated by Antonakakis et al. (2017), the consumption of fossil fuels has been the major key driver for the global economic growth [7]. However, the high



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). importance of renewable sources for mitigating climate change led several authors to research how their use can positively impact economic growth [8–11].

Currently, private companies and governments try intensively to promote renewable energies [12–15]. In developed countries there is already an installed capacity regarding renewable energy production, as well as governmental policies to promote the use of these kinds of energy sources [3,16]. In addition to local and regional policies, international environmental agreements relying on the cooperation between states increased, intensifying the idea that climate change is a transboundary subject [17,18]. Most of the actions taken by the rulers of states focused on the total or partial replacement of fossil fuels by renewable energies, where some emphasis is given to biomass [19–21]. This natural resource was shown to be effective at an environmental and economic level through different processes such as cofiring with coal, which is seen as one of the most polluting fossil resources [22–25]. In the United Kingdom, for example, the use of biomass for electricity generation was driven by the introduction of Renewable Bonds Certificates with the objective of increasing the use of cleaner energy sources [26].

Europe has been quite vulnerable regarding climate change [27]. Inclusively, several initiatives have been launched to promote mitigation practices, such as the European Adaptation Strategy and the Mayors Pact for Climate and Energy [28]. The European Adaptation Strategy, launched in 2013, aimed to create solutions to tackle the problem of climate change, as well as to mitigate its consequences [29,30]. Europe intensified the urgency to act [31]. The Mayors Pact for Climate and Energy, launched in 2015, aimed to voluntarily bring together the efforts of local and regional authorities to achieve the objectives defined by the European Union to mitigate climate change [32]. The Kyoto Protocol is an international agreement affiliated with the United Nations Framework Convention on Climate Change (UNFCCC) adopted in 1997 and effective since 2000 [33]. This protocol aims to mitigate greenhouse gases (GHGs) emissions [34], contemplating three mechanisms based on the market that allow a more effective performance: International emissions trading, clean development mechanisms and joint implementation [35]. A study carried out by Kim et al. (2020) concluded that the protocol has positive effects on the environment through reductions in CO_2 emissions, but has a negative effect on the economy, showing that there is a trade-off between reducing carbon emissions and economic growth [34]. From this perspective, several different approaches were taken. For example, Ingrao et al. (2021) studied the use of life-cycle assessment in systems that produce materials and energy from agricultural residues, such as wheat straw (WS) in the context of a circular bio-based economy [36]. This approach and the introduction of the concept of circular economy fits with the objectives and goals presented by the Kyoto Protocol, and can be seen as an alternative path to counterbalance the negative effect that the decarbonization of the economy may have.

Portugal ratified the Kyoto Protocol and is part of UNFCCC and improved its policies regarding environment protection. According to Carvalho et al. (2014), "Portugal was the first country in southern Europe to develop and publish an integrated assessment of vulnerabilities, impacts and adaptation to climate change in 2002" [37]. Since Portugal was not a very industrialized country comparatively to others, it has a low contribution to GHGs emissions. However, the effects of climate change are also felt in Portugal and, therefore, national policies are crucial, namely the National Strategy for Climate Change approved in 2001, which has three main instruments: The National Program for Climate Change, the National Plan for the Allocation of Emission Licenses and the Portuguese Carbon Fund [37]. In the same work, Carvalho et al. (2014), stated that the renovation of measures did not become as effective as expected, once the National Plan for the Allocation of Emission Licenses provided licenses to industries with CO₂ emission limits, and in practice it was not a solution since it gave companies the opportunity to negotiate with each other and maintain their emissions [37]. The creation of the Portuguese Carbon Fund aimed to align Portugal with the goals defined in the Kyoto Protocol [38,39]. Portugal is a country that has been maintaining its position internationally regarding the decarbonization of the

economy [40]. Portugal is considered by some authors, such as Amorim et al. (2014), as a country with high economic opportunities due to its proximity to Spain, which can be beneficial in terms of cost–benefits to achieve the decarbonization of the electricity sector [41]. Like other European countries, Portugal has committed to achieve its carbon neutrality by 2050, with 0% GHGs emissions [42]. This goal is in accordance with the Paris Agreement, where Portugal is engaged in order to contribute to maintain the increase of global temperature below 1.5 °C [43].

Several studies carried out regarding Portuguese actions to fight climate change resulted in different conclusions. One of the evidences is that the increase in marginal costs in relation to the implementation of national policies is a reality [44]. On the one hand, Pereira and Pereira (2010) stated that reducing CO_2 emissions did not compromise economic activity [45]. On the other hand, the authors suggested that with the reduction of CO_2 , Portugal might be able to obtain economic benefits from the use of natural gas and biomass, as well as the use of electricity in the transports sector [45].

The scope of this research is aimed at offering a broader view of the state-of-the-art in this field, particularly regarding coal and biomass, so as to understand their characteristics and contribution to environmental problems. Taking the literature review into account, coal is one of the most important fossil fuels for energy production, contradicting the European target of decarbonization by 2050. Considering the availability of biomass that Portugal presents, the main objective of this article is to present a viable and sustainable solution to end-of-life coal power plants, using as a case study the Pego Coal Power Plant, which is currently in operation until the end of the current year. The limitations and possibilities for a hypothetical scenario that substitutes coal with biomass are analyzed, both in economic and social terms. Considering that the Portuguese government declared the closure of Portuguese coal power plants (Sines closed in 2020 and Pego will close by the end of 2021), the hypothetical solution analyzed in this study would prevent the closure of the power plant while also reducing the GHGs emissions, thus contributing to the mitigation of climate change, while contributing to reducing the risk of occurrence of rural fires due to the use of waste biomass, and to maintaining social and economic stability in the region.

2. State-of-the-Art

2.1. Coal

Coal is one of the most important primary fossil fuels and is the major source of solid fuel in the world [46]. It covers almost 30% of the global primary energy demand [47], and its role shifted along human history, from a fuel used extensively in all sectors of the economy to one that is now used primarily for electricity generation and in a few key industrial sectors [48]. In the past few decades the concern regarding the environmental impacts of fossil fuels gained the attention of scientists, rulers, global leaders, policymakers, intergovernmental organizations, and other stakeholders [49]. Climate change is at the center of this discussion. The removal of coal from the global energy mix became a priority, since governments seek to reduce GHGs and restrict the development of coal mines, power plants, and associated infrastructure [50]. In fact, after the Paris Agreement on Climate Change, signed in 2015, coal remained under unprecedented scrutiny [51].

Coal become a major target regarding climate change mitigation due to its high emissions of CO₂ per thermal energy unit produced [52]. Besides that, coal emits health-damaging air pollution [47]. In fact, each phase of the coal life cycle has direct and indirect impacts on air, water, soil, ecosystems, and animal and human health [53]. According to Dai et al. (2017), the coal mining phase is characterized by the damage of key ecological factors, such as water, soil and atmosphere, while the coal processing phase is characterized by discharging waste effluents [54]. In the coal conversion phase, the main characteristics are greenhouse effect aggravation and atmospheric ecosystem destruction [55]. The transportation and disposal phases must be considered as well [56].

The cascading effect that most of these impacts have facilitates additional threats and potentially amplifies the consequences [57]. The combination of these impacts with

growing global population and energy demands poses serious consequences to ecosystems and human health [49]. Burke and Fishel (2020) proposed the Coal Elimination Treaty, or CET, to be applied by 2030 as a global supply-side mechanism, and as a way of empowering climate-vulnerable and high-ambition states [58]. The authors argue that "one proposal, treaty, agreement, or policy will not be sufficient to address the global issue of carbon emissions from fossil fuels; and multisector and multilevel level actions must be undertaken immediately to have the chance to arrest average global heating at 1.5 °C" [58].

Recently, 15 European countries announced their intentions to phase out coal, while Austria, Belgium, and Sweden are coal-free already [59,60]. Several other countries have committed to phase out coal, including Portugal (by the end of 2021) [61,62]. Different reasons were presented for this action, which is, to a large extent, irreversible [63]. Undoubtedly, coal has been fundamental regarding human progress, and it has transformed society. However, the impacts from long-term use of fossil fuels, in particular coal, on the environment and on human health, including environmental pollution, anthropogenic climate change, and decreasing resources, are significant [49]. Perhaps the most compelling reason for this trend is the relativeness of fuel costs, as those of alternative fuels (e.g., natural gas, wind energy, and solar power) for generating electricity have fallen drastically, rendering coal in many regions uneconomic, depending to a large extent on their energy mixture and production capacity [49,64]. Despite this situation, for emerging markets, coal is still an important source of energy, and many developing economies, as well as some developed ones, are at a crossroads with their energy, climate, and economic strategies [65]. The future of coal looks bleak considering that coal power is also facing strict and costly regulations of air pollutants in major coal burning countries [47].

2.2. Biomass

It is widely accepted that humans started using fire, in a controlled and generalized way, 300,000 years ago [66]. Wood and other organic alternative materials fueled the earliest camp fires and this skill transformed humans, societies, and cultures [67]. Only relatively recently, fossil fuels started replacing biomass as an energy source, with a major impact in the creation and advancement of industrial civilizations, and the development of modern technologies [49]. The environmental concerns led to a renewed interest in the use of biomass for power generation, mostly due to the decline of fossil fuel reserves and the ever-increasing greenhouse effects produced through fossil fuel utilization [46,68].

Biomass to energy (bioenergy) is one of the main sources of renewable energy in the EU, with a share of almost 60% [69]. Biomass is considered to be carbon neutral, as the CO₂ released during combustion or other conversion processes will be re-captured by the regrowth of the biomass through photosynthesis and because it is part of the current carbon cycle, in opposition to coal carbon, which was captured millions of years ago, in a completely different geological time, where the atmosphere had a different composition [70,71]. The demand for biomass in the EU and worldwide is increasing, both in the heating and in the power sector [72]. Forest biomass (trees, including trunk, bark, branches, needles, leaves, roots) is the main source of biomass not competing with food supply in Europe [73]. The high demand for forest biomass as a material and energy resource led to a competition between industries and the need to improve circularity/resource efficiency [74]. Natural regrowth forests, plantation forestry, annual field crop production, algae production, or residues of any of the above are sources for biomass, and it can also be derived from industrial processes, municipal waste, or land clearing operations [75]. Biomass is a stored source of solar energy in the form of chemical energy, which can be released when the chemical bonds between adjacent oxygen, carbon, and hydrogen are broken via various biological and thermochemical processes [70].

Biomass can be considered as a promising alternative to fossil fuel resources and can deliver energy and multiple products, such as many different green chemicals [76]. It must be produced, processed, and used in a sustainable and efficient way in order to minimize greenhouse gas emissions and maintain ecosystems, without causing deforestation or

degradation of habitats or loss of biodiversity [77]. There were several reasons for not fueling large-scale power plants with biomass instead of fossil fuels [78]. Comparatively to fossil fuels, biomass fuels have relatively low heating values, which can be explained by two of their distinct characteristics: high moisture and high oxygen contents [70]. Common forms of biomass energy include wood pellets, wood chips, torrefied biomass pellets, and charcoal [79].

In comparison to fossil fuels, biomass has much higher volatile matter content (80% in biomass vs. 20% in fossil fuels), and the high volatility may be considered as a positive property (high reactivity) if the combustion technology is adjusted/optimized for these fuels [80,81]. To generate heat and electricity, biomass can be combusted directly (the most used process—approximately 97% of bioenergy produced in the world), and by thermochemical and biochemical processes it can be converted into biofuels in the forms of solid (e.g., charcoal), liquid (e.g., bio-oils, methanol or ethanol), and gas (e.g., methane and hydrogen), which can be used further for heat and power generation [82]. Thermochemical processes include different processes: combustion, pyrolysis, gasification, and liquefaction for bioenergy production [83]. Some advanced thermochemical processes include co-firing/co-combustion of biomass with coal or natural gas, fast pyrolysis, plasma gasification and supercritical water gasification [70].

Despite being a renewable resource, biomass is limited [84]. Harvestable potential from the agricultural, forestry, and industry sectors (i.e., excluding energy crops) is estimated to be around 50 EJ globally, which corresponds to only about 10 to 15% of the current primary energy global supply, and, furthermore, biomass production has many purposes that may compete with energy uses [85].

2.3. The Logistic Problem

The uncertainties of supply-side externalities (e.g., collection and logistics) represent the key challenges in bioenergy supply chains and lead to a reduction in cross-cutting sustainability benefits [86]. Regarding the logistics problem, large volumes with low density must be moved from largely spread production and collection sites to centralized processing facilities, then delivered in their final form to consumers [87]. In fact, the cost and environmental impact of road transportation of large quantities of biomass are considerable [88]. All of the economic, environmental, and social aspects of a biomassbased supply chain must be considered in order to truly understand the sustainability performance of biomass as a bioenergy resource [86].

2.4. Biomass as an Alternative to Coal

Due to environmental problems, there is a need to cut down on the use of fossil fuels [89]. Therefore, it is of interest to investigate the feasibility of replacing coal with less carbon-intensive alternatives such as biomass [90]. There are significant challenges that must be overcome when switching from coal to using biomass as fuel [91]. The main problems are related to the formation of corrosive melts that are deposited on boiler surfaces [92]. As stated by Bolyos et al. (2003), "the deposits greatly reduce heat transfer in the furnace and corrode heat transfer surfaces. In addition, volatile metal chlorides are often formed, resulting in deposition on surfaces, with subsequent Cl-induced corrosion" [88]. A total of 35.4 gigawatts (GW) of coal power capacity is installed in countries that have announced they will phase out coal by 2030 or earlier, putting the coal plants in these countries on a pathway to closure [93–95]. There are two possible uses for biomass and waste in the power industry: biofuels can either be burnt as single fuels in combined heat and power plants of limited capacity, or they can be co-used in existing coal fired power plants, contributing this way to a net reduction in CO_2 emissions [48,96].

Cofiring biomass and coal (directly by burning biomass and coal, or indirectly by gasifying biomass first to produce clean fuel gas that is then burnt with coal) proved to be a cost-effective technology used to achieve the goal of increasing the use of biomass-to-energy processes for power generation, thereby significantly reducing greenhouse gas

emissions [70]. Some authors argue that cofiring biomass and coal has technical, economic, and environmental advantages over the other options, as stated by Demirbaş (2003), appointing as one of the main advantages the fact that the plant would always have the primary fuel, coal, for 100% utilization, if the supply of biomass is abruptly interrupted [48].

3. National Framework

3.1. Characterization of Land Use in Portugal

Portugal is located in the southwestern-most part of Europe, between $36^{\circ}58'$ N and $42^{\circ}9'$ N and $6^{\circ}12'$ W and $9^{\circ}30'$ W, with a total area of 92,225 km². Forest, bushes, and pasture and agricultural areas are the major land use types that can be found in Portugal, according to the most recent data available from the IFN6 and the COS 2015, as presented in Figure 1.



Figure 1. Distribution of land use in Portugal (adapted from the IFN6 report, available at www.icnf.pt, accessed on 30 June 2021).

In 2015 the landcover in Portugal consisted of 3305 million hectares (Mha) of forest, 2240.8 Mha of agriculture, and 2818.1 Mha of bushes and pasture land. Water, urban areas, and unproductive land accounted for the remaining 858.6 Mha [97]. The forest land area of 35.8% places Portugal close to the average of the 28 EU countries (38.3%) [98]. According to the 6° Inventário Florestal Nacional (IFN6), the national forest is mostly constituted by indigenous forest species (72%), although some occupy territories larger than their geographical origin. In structural, functional, and landscape terms, the forest can be organized into four major groups, or forest formations: Pine forests (comprised of maritime pine and stone pine stands); evergreen hardwood forests (traditional Mediterranean cork oak and holm oak forests); deciduous hardwood forests (oaks, chestnut, and others); and industrial productive hardwood forests (eucalyptus) [99].

The climate conditionings mark the vegetation in Portugal [100]. In the South and the East, and even in the sheltered valleys and low-lying lands species can be found that demand heat and dry conditions. Among the most important Mediterranean species, the following stand out for their green and perennial foliage: *Quercus suber*, *Quercus rotundifolia*, *Pinus pinea*, and *Pinus pinaster*. In regions of Atlantic influence deciduous species can be found, such as *Quercus robur*, *Quercus pyrenaica*, *Quercus faginea*, and *Castanea sativa*, as presented in Figure 2 [101].

3.2. Characterization of Energy Production in Portugal

In the recent years the energy consumption in Portugal increased, with consequences to the environment and public health, making the concept of sustainability more important than ever [102]. It can be observed in Figure 3 that in 2020 and 2021, the most used resources in the production of electricity in Portugal were hydropower, wind power and natural gas.



Figure 2. Forestry areas by groups of species (adapted from the IFN6 report, available at www.icnf.pt, accessed on 30 June 2021).



Figure 3. Evolution of electricity production by source in Portugal in 2021 (data collected from the APREN website, available at www.apren.pt, accessed on 30 June 2021).

Portugal has 2200–3000 h of sun per year, being an optimal candidate for the production of solar energy [103]. However, through the observation of the graphic presented in Figure 3, it appears that between 2020 and 2021, the use of solar energy was not significant yet [104]. Wind energy also has a high weight in Portugal, especially in the autumn and winter months of each year, as this is when the winds are felt with highest intensity [105]. Most wind farms are located in mountainous areas in order to take full advantages of this resource [106]. Even so, coastal areas also show a potential to increase energy production; however, the high population density in coastal areas is a barrier and that is why offshore production is now being tested, as can be seen in the example presented in Figure 4 [107].

The Portuguese energy sector is preparing to end the use of coal so as to be able to reach the climate goals defined in the Paris agreement by 2050 [108]. In Figure 5 can be seen how the imports of two of the main fuels used in electricity production evolved over the past two decades.

In fact, it is well known that Portugal is a country that is very dependent on external resources [109]. It is evident that coal imports are reducing, with a large fall in the most recent years, which is directly related to the expected closure of the two main coal fueled power plants, Sines and Pego. However, it is possible to confirm an expected increment

in the imports of natural gas, supposedly to support the substitution of the electricity produced with coal, which shows that the implementation of policies and guidelines to fight climate change are starting to have an impact.



Figure 4. WindFloat Atlantic has a total installed capacity of 25 MW and generates enough energy to supply the equivalent of 60,000 users per year. It is located 20 km from Viana do Castelo and will avoid the emission of 1.1 million tons of CO₂ per year.



Figure 5. Coal and natural gas imports during the past two decades (data collected from the APREN website, available at www.dgeg.pt, accessed on 30 June 2021).

Until the 21st century there was a large consumption of coal by the Portuguese industry; however, the sector has increasingly dropped the intensive use of this resource, which was mostly used to produce electricity, as presented in Figure 6.

Globally, energy production from coal decreased worldwide by approximately 3% in 2019. In general, and according to data from the IEA (International Energy Agency), energy generation from coal is expected to fall by 5.3% per year in order to achieve the targets set for 2030 and 2050 [110]. If the situation of Portugal over time is analyzed, it can be seen in Figure 7 that before the 21st century there was an increase in the energy produced, accentuating the dependency of the country on the energy imports.





Figure 6. Coal consumption in Portugal (for electric energy production and industry) (data collected from DGEG, available at www.dgeg.pt, accessed on 30 June 2021).



Figure 7. Electricity production in Portugal (data collected from the PORDATA platform, available at www.pordata.pt, accessed on 30 June 2021).

4. The Portuguese Situation: Decarbonization and the Pego Power Plant

If the European countries are considered, there are different types of biomass that can be used as energy sources in power production: (a) Surplus and by-products from

agricultural activities; (b) fast-growing energy crops from reutilization of areas that become available due to a necessary reduction of agricultural overproduction within Europe; and (c) wood waste from forestry or wood processing [96]. The transportation of biomass raises many questions, particularly if it is sustainable to transport biomass over long distances. According to McIlveen-Wright et al. (2013), the carbon emitted during transportation, in grammes of carbon per ton of biomass per kilometer, would be 1.45 for sea transport and 31.7 for road transport [111].

According to a study conducted by Wang et al. (2015), in northeast China, the external cost of coal-fired power generation is as much as 90% of the current price of electricity generated by coal, while the external cost of a biomass power plant is 1/1000 of the current price of electricity generated by biomass [112]. In addition, for a biomass power plant, the external costs associated with SO₂, NO_x, and PM_{2.5} are particularly lower than those of a coal-fired power plant [113]. An exclusive biomass utilization for energy production would lead to the construction of many decentralized plants, which is time-consuming and would require high financial investments as well as large storage capacities due to the seasonal fuel availability [114]. If the biomass used as fuel is indigenous, it provides local employment and a boost to the rural economy [111]. Additionally, if all the jobs that would be lost from the closure of the coal power plants are considered, this substitution could have a major positive impact in local economies [115]. The use of biomass as an alternative in coal-fueled power plants can be achieved through the use of biomass waste forms, but this implies that the biomass has a set of characteristics similar to those of coal, in order to use the previously installed systems [116].

To transform a coal power plant, not only the technical problems must be assessed, but also the environmental impact. If the objective is to use imported biomass, or biomass from deforestation areas, these external costs must be considered. In this sense, the use of local biomass waste should be highly considered. The transition from coal to biomass in preexisting power plants is not a global solution that should be put in place anywhere, because the biomass resources are often limited. In this regard, the case of the Pego coal power station will be studied, which is located on the left bank of the Tagus River, in the parishes of Pego and Concavada, which are part of the municipality of Abrantes, Portugal. The high amount of biomass resources of this region calls for a transition from coal towards biomass.

Over the last years there has been an increasing concern regarding the decarbonization of the economy worldwide, not only because of climate change effects but also due to environmental targets that have been established [117]. The large majority of the electricity produced relies on fossil fuels, which generate problems like resource scarcity and pollution that over time contribute to climate change [118]. These negative changes are reflected not only in the environment, but also in the wellbeing of humans and in the economy (e.g., inequality of distribution of fossil fuels between countries and regions which brings high cost for importers) [119]. Coal is the main resource used in electricity generation in Europe, being a major contributor to the greenhouse gases emissions [120]. Society has several needs that depend upon the production of electricity, making this sector highly relevant to economic development [121]. Worldwide, the energy demand increased by more than 50% between 1973 and 2015, with 83% being produced from fossil fuels [122]. The energy sector is responsible for more than two thirds of GHGs emissions, with all of the environmental consequences that this brings [123]. Thus, the proliferation of other technologies is urgent, such as the production of energy from renewable sources.

To achieve goals like decarbonization of the economies, not only the promotion and implementation of public policies and targets is important, but also the engagement of the society as a whole [124]. According to Costa et al. (2021), positive changes in human behavior can contribute to more than 20% of GHGs emissions reduction [125]. In this regard, it becomes essential to increase the awareness of society to environmental problems related to climate change. In the EU, already 90% of the population considers climate change a serious threat [126].

According to the European Commission, having in consideration all of the environmental effects that humans are facing, and the rise in average global temperature, it is essential to undertake immediate and decisive climate action, and to warrant a transition that is socially fair and efficient [127]. This transition is needed not only in order to achieve a better future but also to modernize the European economy, with technological innovations in sectors such as energy, transport, and industry [128]. Many European countries, just like Portugal, started this transition in the energy sector, with the development of renewable energy sources so as to decrease the use of fossil fuels [129]. Coal has been the main resource used in electricity generation in Europe, being a major contributor to the greenhouse gases emissions [125]. It is estimated that until the mid-21st century there will be a radical change in the energy production systems, which will be mostly based on renewable sources [130]. This change will have huge implications at the economical level, like the decrease of dependency on imported oil and natural gas [131].

Regarding the Portuguese situation, the authorities established that until 2023 the country would not rely any more on coal for energy production. The country has two coal power plants: Sines (closed in January 2020) and Pego (still operating until the end of 2021). These are responsible for 20% of the GHGs emissions in Portugal, and their closure is therefore inevitable for the decarbonization of the economy [132]. The Pego power plant was built by EDP between 1987 and 1995, and its purchase by Tejo Energia was made in 1993. In 2009, the unit was retrofitted with a flue gas desulphurization system (FGD) and a selective catalytic reduction system (SCR). The holding group has three companies: Tejo Energia, Pegop, and CarboPego.

5. Results and Discussion

5.1. Biomass Supply in Portugal and the Hypothetical Case of Pego Power Plant Conversion

Biomass represents the third most important energy renewable source in Portugal. There has been a substantial increase in the energy production from biomass since 2000. This situation is related to the Portuguese strategy started in 2006 assigning 100 MW to produce electricity from forest biomass and an additional 150 MW assigned to public interest projects. In 2000, the installed capacity of biomass in Portugal was 427 MW and in 2020 it was 891 MW. This evolution is presented in Figure 8.

Since the Pego power plant is in the municipality of Abrantes, in the Portuguese district of Santarém, which is part of Médio Tejo (NUT III), it was decided to focus on the biomass potential of this region (Figure 9). In order to do this, we analyzed the data made available in 2019 at the 6° Inventário Florestal Nacional.

As can be observed in Figure 10, the area occupied by forest in the Médio Tejo region is 10.2% higher when compared to the forest area in the rest of the country.

For the calculation of the biomass produced in this region, we considered the two main species: Maritime pine and eucalyptus. These two species alone constitute 79.9% of the total forest area in the Médio Tejo region.

The growth volume for maritime pine and eucalyptus was 2932.9 and 3331.6 Mm³, respectively. The total amount of live biomass for maritime pine and eucalyptus in the form of trees was 1954 and 2628.1 kt, respectively. This means that if the total amount of biomass that is needed to convert the Pego coal power plant to biomass is under the yearly growth volume for these two species (6264.5 Mm³), there is a theoretically sustainable supply of biomass for energy production.

For the calculation of the amount of biomass needed to replace coal, since there is no public data regarding coal consumption in the Pego station, were analyzed data collected from the DGEG (Direção-Geral de Energia e Geologia) regarding the coal balance sheet for 2019. The total amount of bituminous coal, which is used for energy generation, was retrieved from the data and distributed between the two coal power stations that existed in Portugal in 2019, having in consideration the installed capacity of each one. According to the information available in REN reports, Sines had a capacity of 1180 MW, while the Pego power plant has a capacity of 576 MW, adding up to 1756 MW.



Figure 8. Evolution in energy sources' installed capacity in continental Portugal (source: APREN).

Since the total amount of coal used for energy production in 2019 was 2,101,758 tons, and assuming that both power plants worked at the same efficiency, it can be considered that the amount of coal used in Sines in 2019 was 1,412,339 tons (67.2%) and in Pego it was 689,419 tons (32.8%). To confirm this correlation, was also analyzed the percentage of GHGs emissions in each power plant. Since there were no data for 2019, we used the data retrieved from the non-governmental organization "Zero", regarding the mean GHGs emissions between 2008 and 2017: Sines was responsible for 12% of national GHGs emissions and Pego was responsible for 5%. Comparing the percentages in both cases (70.6% in Sines and 29.4% in Pego), they are quite similar. This corroborates that using the installed capacity to understand the amount of coal consumed in each station is a good predictor. Being so, in order to keep the same amount of electricity production, we would have to use 689,419 tons of torrefied biomass (which can present a similar heating value to coal, 21 GJ/t) [133]. Since dry biomass has a calorific value of 16 GJ/t, this means that approximately 904,862 tons of dry biomass would be needed to maintain the same power production. Using a reference density of 450 kg/m^3 for the dry biomass, a volume of approximately 1.98 Mm³ can be appointed, which is far below the yearly growth volume of maritime pine and eucalyptus. This means that it would be possible to keep the Pego power station working exclusively with local biomass in a sustainable way. These calculations do not take into consideration other uses for biomass that are already in place in this region, and that would compete with the use of biomass for energy.

To achieve a transition from coal to biomass, some changes would have to be made. According to Bunn et al. (2019), regarding the equipment that is already in use, it is considered that the main components, such as the boiler, turbines, and generators, could maintain the characteristics of the original coal plant [134]. However, maintaining the characteristics of the plant requires changes, above all in the fuel feeding and processing systems, considering that the biomass used in the plant is subjected to the torrefaction process in order to reduce its heterogeneity, its hygroscopic behavior, and its fibrous nature



and increase its energy density, making it a fuel with higher quality [75], and a biomass torrefaction plant would have to be put in place [133].



Figure 9. Location of the Médio Tejo region.



Figure 10. Distribution of land use in Médio Tejo (source: IFN6).

5.2. Other Implications Regarding the Pego Thermal Power Plant Conversion

As previously mentioned, the government declared that the Portuguese coal-fired power stations (Sines and Pego) would have to shut down by the end of 2021. Sines anticipated the measure and ended up closing in January 2020. Since coal is an imported resource, this affected the imports sector, as seen in Figure 5. As can be seen in the referred

figure, coal imports decreased by approximately 99%, contributing to the reduction of external dependence. However, the same will happen when the Pego plant closes or restructures, possibly leaving the import balance null.

In addition to the positive effects on the trade balance related to energy resources, negative consequences will be felt at a local level, namely in terms of unemployment rates. Currently, according to data retrieved from the Sabi database for 2020, the Tejo Energia project has the collaboration of 140 workers, distributed among the three companies as follows (Table 1):

Table 1. Number of employees in the Tejo Energia holding group (Sabi Data).

Firms	Number of Employees
Tejo Energia	10
Pegop	128
Carbopego	2
Total	140

Considering the data available on the PORDATA platform, the unemployment rate in the Médio Tejo region was 5.6% in 2020, which may increase if the Pego power plant closes. In this way, not only would increasing effects be felt on unemployment in terms of direct personnel, but also indirect ones, such as those responsible for storing coal at the Port of Sines, transportation, outsourced services, and many others. However, these effects may not be so negative in the event of an industrial restructuration, which would involve transforming the plant from coal-fueled to biomass-fueled, readapting and reusing most of the existing potential (Figure 11):



Figure 11. Restructuration of the Pego power plant.

In this way, a large part of the productive structure of the company and jobs would be kept, which could be of added value to the local community, although indirect jobs at the current state would disappear, or readjusted, but other indirect jobs would be created in different sectors. The reconfiguration of the Pego plant is important because Tejo Enegia is one of the biggest employers in the Médio Tejo region. At the time, with the conversion to biomass, many undirect jobs can be created as well, or at least preserved, if the jobs related with forestry operations associated with the biomass supply to the power plant are considered, and those related to the biomass transportation from collection sites to the power plant. This situation can be responsible as well for the development of interrelated activities that can contribute to the maintenance of local and regional economic activity, with very important social impacts.

As verified by the growth rate presented for the two main forest species present in the region, pine and eucalyptus, a continuity of supply to the energy production plant can be ensured, even if there may occur some constraints that could endanger this supply. For example, with the emergence of competition from other forest-based industries, or even through the occurrence of some type of event, such as rural fires, which may reduce the recovery capacity of the forest resource. It is also important to maintain the possibility that this rate of growth and forest recovery may be reduced by the effects of climate change,

namely through the reduction of precipitation, which, incidentally, has already occurred in the region, including a significant reduction in the flow of the Tagus River. However, this capacity for forest growth is only considering the two main species in the region, which are pine and eucalyptus, leaving out species such as acacias, which can also contribute with considerable volumes of biomass, as well as the residues resulting from agricultural activities, with the pruning of vines and olive trees, among others. In this perspective, even with the occurrence of a set of factors that could reduce the forest regeneration capacity in the region, it is very acceptable to consider that the resource has the capacity to ensure the supply of biomass in quantity and quality to allow the functioning of the thermopower plant, with all the advantages that have already been presented, for an extended period of time, preferably for dozens of years. In any case, given the size and location of the region under analysis, there is always the possibility of supplies coming from neighboring regions.

6. Conclusions

Coal is one of the most polluting resources used in energy production. Thus, it is urgent to find solutions that fight the climate change that comes with it, as well as guaranteeing energy supply to society. The declaration of the end of the use of coal in Portugal has the objective to make the transition from unsustainability to sustainability. However, the closure of the Sines and Pego power plants could bring problems to society, particularly locally. With the closing of the Sines plant in January 2021, it became interesting to carry out this investigation with a focus on the Pego plant. What was verified is that one of the most viable solutions that is aligned with the policy adopted in Portugal as well as the objectives in the 2030 Agenda is transforming the Pego thermal power plant into a biomass power plant. Biomass is a renewable resource highly available in Portugal and particularly in the Médio Tejo region where the Pego plant is located. Thus, there is an alignment with policies to fight climate change, using forest area, which will have a higher degree of monitoring and, therefore, the risk of wildfires will be reduced. Besides this advantage, the use of biomass for energy production is characterized by low levels of GHGs emissions when compared to coal. Another positive impact in the Pego region with the transition of the power plant from coal to biomass is that there will not be an increase in the unemployment rate, and the energy supply in Portugal would not be compromised. In conclusion, it is important to look at these types of policies as opportunities for improvement, not only at an environmental level, but also at an economic and social level. For this reason, it is necessary to identify viable solutions to reduce the negative impacts within the entire ecosystem, without compromising current and future generations, such as the transformation of the Pego coal power plant to a biomass power plant.

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