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Management of Energy Enterprises in Zero-Emission Conditions: Bamboo as an Innovative Biomass for the Production of Green Energy by Power Plants

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Abstract: Managing energy-producing companies as well as managing the entire energy sector in the light of legal and environmental requirements requires a new vision, mission, and strategy. The paper analyses the strategies of energy enterprises. It is not enough now to produce energy and deliver it at appropriate, acceptable prices to consumers; it must be generated with the least negative impact on the environment. To achieve that plan, companies should cut the carbon intensity of their products by 20% by 2030, 45% by 2035, and 100% by 2050, using a baseline of 2016. To compared to 1990 levels, the greenhouse gas emission reduction target for 2030 should be increased to 55%. Bioenergy will represent 18% of total final energy consumption in 2050. Additionally, this requires the development of a long-term strategy that can force companies to completely reorganize their production or start a new operation and activities. A low-cost strategy or a competition strategy are insufficient, and it is necessary to look for new strategies that combine adaptation to the requirements of the external environment with the use of innovative solutions. The article analyzes the possibilities of implementing an innovative strategy based on biomass, especially bamboo biomass. The reduction in CO_2 emissions of bamboo, taking into account life cycle emissions, can reach up to 85%. The novelty is to show the possibility of producing electricity by a large-scale power plant solely based on bamboo biomass on the example of a power plant located in the Tokushima prefecture, Japan. Another novelty is the fact that this article draws attention to the problem of burning bamboo in a power plant. The problem is that, as a result of burning bamboo, the clinker settles quite quickly. The study analyzes the selected ingredients for co-firing, which improve the combustion parameters of bamboo biomass (e.g., blended 20% bamboo with 80% pine or 30% bamboo with 70% tree bark). The importance of this research lies in the fact that it shows new innovative solutions in the energy sector that will help to achieve emission reductions. In addition, the article proposes to use eco-innovations and pay attention to eco-efficiency. Such solutions are an opportunity for ecological development through the use of bamboo as a fuel, which is classified as a renewable energy source by power plants.

Keywords: strategy; energy sector; sustainable development; bamboo; biomass; mechanical properties; eco-innovations

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1. Introduction

In Glasgow in 2021, during the climate summit "Conference of the Parties COP26", countries were asked to propose ambitious emission plans concerning reduction targets for 2030 that would be in line with achieving zero emissions by 2050 [1]. The pathway to a net-zero future is narrowing [2,3]. To achieve these ambitious targets, individual countries will have to accelerate the energy exit based on coal, reduce deforestation, accelerate the shift to electric vehicle use and encourage investment in renewable energy sources [4]. During the summit, it was reported that the world is on an unstoppable path to a low-carbon future, as more than 90 countries pledged to cut greenhouse gas emissions and halt deforestation by 2030. It is therefore a success that more countries have declared carbon neutrality. It is also very important to encourage a move to shift finances to help poorer countries to achieve zero carbon and create markets for innovative technologies. Richer nations have committed to double funding, known as adaptation finance, to help low- and middle-income countries (LMICs) deal with damaging climatic effects [5,6].

This means that energy companies will have to adapt their energy production to align with environmental requirements and switch to new production technologies or re-start their commitment to new environmentally friendly solutions. New technologies will help to become more competitive in the use of natural resources in a broader context [7]. Corporations are increasingly turning to technological innovations to meet net-zero emission targets [8]. Advanced technology development and the Mission Innovation (MI) and Breakthrough Energy (BE) programs announced at COP26 will work together to accelerate the commercialization of clean energy technologies in common priority areas, starting with green hydrogen, sustainable aviation fuel, direct capture of CO_2 from the air and long-term energy storage. Hydrogen and derivatives will account for 12% of final energy use by 2050 [2,3]. To date, E.U. countries have very slowly adopted solutions in the fields of energy and climate policy, including efforts to reduce greenhouse gas emissions, improve energy efficiency, and pursue renewable energy sources by 2030; thus, it can be clearly seen that these efforts should be accelerated. The International Energy Agency (IEA) in its report from 2021 "Net Zero by 2050: A Roadmap for the Global Energy Sector" [9] emphasizes that, to achieve the goal of climate neutrality, all countries should achieve climate neutrality in the electricity production sector by 2040 and developed countries even five years earlier [9,10]. The International Energy Agency (IEA) punctuates that, to meet the goal of climate neutrality in the energy sector, from 2025, the manufacturers of solid fuel boilers should stop selling these products. The sales of diesel and gasoline vehicles should end by 2035. The agency emphasizes that the energy sector as a branch of the economy is responsible for 75% of greenhouse gas emissions [11]. The climate goals will be all the more difficult to meet as by 2050 the global economy will be twice as large as it is today, with two billion more inhabitants, but the energy demand will decline by 8 percent. The IEA points out, similarly to the conclusions of the COP26 summit [1], solutions that should help to achieve climate neutrality, namely technologies, such as carbon capture, utilization, and storage (CCUS) and all the previously described activities. The main four activities that will be undertaken to implement the set assemblies are schematically presented in Figure 1.

To meet the described climatic requirements, similar activities are also planned in Poland. Within two decades, Poland plans to build a new, zero-emission energy system, of the same size as the current one. This will probably facilitate the secure and gradual transformation of the electro energy sector that is adjusted to Polish circumstances, in the direction of the acquisition of energy from low- and zero-emission sources over many years. To phase out coal assets, they will focus on the execution of low- and zero-emission investments [12]. The new system will be based on two pillars. The first will be nuclear energy from six 6–9 GW reactors, which are to be put into operation from 2033. The second pillar will be renewable energy sources. Offshore wind energy is expected to play a key role in this area, with the goal of installing 8–11 GW of capacity by 2040 [13].

Zero-emission renewable energy is expected to drive energy transformation, ensuring an almost 90% share in electricity production in 30 years [14]. Over 70% of this energy is to be solar and wind power, and the remaining 20% is mainly nuclear power. Nuclear energy will also have a significant impact on the way to achieve climate neutrality. As part of renewable energy, the energy produced from biomass has a significant role to play in the decarbonization process and changes in the global energy market. In Poland, the production of electricity from coal is systematically decreasing. Achieving carbon neutrality in Poland by 2050 means making a great economic, social and technological effort [15]. Poland faces the challenge of energy transition that will inevitably lead to a reduction in domestic coal exploitation and, in consequence, mine closures [16]. For the first time in history, in 2020, its share in the production mix was below 70%. Renewable sources are slowly starting to play a greater role in it. The production of energy from RES in 2020 amounted to nearly 28 TWh, which accounted for over 18% of the share in total production [17]. To date, in Poland, energy policy has been traditionally dominated by the stakeholders of high-emission industries, primarily mining and coal-based energy. The energy service is a logistic chain—mining, production, transmission, and distribution [18]—and it involves optimizing both material resources and equipment usage, as well as using energy-intensive equipment under various constraints. The use of biomass is proposed to minimize the share of carbon in the logistics chain. The focus on transitioning to a low-carbon or zero-emission economy shows the growing importance of renewable energy in the energy system, specifically in the areas of energy efficiency, electrification of transport (i.e., electromobility), and other sectors [19].

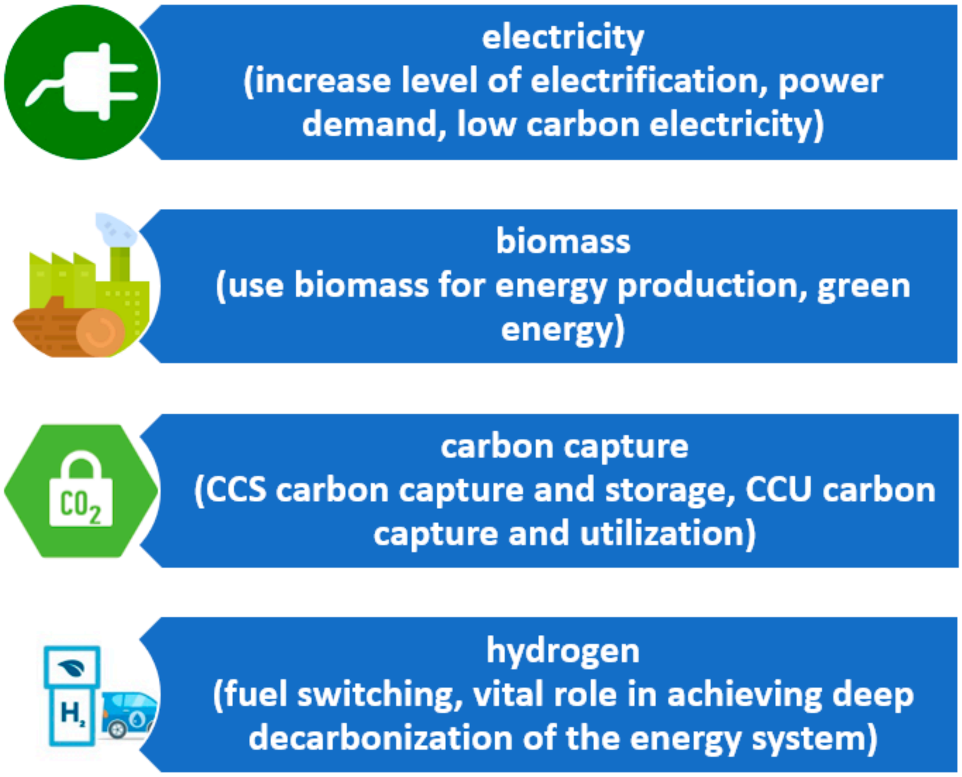

Figure 1. Four main areas of action to achieve zero emissions economy. Source: own elaboration based on [1,4,6,10].

The conducted research aims to analyze the potential of bamboo biomass, which can be used for energy production by energy companies. The production of energy based on bamboo biomass has many advantages, as well as some disadvantages, which were also noted in the conducted research, and solutions were proposed to solve the emerging problems.

2. Materials and Methods

The research was carried out using secondary methods called, in management sciences, desk research based on the available world literature in the field of energy, biomass, and innovative use of bamboo. The data contained in the annual reports of energy companies and from other literature and specialist journals, such as Energy Manager Magazine, Management, Energies, Sustainability, Energy Future, Control Engineering, Biomass and Bioenergy or Energy Reports, were analyzed. The summarized suggested solutions are presented in Table 1.

Table 1. List of sources constituting the basis of desk research.

Main Issues to Consider	Name of Source	Group of Publications
The use of furnace and post-mining waste for the production of new products. Decommissioning ineffective coal blocks. Investing in renewable energy sources. Development of nuclear energy.	Enea Annual Report (www.enea.pl) * Current Reports Tauron (www.tauron.pl) * Exxonmobil Annual Report (www.corporate.exxonmobil.com) *	Annual reports of the energy company
Bamboo as a material for energy production, a material for co-combustion, or as an independent input for combustion in a power plant fired only with bamboo or as a material for creating charcoal.	World Bamboo and Rattan (ISSN 1672-0431) Journal of Bamboo Research (ISSN1000-6567) The Journal of Bamboo and Rattan (ISSN 1569-1594) INBAR (www.inbar.int) *	Bamboo journals
Shutting down coal power plants, moving away from coal as energy. More areas on Earth should be planted with new forests to produce green biomass and hydrogen as fuel needs to be developed.	Energies (ISSN 1996-1073) Energy Policy (ISSN: 0301-4215) Energy Future (ISSN 2278-7186) Energy Journal (ISSN 0195-6574) Energy Manager Magazine (https://www.energymanagermagazine.co.uk/) * Sustainability (ISSN 2071-1050) Management (eISSN 2299-193X)	Energy journals
Achieving the goal of climate neutrality (all countries should attain climate neutrality in the electricity production sector).	IEA (International Energy Agency) IRENA (International Renewable Energy Agency)	Energy agencies

* accessed on 6 January 2022.

The study analyzed the use of biomass in power plants and the problems that need to be solved when burning biomass in boilers. Similarly, problems with bamboo combustion were analyzed and technical and technological solutions were proposed to eliminate the emerging defects. The structure of the article is as follows: first, the general situation regarding zero-emission issues was analyzed in the light of the latest studies and the innovation strategy was discussed. Then, the energy properties of biomass and the possibility of its use in the energy sector to achieve the zero-emission assumptions were discussed. Finally, it was proposed to use bamboo biomass as an innovative material used by energy companies. This aspect is new in the world, as only one power plant is fired entirely with bamboo biomass.

3. Results

3.1. The Zero-Emission Program in the Strategy of Energy Companies

Due to the zero-emission plan being implemented, the oldest coal-fired power units will be decommissioned in energy-producing companies in the coming years. This will create an additional need for baseload energy sources that are flexible at the same time. One of the strategies may be to modernize the existing coal-fired units and supply them entirely with biomass. The possibility of the effective use of biomass blocks is confirmed by examples from European countries, where the large-scale use of biomass in transformed coal-fired power plants, operating both in the base and at the peak, reduces the consumption of coal and natural gas. After the conversion of the coal unit, the companies have reused some of the redundant infrastructure to load them with biomass. Modern power plants must have the capacity to regulate the power depending on the changing load on the power system. These solutions are a significant milestone in the transformation of power stations based on innovative solutions for this upgrade, using all innovative knowledge, e.g., the incorporation of oxy-fuel combustion technology into conventional power generation systems. The above-mentioned solutions extend the life of the plant whilst delivering cleaner, reliable power for industry. Another strategy can be the construction of a Green

Power Unit fired exclusively with biomass in which wood and agricultural biomass, mainly straw pellets, are burned. The next strategy used by power plants could be to cooperate with private entities to build RES power plants using the potential of local natural resources [20]. In addition, the closure of hard coal and lignite mines, planned in the next few years, will result in the necessity of a wider use of alternative sources by enterprises, including biomass, as well as other uses for the closed mines. To this end, key technological options are being developed that may be relevant for closed mines. The planned directions include the non-energy use of coal and the reuse of mines for non-production purposes, such as to capture and store CO_2.

3.2. Energetic Properties of Biomass

Biomass is an energy material derived from products consisting of plant and animal waste and residues. It is formed in agriculture and forestry, in households, and in industry. Biomass is a cheap and accessible raw material that can be easily transformed into an efficient source of energy. The possibility of using local biomass resources and thus the possibility of producing electricity and heat not burdened with the energy policy of fossil fuels allows meeting the zero-emission requirements and implementing the decarbonization process. Biomass is a renewable energy carrier that is competitive to fossil fuels, because its combustion results in lower NOx and SOx emissions, and does not contribute to the increase in the greenhouse effect, because the CO_2 balance in the biomass energy conversion cycle is zero. The ecological effect of biomass combustion is a level-headed CO_2 emission balance, mainly because the carbon dioxide released into the environment was previously collected from this environment. Therefore, the CO_2 emission factor used in monitoring systems is zero for biomass. It is assumed that, in that case, the CO_2 emitted during biomass combustion is absorbed by plants that will be used as biofuel in the future. As a fuel, biomass means a decomposable matter of entirely natural origin. The conversion of biomass into electricity or heat contributes significantly to the utilization of organic waste, as well as to the management of wastelands (energy crops). Thanks to this solution, it is possible to cultivate even low-quality soil, not very fertile or in some way contaminated. From a purely economic point of view, biomass as an energy source also has many advantages. First of all, it is relatively cheap, easily and widely available. Its resources are quite evenly distributed, especially in comparison with other energy resources, which often have to be transported over long distances. However, when it comes to transport, the disadvantages of biomass also emerge. Biomass is typically a local fuel and it should not be transported over longer distances, because in such cases the cost of transport often exceeds the value of the transported biomass and the use of road transport damages the environment. Transporting biomass over long distances by road increases energy inputs related to fuel consumption (gasoline, diesel, or gas) and increases CO_2 emissions to the atmosphere. The costs associated with the supply chain are highly dependent on the specific regional raw material availability and the location of the power plant [21]. The moisture content has a great influence on the efficiency of biomass as an energy raw material. This often creates problems related to storage and transport, as appropriate conditions are necessary. A useful of solution is the use of biomass for energy purposes, e.g., by processing it into briquettes and pellets. The use of bamboo biomass briquettes is very effective and efficient [22]. Bamboo pellets are characterized by faster combustion (0.188 g/s) and heat generation (3494 J/s) than other pellets, e.g., pine pellets. Bamboo has a higher content of volatile substances (81.87%) than, for example, pine (80.34%), which indicates that it is easier to light and burn. The calorific value of bamboo pellets (18,495 J/g) is higher than that of pine pellets (18,298 J/g) [23]. The processed biomass in that way is easy to store or sell, and at the same time has a homogeneous energy value. Summarizing the cost aspects, the most visible elements are the raw material costs and the operating costs of pelleting, including additional costs related to drying. Although biomass is considered harmless to the environment, it should be emphasized that, during its combustion, certain amounts of, for example, sulfur dioxide or nitrogen oxides are emitted. However, these amounts are significantly lower than in the case of the analogous use of fossil fuels. The technical analysis related to the evaluation of the used fuels includes the determination of moisture, ash, volatile matter, the heat of combustion, and calorific value. The combustion of fossil fuels containing many chemical elements causes significant environmental pollution, and at the same time, through these negative effects of combustion, contributes to its systematic degradation. Coal is a fossil fuel, which usually contains a lot of sulfur in its chemical composition, which, during combustion, is released into the atmosphere in the form of sulfur dioxide. SO_2 damages forest areas that die from acid rain. SO_2 also acidifies the environment and helps to increase the acidity of water and soil [19]. In the process of generating energy, power plants and combined heat plants emit nitrogen oxides into the atmosphere, known in the literature as NOx, in addition to SO_2 and CO_2. On the other hand, biomass has much better combustion characteristics. Recognizing these environmental problems, many countries are promoting the use of alternative raw materials for electricity production in biomass power plants. Biomass as a RES is effective, it is not as efficient as coal. The calculations show that two tons of biomass are the energy equivalent of one ton of hard coal. Additionally, this is only if we take into account dry biomass, i.e., the one with the highest efficiency. Raw biomass materials can be divided into two types. The first type of raw material is fast-growing trees, such as acacia, willow, or in tropical climates eucalyptus, august and mimosa. The second type of raw material is waste from agriculture and forestry, such as straw, corn, palm fiber, or tapioca rhizome in tropical zones. Due to the high costs of collecting them, more and more attention is paid to bamboo as an alternative energy resource that allows reducing the costs of energy production [24].

3.3. Biomass Power Plant

In addition to the constantly rising energy costs and depleted resources of fossil fuels, the problems of climate change make it necessary to search for new, ecological, widely available, and efficient methods of energy production. When thinking about the energy of the future, it must be assumed that the sector will depart from the conventional model of power plants operating continuously and that energy consumers will passively and predictably receive electricity or heat [25]. The progressing digitization of the sector will optimize power grid operations and will increase the efficiency of the distribution network. Due to the growing requirements of the ecological environment and, consequently, the legal environment (directives, regulations), energy companies should pursue the implementation of innovation strategies that will reduce pollution, emissions and the negative impact on the environment. An innovation strategy should define the role and intensity of innovation for achieving the goals and stimulating the company’s development. The innovation strategy can be described as a business plan of action and development to encourage, mobilize, motivate, and advance technology by investing financial and human resources in research and development. An effective innovation strategy is to indicate the ways of achieving the set goals, gaining the right position in the changing market environment. Therefore, energy companies should look for innovative raw and energy materials alternatives to coal. One such solution may be the use of biomass, which is a renewable energy source. Biomass can be converted into electricity by several methods. The most common is the direct combustion of biomass material, such as agricultural waste or wood materials, in boilers. More than 90% of the world’s main energy supply comes from direct combustion. It is the most widely used and recognized technology for the supply of heating and energy services [26]. Other options include treating the biomass by gasification, pyrolysis, or anaerobic digestion, followed by incineration. Depending on the method of biomass combustion, power plants can be divided into two basic types: separate and cogeneration. Self-contained facilities are facilities that use only biomass to produce electricity and do not provide heat recirculation; such facilities are installations with standard systems. They have the lowest efficiency, estimated at around 25%, but they are the most common in many parts of the world. Cogeneration plants include power plants that use cogeneration equipment and are called combined heat and power (CHP). The biomass is burned to produce highpressure steam, which then drives a turbine that produces electricity. Thermal power stations or "cogeneration" installations use waste steam after it leaves the turbine for heating, drying, or other production processes or for heating buildings. These combined heating and energy (CHP) systems significantly increase the overall energy efficiency. Thanks to this solution, CHP plants can increase the energy efficiency of the plant by up to 80%. A typical example would be a sawmill that uses heat to dry wood in furnaces. Combined heat and power plants maximize the use of thermal energy from wood fuel. Typically, woody biomass, such as wood chips, pellets, and sawdust, is burned or gasified to generate electricity. The main way of thermochemical conversion is shown in Table 2.

Table 2. Thermochemical conversion of biomass. Source: own elaboration based on [27].

Thermochemical Conversion		
direct combustion (steam turbine, electricity)	gasification (gas turbine)	pyrolysis (gas, charcol, torrefaction)

The use of different methods of biomass conversion has advantages and disadvantages. The use of biomass in direct combustion or co-combustion processes is the least economically viable way of converting chemical energy into useful energy. A more effective method is conversion in cogeneration and trigeneration systems due to their greater efficiency. However, the conversion to liquid or gaseous biofuels is the most cost-effective process. The advantage of pyrolysis compared to combustion or gasification is that a property of the pyrolysis product is that it can be transported without problems, which significantly reduces the costs of this fuel transport. The process of torrefaction of biomass makes the new fuel in the form of carbonized biomass more brittle, thus reducing energy expenditure on the grinding process. In addition, the new biofuel has hydrophobic properties that the unprocessed biomass does not possess, which make the storage of biomass more effective due to the reduction in biological activity and the degradation process of the stored fuel. The key parameter influencing the properties of the product is the thermochemical conversion temperature. However, due to the imperfections of certain processes, such as gasification (high drying costs and expensive methods of removing tar and soot from post-process products) or pyrolysis (high costs and energy consumption of the process), activities are carried out all over the world to contribute to the creation of efficient methods to obtain useful energy from biomass that are not harmful to the environment.

Among renewable energy sources, biomass offers some advantages due to its low cost and supposedly zero carbon emissions compared to fossil fuels. Although the composition of the biomass is very heterogeneous, all materials have one thing in common: in most cases, their water content must be significantly reduced before they can be used for energy purposes [28]. The moisture content of biomass is often quite high, which lowers its calorific value, significantly lowers the combustion temperature, and causes operational problems. For this reason, when burning biomass for energy production, the biomass is often subjected to a drying process before combustion. To lower the drying costs or to maximize the output of the biomass power plant, as mentioned above, the appropriate integration of heat between the steam power plant and the drying process has to be considered. With proper drying and heat integration, the overall efficiency of a biomass power plant can be significantly improved [29]. The comparison of moisture content in biomass and other fuels is as follows: biomass 3–58%, peat 70–90%, lignite 15–70%, hard coal 1–18%, and anthracite approx. 1%.

3.4. Bamboo as Biomass

Bamboo (Supplementary Materials) is a common term used for a wide group (1250 species) of large woody grasses, ranging in height from 10 cm to 40 m. Bamboo is a sustainable and environmentally friendly material [30]. Bamboo may have potential as a bioenergy material. Bamboo has good fiber quality and has many important fuel properties, including bioenergy substances, such as low ash content and alkalinity index, for example. As bamboo quality and growth improve with systematic shearing, bamboo can be harvested every three to four years without harming the environment. If we compare the average lifespan of a redwood tree, which is about 500 years, with bamboo, we can notice that bamboo can be harvested and spawned more than 150 times within one redwood lifetime. This shows the virtually endless possibilities of harvesting bamboo. Bamboo can absorb up to 12 tons of CO_2 per hectare per year, stabilizing the gas content in the atmosphere and releasing 30% more oxygen than other plants [31]. The energy produced from bamboo biomass has great potential and can become an alternative to traditional fossil fuels. The combustion of bamboo or wood biomass is beneficial from the point of view of emissions because, despite the higher CO_2 emissions (approx. 105–110 kg/GJ) to produce the same energy unit as coal (94 kg/GJ hard coal, 109 kg/GJ brown coal), bamboo, thanks to its rapid growth and the short cycle of regeneration, absorbs much more CO_2 in photosynthesis than it generates during combustion [32]. Taking into account that the CO_2 emissions of the lifecycle of bamboo are strongly dependent on the details of supply chains, production techniques, forestry or farming practices, transport distances, the carbon emissions for woodchip are around 16 kg/GJ and for bamboo they are much less [33]. The reduction in CO_2 emissions, taking into account the above-mentioned lifecycle emissions, can reach up to 85%. Bamboo biomass comes from the stems, branches, and other parts of the plant. Bamboo biomass can be processed in many different ways (biochemical or thermal), or it can be converted to produce various energy products (synthesis gas and biofuels or charcoal, and torrefaction) that can become a substitute for existing fossil fuels. However, it should be noted that the use of bamboo biomass alone cannot meet the world's energy needs. Therefore, it must be combine with other sources to make the best use of its potential and ensure a sustainable energy supply [34]. Bamboo biomass has a relatively high calorific value compared to other types of biomass, which means that it is a good raw material for direct combustion (e.g., co-incineration in a combined heat and power plant). Many different bamboo energy projects are being carried out around the world. In Table 3, some examples of projects are presented.

Table 3. Selected projects concerning energy from bamboo.

Name of the Project	Organization	Country
NEDO projects in the spotlight	Kumamoto/Bamboo Energy Co., Ltd. [35]	Japan
EIT InnoEnergy supports Bamboo Energy	Institute for Energy Research of Catalonia (IREC) [36]	Spain
Bamboo Energy Fund–Bamboo Energy Access Multiplier (BEAM)	EDFIMC–ElectriFI [37]	Belgium (HQ) realization places: Sub-Saharan Africa and Asia
BAMBOO E.U.-funded project	Bamboo project is funding from the European Union's Horizon 2020 research and innovation program under grant agreement N°820771 [7]	European Union

Source: own elaboration based on [7,35–37].

In African countries, bamboo biomass is very popular and most often used as fuel or as the basis for the production of charcoal. Bamboo charcoal burns longer and has a lower environmental impact as it produces less smoke and air pollution than natural charcoal [38]. One of the innovative solutions in the energy sector is the construction of a power plant entirely fired with bamboo biomass. In Japan, a power plant that uses entirely bamboo biomass is being put into operation. This type of power plant is the first bamboo biomass installation in the world. A comprehensive system of power plants was developed, ranging from cutting, crushing, and burning bamboo to generate electricity. The power plant overcame the emerging problems caused by the minerals contained in the bamboo ash during combustion. Companies that have partially or completely switched to energy produced from biomass have become environmentally friendly and those that use bamboo have started implementing eco-innovation strategies.

Bamboo grows rapidly and retains its maximum properties, e.g., in tropical climates as early as 6 months after the appearance of the buds. This is the feature that distinguishes bamboo from ordinary trees. Bamboo is usually cut after 3 or 4 years, and the amount of bamboo per hectare is from 100 to 500 clumps or about 2000 to 14,000 shoots, depending on the type and fertility of the soil, while the diameter varies from 2 to 10 cm. Clumps of bamboo are shown in Figure 2. Bamboo is used in daily life by about 2.5 billion people, mainly for fiber and food production in Asia [39], but also as a construction material [40]. In the construction sector, one cubic meter of bamboo construction can reduce around 250 kg of CO_2 from the atmosphere. Compared to other wood materials, cement, and steel, bamboo materials have the highest carbon storage component. The storage of carbon in structures made of bamboo per ton is about 140 kg more than in the case of elements made of wood [41].

Figure 2. Moso bamboo. Sources: Author's photo archive (*Phyllostachys pubescens* Moso Bamboo).

Bamboo has potential as a fiber plant for textile [42] and niche markets. Overall, bamboo is much more productive than many other potential bioenergy crops and has many desirable properties as a fuel compared to some other bioenergy feedstocks. It is characterized by properties, such as low ash content and an alkali index. Its calorific value is lower than that of many biomass-based wood materials, but higher than that of most agricultural waste, grasses, and straw. While non-fuel uses of bamboo biomass may in fact be more cost-effective than energy recovery, it may also be possible to co-produce bioenergy with other biomaterials. To obtain selected bamboo species with the most favorable energy properties, further research is necessary in the field of reproduction techniques, establishment and management of stands, and the development of mechanized harvesting [43]. The use of bamboo for the production of energy and heat on an industrial scale allows to reduce the negative impact on the environment, so it can be classified as an eco-innovation. The basic principle of eco-innovation is to reduce the negative impact on the environment, and eco-innovation is a widely accepted beneficial strategy when used in a systematic, conscious, and thoughtful manner [44,45].

The direct combustion of bamboo biomass can be used on an industrial scale, e.g., in the form of cogeneration to produce heat and electricity in a combined heat and power plant in the electricity production process [46]. Bamboo burns almost as well as wood and has a relatively high heat value. Although the density of woody biomass varies greatly, the calorific value per kilogram is quite similar. The lower moisture content at harvest gives an energy "bonus". The moisture content in the stems decreases with increasing distance among the individual nodes in the stem [47]. The bamboo family is characterized by rapid growth and an increase in wood mass as well as little interference in the environment. The main advantages of using bamboo for energy crops are its better growth rate than other energy crops, its short rotation period, and the ease with which it can be grown and regenerated. If growing conditions are optimal and the fields are irrigated, bamboo will reach its full height in three years (20 m), while in dry conditions, this period can take up to five years. The production of one megawatt of energy requires only 80 hectares of bamboo to be planted, while the use of sugar cane requires the planting of 600 hectares. In addition, the ash content of bamboo biomass is low and ranges from 1 to 2%, while that of sugar cane is 3% [48] and, in the case of wood waste biomass, it can reach up to 12%. Bamboo has some desirable fuel properties, such as the already mentioned low ash content and a low alkalinity index, with a lower calorific value than much woody biomass, but higher than most agricultural waste, grasses, and straw [43,49]. The main components of the ash produced by burning bamboo are potassium dioxide (K2O) and silica (SiO_2). The ashes also contain chlorine (Cl), calcium (CaO), and magnesium (MgO) [50]. To assess the quality of bamboo as a biofuel, it is also necessary to know the content of chlorine (Cl) and sulfur (S). A large amount of these elements causes the corrosion and contamination of boilers, pipes, feed lines, and an increase in emissions of SOx, Cl_2, and HCl. The ash content ranges from 1.7 to 5%, which is a good result compared to other biomaterials that, such as rice husk, contain 17% ash after burning. The high calorific value (HHV) of bamboo is higher than most energetic materials or agricultural residues. The HHV value is presented in Table 4.

Table 4. The calorific value of dry bamboo and other biomaterials.

Biomass	HHV (Higher Heating Value) MJ/kg
Bamboo	19.8
Eucalyptus	19.6
Hybrid popular	19.7
Willow	19.7
Forest residue	16.5
Corn stover	17.4
Herbaceous biomass	18.1
Poultry litter	14.2
Chicken litter	11.5

Source: own elaboration based on [49,51,52].

The physicochemical properties of bamboo also depend on the type and age of the plant and the location of the parts that are examined (culm pieces), i.e., closer to the root and in the middle or on the top, as well as the location and climatic conditions. Depending on the location, the moisture content changes and this influences the califeric value. Diffrences between moisture content can achieve even 60% between the bottom and top part. In the case of bamboo age, the differences in califeric value reach about 6% in favor of 2.5-year-old bamboo compared to 10-year-old bamboo [53]. As the bamboo family has a wide range of different varieties, we can distinguish those that have the best burning properties, e.g., apus bamboo, nigra bamboo, vulgeris bamboo, bamboo emeiensis, and phyllostachys pubescens. Various technologies can be used to convert bamboo biomass into another form of energy, including thermal conversion (direct combustion, gasification, and pyrolysis) and biochemical conversion. Thus, bamboo biomass can be used in various forms [54]. In the process of biomass combustion, the melting characteristics of ash are important. There is a significant drawback with bamboo as its ash melts and forms a hard mass called clinker that can damage the stove and other installations [55,56]. The melting point of bamboo ash is lower than that of other biomaterials, such as corn straw, Bermuda grass, or red pine. A mixture of 30 percent bamboo and 70 percent tree (cedar) bark or 20 percent of bamboo and 80 percent of pine (*Pinus massoniana*) bark can be used to properly remove the clinker that reduces combustion efficiency [34,57].

The conducted research showed that, during the burning of bamboo at the temperature of 815 °C, a serious sintering phenomenon occurred. The ash composition and the physicochemical properties of the biomass were the decisive factors influencing the fouling, slagging, and corrosion processes in direct biomass combustion. Although ash is only a small fraction by weight, it appears to be a major determinant of the combustion behavior of a lignocellulosic material [26]. Due to the low ash content, the slag and fly ash produced by the biomass-fired power plant is minimal [58].

3.5. The Possibility of Growing Bamboo in Poland

Bamboo is a plant of many different varieties that can grow in various climatic and landscape conditions because it easily adapts to a selected place. Thanks to its adaptability, it can grow in various types of soil, in various temperature ranges, at various heights, and in various humidity conditions. In the Polish climate, bamboo can easily find the conditions for growth, so there are many varieties of cold-resistant bamboo to consider. Most of the bamboo species found in Poland can be classified as Phyllostachys or Fargesia.

Based on Figure 3, we can conclude that in Poland more than half of the territory is suitable for bamboo cultivation. Among the varieties of Phyllostachys, almost every species of bamboo spreads very quickly thanks to the aggressive root system in the form of rhizomes spreading in the soil, which is called the runner system. In addition, it is important that many of the varieties of this bamboo are cold resistant, down to minus 15–20 °C.

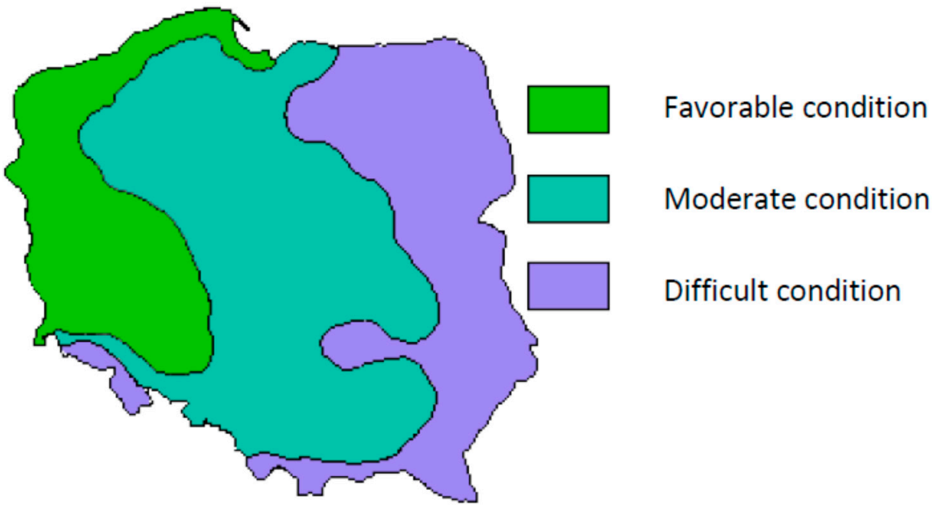

Figure 3. Distribution of zones for the cultivation of sensitive plants in Poland. Source: Hoser Sz. Fargesia [59].

In the Phyllostachys family, the most popular is the moso species, which among all bamboos occupies more than a third of the total surface of bamboo forests. This popularity means that many researchers conduct research on its genetic properties to delve into the structures of chromosomes, genes, DNA structure, and genomic sequences to learn about the properties and possibilities of increasing the economic use of bamboo [60]. In Poland, some varieties of bamboo can be grown from the entire rich family of bamboo, such as small-leaved (*Phyllostachys parvifolia*), bamboo incense (*Phyllostachys atrovaginata*), and Ink-finger (*Phyllostachys nuda*). Another popular and major type of bamboo, also native to China and Southeast Asia, is Fargesia. The bamboos of the Fargesia family are mostly dense clumps, unlike the Phyllostachys family. Dense clumps of Fargesia and their frost resistance have made many of its varieties very popular in gardens and among gardeners. In Poland, where the climate is temperate with hot summers and cold winters, the following varieties will grow well: umbrella bamboo (*Fargesia murielae*), blue fountain bamboo (*Fargesia nitida*), and clumping bamboo, also known as "rufous bamboo" (*Fargesia rufa*). As mentioned, in Poland, with a moderate climate, there are very clear differences concerning the wintering conditions of plants depending on the location of plantations in individual regions of the country. In the Pomeranian part and the part lying along the western border of Poland, and also in the south-east, the climatic conditions favorable to the cultivation of more sensitive and vulnerable plants are quite favorable, while in other regions of Poland, the conditions change, from moderate in the central part to difficult, which characterizes the area of eastern Poland from the north to the southern regions (see Figure 3). The creative uses of bamboo in Poland apply to horticulture, small architecture (gardens and parks), and in industrial design [61].

4. Discussion

Many developed countries have changed to alternative sources of energy that are more environmentally friendly [26,62,63]. In developing countries, renewable sources, as well as residues from agriculture (such as corn stover, poultry litter, and rice husk), are potential materials for electricity production [64]. Research on the implementation of an appropriate strategy by electricity-producing companies shows that eco-innovation and adaptation to new environmental conditions are necessary if companies want to operate in a market that is heading towards zero emissions. It can be achieved, e.g., by processing bamboo and making better use of bamboo as a biomass fuel [34]. More and more scientific works are concerned with research on the energy properties of bamboo and the possibility of co-firing bamboo with other bio-additives [53,65–68]. The energy market needs a profound transformation, and innovative initiatives concerning bamboo biomass are a clear example of how technology can contribute to the greater penetration of renewable energies and more efficient management of the energy system [35]. The results of the conducted research indicate the possibility of using bamboo in the energy sector in the combustion process with the use of additional biomaterials improving the properties of bamboo biomass [26,69]. The physicochemical properties of the burnt bamboo biomass lead to ash-related operational problems, such as low-ash melting points, slag formation, contamination, and corrosion [47,70–72]. The emerging ash problems constitute a challenge to search for and take appropriate actions aimed at the use of bamboo in the energy production process, e.g., for slag thermal conversion systems, such as airflow gasification, where slag formation on the gasifier walls is necessary for operation [73]. Actions are proposed to increase the use of bamboo in the energy sector, including energy production from bamboo combustion and anaerobic digestion to produce biogas as a transport fuel. There is no unambiguous evaluation of bamboo in the literature, e.g., displacement of wildlife and a decrease in the biodiversity of existing ecosystems due to bamboo production [74]; however, bamboo supporters have a significant advantage. Bamboo presents as a viable material alternative for energy use, both through natural biomass and in the production of briquettes, pellets, and charcoal [75]. From the point of view of scientific honesty, research should be continued, so further research should be undertaken to understand the properties of bamboo even better.

5. Conclusions

Energy transformation is a necessity, which must also become an opportunity to reduce emissions and improve the condition of the natural environment through the implementation of innovative investments. To achieve this goal, power plants in the E.U. must reduce the consumption of and dependence on fossil fuels, while improving energy savings. The results of the conducted research show that:

(1) One of the most important environmental challenges that energy companies and energy-intensive industries are currently facing is the transition of the energy sector towards a safe, competitive, and low-emission energy system;
(2) Energy companies will increasingly take into account the use of innovative green materials that are renewable energy sources in their development strategies;
(3) Biomass used for energy production should come from energy crops, such as bamboo cultivation, or from regions where forest resources that absorb CO_2 are stable;
(4) Enterprises will move towards eco-innovation. Research has shown the wide application of biomass, including bamboo biomass, by energy companies;
(5) In many cases, businesses require minor changes to the existing infrastructure and technologies to use biomass;
(6) Bamboo has sufficient mechanical and chemical-physical properties to be a material used by energy companies for direct combustion or used after specialized treatment (e.g., pyrolysis, torrefaction). An example is a power plant in Japan that is fully fired with bamboo biomass;
(7) During the process of bamboo burning, a layer of clinker is formed, so additives need to be used for biomass as well as to regulate the combustion temperature and oxygen concentration.

The research results can be used by energy companies in the process of building an innovation strategy and implementing new and innovative solutions. The value of the research is to show new possibilities of using bamboo in the energy production process, presenting weak points on which further research should be carried out. In addition, they can be a starting point from which to undertake further detailed research on the properties of bamboo in the combustion process in order to eliminate the perceived and described defects (clinker or tar particles deposition in pipes and devices).

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