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Review

The Potential of the Bioenergy Market in the European Union—An Overview of Energy Biomass Resources

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Abstract: One of the bases of the European policy and energy strategy is the biomass and bioenergy obtained from it. It is estimated that by 2023, the annual demand for biomass will have increased from the current level of 7 EJ to 10 EJ. There are significant differences between estimates of the bioenergy potential due to the fact that the authors of publications do not use consistent methodology and assumptions. Forest biomass, agricultural residues, and energy crops are the three main sources of biomass for energy production. Energy crops are likely to become the most important source of biomass. Land use and its changes are a key issue in the sustainable production of bioenergy as the availability of biomass determines its potential for energy security. This article is a review of the latest publications on the bioenergy potential of the member-states of the European Union. The consumption of energy and its potential were presented, with a special focus on renewable sources, especially biomass. The potential of biomass resources was presented and the types of biomass and its sources of origin were indicated. The research was conducted on the member-states of the European Union, whose policy is based on long-term development from the dependence on fossil resources to the dominance of renewable resources. As results from the research, in recent years, there has been a significant increase in the potential of both forest biomass (from 4.8 EJ per annum to the forecasted 15 EJ per annum) and agricultural biomass from (from 2.3 EJ per annum to the forecasted 7 EJ per annum). The increase in the demand for energy biomass in the EU member-states is balanced by partial imports from non-EU countries.

Keywords: bioenergy market; energy biomass; forest biomass; agricultural biomass; resources; energy security

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1. Introduction

The progressing climate change and the need to diversify energy sources have posed significant global challenges. The European Commission published the *2020 Energy Strategy*, which called the EU member-states to increase the use of renewable resources in their energy systems, whereas the European Council presented the long-term goal and principles of its implementation. According to the document, the EU and other industrialized countries have assumed the long-term goal to reduce the emissions of greenhouse gases by 80–95% by 2050 [1–3]. Biomass is an essential element in these renewable energy forecasts. Its share in the renewable energy resources in the EU-27 is expected to amount to 56%. According to the global perspective concerning energy production, it is important to use more renewable resources in general, especially biomass [4]. As energy security and the mitigation of climate change are fundamental elements of the current energy policy of the European Union, individual member-states were committed to achieve the goal of generating 20% of energy from renewable sources by 2020 [5–7]. It is noteworthy that government programs aimed at increasing the use of renewable energy sources are not limited to Europe [8].

However, the overall target for renewable energy in the European Union is much higher than in other parts of the world. The US Energy Policy Act [9,10] promotes various renewable resources: wind, sun, water, geothermal resources, and biomass mainly in the form of liquid biofuels [11–14]. As results from numerous studies on energy biomass resources conducted in the last 20 years in Europe [15–36] and around the world [37,38] have indicated, the potential of bioenergy has increased. It is supposed to provide a greater amount of biofuels from wood and agricultural biomass both for industrial and other purposes.

In order to perform a comparative study [39,40], the annual demand of the EU member-states for energy, which has so far been set at 1,483,000 TOE (1 TOE = 41.868 GJ), was verified, and the estimates of potential biomass resources for energy production in the EU were summarized. The geographic scope of biomass use was taken into account. All resource potentials were expressed as the average calorific value. Individual estimates observed over time confirmed the general upward trend in the use of biomass. Agricultural residues, such as cereal straw, maize stover, and rapeseed straw, are readily available resources from farmland. Currently, the estimates of these resources range from 0.8 to 3.9 EJ per annum. There are no noticeable upward or downward trends in the estimates which could indicate a higher or lower use of the resources in the future. Depending on the source of data, the forecasts range from 0.9 to 3.1 EJ per annum in 2030 and from 0.6 to 5.0 EJ per annum in 2050 [41–43]. Forest biomass consists of wood felling remains and wood biomass from early thinning and forest management. Estimates of the current bioenergy potential of forests vary considerably from 0.8 to 6.0 EJ per annum. Estimates for 2050 range from 0.8 to 10.6 EJ per annum.

In 2010, the European Environment Agency (EEA) estimated the secondary biomass resources at 3.1 EJ per annum and forecasted their increase to 3.2 EJ per annum in 2030. Ericsson et al. [2] focused on industrial wood residues and estimated the EU-25 resources at 1.1 EJ per annum between 2020 and 2040. According to other sources, this potential in the EU-27 was estimated at 1.0 EJ per annum in 2010, and it is forecast to increase to 1.3 EJ per annum in 2030. For comparison, the EEA [22] estimated the potential of wood processing residues in the EU-25 at only ~0.4 EJ per annum.

Biomass fuels are typically used most efficiently and beneficially when both electricity and heat are generated in biomass-based cogeneration systems. Biomass conversion technologies convert biomass waste into heat, electricity, and biofuels through the use of appropriate technologies [44]. Conversion processes are typically thermochemical or biochemical. The simplest way is to burn biomass in a furnace, using the heat generated to produce steam in a boiler, which is then used to drive a turbine. Advanced biomass conversion technologies include biomass-integrated gasification combined cycle (BIGCC) systems, co-firing (with coal or gas), pyrolysis, and second-generation biofuels [45].

Biomass CHP systems provide seamless system integration for different technologies, thermal applications, and fuel types. A biomass-fueled CHP system is an integrated energy system with three main components [46]: biomass reception and feedstock preparation; energy conversion—the conversion of biomass to steam for direct combustion systems or to biogas for gasification systems; electricity and heat production—the conversion of steam, syngas, or biogas to electricity and process steam or hot water. The cheapest forms of biomass are agricultural or forestry residues. Forest residues and wood waste are a large potential resource for energy production and include forestry residues, forestry clearcuts, and sawmill residues. Converting biomass resources into productive heat and/or electricity requires a number of steps and considerations, including, most importantly, assessing the availability of suitable biomass resources, determining the economics of collection, storage and transportation, and evaluating available technology options for converting biomass into usable heat or electricity [47].

The current geopolitical situation and previous energy policy in EU countries did not fully take into account the risk of reducing the availability of conventional fuels. It was based on the strong position of the energy lobby despite the direction of change set by the European Parliament and the Council. A lack of security of the fuel supply caused problems in the energy policy of many countries. Ensuring "green" energy security is in accordance with Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity production from renewable sources [1], and Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of energy from renewable sources [5]. The premise is to use the energy potential of each EU country using the best energy sources, for example, solar energy in countries such as Italy, Spain, or Portugal, and wind energy in Sweden, the Netherlands, Germany, or Poland. Each country can obtain energy from biomass, and it depends on the legal regulations in each country whether opportunities will be created to obtain more energy from biomass, whose potential is much greater than the scope of current use. The EU directive to abolish the availability of wood as a source of renewable energy could become problematic. The European Parliament wants to consider primary woody biomass as an unsustainable resource although wood, in terms of renewable energy, provided 22% of its potential by 2020 [45,46].

The aim of this study was to assess the EU market of bioenergy mainly in terms of the availability of energy biomass used for its production. The importance and the main structural characteristics of energy security projects related to the production of agricultural and forest biomass were analyzed. The potential and real biomass resources were indicated, taking the geography of the EU into account. The energy potential of these resources was also analyzed.

2. Materials and Methods

Due to the very wide range of topics related to energy biomass, the authors of this study narrowed the focus down to plant biomass, mainly forest biomass. The following sources of data were used for a detailed assessment of forest biomass resources used for bioenergy production: National Renewable Energy Action Plans (NREAPs); Joint Wood Energy Inquiry (JWEE), supplemented with data from the Joint Forestry Sector Questionnaire (JFSQ) for the entire EU forestry sector; and Eurostat [23,43]. The results presented in our study come from the research on the development of forest biomass flows and detailed analysis of the Wood Resource Balance (WRB) [48,49] based on the aforementioned sources of data.

In addition to the data available in terms of statistics of individual EU countries, the sources of information are summaries presenting the overall figure of timber and forest resource management [50].

The paper reviewed the presented data based on the latest available literature on the subject. The data were reviewed to present the difference in the assessment of agricultural and woody biomass abundance. Significant discrepancies in the assessment of the volume of energy value of available biomass were pointed out. The growing role of biomass in the EU energy sector and in global CO_2 reduction was pointed out.

3. Results

As results from both research and the trend set by the EU policy have indicated, in the future, biomass will be one of the main sources of renewable energy in the form of solid fuels because it is a convenient and widely used resource [51,52]. According to Directive 2003/54/EC and Directive 2009/28/EC of the European Parliament and of the Council, biomass is "the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste" (Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity; Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources) [53–55]. Biomass includes vegetal organic matter, which is the source of agricultural and forest biomass;

organic matter of animal origin; as well as all substances obtained as a result of their processing [56,57]. As results from reference publications have indicated, the most common sources of agricultural biomass are cereal straw, energy crops, and organic residues from the food industry [58,59]. The most common sources of forest biomass are firewood, logging residues, and all by-products and waste generated during the production process in the wood industry [60–62]. Biomass of animal origin mostly consists of manure, slurry, animal fats, and bone meal [63]. A list of basic biomass sources is shown in Table 1.

Table 1. Sources of biomass for energy.

Types and Sources of Biomass	Primary Biomass	Secondary Biomass [1]
Vegetal agricultural biomass	grassy energy crops (giant miscanthus, Virginia mallow); timberland (willow, poplar, black locust, and others)	cereal, rapeseed, and grass straws; organic residue from food industry; cereal grains, sugar crops, oilseeds, other crops, and by-products from crops
Vegetal forest biomass	firewood	logging residues, wood shavings, sawdust, wood chips, others, including wastepaper and waste generated by wood-processing plants
Animal biomass		manure and slurry; fats and bone meal

[1] Source: Authors' original compilation based on [58–62].

Each type of biomass, regardless of its source or division criterion, is different in terms of moisture content, volume, and physical and chemical properties possessed. These factors also ultimately determine the calorific value, which is crucial from the point of view of converting biomass into heat, electricity or, for example, fuel used in transportation [64].

Regardless of the source of biomass, it can be obtained from special plantations, as a by-product in the production process, or from post-production waste. In all cases, these are subcategories which are reference points to the initial state. In the first case, it is a land subcategory—when agricultural and forest biomass are obtained from plantations with soils of lower quality classes, agricultural lands, and wastelands. This enables the optimal use of land for biomass production, which otherwise would not be used so comprehensively [65]. In the second case, which can better illustrate optimization activities, waste and by-products generated in the production process can be handled. If they are treated as classic waste, they pose a problem. However, they can also be treated as sources with energy potential, which can be reused in the combustion process. According to the principles of circular economy, depending on the source of biomass, new products such as briquettes, pellets, and biogas can also be obtained (Table 2).

Table 2. Biomass combustion material.

Vegetal Biomass [1]		Animal Biomass
Agricultural Biomass	Forest Biomass	
briquettes pellets biogas	briquettes pellets woodchips from woody plants in plantations	biogas

[1] Source: Authors' original compilation based on [59,60,62,63].

The most popular types of processed biomass are pellets and briquettes. Their calorific value is in the range of 16.5–19 MJ/kg and 16.5–18 MJ/kg, respectively, at a moisture content of about 7% [66]. They are characterized by a higher density than firewood, which affects the smaller volume of energy material needed to obtain the same amount of energy than in the case of firewood or wood chips. The average calorific value for wood, depending on its species and at a moisture content of about 18%, is about 14 MJ/kg [67], and for wood chips at a moisture content of 20–60%, the average value is at the level of 6–16 MJ/kg [59,68]. These values are an important criterion in the selection of energy carriers. Biogas, on the other hand, is the result of the processing of organic compounds contained in biomass, most often due to methane fermentation. The biogas product thus formed can be used both in the process of generating heat or electricity and as a fuel for transportation [63,69].

Although the share of biomass in the energy mix of the EU member-states is still not very significant, it may play an important role in the energy sector [70]. One of the factors in favor of this solution is the fact that it can be handled locally, especially in the enterprises where it is generated [71]. This option not only ensures energy security for the entity generating heat or electricity, but it may also be an added value in the energy balance of the local market due to frequent production surpluses [60,72]. Moreover, it is necessary to stress the fact that unlike other renewable energy sources, biomass can be stored, and it is not affected by weather conditions. Therefore, it can be an ideal complementary source of green energy when there is an increased demand for it [73,74].

As results from the observations of energy transformation activities in various countries around the world as well as analyses of available reports, summaries, and scientific publications have indicated, the share of renewable energy sources in energy fuels is increasing while fossil fuels are being abandoned [75–80]. This trend is particularly noticeable in the EU member-states due to the introduction and implementation of special legal regulations [81,82]. The pursuit of energy independence reduces all kinds of risks from the external environment. It is absolutely crucial and particularly noticeable in crisis situations. Therefore, when selecting energy sources, it is important to take all threats into account because they may ultimately determine the energy security level of a particular country [83]. Energy obtained from renewable sources gives a greater guarantee of economic stability because its sources can be found locally. The share of energy from renewable sources has increased in all EU member-states (Figure 1).

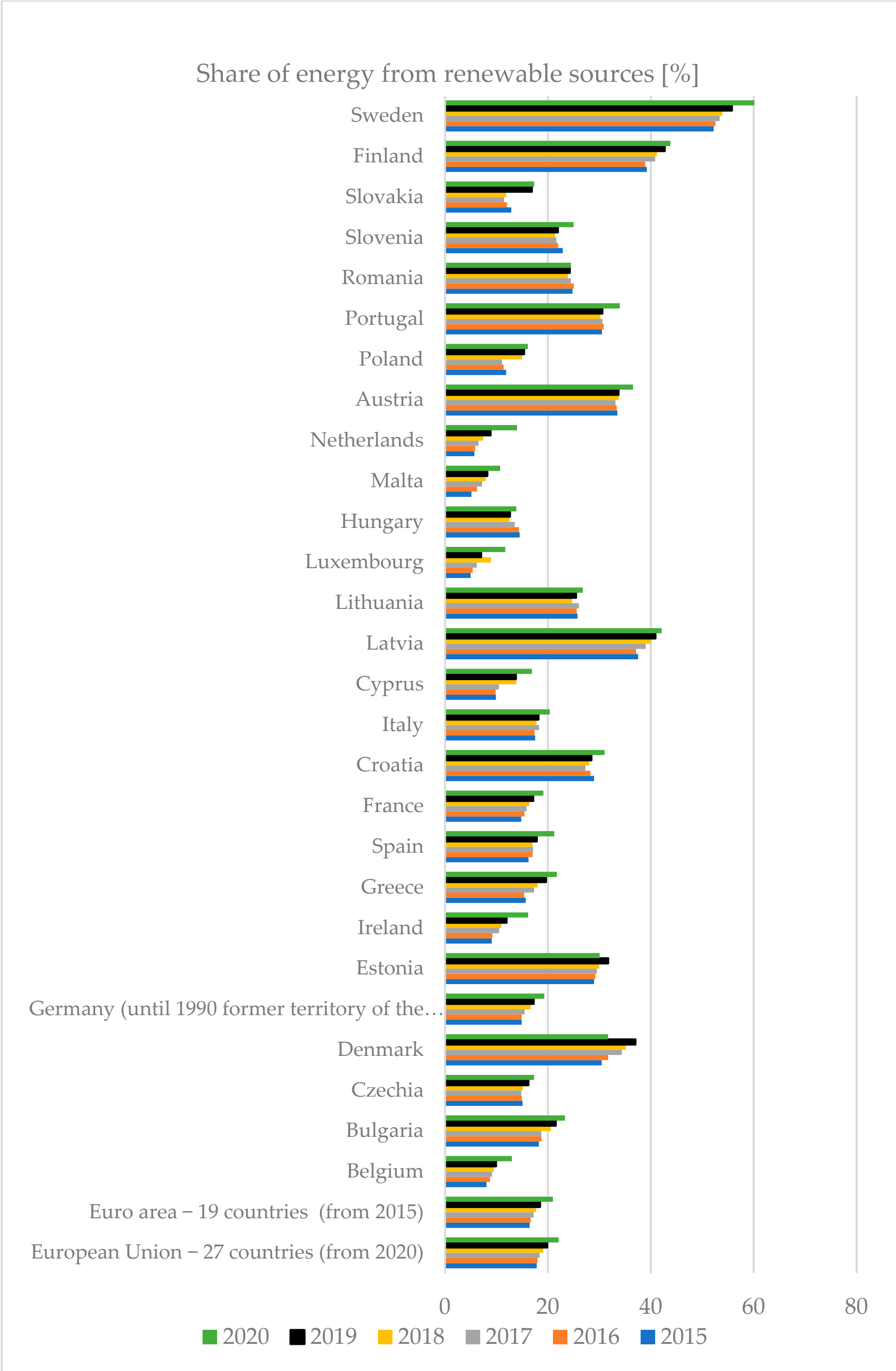

Figure 1. The percentage share of renewable energy in individual EU member-states between 2015 and 2020. Source: Authors' original compilation based on the Eurostat data [84].

Despite a marked increase in the share of renewable energy in individual EU countries over the past few years, significant variations in the share are evident. Among the countries with the highest share are Sweden, Finland, Lithuania, and Denmark, i.e., mainly those countries that have been pursuing intensive pro-environmental policies for many years and implementing solutions that are environmentally most beneficial [85]. In contrast, countries such as Germany and France, for example, which are leading in the area of pro-environmental policy in the EU [86], have a share of renewable energy comparable to countries such as Greece or Spain, and smaller even than, for example, Romania, Slovenia, or Bulgaria. Such a situation shows that when analyzing the figures, in addition to the properly set and implemented directions in terms of climate protection or the level of development determined by the measure of GDP, one should also take into account the population of a country, its area, level of education, or level of industrialization as a measure of technological development and implemented investments that generate energy demand [87]. Such a comprehensive approach to the growth of bioenergy allows us to better interpret and understand the rate of change in energy substitution.

On the one hand, the growing share of renewable energy results from its increasing production. On the other hand, it results from the possibility of importing biofuels. As shown in Figure 2, the degree of energy dependence in individual countries is considerably diversified both in terms of renewable sources and biofuels and in terms of total energy imports.

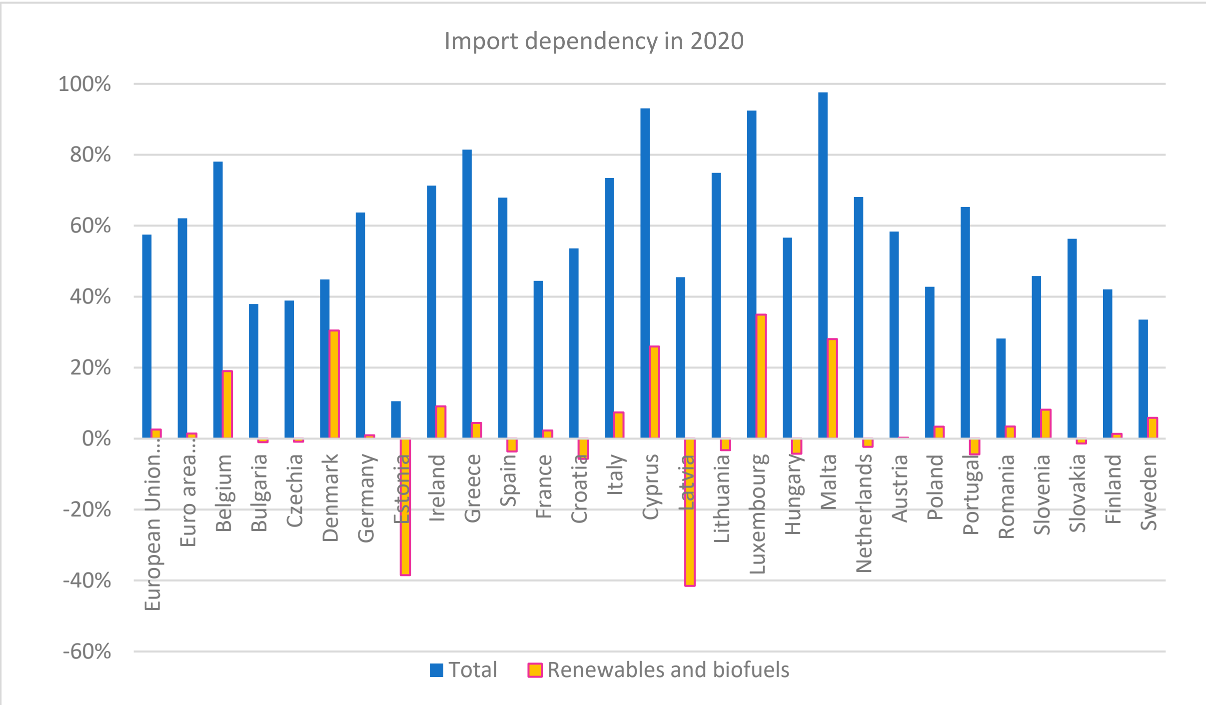

Figure 2. The dependence of the EU member-states on sources of energy. Source: Eurostat, calculation based on energy balances [88].

Analyzing the comprehensive data on the level of energy dependence of EU countries on external energy sources, one can see the scale of this phenomenon. The energy dependency rate for the EU-27 in 2020 averaged 57.5%, and among the countries with the highest dependency rate were Malta, with almost 98%, and Cyprus, with around 93% [88]. Such a high level of dependence shows how much risk there is for individual countries and the Union as a whole in an emergency situation related to the reduction or non-delivery of energy carriers, and how vulnerable the economies of individual countries may be to external factors. That is why it is so important to increase the share of energy produced in individual countries from renewable sources, which will ultimately increase the degree of energy independence.

The potential of the energy market and the way it operates is also influenced by the supply of energy and the export of energy sources. Figure 3 shows the values of these parameters in the EU member-states in 2020.

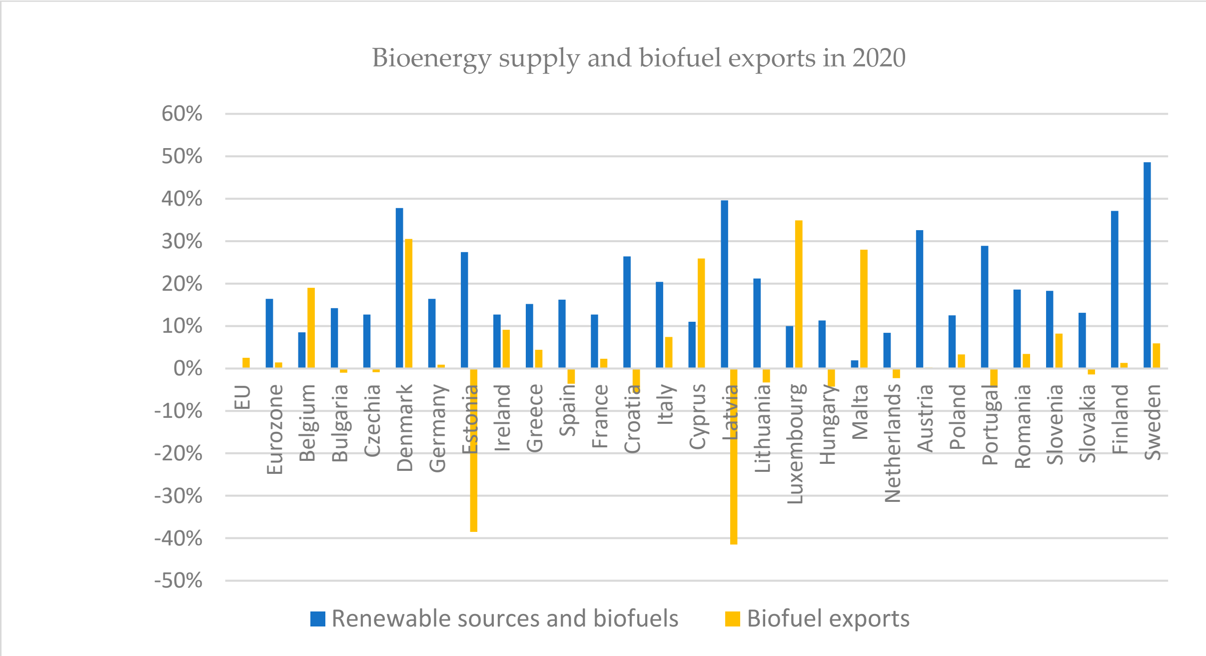

Figure 3. The supply of bioenergy and the export of biofuels in the EU member-states. Source: Authors' original compilation based on the Eurostat data [88,89].

Analyzing the values for energy supply in individual EU countries shows considerable variation (Figure 3). Such significant discrepancies between countries indicate differences in the pro-environmental policies implemented and the pace of pro-environmental solutions. On the other hand, the level of exports in these countries may indicate an underutilization of national potentials for generating energy from renewable sources.

The share of renewable energy in the entire energy mix can also be considered through industrial classification areas. According to the NACE data (Nomenclature des Activités Économiques dans la Communauté Européenne) [89], the European industry standard classification system, the share of energy bioproducts in all types of activities amounts to about 3.5% of all energy products. However, this share amounts to 85.5% in the Agriculture, Forestry and Fisheries category (Table 3). These data confirm the fact that environment-friendly solutions are being introduced in the energy sector of agriculture, forestry, and fisheries, and indicate that bioenergy has an enormous potential in this group of industries.

Table 3. The supply and use of energy in 2019 according to NACE data (Nomenclature des Activities Économiques dans la Communauté Européenne)—the European industry standard classification system [TJ].

NACE_R2 (Labels)	Energy Products [1]	Wood, Wood Waste and Other Solid Biomass, Charcoal [1]	Liquid Biofuels	Biogas
		TJ		
Total—all NACE activities	1,946,381.0	48,271.4	13,312.0	6677.7
Agriculture, forestry, and fishing	54,319.3	46,454.8	0	0
Manufacturing	1,580,356.0	1816.6	13,312.0	0
Electricity, gas, steam, and air conditioning supply	292,363.2	0	0	0

Table 3. *Cont.*

NACE_R2 (Labels)	Energy Products [1]	Wood, Wood Waste and Other Solid Biomass, Charcoal [1]	Liquid Biofuels	Biogas
Water supply; sewerage, waste management, and remediation activities	14,990.6	0	0	6677.7
Construction	98.4	0	0	0
Wholesale and retail trade; repair of motor vehicles and motorcycles	40.1	0	0	0
Accommodation and food service activities	7.4	0	0	0
Public administration and defense; compulsory social security	42.5	0	0	0
Education	3934.0	0	0	0
Human health and social work activities	229.7			

[1] Source: Authors' original compilation based on the Eurostat data [89].

4. Discussion

4.1. Agricultural Biomass

Currently, agricultural crops generating the share of agricultural energy biomass in Europe are mainly based on traditional food and forage crops, such as rapeseed, sugar crops, and starch crops [90]. It is expected that energy crops will play a greater role in future energy scenarios related to the supply of agricultural biomass. Researchers [34] estimate that by 2030, the potential of traditional agricultural by-products will have increased to 7.3 EJ per annum, whereas the potential of lignocelluloses crops will have increased to about 15 EJ per annum.

Agricultural residues have a significant share in energy biomass. The high share of cereal production is an important element of securing the energy potential of agriculture in the EU-27 [91]. As the market and political perspective is striving for complete independence from fossil fuels, especially those from Russia, the use of energy generated from biomass may affect the reduction of greenhouse gas emissions and improve energy security [51,92]. Agricultural biomass, as a source of renewable energy, has numerous advantages. It is widely available, ensures the maintenance of producer groups, and decentralizes energy production [93,94]. The significance of biomass and its use depending on the supply chain are also important elements of the discussion. Land use dynamics, population dynamics, economic development, the demand for food, feeds, fibers, and energy services, changes in the intensity of agricultural production, as well as the availability and costs of advanced energy conversion technologies, play a vital role (Figure 4). It is assumed that agricultural biomass will become an increasingly important resource in the biofuel economy. This will require sustainable management because biomass comes from various sectors of the economy which are regulated by different aspects of the EU policy [95–102]. The management of residual biomass is the untapped potential which can increase the volume of resources for energy production [1,103,104].

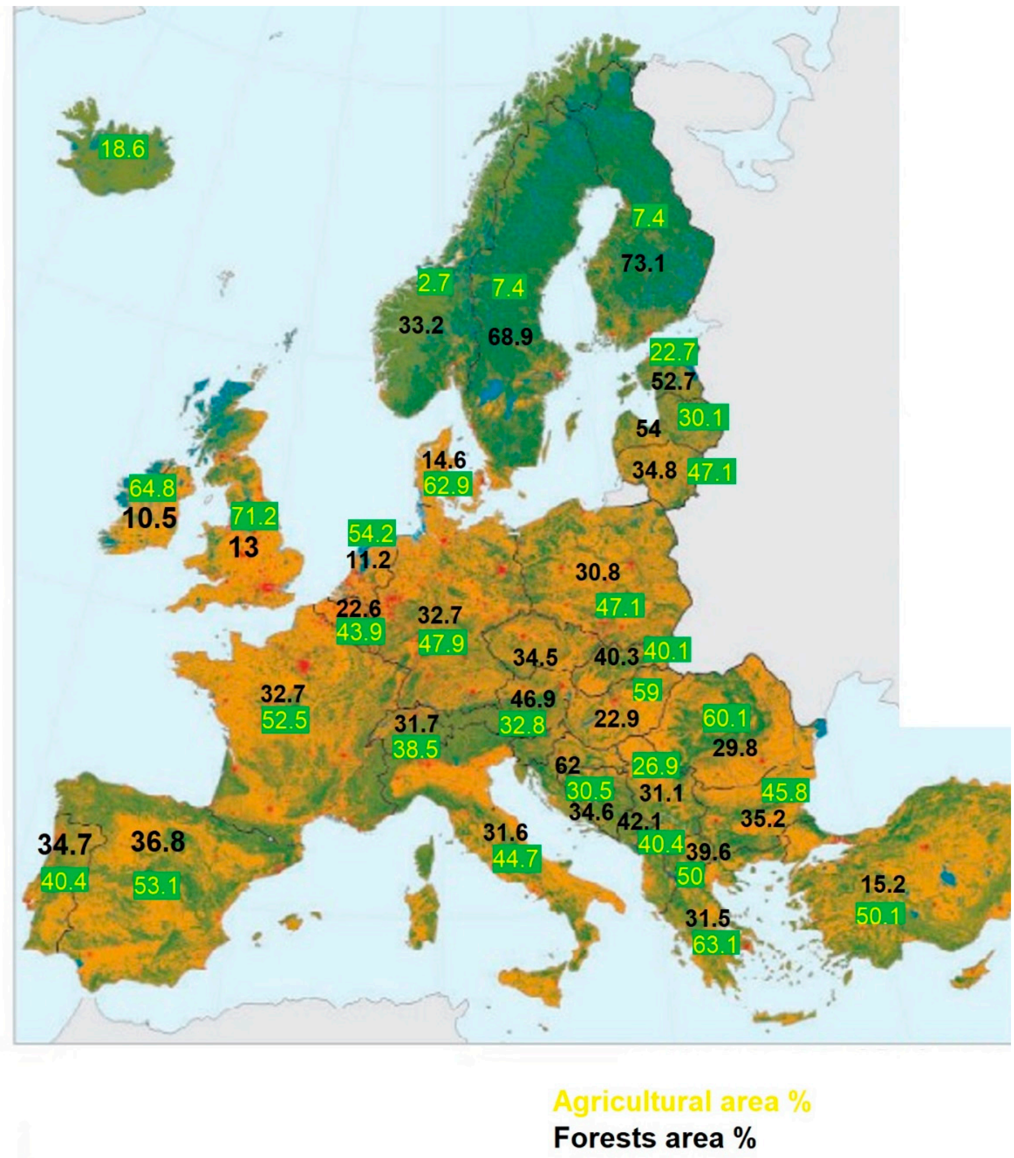

Figure 4. The area potential for agricultural and forest biomass in the EU member-states. Source: [105].

Over the years, the area of agricultural land in the European Union has undergone considerable changes. The earlier upward trend, which was observed due to the increase in the agricultural area from 156,000 ha in 2016 to 175,000 ha in 2018, will tend to decrease in the following years. These are the forecasts of the European Commission, which indicate that in 2031, the area of agricultural land should drop to 160.5 million hectares, mostly due to the decreasing yields and, consequently, lower attractiveness and profitability. On the other hand, the area of forests will continue to grow thanks to the role they play in the climate challenge. According to the forecasts, in 2031, the forest area will be 161.4 million hectares, so it will be greater than the area of agricultural land [106]. It is noteworthy that the dominant share of the EU area (on average, about 38%) is a significant production potential not only for food but also for energy production (Table 4).

Table 4. The area of agricultural land and forests in the EU member-states in 2016.

Area	Farmland (Housand Hectares) [1]	Land area (Housand Hectares) [1]	Percentage of Agricultural Land in Total Area %	Forest and Other Wooded Land (Housand Hectares) [1]	Percentage of Agricultural Land in Total Area %
Belgium	1354.3	3045.1	44	722	24
Bulgaria	4468.5	11,000.1	41	3917	36
Czechia	3455.4	7721.2	45	2677	35
Denmark	2614.6	4198.7	62	665	16
Germany	16,715.3	35,329.6	47	11,419	32
Estonia	995.1	4346.6	23	2533	58
Ireland	4883.7	6865.5	71	848	12
Greece	4553.8	13,004.8	35	6537	50
Spain	23,229.8	50,265.4	46	27,954	56
France	27,814.2	63,388.6	44	18,096	29
Croatia	1563.0	5589.6	28	2557	46
Italy	12,598.2	29,773.4	42	11,432	38
Cyprus	111.9	921.3	12	386	42
Latvia	1930.9	6329.0	31	3519	56
Lithuania	2924.6	6264.3	47	2263	36
Luxembourg	130.7	258.6	51	91	35
Hungary	4670.6	9124.8	51	2253	25
Malta	11.1	31.3	35	1	3
Netherlands	1796.3	3418.8	53	370	11
Austria	2669.8	8251.9	32	4029	49
Poland	14,405.7	30,723.6	47	9483	31
Portugal	3641.7	9099.6	40	4855	53
Romania	12,502.5	23,427.0	53	6945	30
Slovenia	488.4	2014.5	24	1265	63
Slovakia	1889.8	4870.2	39	1946	40
Finland	2233.1	30,431.6	7	23,155	76
Sweden	3012.6	40,730.0	7	30,344	75
Total	156,665.6	41,425.1	38	180,262	44

[1] Source: EU agricultural outlook [106,107].

4.2. Forest Biomass

The forest area in individual EU-27 member-states is constantly growing, depending on the directions of development [79,108]. Resources from forestry and the forest and wood industry make a major contribution to the production of renewable bioenergy from wood products. Currently, forest biomass is mainly used to satisfy individual consumers' demand for energy materials. However, in the nearest future, energy production may become the main factor changing this structure in favor of greater industrial use. The potential supply of forest biomass, such as logging residues (wood smalls) and bark, should not change significantly, as it depends on planned economic activities related to wood harvesting in forest areas. According to the forecasts, the biomass potential from the remains of the wood industry will increase by about 30% in the same period [60,109].

Forest resources are an important source of biodiversity and basic ecosystem services [110]. It is necessary to maintain forest biodiversity and related goods and services to meet the demand for raw materials and social resources [111–114]. According to some assumptions [115], the desired services of forest ecosystems will be provided while maintaining a sustainable forest policy and timber production. So far, researchers have observed that the production of raw wood material has decreased in favor of climate projects [116–118]. It is necessary to maintain balance in the provision of forest ecosystem services as a link between landscape biodiversity and biomass production [119–125] and the management of natural resources [126–128]. The key role of researchers in the assessment of the current forest policy is to set a strategy defining the limits of biomass use, as well as for energy production and the development within the forest ecosystem itself. It is necessary to take the share of cumulated CO_2 in the production of wood biomass into account because it is an important component of these relationships [129,130]. It is noteworthy that wood production was traditionally assessed with a number of different parameters, such as the periodic annual growth, average annual growth, volume of trees, and total wood production.

The socioeconomic requirements referring to forest functions are met by condensing the results concerning the biodiversity and selected functions of the ecosystem. Bearing this in mind, the developed methods were used to compare and assess the results of decisions on the management of forest resources for energy production in relation to the development of carbon sequestration resulting from the EU policy.

Currently, the use of forest biomass in Europe and individual EU member-states is diversified because there are differences in the availability of forest resources resulting from the real distance from the source of wood harvesting, the available technology, the type of power plant, the national law, and other issues affecting the development of the bioenergy sector [5]. In Finland, the share of biomass in the total energy consumption amounts to 25% (93 TWh) [12]. In Sweden, the total share of energy produced from biomass is 23% (129 TWh), with 49% of energy produced from wood-based fuels [13]. In these cases, wood comes mainly from forest resources, although since the 1980s, Sweden has also had a well-developed system of fast-growing plantations [14,131]. The total forest fuel harvesting potential in the Nordic and Baltic states was estimated at 236 TWh [4]. As results from the latest research indicate, the production of biomass and waste in this area amounts to 313.8 TWh [132], whereas the plant production in the EU-27 is estimated at 485 million tons of dry biomass [133]. Many researchers have stressed the fact that trends in the use of biomass for energy production pose a threat to the resources used for the production of wood and wood materials [134–136]. In the near future, a further increase in the demand for biomass is expected. In 2020, the availability of this material was exceeded [137], and it is expected to increase even more by 2030 [131,138,139]. In consequence, there will be a significant deficit of wood. Therefore, the cultivation of energy crops is indicated as the main future direction of securing the growing demand for biomass. It is very likely because the cultivation of such crops is currently subsidized by financial support systems of the EU Common Agricultural Policy. Combining forest biomass resources from forests and plantations will play an important role in the development of energy alternatives. The increase in the available wood potential, including the cultivation of short-rotation energy crops (1–10 years), may result in forest biomass being the main source of energy. However, short-rotation crops are only one of many bioenergy supply options. In the long run, tree species occurring in natural afforested areas with a longer rotation may also secure energy crops. Forest plantations are characterized by different flexibility in the renewal of crop resources, planned harvest flexibility, storage capacity, biomass productivity, and growth rate. The use of these features may be beneficial for the development of a safe and efficient supply of forest bioenergy.

Researchers have used different classifications of the potential of energy biomass resources and a different geographic scope of their intensity. As a result, it is uncertain what the actual potential of energy biomass presented in various studies is. There are also unclear indications referring to the amount of biomass with different fractions available for energy production in individual EU member-states [79,80,131,137–139]. Resource potentials usually depend on technical, economic, or sustainable development (circular) conditions. Subgroups of potentials refer to the practical use of a particular potential over a period of time. The comparison of the results of different estimates of the same biomass resource does not give a clear picture of the resources in a sustainable energy management. The methodological variability and inconsistency in the presentation of energy biomass resources may limit the acquisition of data on the type of the technical potential of biomass for energy production in the EU resources [140,141].

As was signaled in earlier studies, the current amount of forest biomass should be considered in the context of its significant potential in the countries located close to the EU member-states [4,11]. This is economically justified due to the costs of transport. Individual EU member-states have different possibilities to supply biomass. In 2020, the forest area in the EU was 158 million hectares, whereas the total forest area in Europe was 206.5 million hectares [139,142,143]. These data show that there are very large but not fully used forest biomass resources in Europe. Therefore, if the import of biomass is taken into account, then the potential bioenergy resources are likely to increase significantly.

According to scientists, so far, the trade flows of solid biomass between European countries have been small, i.e., about 50 PJ per annum. The largest flow was from the Baltic countries (Poland, Estonia, Latvia, and Lithuania) to the Scandinavian countries, especially Denmark and Sweden, and Finland to some extent [11]. This biomass trade mainly included wood fuel such as wood pellets and briquettes. The current trade of this fuel in Europe was confirmed by the EU Wood Pellet Annual of 2022 [144]. According to this report, the EU is the world's largest market for wood pellets due to the fact that there is higher demand for this fuel for several reasons: housing, the rising prices of fossil fuels, and the modernization of heating systems by both individual customers and industrial entities. The main users of wood pellets in the EU are Italy, the Netherlands, Germany, Denmark, France, Sweden, Belgium, and Austria [144].

The trade of wood pellets is justified mainly due to the fact that it has a higher energy value than other by-products such as woodchips and sawdust, which are traded with problems because of storage and transport. In addition to logistical issues, the import of unprocessed wood products is also limited by phytosanitary regulations, which limit the spread of pests and diseases [145,146].

The real potential of biomass is defined as part of the theoretical potential which is available under given technical and structural conditions and at the current state of the art, conditions, and technological possibilities. Spatial constraints resulting from the competition with other land use types, ecological, and other non-technological aspects are also taken into account in the assessment of available energy biomass resources (share of plantation area biomass in Figure 5). Most of the assumptions indicate the technological potential of agricultural residues, where the total theoretical potential in the EU amounts to about 3 EJ per annum (according to other sources, it is only 0.8 EJ per annum [40,147,148]). Research results [20,77] also indicate a significant potential within forestry resources, where the potential of wood residues ranges from 5.2 EJ per annum to 3.3 EJ per annum. Accordingly [60,149], estimates of the theoretical energy potential of forest biomass range from 7 EJ per annum to at least about 1.7 EJ per annum. As results from the data in reference publications [108] have indicated, the difference between the practical and theoretical potential is 6:11. Some reference materials also provide the sustainable potential of forest biomass. Hetch [47] estimated this potential for the EU-27 at 1.4 EJ per annum. However, this value has now increased to 7.5 EJ per annum. Fischer [15] estimated the potential for Europe without the former Soviet republics at 11.3 EJ per annum, with an upward trend rising to 14.2-18.1 EJ per annum. The EEA [23] estimated the potential for the EU-25 at about 1.8 EJ per annum, which tended to decrease to 1.6 EJ per annum as the European Green Deal was introduced. Although the geographical coverage of energy biomass availability is not identical in the entire EU, these discrepancies point to the diversification level in spite of the fact that the potential of sustainable bioenergy from forest biomass is almost constant.

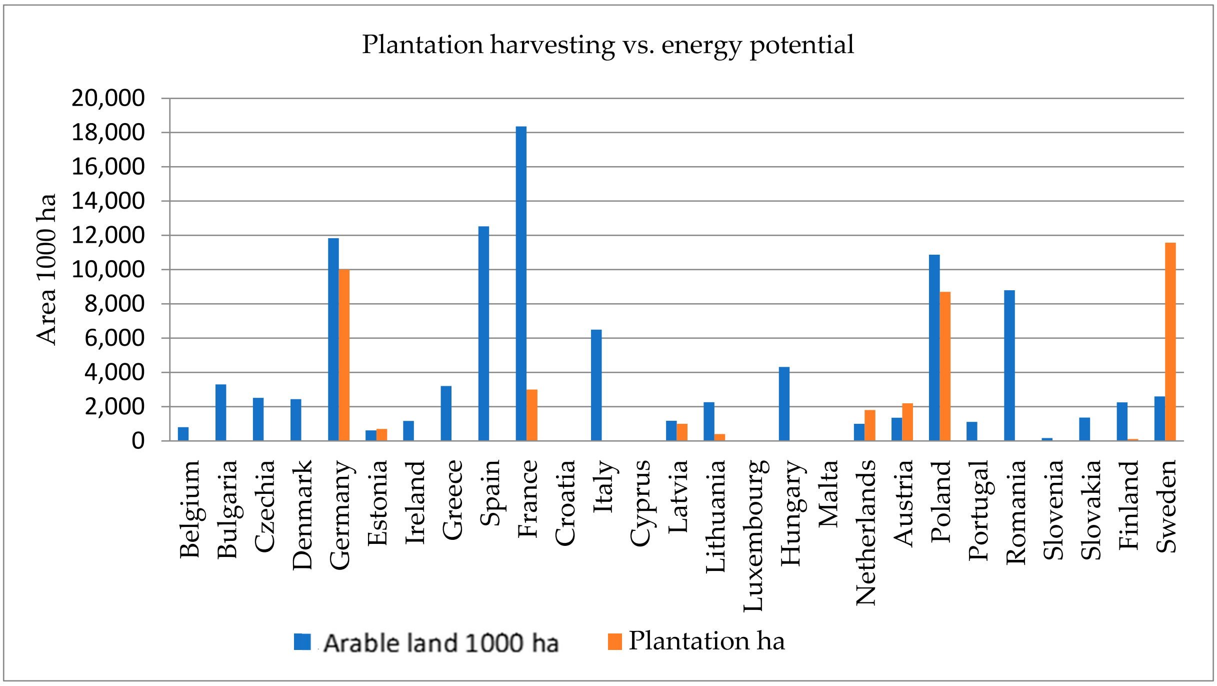

Figure 5. The development of the potential of various dedicated energy crops on arable land or grassland between 2020 and 2022 [149–151].

Due to the high variability of forest and agricultural resources, the geographical coverage makes the direct comparison of individual European countries difficult. Johansson [28] estimated the potential of agricultural residues in Europe after 2025 at 1.41 EJ per annum and the potential of forest biomass and the wood industry at 1.69 EJ per annum. Bauen et al. [19] estimated the potential of plant residues after 2020 at 3.4 EJ per annum and the potential of forest residues at 4.8 EJ per annum [75,77].

4.3. Summary

The current situation in the energy sector shows that access to conventional fuels is more and more limited, and their prices are increasing drastically (Figure 6). This will ultimately increase the share of alternative energy sources. Due to the fact that these actions should be undertaken in a relatively short time, they may and should focus on the processing of readily available and cheap raw materials. Apart from that, due to the applicable EU regulations concerning the reduction of CO_2 emissions and the limited time of implementation of future energy investments, this choice is narrowed down to renewable sources, especially biomass.

An important issue in the scope of work for sustainable development SDGs (Sustainable Development Goals) is the issue of energy-related issues, which promote a useful basis on supporting the transition to a global low-carbon society. Increasing energy access in developing countries is key to cooperation to improve energy efficiency, promote biomass energy, promote clean coal technology, and eradicate energy poverty. It is important to strengthen international cooperation to create an environment conducive to poverty reduction. Further development and deployment of clean coal technologies is important to reduce greenhouse gas emissions and SO_2 and NO_x, as well as to improve air quality, health benefits, and energy efficiency [152–155].

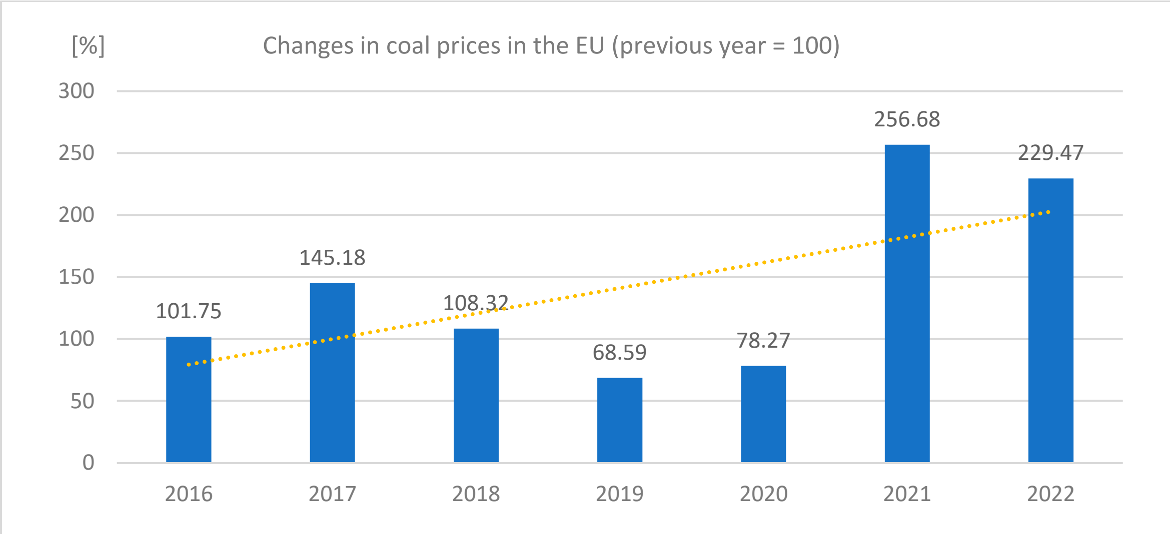

Figure 6. Changes in coal prices on the Rotterdam stock exchange between 2015 and 2022. Source: Authors' original compilation based on [82].

The analysis of the dynamics indicators in Chart 2 reveal considerable fluctuations in coal prices in a relatively short period of time (Figure 7). This could be interpreted as considerable diversification of the demand for this raw material and may indicate market instability. As a result, the increase in coal prices translates into the increase in energy prices. Taking the high uncertainty in the markets into account, it can be assumed that coal prices will remain high in the near future. Therefore, intensified production and the use of bioenergy, especially from biomass, could be a solution to this problem.

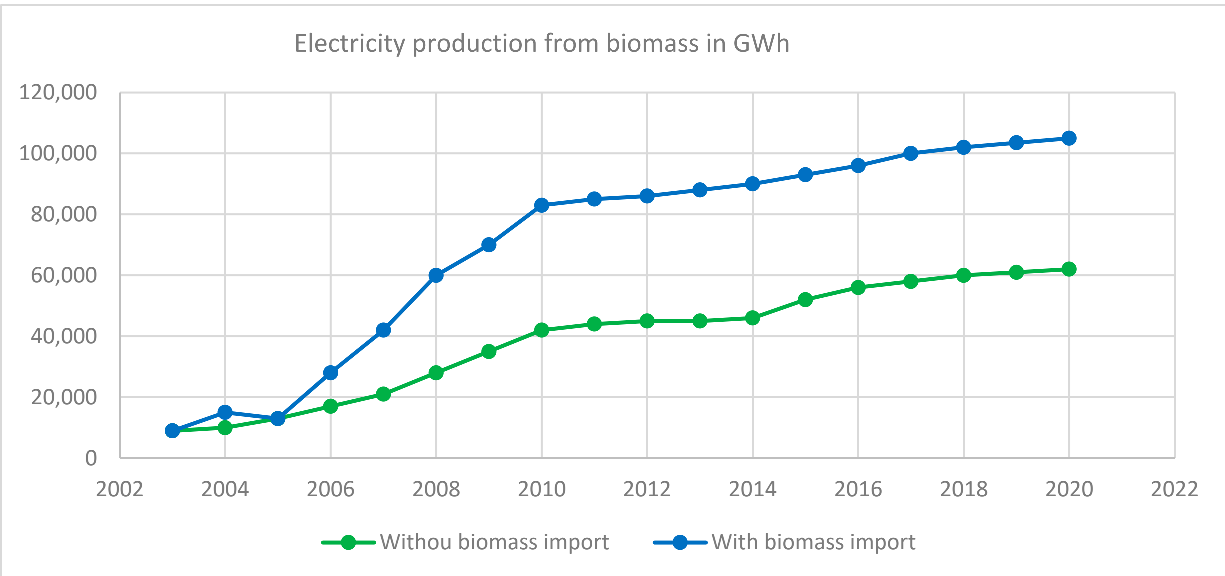

Figure 7. Electricity production from biomass in GWh. Source: Authors' original compilation based on the Eurostat data [108,156].

As results from the observations discussed above, a properly constructed energy mix with a significant share of energy from renewable sources, including biomass, will ensure energy independence in the EU member-states on the condition that well-planned investments are made in this sector. The primary goal should be to guarantee energy stability, ensuring both the continuity of industrial processes and an adequate standard of living for citizens. The next step should involve the generation and securing excess power in the energy mix, because as the current market situation shows, energy surpluses are an excellent currency at the time of crisis. The optimal solution would be to limit such surpluses in the conditions of energy overproduction [157].

Growing demand for bioproducts is being driven by the replacement of fossil fuels with renewable energy sources. Fossil carbonaceous resources produce about 10B tons, and global agriculture and forestry produce 7B tons of biocarbon annually [158,159]. Hence, to replace fossil fuels, global biomass production must double [160]. It should be emphasized that the use of fossil fuels is limited, so it is necessary to move to a sustainable energy system that also takes into account the lower energy content of biomass. Supporting this area are modern technologies for converting woody biomass to renewable energy. The biochemical conversion of biomass and agricultural waste to biogas is also of interest due to its high thermodynamic efficiency [161,162].

It is difficult to produce methane from woody biomass due to its low biodegradability and high contents of structural carbohydrates and lignin. In this case, a pretreatment step is necessary to weaken the lignocellulosic structure and increase susceptibility to enzymatic decomposition [162,163]. Thermal conversion focuses on developing technologies that emit less carbon (e.g., high-efficiency combustion). Such technologies include biomass combustion with power generation and utility heat systems [164]. Particulate emissions from combustion must be controlled when medium and large combustion systems are used. However, these medium and large systems require a large feedstock basin. Seasonal harvesting and transportation distances are often excessive costs of biomass generation. The reason for this is the low bulk density of the resulting biomass and the relatively low hourly output of harvesting machinery [165,166].

5. Conclusions

The current demand for biomass for energy production in the European Union ranges from 10.0 to 15.0 EJ per annum. It is sufficient to satisfy the greater part of the increasing demand. In the future, the amount of agricultural and forest residues should not increase significantly due to the implementation of the European Green Deal. According to the authors, in the near future, the demand for biomass for energy production is likely to increase not only in Europe but also in other regions of the world. However, this requires further technological development and a greater pressure on technology integration to meet the great challenge of securing the energy supply.

Further development of renewable forest and agricultural resources will satisfy the future demand for biomass not only for energy production but also for consumption. It is necessary to increase the production of biomass per unit area and explore the potential of new biomass sources to reduce the pressure on native ecological systems. Further emphasis on the optimal use of various components of energy biomass may improve the usability of biomass and bioenergy and reduce the negative influence of the combustion of fossil fuels on the environment.

In order to ensure energy security, it is necessary to become completely independent from fossil fuels, especially those from Russia. The use of energy from biomass may reduce greenhouse gas emissions and improve energy security as part of the sustainable economic development in the EU.

This paper, due to the very broad scope of the subject, does not show all possible solutions for biomass bioenergy. In subsequent publications, the authors intend to demonstrate the profitability of biomass bioenergy production, taking into account investment costs, and to show the potential of "green" energy, which, generated at production facilities, can be redirected to the needs of local communities. Such solutions, which can be applied from the bottom up, with appropriate regulations, can contribute to an even greater and faster increase in the share of bioenergy in countries and environmental benefits for their residents.

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