energies

Article

The Role of Agricultural Biomass as a Renewable Energy Source in European Union Countries

Dorota Janiszewska * and Luiza Ossowska

Department of Economics, Koszalin University of Technology, 75-343 Koszalin, Poland
* Correspondence: dorota.janiszewska@tu.koszalin.pl

Abstract: The aim of the research is to assess the potential of agricultural biomass available in European Union countries that can be used for energy purposes. The research took into account the potential of agricultural biomass from: straw from cereal crops, hay from permanent grasslands, natural fertilizers from animal husbandry, cultivation of energy crops on fallow land and waste wood from permanent crops. The study estimated the theoretical potential presenting the energy value of all existing agricultural biomass resources in EU countries and the technical potential taking into account agricultural biomass resources that are not used in agriculture. The research was based on Eurostat data for 2019. The conducted research shows that European Union countries are characterized by a significant potential of agricultural biomass. However, due to the high demand for this resource in agriculture, about 15% of the existing potential can be used for energy purposes. Among the analyzed sources, the highest potential is characterized by straw from cereal crops and by the cultivation of energy crops on fallow land. The conducted research also indicates a large spatial differentiation of the potential of agricultural biomass in European Union countries, which may have a negative impact on the economic efficiency of using this renewable energy source.

Keywords: agriculture biomass; energy potential; EU countries

Citation: Janiszewska, D.; Ossowska, L. The Role of Agricultural Biomass as a Renewable Energy Source in European Union Countries. *Energies* **2022**, *15*, 6756. https://doi.org/10.3390/en15186756

Academic Editors: Ioannis Dimitriou, Mark Brown, Biljana Kulisic and Evelyne Thiffault

Received: 29 August 2022
Accepted: 13 September 2022
Published: 15 September 2022

1. Introduction

As emphasized by the European Commission in "A new Circular Economy Action Plan for a cleaner and more competitive Europe", there is only one planet Earth, but by 2050, global consumption will be as large as if there were three [1]. The 2018 OECD communication indicated that by 2060, the consumption of materials such as biomass, fossil fuels, metals and minerals will double, and the amount of waste will increase by 70% [2]. All of this negatively affects the quality of the environment and the size of natural resources, and requires action for a climate-neutral, resource-efficient and competitive economy. Moreover, according to some opinions, the ongoing war between Russia and Ukraine in the geopolitical sense may contribute to the acceleration of the energy transformation [3]. In the face of the crisis, it is crucial to focus on ensuring the continuity of fuels and energy as well as the economic and political security of domestic energy resources [4]. However, the current energy crisis has revealed that the transition to renewable energy is too slow and that serious efforts are needed to accelerate the transition from fossil fuels to renewable energy [5].

Renewable energy for the European Union has long been an important aspect of the functioning of the Community. Already in 1986, one of the first documents on energy in the European Union appeared, which was the Council Resolution on new community goals regarding energy and the divergence of the Member States, which contained a postulate to promote renewable energy sources [6]. Later successes in the use of renewable energy were influenced by a number of introduced reforms of a social and economic nature. One of the most important documents was Directive 2001/77/EC [7], which reflected the declarations and proposals contained in the White Paper "Energy for the future—renewable energy sources" [8]. In this directive, the Community made the promotion of renewable energy sources a priority, mainly due to its positive impact on environmental protection and sustainable development. In contrast, the 2005 Commission Communication [9] referred to the increased use of biomass as a renewable energy source in the energy sector. It was highlighted that biomass has many advantages over conventional energy sources as well as some types of renewable energy. The key document in the field of promoting the use of energy from renewable sources was also Directive 2009/28/EC [10], which considered it appropriate to set mandatory national targets, according to which, in 2020, 20% of energy and 10% of energy in the Community should come from renewable sources in the transport sector. Today, providing clean, affordable and secure energy is one of the key elements of the European Green Deal. In this respect, further decarbonization of the energy system by creating a sector based largely on renewable sources, while at the same time rapidly phasing out coal and reducing the emission of gas [11], was considered crucial for achieving the 2030 and 2050 climate goals. In order to face the emerging challenges (limiting dependence on non-renewable resources, sustainable management of natural resources, food security), the European Union is moving towards a bioeconomy. Bioeconomy should be understood as the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy [12].

The share of energy from renewable sources in European Union countries is growing every year. Over the last 15 years, the share of energy from renewable sources has more than doubled and has amounted to 22.1% in 2020 (10.2% in 2005). The largest share of renewable energy is in Sweden (55.8%), Finland (42.7%) and Latvia (40.9%). Conversely, the lowest share of energy from renewable sources is in Luxembourg (7.0%), Malta (8.2%) and Netherlands (8.9%) [13]. Biomass dominates among renewable energy sources in European Union countries, which is one of the most popular and universal raw materials on earth [14,15]. Biomass in European Union countries currently accounts for 60% of all renewable energy sources and 10% of all energy sources [16]. The largest share of biomass in renewable energy is in Estonia (94%), Latvia (92.4%) and Lithuania (91.1%). A significantly lower share of biomass in renewable energy is found in Malta (9.3%), Cyprus (15.2%) and Ireland (23.5%) [13]. Conversely, the dominant source of biomass in the European Union is woody biomass, the share of which is over 60%. The largest share of forestry in the production of renewable energy is in Estonia, Latvia Lithuania, and the lowest in Malta, Cyprus and Ireland. Agricultural biomass (equally from agricultural crops and agricultural by-products) accounts for 27%. Countries such as the Netherlands, Germany and Belgium produce the most energy from agriculture in the European Union. The least amount of energy from this source is Estonia, Sweden and Bulgaria, while the remaining 12% originates from waste (municipal, industrial, etc.) [17,18].

However, the dominant wood biomass can only continue to play a significant role as a renewable energy source if it is produced and used in a sustainable and efficient manner, taking into account the cascading principle and the European Union's carbon sequestration and biodiversity objectives [19]. According to the EU Biodiversity Strategy for 2030, in order to mitigate the potential climatic and environmental threats related to the use of wood biomass, the use of whole trees for energy production should be minimized [20]. Thus, according to the cascading principle, biomass should be used in the following order: reuse, recycling, bioenergy and disposal. Therefore, the exploitation of biomass that does not violate the aforementioned principle is of interest. According to Alatzas et al. [21], waste, residues and surplus biomass generated in agriculture comply with these criteria, and further research into the possibilities of exploiting this resource raises high hopes. According to a 2009 report by the European Commission, biomass was expected to contribute to around two-thirds of the share of renewable energy [22]. Therefore, according to Scarlat et al. [23], the use of biomass for bioenergy production must take into account the use of all available resources in a sustainable manner without negative impacts. Therefore, only the technical potential of agricultural biomass should be used for energy purposes. As emphasized by Gavrilescu [24], from an ethical point of view, only biomass that does not compete with food production should be used for the production of fuels, energy and heat. Hence, only surplus biomass should be used for energy purposes.

Due to the fact that the current energy crisis forces a quick transition to energy from renewable sources, and taking into account the need to use residual biomass, the aim of the article is an attempt to estimate the potential of agricultural biomass available in the European Union that could be used for energy purposes. On the basis of the estimated potential, the possibility of increasing the share of renewable energy from agricultural biomass was assessed.

2. Literature Review

Biomass provides people with food, fiber and fuel. In addition, it is an essential resource for all animals and microorganisms. The production of biomass replenishes the carbon in soil and vegetation, which is consumed by these animals and microorganisms and returned to the atmosphere [25]. Taking into account the political perspective, the use of energy from biomass can be an attractive option to reduce greenhouse gas emissions and improve energy security [26].

Biomass is derived from a wide range of feedstocks, such as biomass from agriculture (crop residues, bagasse, animal waste, energy crops, etc.), forestry (logging residues, wood processing by-products, black liquor from the pulp and paper industry, fuelwood, etc.), and other types of biological waste (food waste, food industry waste, the organic fraction of municipal solid waste, etc.) [17], whereas agricultural biomass is defined as a subset of biomass produced directly from agricultural activities, including cereal grains, sugar crops, oilseeds, other arable crops and crop by-products such as straw, vegetative grasses, farm forestry (e.g., willow and poplar), and livestock by-products, for example, manure and animal fats [27]. Agricultural biomass has many advantages as a source of renewable energy. The most important of them are the utilization of waste and residues from agricultural activities, reduction of agricultural emissions, the diversity of the use of agricultural biomass (production of heat, electricity, fuels in transport), widespread availability of raw materials and improvement of energy security at the regional level through decentralization of energy production. Moreover, it is possible to obtain additional income from the overproduction of agricultural raw materials and the creation of new jobs [28,29]. However, as emphasized by Daioglou et al. [26], the role of biomass and its benefits depend mainly on the supply chain, including factors such as land use dynamics, the amount and type of fossil fuels replaced, and potential feedbacks in the energy system. However, according to Nakicenovic et al. [30], the future of bioenergy development is influenced by many unpredictable factors, such as: population dynamics, economic development, food demand, feed, fiber and energy services, changes in agricultural and forestry production intensity, land protection decisions, and availability and costs advanced energy conversion technologies. Hence, it is important to analyze possible options for the development of the sector, taking into account the above-mentioned factors.

In this context, biomass will become an increasingly important resource in the bio-fuel farm. However, this will require sustainable management, as biomass comes from many different sectors of the economy that are regulated by different policies [31]. In addition, Hamelin et al. [32] believe that the use of residual biomass is of crucial importance for the European bioeconomy. Similarly, Kluts et al. [33] and Haase et al. [34] consider that biomass residues from primary, secondary and tertiary economic activities play a key role in providing the raw materials needed to create sustainable bio-farm pathways. Additionally, as indicated by Tonini et al. [35] and Hamelin et al. [36], the use of biomass as the main bioeconomy feedstock has a lower environmental impact than that produced on land. In addition, the residual biomass is an unused potential that can increase the resources of biomass that can be used for energy purposes [34,37].

Imperial College London [38] in its report, *Sustainable biomass availability in the EU to 2050*, described three possible scenarios for the use of biomass for energy purposes.

Scenario I provides for a low mobilization of biomass, assuming that agricultural practices will be at the level of 2020, approx. 25% of unused, abandoned and degraded land will be usable for biomass cultivation, and the main emphasis will be on the use of residues and waste in the bioenergy and non-energy sectors. Scenario II assumes improved mobilization of biomass in selected countries through improved agricultural practices (improving soil and biomass productivity), the use of approx. 50% of unused, abandoned and degraded land for biomass cultivation, and an emphasis on the use of waste residues in the bioenergy and non-energy sectors. Conversely, scenario III assumes increased availability due to R + I and improved mobilization through improved management practices in agriculture, the use of approx. 75% of unused, abandoned and degraded land for the cultivation of biomass; better research and innovation leading to higher yields, efficiency of harvesting equipment and emphasis on the use of residues and waste in the energy and non-energy biocomponents sectors.

As Tripathi [39] emphasizes, due to the intensification of agricultural and industrial activities caused by the growing population and its growing demand for food and other basic products, waste is a growing problem. Both the neutralization, utilization and methods of managing agricultural waste are inefficient and rarely used. Moreover, especially in developing countries, most of the biomass residues are left as organic matter in the field or are burned in the open, which has a negative impact on the environment. In addition, according to Vaish et al. [40], biomass sources are still underused, mainly due to the lack of standard national resource estimation policies. Therefore, there is a need to use alternative, sustainable energy sources and the supply of raw materials. According to Odavic et al. [41], the low level of utilization of the existing biomass potential from agricultural production may be caused by the low energy value of this resource per unit of transport volume and too large spatial dispersion. Waste from this source is underused, and thus far, there has not been much research focused on this issue. However, the available studies indicate a significant role of agricultural biomass in the production of energy from renewable sources in European Union countries.

Research by Ericsson and Nilsson [42] indicates that agricultural policy in the European Union will be a key factor for the future of bioenergy. According to the authors, the greatest potential in Europe is in the field of energy crops. Moreover, as the authors emphasize, due to the surplus of food production in European Union countries, this source of biomass may be an interesting alternative to food crops. Additionally, the analyses carried out also indicate that the potential biomass resources in European Union countries are unevenly distributed. Scarlat et al. [23] indicated that in European Union countries, there is a significant potential in terms of production and in the use of agricultural crop residues for energy purposes. According to the authors, this source of biomass may play an important role in sustainable energy production; however, when using it, certain limitations of this source should be taken into account, i.e., resources, logistics, technological, economical and social, which affect the security and continuity of biomass supplies. Moreover, the authors also emphasize that due to different geographic and climatic conditions and the status of agriculture activities, agricultural crop residues available for bioenergy in each European Union country show large spatial and temporal differences. Hamelin et al. [32] made a detailed analysis of the theoretical potential of biomass residues for energy purposes in the European Union. In their analysis, the authors took into account the biomass from: agriculture (straw, manure, residues from pruning permanent plantations); forestry (forestry residues); urban greenery management (residues from managing urban green areas and roadside vegetation); and food waste (agri-industrial food process waste and municipal biodegradable waste). The conducted research shows that straw from cereal cultivation is the main source of biomass that can be used in the European Union. This type of biomass accounts for about 8% of the marginal energy consumption in the European Union.

Agricultural biomass is also of interest to the authors who conducted research on its potential outside Europe. Research by Demirel et al. [43] in Sudan also indicates that the amount of biomass from agricultural waste is significant, which is the basis for energy production from this source. Due to this source, it is possible to reduce the energy shortage problems in the country. In addition, in these studies, biomass density varies depending on the crops and regions of Sudan. Vaish et al. reached similar conclusions in their research [40], as they conducted research on the potential of biomass remaining in crops in the agricultural provinces of India. According to the authors, the existing surplus of agricultural biomass has enormous potential to contribute to energy generation applications and to increase the total installed capacity of renewable sources in the country. Research by Mohammed et al. [44] in Ghana also indicates that the country has adequate bioenergy potential, giving high hopes for future energy supplies in the country. It is similar in other African countries, such as: Nigeria [45], Madagascar [46] or the countries of North Africa [47]. Researchers also point out that energy consumption from biomass lowers carbon emissions. Analyses of the potential of agricultural biomass were also carried out by Odavić et al. [41]. The authors' research carried out on the example of the Serbian region shows that this area also has a significant potential for biomass from agricultural production. For Serbia, the development of the domestic energy market is an important factor in achieving a competitive national economy and energy independence. It is an example of interest in energy from agricultural biomass in European but non-EU countries.

However, despite the significant role and significance of the analyzed renewable energy source indicated in various studies, the potential of biomass from agriculture cannot be perceived as a constant value over time, but rather as dynamic under the influence of changes in many factors and characteristics. These features include mainly: the amount of available agricultural land, the structure of crops, allocation of energy crops, the learning curve effect and the impact of climate change [48].

3. Study Context and Methods

The paper assesses the theoretical and technical potential of agricultural biomass. The theoretical potential should be understood as the entire amount of agricultural biomass that is produced in a given area and its energy value, regardless of the way it is used and the possibility of obtaining it. Conversely, the technical potential is the amount of agricultural biomass reduced by the amount used for purposes other than energy, which can be obtained under specific technologies, taking into account the energy efficiency of devices converting the raw material into usable energy [49,50].

The theoretical and technical potential has been estimated for such sources of agricultural biomass as: straw from arable land, hay from permanent grasslands, energy crops grown on fallow land, waste wood from permanent crops (orchards) and natural fertilizers from livestock farming.

The subjective scope of the study covers 28 European Union countries. The survey was based on data published by Eurostat for 2019. Due to the lack of available data, the area of fallow land was assumed for 2016.

The theoretical potential of straw for energy purposes was estimated on the basis of cereal cultivation area, grain yield, straw yield to grain yield ratio and straw energy value. The following formula was used:

$$P = \sum_{i=1}^{n} A \cdot Y \cdot w_{zs} \cdot 13 \times 80\% \quad (1)$$

where: P—straw potential, A—cultivation area of a given plant species (ha), Y—actual grain yield of a given plant species (t/ha), w_{zs}—ratio of straw yield to grain yield, 13 GJ/t—straw energy value.

When estimating the theoretical potential of straw, the following plants were taken into account: wheat, rye, barley, oats, triticale, cereal mixtures, maize and rape. For individual plants, the following ratios of straw yield to grain yield were adopted: wheat—1:0.8; rye—1:1.4; barley—1:0.90; triticale—1:0.8; oats—1:1.05; corn—1:1.5; cereal mixtures—1:0.95; rapeseed—1:1.0 [51].

The technical potential of straw that can be used for energy purposes was estimated taking into account the demand for straw in agriculture (forage, bedding and fertilizing purposes), the energy value of straw and the efficiency of devices converting straw into energy. The following formula was used [52]:

$$N = P - \left(Z_s + Z_p + Z_n\right) \cdot 13 \times 80\% \quad (2)$$

where: N—excess straw for alternative (energy) use, P—production of straw from cereals, Zs—demand of straw for bedding, Zp—demand of straw for fodder, Zn—demand for straw for fertilization purposes, 13 GJ/t—energy value straw, 80%—the efficiency of devices.

The following normative annual feed requirements of straw were adopted: cattle: 1.0; pig: 0.0; sheep: 0.2; horses: 0.8, whereas the standards for bedding: cattle: 0.75, pigs: 0.35, sheep: 0.2, horses: 1.0. [53]. The straw dose for fertilizing purposes was assumed at the level of 1.17 t/ha per year [54].

The theoretical potential of hay for energy purposes was calculated on the basis of the area of permanent grassland, average hay yield, energy value of hay and the efficiency of equipment. The following formula was used [55]:

$$P_{ts} = A \cdot Y \cdot 13.4 \times 80\% \quad (3)$$

where: P_{ts}—theoretical potential of hay; A—area of permanent grassland, 13.4 GJ/t—energy value of hay; 80%—equipment efficiency.

The technical potential of hay that could be used for energy purposes was estimated taking into account the demand for hay in agriculture (forage purposes). The following formula was used [55]:

$$P_{ces} = P_{ts} - (DJP_s \cdot S_k) \cdot 13.4 \times 80\% \quad (4)$$

where: P_{ces}—technical potential of hay, P_{ts}—theoretical potential of hay, DJPs—number of large units of conversion of animals, 13.4 GJ/t—energy value of hay; 80%—equipment efficiency.

The average yield of hay from permanent grassland was assumed at the level of 5t/ha [56,57]. Physical units of ruminants were converted into large units according to the following indicators: cattle—0.8; sheep—0.1; goats—0.1 [49]. Moreover, the daily dose of hay per LU was assumed at the level of 20 kg, i.e., per year (assuming a reserve of 20%) of 8.76 t/LU [55].

In order to estimate the theoretical potential of plantations of perennial energy crops (e.g., willow), the following formula was used:

$$P_{re} = A_{gp} \cdot Y_{re}\ (t/ha) \cdot 18\ (GJ/t) \cdot 80\% \quad (5)$$

where: P_{re}—potential of perennial plants intended for energy purposes, A_{gp}—area of land suitable for cultivation of energy crops (ha), Y_{re}—average yield of selected energy crops (ts m/ha/year), 18 GJ/t—energy value of willow, 80%—efficiency of biomass combustion devices.

The average yield of energy crops was assumed at the level of 8 t/ha, while fallow land was assumed as the acreage of land that could be used for the cultivation of energy crops. It was assumed that only 50% of fallow land can be used for the cultivation of plants for energy purposes. Therefore, the technical potential is half of the theoretical potential.

The theoretical potential of agricultural biomass from annual sanitary cuts or the liquidation of orchards was estimated using the following formula [58]:

$$Z_{ds} = A \cdot u_d \cdot w_e \cdot 80\%\ (GJ/year) \quad (6)$$

where: Z_{ds}—energy potential of orchard waste wood resources (GJ), A—orchard area (ha), u_d—waste wood yield (in m^3) from 1 ha of orchards, e—energy value of wood, 80%—equipment efficiency.

It was assumed that 0.35 tons of wood can be obtained from 1 ha of orchards, while one ton of biomass with a moisture content of 40% corresponds to the calorific value (calorific value) of 9.9 GJ, while the efficiency of the devices is 80% [55]. Due to the fact that this type of biomass is not used in food production, the technical potential is equal to the theoretical one.

The theoretical potential of agricultural biomass from animal production, i.e., natural fertilizers, was estimated on the basis of the number of livestock in LU, the estimated amount of fertilizer generated by the conversion unit, methane content in biogas and the energy value of biomethane. The following formula was used for the calculations [58]:

$$P_{br} = L \cdot W_{bsd} \cdot 365 \cdot z_{CH4} \cdot w_{em} \cdot 80\% \text{ (MJ/year)} \quad (7)$$

where: P_{br}—agricultural biogas potential (m^3), L—DJP number, W_{bsd}—biogas production index per DJP (m^3 DJP-1 $^{d-1}$), z_{CH4}—methane content in biogas (vol.%), w_{em}—energy value of m^3 of biomethane (MJ), 80%—equipment efficiency.

The following norms were adopted to convert the livestock population into LU: cattle—0.8; pig—0.3; poultry—0.02. The biogas production index per LU was adopted at the level of: cattle—1.5; pig—1.0; poultry—3.75. The methane content in biogas was assumed to be 57%, while the energy value of biogas was 36 MJ [55].

To estimate the technical potential of biomass from animal husbandry, which can be used for energy purposes, the theoretical potential was reduced by the demand for natural fertilizers in plant production. For this purpose, after estimating the production volume of natural fertilizers, the share of individual fractions of organic fertilizer was determined. Then, the nitrogen content in each fraction was estimated (Table 1).

Table 1. Shares of manure, liquid manure, slurry and straw manure in animal excreta (in%) and its nitrogen content (kg N/t).

Type of Breeding	Manure		Liquid Manure		Slurry		Straw Manure	
	%	kg N · t^{-1}	%	kg N · t^{-1}	%	kg N · t^{-1}	%	kg N · t^{-1}
Cattle	27	6.39	5	4.61	41	5.3	27	9.74
Pig	8	11.09	5	3.08	84	4.31	3	2.41
Poultry	0	0	0	0	3	6.18	97	19.86

Source: [50].

The demand for natural fertilizers for fertilizing the area under cultivation was assumed at the level of 85 kg N/ha—optimistic scenario [55]. After the performed calculations, the amount of natural fertilizers that could be used for energy purposes was assessed.

4. Results

The conducted research shows that the theoretical potential of agricultural biomass in European Union countries in 2019 was at the level of 198.3 thousand Ktoe, including 41.2% of the potential coming from straw, 40.0% of the potential of hay from permanent grasslands, 10.5% of the potential of natural fertilizers from animal husbandry, 7.9% of energy plantation (e.g., willow) and 0.4% of waste wood from permanent crops. In individual European Union countries, the theoretical potential from all analyzed sources of agricultural biomass in 2019 ranged from 6.4 to 34,528.5 Ktoe, with an average of 7082.9 Ktoe. The smallest countries of the European Union had the lowest potential, such as Malta—6.4 Ktoe, Cyprus—76.1 Ktoe and Luxembourg—160.5 Ktoe. Conversely, the greatest potential was recorded for France—34,528.5 Ktoe, Spain—23,632.4 Ktoe and the United Kingdom—22,194.9 Ktoe (Table 2). The three countries mentioned accumulated over 40% of the overall theoretical potential of agricultural biomass in the European Union.

Table 2. The theoretical potential of agricultural biomass in EU countries in 2019.

Country	Theoretical Potential of Agricultural Biomass					Total
	Straw from Cereal Crops	Permanent Grassland Hay	Natural Fertilizers from Animal Husbandry	Growing Energy Crops on Fallow Land	Waste Wood from Permanent Crops	
	Ktoe					
Belgium	650.2	608.7	655.3	25.2	1.3	1940.7
Bulgaria	3023.1	1803.2	120.6	339.9	10.1	5296.8
Czechia	1988.2	1269.8	291.6	51.2	2.7	3603.5
Denmark	2317.9	264.6	799.0	93.4	1.6	3476.6
Germany	9822.5	6082.8	3019.8	858.4	13.2	19,796.7
Estonia	406.8	370.2	55.4	45.9	0.3	878.6
Ireland	508.8	5223.9	1164.0	9.1	0.1	6905.9
Greece	773.0	2728.8	121.8	349.2	79.3	4052.1
Spain	4981.8	9289.5	2460.5	6570.8	329.8	23,632.4
France	17,323.3	12,303.5	3570.8	1261.3	69.6	34,528.5
Croatia	1137.7	776.0	115.2	50.2	4.9	2084.0
Italy	4042.9	4854.4	1442.7	1039.6	159.9	11,539.5
Cyprus	12.9	2.0	28.2	31.1	1.8	76.1
Latvia	778.6	809.0	80.6	145.1	0.6	1813.8
Lithuania	1260.4	930.9	129.7	187.3	2.0	2510.3
Luxembourg	37.3	86.9	35.5	0.6	0.1	160.5
Hungary	4789.0	1011.9	272.8	387.2	11.3	6472.2
Malta	0.0	0.0	3.9	2.4	0.1	6.4
Netherlands	341.1	982.6	1136.3	20.3	2.5	2482.8
Austria	1545.1	1611.5	430.8	138.0	4.4	3729.9
Poland	7445.9	4004.3	1548.3	455.7	22.5	13,476.7
Portugal	325.8	2402.9	383.0	692.7	51.6	3856.0
Romania	9326.3	5693.8	486.2	1069.1	20.8	16,596.3
Slovenia	195.3	355.6	91.7	2.9	1.8	647.3
Slovakia	1204.6	663.7	99.4	122.1	1.2	2091.0
Finland	957.5	30.1	186.5	500.7	0.2	1675.1
Sweden	1433.6	590.5	296.6	474.6	0.2	2795.6
United Kingdom	5106.0	14,594.4	1800.3	691.8	2.4	22,194.9
Sum	81,735.8	79,345.5	20,826.4	15,616.0	796.5	198,320.1
Share %	41.2	40.0	10.5	7.9	0.4	100.0

Source: author's own elaboration.

However, the biomass generated in animal and plant production is widely used in agriculture; therefore, to estimate the real potential that can be used for energy purposes, the theoretical potential should be reduced by this demand. After taking into account the needs of agriculture, the potential of agricultural biomass that can be used for energy purposes is only 15.4% of the theoretical potential (Table 3). The greatest share in the estimated technical potential of agricultural biomass is that of straw—65.5%, and the potential of energy crops—25.6%. A much lower share was recorded for the potential of natural fertilizers—4.3%, waste wood—2.6% and hay—1.9%. Conversely, in individual European Union countries, the technical potential of all analyzed sources of agricultural biomass ranged from 0.4 to 5780.5 Ktoe. However, the average was 1089.6 Ktoe. The lowest potential of all analyzed sources of agricultural biomass was recorded in Luxembourg—0.4 Ktoe, Malta—1.3 Ktoe and Slovenia—3.3 Ktoe. Conversely, the highest potential was in Romania—5780.5 Ktoe, France—5219.9 Ktoe and Spain—3615.2 Ktoe. The three mentioned countries accumulate almost 50% of the total potential from all sources of agricultural biomass in the European Union.

Table 3. Technical potential of agricultural biomass in EU countries in 2019.

Country	Technical Potential of Agricultural Biomass					Total
	Straw from Cereal Crops	Permanent Grassland Hay	Natural Fertilizers from Animal Husbandry	Growing Energy Crops on Fallow Land	Waste Wood from Permanent Crops	
	Ktoe					
Belgium	0.0	0.0	30.8	12.6	1.3	44.7
Bulgaria	1962.9	518.6	0.0	170.0	10.1	2661.6
Czechia	732.2	0.0	0.0	25.6	2.7	760.5
Denmark	20.1	0.0	0.0	46.7	1.6	68.4
Germany	390.6	0.0	0.0	429.2	13.2	833.0
Estonia	132.9	0.0	0.0	23.0	0.3	156.2
Ireland	0.0	0.0	907.9	4.5	0.1	912.6
Greece	0.0	0.0	0.0	174.6	79.3	253.9
Spain	0.0	0.0	0.0	3285.4	329.8	3615.2
France	4519.6	0.0	0.0	630.7	69.6	5219.9
Croatia	633.4	0.0	0.0	25.1	4.9	663.4
Italy	0.0	0.0	0.0	519.8	159.9	679.7
Cyprus	0.0	0.0	0.0	15.5	1.8	17.3
Latvia	314.6	74.6	0.0	72.5	0.6	462.4
Lithuania	460.1	0.0	0.0	93.6	2.0	555.8
Luxembourg	0.0	0.0	0.0	0.3	0.1	0.4
Hungary	3215.2	0.0	0.0	193.6	11.3	3420.1
Malta	0.0	0.0	0.0	1.2	0.1	1.3
Netherlands	0.0	0.0	375.0	10.1	2.5	387.6
Austria	180.3	0.0	0.0	69.0	4.4	253.7
Poland	1066.7	0.0	0.0	227.9	22.5	1317.0
Portugal	0.0	0.0	0.0	346.4	51.6	397.9
Romania	5225.1	0.0	0.0	534.6	20.8	5780.5
Slovenia	0.0	0.0	0.0	1.5	1.8	3.3
Slovakia	665.5	0.0	0.0	61.1	1.2	727.7
Finland	166.5	0.0	0.0	250.3	0.2	417.1
Sweden	311.6	0.0	0.0	237.3	0.2	549.2
United Kingdom	0.0	0.0	0.0	345.9	2.4	348.3
Sum	19,997.4	593.2	1313.7	7808.0	796.5	30,508.8
Share %	65.5	1.9	4.3	25.6	2.6	100.0

Source: author's own elaboration.

The theoretical potential of straw from cereal crops was 81.7 thousand Ktoe, while in individual EU countries, the potential from this source ranged from 0 to 17,323.3 Ktoe, with the average being 2919.1 Ktoe. The lowest potential of this biomass source was recorded in such countries as: Malta—0.0 Ktoe, Cyprus—12.9 Ktoe and Luxembourg—37.3 Ktoe. Conversely, a much greater potential from straw was recorded in France—17,323.3 Ktoe, Germany—9822.5 Ktoe and Romania—9326.3 Ktoe. Taking into account the demand for straw in agriculture, the technical potential of this source of agricultural biomass was 20 Ktoe, i.e., 24.5% of the theoretical potential. After taking into account the demand for straw in agriculture (the demand for litter, fodder and fertilizer needs), it also turned out that in 12 out of 28 countries, there are shortages, which means there is no potential to be used for energy purposes. In individual EU countries, the technical potential of straw from cereal crops ranged from 0 to 5225.1 Ktoe. The average for EU countries was 714.2 Ktoe. The highest straw surplus that can be used for energy purposes was recorded in Romania—5225.1. Ktoe, France—4519.6 Ktoe and Hungary—3215.2 Ktoe.

The theoretical potential of hay from permanent grassland was 79.3 thousand Ktoe. In individual European Union countries, the potential from this source ranged from 0 to 14,594.4 Ktoe, with the average being 2833.8 Ktoe. The countries with the lowest potential were: Malta—0.0 Ktoe, Cyprus—2.0 Ktoe and Finland—30.1 Ktoe. Conversely, the highest potential from this source was recorded in the United Kingdom—14,594.4 Ktoe, France—12,303.5 Ktoe and Spain—9289.5 Ktoe. After taking into account the demand for hay in agriculture (forage purposes), it was estimated that the technical potential was at the level of 593.2 Ktoe and constituted only 0.7% of the theoretical potential. Of the 28 countries surveyed, 26 have shortages of hay; therefore, the possibilities of using hay for energy purposes in European Union countries are small. Countries with surplus hay that can be used for energy purposes are Latvia—74.6 Ktoe and Bulgaria—518.6 Ktoe.

The theoretical potential of natural fertilizers from animal husbandry was 20.8 thousand Ktoe. However, in individual countries of the European Union, the potential from this source was quite varied and ranged from 3.9 to 35,570.8 Ktoe. However, the average for all countries was 743.8. The lowest potential was found in the countries of the European Union that were the smallest in terms of area, i.e., Malta—3.9 Ktoe, Cyprus—28.2 Ktoe and Luxembourg—35.5 Ktoe. A much higher potential was recorded in France—35,570.8 Ktoe, Germany—30,019 Ktoe and Spain—2460.5 Ktoe. Due to the high demand for natural fertilizers in agriculture (in plant production), the technical potential was estimated at the level of 1.3 thousand Ktoe, which was only 6.3% of the theoretical potential. Only in 3 out of 28 countries, the potential that could be used for energy purposes from this source was observed. Countries with a potential for energy use are Ireland—907.9 Ktoe, Netherlands—375.0 Ktoe and Belgium—30.8 Ktoe.

The theoretical potential of energy crops grown on fallow land was estimated at 15.6 thousand Ktoe. In individual European Union countries, it ranged from 0.6 to 6570 Ktoe, with an average of 577.7 Ktoe. The lowest potential from the analyzed source was recorded in Luxembourg—0.6 Ktoe, Malta—2.4 Ktoe and Slovenia—2.9 Ktoe. Conversely, the highest potential from this source was estimated for Spain 6570.8 Ktoe, France—1261.3 Ktoe and Romania—1069.1 Ktoe. Due to the fact that it was assumed that not all fallow land can be used for plant cultivation for energy purposes, the technical potential was estimated at 7.8 thousand Ktoe, which is 50% of the theoretical potential. In individual European Union countries, the technical potential from this source ranged from 0.3 to 3285.4 Ktoe, with the average being 278.9 Ktoe. The lowest potential was recorded in Luxembourg—0.3 Ktoe, Malta—1.2. Ktoe and Slovenia—1.5 Ktoe. Conversely, the highest technical potential of agricultural biomass from this source was recorded in Spain—3285.4 Ktoe, France—630.7 Ktoe and Romania—534.6 Ktoe.

Theoretical potential from permanent crop waste wood was 796.5 Ktoe. In individual European Union countries, the potential from this source ranged from 0.1 to 329.8 Ktoe, with the average for all analyzed units being 28.4 Ktoe. The lowest potential from the analyzed source was recorded in Malta—0.1 Ktoe, Luxembourg—0.1 Ktoe and Ireland—0.1 Ktoe. Conversely, the highest potential from this source was recorded in Spain—329.8 Ktoe, Italy—159.9 Ktoe and Greece—79.3 Ktoe. Due to the fact that this source of agricultural biomass does not compete with food production, the size of the technical potential is the same as the theoretical one.

5. Discussion

In accordance with the aim of the research, an attempt was made to estimate the potential of agricultural biomass available in European Union countries that can be used for energy purposes. The research took into account the technical potential of agricultural biomass derived from: straw from cereal crops, hay from permanent grasslands, natural fertilizers from animal husbandry, cultivation of energy crops on fallow land and waste wood from permanent crops. The conducted research shows that agricultural biomass is the potential that can be used for energy purposes. This is also confirmed by the studies of other authors who dealt with the problem of biomass potential in the European Union [23,32]. Similar conclusions were also reached by authors conducting research on the potential of biomass in other parts of the world [40,41,43,44]. Therefore, it is necessary to agree with both Ericsson and Nilsson [42] that European agricultural policy will be an important element of the energy of the future, and Hamelin et al. [32], Kluts et al. [33] and Haase et al. [34] that residual biomass is crucial for the European bioeconomy.

However, as Gavrilescu [24] points out, the use of agricultural biomass for energy purposes cannot conflict with food production. This is especially important in areas with limited food production capacity, such as African countries [45–47], but it is also important for EU countries. Therefore, taking into account the needs of agriculture for biomass, the conducted research shows that in practice, about 15% of the identified potential can be used for energy production. Among the analyzed sources, straw from cereal crops is characterized by the greatest potential that can be used for energy purposes. This is also confirmed by studies conducted by other researchers [23,32]. This type of biomass accounts for as much as 65.5% of the identified technical potential. The second largest identified source of biomass that can be used is the cultivation of fast-growing energy crops. This resource accounts for 25.6% of the identified potential. The analyses carried out on the use of this source for energy purposes concerned only crops on fallow land, so as not to create competition for food production. However, research by Daioglou [26] indicates that this resource could be used more widely, but it would require increasing the productivity of both plant and livestock production. The author pays special attention to the possibility of increasing the availability of pastures, which are highly productive land for biomass production.

The conducted research also shows that in European Union countries, there is quite a large spatial differentiation in terms of the potential of agricultural biomass available for energy purposes. This problem was also noticed by other researchers [23,32,42]. Therefore, there may be some doubt about the use of this resource for energy purposes in the economic context. However, as emphasized by Odavić [41], apart from economic aspects, one should take into account the environmental and social effects that the development of this branch of the economy may bring for the local community, especially those related to rural areas.

Based on the research results obtained, it can be concluded that agricultural biomass is a promising and prospective source for energy production, which may reduce the negative environmental impact of the energy sector. This applies not only to EU countries, but also to other European countries, as well as to the whole world, such as Serbia [41] or African countries [45–47]. Moreover, referring to the discussion on the energy crisis [3–5], biomass is a source of energy that is not only renewable, but also local, contributing to building energy independence. However, the studies conducted have their limitations. First, the research was carried out on the basis of secondary data, which are a limited resource about the studied phenomenon. Second, due to the specificity of the surveyed countries (e.g., the diversification of the agricultural potential), there are difficulties in standardizing the studied phenomenon. Additionally, agreeing with Kńapek et al. [48], in order to obtain adequate energy efficiency and production continuity, it is also necessary to conduct further analyses not only in terms of static but also in dynamic terms, concerning the spatial differentiation and variability of the availability of agricultural biomass that can be used for energy purposes. Moreover, for application purposes, future research should also focus on a more detailed regional and local analysis of the existing potential of agricultural biomass.

6. Conclusions

The analysis of the literature shows that the use of agricultural biomass for energy purposes brings many benefits of an economic, social and environmental nature. The estimates made indicate a significant potential of agricultural biomass. However, due to the variety of uses of biomass in agriculture, only a small part of the existing potential can be used for energy purposes. The total potential that can be used for energy purposes was estimated at 30.5 thousand Ktoe, of which 65.5% is the potential of straw from cereal crops, 25.6% the potential of energy crops grown on fallow land, 4.6% natural fertilizers from animal husbandry, 2.6% waste wood from permanent crops, and 1.9% permanent pasture hay. However, from the point of view of many variables that affect the use of biomass for energy purposes, such as the amount of available agricultural land, the structure of crops, the allocation of energy crops and climate change, perceived by various researchers, there are still doubts as to its widespread use as a source of renewable energy.

Due to the current geopolitical situation, interest in renewable energy sources in Europe is growing, and this also applies to agricultural biomass. This geopolitical situation will probably contribute to an increase in energy production from agricultural biomass in the near future. Agricultural biomass is a fairly stable source of raw material, because regardless of the situation, agricultural production must be carried out for nutritional purposes, whereas according to the adopted assumptions, only agricultural waste left after the use of raw materials for nutritional purposes can be used for energy production. Agricultural biomass may turn out to be much more resistant to energy crises also due to its local nature.

Author Contributions: Conceptualization, D.J. and L.O.; methodology, D.J. and L.O.; software, D.J. and L.O.; formal analysis, D.J. and L.O.; investigation, D.J. and L.O.; resources, D.J. and L.O.; data curation, D.J. and L.O.; writing—original draft preparation, D.J. and L.O.; writing—review and editing, D.J. and L.O.; visualization, D.J. and L.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commision. *A New Circural Economy Action Plan for a Cleaner and More Competitive Europe*; COM (2020) 98 Final; European Commission: Brussels, Belgium, 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A98%3AFIN (accessed on 10 November 2021).
2. Global Material Resources Outlook to 2060, OECD, 2018. Available online: https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf (accessed on 10 November 2021).
3. Żuk, P.; Żuk, P. National energy security or acceleration of transition? Energy policy after the war in Ukraine. *Joule* **2022**, *6*, 703–712. [CrossRef]
4. Agaton, C.B. Will a Geopolitical Conflict Accelerate Energy Transition in Oil-Importing Countries? A Case Study of the Philippines from a Real Options Perspective. *Resources* **2022**, *11*, 59. [CrossRef]
5. Hosseini, S.E. Transition Away from Fossil Fuels Toward Renewables: Lessons from Russia-Ukraine Crisis. *Future Energy* **2022**, *1*, 2–5. [CrossRef]
6. Council Resolution of 16 September 1986 Concerning New Community Energy Policy Objectives for 1995 and Convergence of the Policy of the Members States, OJ C 241. Available online: https://eur-lex.europa.eu/legal-content/SV/ALL/?uri=CELEX:31986Y0925(01) (accessed on 10 November 2021).
7. *Directive 2001/77/EC of the European Parliamentn and of the Council of 27 September 2001 on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market*; Council of the European Union: Brussels, Belgium, 2001. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0077&from=ES (accessed on 10 November 2021).
8. *Energy for the Future: Renewable Sources of Energy—White Paper for a Community Strategy and Action Plan*; COM (97) 599 Final; European Commission: Brussels, Belgium, 1997. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A51997DC0599 (accessed on 10 November 2021).
9. *Biomass Action Plan*; COM (2005) 628 Final; European Commission: Brussels, Belgium, 2005. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0628:FIN:EN:PDF (accessed on 10 November 2021).
10. *Directive 2009/28/EC of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC*; Council of the European Union: Brussels, Belgium, 2009. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF (accessed on 10 November 2021).
11. European Commission. *The European Green Deal*; COM (2019) 640 Final; European Commission: Brussels, Belgium, 2019. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A52019DC0640 (accessed on 10 November 2021).
12. Liebert, M.A. Innovating for sustainable growth: A Bioeconomy for Europe. *Ind. Biotechnol.* **2012**, *8*, 57. [CrossRef]

13. European Comission. *Energy, Transport and Environment Statistics*, 2020th ed.; Publication Office of the European Union: Luxembourg, 2020; pp. 10–40. Available online: https://ec.europa.eu/eurostat/web/products-statistical-books/-/ks-dk-20-001 (accessed on 30 November 2021).
14. Țenchea, A.I.; Tokar, D.M.; Foris, D. The use of biomass as a renewable energy source in a fluidized bed combustion plant. *Bull. Transilv. Univ. Braşov Ser. II For. Wood Ind. Agric. Food Eng.* **2019**, *12*, 117–126. [CrossRef]
15. Janiszewska, D.; Ossowska, L. Biomass as the Most Popular Renewable Energy Source in EU. *Eur. Res. Stud. J.* **2020**, *23*, 315–326. [CrossRef]
16. Raport: Bioenergy Landscape. Brussels 2019. Available online: https://bioenergyeurope.org/article/275-bioenergy-landscape-2.html (accessed on 10 November 2021).
17. The European Commission's Knowledge Centre for Bioeconomy. European Union 2019. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC109354 (accessed on 10 November 2021).
18. European Commission. *Cap Context Indicators 2014–2020*; Agriculture and Rural Development; European Commission: Brussels, Belgium, 2017; pp. 190–191.
19. European Commission. *New EU Forest Strategy for 2030*; COM (2021) 572 Final; European Commission: Brussels, Belgium, 2021. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0572&from=EN (accessed on 10 November 2021).
20. Europian Commision. *EU Biodiversity Strategy for 2030*; COM (2020) 380 Final; European Commission: Brussels, Belgium, 2020. Available online: https://www.eumonitor.eu/9353000/1/j4nvhdfcs8bljza_j9vvik7m1c3gyxp/vl8tqb8jwtyy (accessed on 10 November 2021).
21. Alatzas, S.; Moustakas, K.; Malamis, D.; Vakalis, S. Biomass potential from agricultural waste for energetic utilization in Greece. *Energies* **2019**, *12*, 1095. [CrossRef]
22. *The Renewable Energy Progress Report: Commission Report in Accordance with Article 3 of Directive 2001/77/EC, Article 4(2) of Directive 2003/30/EC and on the Implementation of the EU Biomass Action Plan*; SEC (2009) 503 Final; European Commission: Brussels, Belgium, 2009. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52009DC0192 (accessed on 10 November 2021).
23. Scarlat, N.; Martinov, M.; Dallemand, J.F. Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use. *Waste Manag.* **2010**, *30*, 1889–1897. [CrossRef]
24. Gavrilescu, M. Biomass power for Energy and sustainable development. *Environ. Eng. Manag. J.* **2008**, *7*, 617–640. [CrossRef]
25. Krausmann, F.; Erb, K.-H.; Gingrich, S.; Haberl, H.; Bondeau, A.; Gaube, V.; Lauk, C.; Plutzar, C.; Searchinger, T.D. Global human appropriation of net primary production doubled in the 20th century. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 10324–10329. [CrossRef]
26. Daioglou, V.; Doelman, J.C.; Wicke, B.; Faaij, A.; van Vuuren, D.P. Integrated assessment of biomass supply and demand in climate change mitigation scenarios. *Glob. Environ. Change* **2019**, *54*, 88–101. [CrossRef]
27. Biomass and Agriculture: Sustainability, Markets and Policies, OECD, Paris 2004. Available online: https://vdoc.pub/download/biomass-and-agriculture-sustainability-markets-and-policies-5etfsvelmih0 (accessed on 10 November 2021).
28. Janiszewska, D.; Ossowska, L. Diversification of European Union Member States due to the production of renewable energy from agriculture and forestry. *Probl. World Agric.* **2018**, *18*, 95–104. [CrossRef]
29. Gokcol, C.; Dursun, B.; Alboyaci, B.; Sunan, E. Importance of biomass energy as alternative to other sources in Turkey. *Energy Policy* **2009**, *37*, 424–431. [CrossRef]
30. Nakicenovic, N.; Alcamo, J.; Davis, G.; De Vries, B.; Fenham, J.; Gaffin, S.; Gregory, K.; Grübler, A.; Jung, T.Y.; Kram, T.; et al. Special Report on Emissions Scenarios. Intergovernmental Panel on Climate Change, Cambridge, UK. 2000. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf (accessed on 10 November 2021).
31. Muscat, A.; de Olde, E.M.; Kovacic, Z.; de Boer, I.J.M.; Ripoll-Bosch, R. Food, energy or biomaterials? Policy coherence across agro-food and bioeconomy policy domains in the EU. *Environ. Sci. Policy* **2021**, *123*, 21–30. [CrossRef]
32. Hamelin, L.; Borzęcka, M.; Kozak, M.; Pudełko, R. A spatial approach to bioeconomy: Quantifying the residual biomass potential in the EU-27. *Renew. Sustain. Energy Rev.* **2019**, *100*, 127–142. [CrossRef]
33. Kluts, I.; Wicke, B.; Leemans, R.; Faaij, A. Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward. *Renew. Sustain. Energy Rev.* **2017**, *69*, 719–734. [CrossRef]
34. Haase, M.; Rösch, C.; Ketzer, D. GIS-based assessment of sustainable crop residue potentials in European regions. *Biomass Bioenergy* **2016**, *86*, 156–171. [CrossRef]
35. Tonini, D.; Hamelin, L.; Astrup, T.F. Environmental implications of the use of agroindustrial residues for biorefineries: Application of a deterministic model for indirect land-use changes. *GCB Bioenergy* **2016**, *8*, 698–706. [CrossRef]
36. Hamelin, L.; Naroznova, I.; Wenzel, H. Environmental consequences of different carbon alternatives for increased manure-based biogas. *Appl. Energy* **2014**, *114*, 774–782. [CrossRef]
37. Elbersen, B.; Startisky, I.; Hengeveld, G.; Schelhaas, M.-J.; Naeff, H.; Bottcher, H. Atlas of EU Biomass Potentials. 2012. Available online: http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_atlas_of_technical_and_economic_biomass_potential_en.pdf (accessed on 20 February 2022).
38. Sustainable Biomass Availability in the EU to 2050. Imperial College, London 2021. Available online: https://www.concawe.eu/publication/sustainable-biomass-availability-in-the-eu-to-2050/ (accessed on 20 February 2022).

39. Tripathi, N.; Hills, C.D.; Singh, R.S.; Atkinson, C.J. Biomass waste utilisation in low-carbon products: Harnessing a major potential resource. *Clim. Atmos. Sci.* **2019**, *2*, 35. [CrossRef]
40. Vaish, S.; Kaur, G.; Sharma, N.K.; Gakkhar, N. Estimation for Potential of Agricultural Biomass Sources as Projections of Bio-Briquettes in Indian Context. *Sustainability* **2022**, *14*, 5077. [CrossRef]
41. Odavić, P.; Milić, D.; Zekić, V.; Tica, N. Potential of agricultural biomass: Comparative review of selected EU regions and region of Vojvodina. *Contemp. Agric.* **2017**, *66*, 62–67. [CrossRef]
42. Ericsson, K.; Nilsson, L.J. Assessment of the potential biomass supply in Europe using a resource focused approach. In Proceedings of the World Conference and Technology Exhibition on Biomass for Energy and Industry ETA Florence Renewable Energies, Rome, Italy, 10–14 May 2004.
43. Demirel, B.; Gurdil, G.A.K.; Gadalla, O. Biomass energy potential from agricultural production in Sudan. *ETHABD* **2019**, *2*, 35–38.
44. Mohammed, Y.S.; Mokhtar, A.S.; Bashi, N.; Saidur, C.R. An overview of agricultural biomass for decentralized rural energy in Ghana. *Renew. Sustain. Energy Rev.* **2013**, *20*, 15–22. [CrossRef]
45. Jekayinfa, S.O.; Orisaleye, J.I.; Pecenka, R. An Assessment of Potential Resources for Biomass Energy in Nigeria. *Resources* **2020**, *9*, 92. [CrossRef]
46. Tolessa, A.; Bélières, J.F.; Salgado, P.; Raharimalala, S.; Louw, T.M.; Goosen, N.J. Assessment of Agricultural Biomass Residues for Anaerobic Digestion in Rural Vakinankaratra Region of Madagascar. *Bioenerg. Res.* **2022**, *15*, 1251–1264. [CrossRef]
47. Shahbaz, M.; Balsalobre-Lorente, D.; Sihna, A. Foreign direct Investment–CO_2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *J. Clean. Prod.* **2019**, *20*, 603–614. [CrossRef]
48. Knapek, J.; Kralík, K.; Vavrov, K.; Weger, J. Dynamic biomass potential from agricultural land. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110319. [CrossRef]
49. Siejka, K.; Tańczuk, M.; Trinczek, K. Koncepcja szacowania potencjału energetycznego na przykładzie wybranej gminy województwa opolskiego. *Inżynieria Rol.* **2008**, *6*, 167–174.
50. Kowalczyk-Juśko, A. Metodyka szacowania regionalnych zasobów biomasy na cele energetyczne. *Zesz. Nauk. SGGW—Ekon. I Organ. Gospod. Żywnościowej* **2010**, *85*, 103–116.
51. Jasiulewicz, M. *Biomass Potential in Poland*; Publishing House of the Koszalin University of Technology: Koszalin, Poland, 2010; p. 86.
52. Gradziuk, P. *Biopaliwa*; Wydawnictwo "Wieś Jutra": Warszawa, Polska, 2003; p. 31.
53. Kowalczyk-Jusko, A. Principles of preparing the balance of renewable energy sources and evaluation of biomass resources. In *Renewable Energy Sources*; Kołodziej, B., Matyka, M., Eds.; Agricultural Energy Resources; State Agricultural and Forest Publishing House: Poznań, Poland, 2012; pp. 436–456.
54. Kuś, J.; Madej, A.; Kopiński, J. Bilans słomy w ujęciu regionalnym. *Rap. PIB Reg. Zróżnicowanie Prod. Rol. W Polsce* **2006**, *3*, 220, 211–226.
55. Box, R. *Assessment of Biomass Biomass and Waste in the EU-27 and Switzerland and their regionalization*; Institute of Soil Science and Plant Cultivation: Puławy, Poland, 2013; pp. 7–10.
56. Jędrejek, A.; Jarosz, Z. Potencjał biomasy rolniczej na cele energetyczne w województwie lubelskim. *Rocz. Nauk. Stowarzyszenia Ekon. Rol. I Agrobiz.* **2017**, *19*, 98–103.
57. Szajda, J.; Łabędzki, L. Szacowanie plonów rzeczywistych z użytków zielonych na podstawie plonów maksymalnych i potencjału wody w glebie. *Woda-Sr.-Obsz. Wiej.* **2016**, *16*, 93–114.
58. Klugmann-Radziemska, E. *Renewable Energy Sources—Computational Examples*; Gdańsk University of Technology Publishing House: Gdańsk, Poland, 2006; p. 52.