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Expectations for bioenergy considering carbon neutrality targets in the EU

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Abstract: The EU has set the ambitious target of raising the share of EU energy consumption produced from renewable resources to 32% by 2030 with a target of climate neutrality by 2050. The aim of this paper is to assess the role of biomass usage in the context of these targets. The paper identifies progress made between 2013–2022 by focusing on a selection of EU countries. The largest bioenergy increments of 130PJ, 77PJ and 60PJ were reported for Poland, Sweden, and the Netherlands. This study valuates the crucial role in co-generation and heat in EU regions, with biomass usage between 55-80% of the combined heat and power (CHP) energy in Nordic countries. The future perspectives for bioenergy based on EU policies, biomass resources and technical issues were addressed. The EU possess around 9% of the global biomass supply, ensuring a certain level of biomass resource dependence. Thus, the biomass usage demand in energy production, non-energy sectors and transport is expected to rise leading to increments of 13%-76% on biomass imports. It appears that bioenergy development is mostly limited by economic issues and uneven support for bioenergy in different EU countries as well as environmental issues. The study shows a promising and sustainable potential of bioenergy in the EU as a renewable energy source while minimizing negative impacts on the environment and the economy. By 2050, liquid biofuels are likely to be increasingly used in the transport sector. Non-energy sector usage of biomass is still in an early stage of development, except for the pulp and paper industry, and significant use of biomass in non-energy sectors seems unlikely in the near future.

Keywords: European Union; renewable energy; bioenergy; woody biomass; carbon neutrality

1. Introduction

The EU has set a target of being climate neutral by 2050 with an intermediate target of cutting greenhouse gas (GHG) emissions by at least 55% compared to 1990 levels by 2030. These goals require significant changes in many sectors, including energy production. As part of efforts to attain their climate targets, the EU plans to reduce coal consumption by more than 70% compared to 2015, and usage of oil and gas should be reduced by more than 30% and 25%, respectively [1]. Current geopolitical changes (e.g., the desire to gain independence from Russian fossil fuels) mean that achieving fossil fuel replacement by renewable energy is becoming more urgent than ever. In May 2022, the European Commission introduced the REPowerEU Plan, which aims to fast forward the green transition to enable a rapid reduction in usage of Russian fossil fuels [2].

According to the Renewable Energy Directive (REDII) (2018/2001/EU), the EU has a target of 32% renewable energy share in gross final energy consumption (GFEC) by 2030 [3]. The earlier target set by REDI in 2009 was 20% renewable energy (RE) share by 2020, which was successfully reached [4]. The REDII was revised (REDIII) and set more ambitions targets regarding renewable energy with 40% RE in final energy consumption by 2030 and focus on establishing a common energy source promotion system across different sectors. The focus is done mostly to new types of energy (e.g., hydrogen, biofuels and other renewable fuels) rather then classic RE sources (e.g., solar and wind). (European Environmental Bureau, 2022) [5].

Previous research (e.g., [6,7]) has drawn attention to the importance of biomass for energy production (bioenergy) and its role in meeting EU targets. Bioenergy is currently the main source of

RE in the EU with a share of almost 60%. The heating and cooling sector is the most significant end-user, accounting for about 75% of all bioenergy use [8].

Discussing the role of biomass in RE targets (20% of RE share by 2020), Proskurina et al. [9] noted that almost all EU member states (MS) are making considerable efforts to first reach the 20% target by 2020 and subsequently the new target of 2030, and a trend of an increasingly larger share of renewable energy in gross final energy consumption can be seen throughout the EU. In later work analyzing bioenergy development in light of the EU's climate neutrality target, Proskurina et al. [10] conclude that issues such as resource potential, bioenergy policy and country difference in terms of biomass usage should be more addressed more thoroughly when considering future prospects for bioenergy development. Analyzing policy measures promoting biomass use for energy generation in the EU (2005–2015), Banja et al. [11] concluded that EU policy has had a major effect on the progress of the bioenergy sector and that stable support is a motivational factor for bioenergy development.

Bioenergy is not "fully" sustainable as the dedicated land for bioenergy inherently comes at the loss of the potential land for producing food, feed or sustained carbon storage. Sustainability involves energy security and the use of environmental resources for future generation. In this context, production of biofuels usually takes place on farmland that was previously used for other agricultural purposes, such as growing food or feed. It can lead to the expansion of agricultural land into cropland, eventually into high-carbon areas such as forests, wetlands and peatlands. This process is called Indirect Land Use Change (ILUC). Since this can lead to the release of CO2 stored in trees and soil, indirect land use change threatens the greenhouse gas emissions reduced by growing biofuels. RED II introduces the sustainability of forest raw materials and greenhouse gas criteria for solid and gaseous biomass fuels [12].

According to the REDIII, biomass, especially the use of wood, will no longer be supported by the European Commission, because sustainability criteria regarding environmental externalities on air and water pollution and biodiversity loss for biomass use going beyond the current sustainability criteria on forest feedstocks. Thus, biomass feedstock for bioenergy development will be sustainably sourced waste that is considered as the main input for biomass to ensure circularity. It is expected that first generation biofuels will be phased out by 2030. Instead, second generation biofuels, cascading use of biomass will be more popular and priority [5].

The overall sustainability and environmental benefits of bioenergy may depend on the use of feedstock or energy crops. For example, residual biomass naturally releases gases when it decomposes. This can produce methane, which is a far more potent greenhouse gas than carbon dioxide, if it occurs in an environment with no oxygen, such as food waste buried in landfills. Rather than allowing the methane to be released into the atmosphere, placing it in a sealed tank allows it to be captured and combusted. Burning methane leaves the environment with carbon dioxide and water that are better for the environment. Different principles, criteria and indicators for the logistic chain in bioenergy should be considered for every case, in order to facilitate the evaluation of the environmental, social and economic aspects of sustainability.

In view of recent rapid changes in EU policy, there is a need to discuss progress towards reaching local RE targets and to evaluate the direction of biomass usage in the EU. The novelty of this paper lies in extending current knowledge about EU development in the bioenergy sector and providing an expectation about future biomass development towards carbon climate neutrality. The research question considered in this study aims to evaluate possibilities for an increase in bioenergy usage in the context of European Union RE targets. To answer this research question, the study first evaluates bioenergy progress including bioenergy policy issues during 2013–2022 in several countries of the EU which are more visual in terms of bioenergy progress. The study then looks at resource potential and possibilities for fossil fuel replacement in different sectors, including transportation and non-energy production industries. Finally, the work presents conclusions on prospects for future biomass usage in the EU.

2. Materials and Methods

Examination of the status of bioenergy in the EU includes data from the Eurostat database [4], which is the most comprehensive source of comparable statistics about EU member states. To meet the first objective of the investigation, the work began by exploring bioenergy progress in EU member states based on a group division. The 27 EU member countries were divided into three groups. The division was based on the share of renewable energy in the gross final energy consumption (GFEC) of the respective countries in 2020. EU member states with a RE share in GFEC of more than 25% were ranked as Group 1 (Leading countries), countries whose renewable energy in GFEC is between 20–25% as Group 2 (Intermediate countries), and countries whose required RES share is less than 20% as Group 3 (Lagging countries). Such method also allows to see connection of RE and bioenergy development in countries as well as find out the most interesting countries in terms of bioenergy development in last years. Study discusses the most prominent countries in terms of bioenergy progress in each of these three groups.

To meet the second objective of this paper, decisions about possible expectations of biomass usage are presented based on a review of relevant literature in combination with official reports and latest news. Again, the work focuses on member states of greatest interest in terms of biomass usage development.

The limitations of this study revolve around the following aspects:

- Definition of energy consumption. Gross inland consumption (GIC) is the first aggregate of the national energy balance. Gross final energy consumption (GFEC) is calculated after subtraction of transformation losses and transformation and internal consumption in the energy sector.
- Period of inventory. The period of study 2013–2022 was chosen as the main starting point. As member states still require progress in bioenergy development to reach local targets for 2020, this brief period may be subject to inconsistent data compilation.
- Market changes. The forecast in this study does not include possible changes on global energy markets, such as changes in fossil fuel prices, and significant economic changes in particular member states or in the EU in general. When fossil fuel prices rise, for example, as a result of carbon taxes, EU Member States might invest heavily in "carbon tax-free" RES, to guarantee the long-term supply of fuels.

In order to analyze biomass development perspective, it is important to understand that biomass usage is very broadly. As was mentioned before, REDIII is also focusing on the different biomass usage ways and zero fossil fuels consumption. To reach zero fossil fuel consumption, it is important to take into consideration biomass demand by different industries and its possibilities of using biomass instead of fossil fuel. Thus, paper includes biomass possibility in electricity (section 3.2.1) and transport sectors (section 3.2.4), where its share is not large as well as one section of this study (section 3.2.3) covers role of biomass usage in industry sector as non-energy demand. Non-energy demand for biomass refers to its use as a raw material for manufacturing a variety of products such as bio-based polymers, bioplastics, biofuels, biochemicals, etc. Industrial sector, for example, require energy indirectly but are not considered as energy consumption themselves. Thus, there is possibilities of doble counting. For example, in the case of pulp and paper, industry use biomass for production of pulp and paper as well as produce energy from biomass and use this energy within the own production (e.g. in Sweden and Finland). One of the attempts to evaluate biomass usage including torrefied biomass in different industries was presented in [13,14].

3. Results and discussion

This section briefly presents current progress in bioenergy in the EU. The study then discusses possibilities for an increase in biomass usage focusing on resource potential and opportunities in different areas including the non-energy and transport sectors.

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3.1. Bioenergy progress

All EU countries, except for France, met their local renewable energy target for 2020 (Table 1). It seems that France set a very ambition target for 2020 of 23% and was unable to make the progress envisioned. As can be seen in Table 1, the largest increases in bioenergy share in the period 2013–2020 occurred in Poland, Sweden, the Netherlands, and Denmark.

Table 1. Changes in EU renewable energy (RE), gross inland energy consumption (GIC) and bioenergy usage in 2013–2020 [4].

	Share of enrgy from RE in GFEC[1] (in %)				**Total GIC[2] (in PJ)**			**Bioenergy in GIC (in PJ)**		
	2013	**2020 target**	**2020**	**changes**	**2013**	**2020**	changes	2013	2020	changes
Over 25 % leading countries (Group 1)										
Sweden	52,1	49	60,1	8,0	2066	1893	-173	451	528	77
Finland	36,8	38	43,8	7,0	1438	1345	-93	373	402	29
Latvia	37,1	40	42,1	5,0	186	183	-3	57	66	9
Austria	32,6	34	36,5	3,9	1378	1349	-29	247	231	-16
Portugal	25,7	31	34,0	8,3	938	895	-43	117	130	13
Denmark	27,2	30	31,7	4,5	764	665	-99	137	190	53
Croatia	15,1	20	31,0	15,9	358	348	-10	54	62	8
Estonia	25,6	25	30,1	4,5	246	188	-58	33	55	22
Lithuania	23	23	26,8	3,8	296	320	24	48	64	16
25-20% Intermediate countries (Group 2)										
Slovenia	21,5	25	25,0	3,5	274	265	-9	32	27	-5
Romania	23,9	24	24,5	0,6	1322	1349	27	160	163	3
Bulgaria	19	16	23,3	4,3	715	747	32	49	78	29
Greece	15	18	21,7	6,7	1008	856	-152	50	50	0
Spain	15,4	20	21,2	5,8	5055	4681	-374	291	294	3
Italy										
Up to 20% Lagging countries (Group 3)										
Germany	12,4	18	19,3	6,9	13849	11921	-1928	1121	1138	17
France	14,2	23	19,1	4,9	11133	9367	-1766	629	641	12
Slovakia	9,8	14	17,3	7,5	660	689	29	39	68	29
Czechia	12,4	13	17,3	4,9	1819	1683	-136	147	183	36
Cyprus	8,1	13	16,9	8,8	92	96	4	2	4	2
Ireland	7,8	16	16,2	8,4	562	574	12	18	26	8
Poland	11,3	15	16,1	4,8	4124	4311	187	326	456	130
Netherlands	4,5	14	14,0	9,5	3140	3012	-128	119	179	60
Hungary	9,8	13	13,9	4,1	997	1095	98	124	107	-17
Belgium	7,9	13	13,0	5,1	2365	2154	-211	127	134	7
Luxembourg	3,6	11	11,7	8,1	177	166	-11	6	18	12
Malta	3,8	10	10,7	6,9	37	32	-5	0,2	0,7	0,5
EU	15	20	22,1	5,0	60919	56109	-4810	5334	5875	541

[1]GFEC=Gross final energy consumption.

[2]GIC=Gross inland energy consumption.

3.1.2. Leading countries

Leading countries in renewable energy are also countries with the most developed bioenergy sector (Table 1). Nordic (Sweden, Finland, and Denmark) and Baltic countries (Latvia, Estonia, Lithuania), as well as Austria, Portugal and Croatia have an RE share in GFEC of more than 25%. Over the period studied, Sweden, Denmark and Finland increased their use of biomass as a share of gross internal energy consumption (Table 1). In the Nordic area, biomass is particularly important for co-generation and heating with biomass providing 80%, 64% and 55% of CHP energy in Finland, Denmark and Sweden, respectively, in 2018 [15]. Sweden along with Lithuania have the highest rates of total biomass in total derived heat production. Estonia made considerable progress in biomass utilization in the heating sector, and the country has the largest biomass share in total residential heat production: 50% in 2017 [16].

3.1.2. Intermediate countries

In the intermediate countries group, Bulgaria has shown the most significant progress in bioenergy utilization (Table 1). The country increased woody biomass product production from 84 000 tons (2012) to 215 000 tons (2020). This significant change can be explained by an increase in wood pellet production from 66 000 tons in 2012 to 204 000 tons in 2020. Wood pellet production in Bulgaria focuses mainly on export and the local domestic heating sector, where wood is a very popular form of heating and used in around 1.8 million households. One factor underlying the change is that a higher price for firewood led to many households replacing firewood with wood pellets and briquettes. Consequently, domestic consumption of woody biomass increased from 63 000 tons in 2012 to almost 100 000 tons in 2020. COVID-19 had no noticeable effect on the production and consumption of woody biomass. In the electricity production sector, the usage of wood waste increased from 265 000 tons (2016) to 483 000 tons (2020), which reflected an increase in recovery of wood waste from 247 000 tons (2016) to 306 000 tons (2020). It seems that the trend of bioenergy development will continue [17].

Bulgaria has an integrated energy and climate plan for 2021–2030 [18] which foresees that biomass usage will increase in heating and cooling, electricity, and transport. It is expected that the country will increase electricity generated by power plants using biomass by 46% by 2030. The use of biodegradable waste is forecast to increase from 14 GWh in 2020 up to 115 GWh in 2030. It is important to note that the country plans to increase biomass usage without negative impacts on the land use, land-use change, and forestry (LULUCF) sector thanks to use of forestry products and forestry residues. According to the plan, Bulgaria intends to integrate more next-generation biofuels in energy production to replace fossil fuels. Next-generation biofuels require less land than first-generation biofuels, which are based on cultivation crops (the main source of biomass in Bulgaria). It is expected that land use for production of conventional biofuels necessary will decrease. Thus, despite the foreseen increase in biofuel production, no changes in land usage are anticipated for the next decades [18].

3.1.3. Lagging countries

In the lagging countries group, Poland, the Netherlands, Slovakia, and the Czech Republic increased biomass usage in gross energy consumption (Table 1). Bioenergy usage in Poland developed dynamically over the period studied, although there was a decrease in bioenergy usage in 2018–2021 due to more active development of wind and solar energy. Poland has a considerable share of woody biomass utilization in the household sector with usage of 10–12 million m3 p.a. in 2018–2021.Woody biomass is the main fuel for bioenergy in Poland with a share of 65% in 2019 [19].

Slovakia also saw an increase in solid biomass usage in households over the period studied. From 2018–2019, Slovakia increased bioenergy in total final energy consumption from 50PJ to 72PJ, mainly thanks to the use of solid biomass in households. In the heating and cooling sector, biomass consumption increased from 37TJ to 56TJ [20]. Slovakia has considerable potential for bioenergy development, and the country currently utilizes less biomass compared with local biomass resource potential [21].

Although the role of wind and solar energy in the Netherlands has been growing since 2012, bioenergy remains the main RES in the heating and transport sectors. The country has increased biomass usage in coal power plants to decrease coal usage. A cascading approach to using biomass has been in operation since the introduction of a new biomass policy in 2020. This approach to long-term change is very important for a country that has a lack of indigenous biomass resources and suggests that biomass usage will increase in the future [22].

As part of the new policy program to reach carbon neutrality introduced in 2022, the Government of the Netherlands is supporting use of second-generation biofuels and non-energy production related biomass applications. To control emissions and address sustainability issues in biomass supply, the Dutch government is focusing on strict certification processes [23]. Biofuels in the transport sector is supported by the Biofuels Obligation Act, which requires fuel suppliers to include a minimum percentage of biofuels in their total sales. As of 2021, the minimum percentage is 10%, and it is expected to increase to 16.4% by 2030 [24].

3.2. Biomass perspective

This section of paper present and discuss the future perspective of future biomass usage in not very popular areas such as electricity, transport and non-energy industries.

3.2.1. Biomass in electricity production

Bioenergy is an energy source with an important role in the world's electricity mix. Biomass for electricity generation can be produced from agricultural residues, forestry residues, urban waste and even animal waste. By using a waste product as an input, the generation of bioelectricity has a lower cost than other renewable sources. In many cases, bioelectricity is produced in an efficient cogeneration process that produces thermal and electrical energy simultaneously, for instance, in sugar and ethanol mills [25]. Thus, discussion about the utilization of bioenergy should not be restricted to biofuels alone and should also consider bioelectricity [26].

The countries of the European Union have introduced incentive policies promoting alternative renewable sources of electricity. These policies range from tax incentives to instruments such as premium pricing and the green certificates market [27]. In Nordic nations, in particular, the incentives provide significant support for energy forms like wind, solar, and biomass. Analysis of the use of renewable energy sources in Portugal and Germany, Finland, and Denmark demonstrates how well these nations' policies have promoted electricity produced from biomass despite difficult environmental circumstances. For example, in the case of Portugal, whose policies have specifically promoted bioelectricity, the premium price of 110 euros per MWh provided by the Portuguese government adequately internalizes all the advantageous externalities of bioelectricity [28]. Moreover, a program was established in 2006 to promote bioelectricity using forestry waste as an input. Since 2005, biomass generation and wind power have been integrated, and this integration makes it possible to gain tax advantages and attract financial subsidies.

Scandinavian nations have a long history of using renewable energy sources, particularly biomass. The methods used for promotion of RES differ, however, from nation to nation. For example, in bioenergy, Finland uses tax breaks and subsidies to promote bioelectricity, whereas Denmark uses price premiums as its primary marketing tool [29].

However, use of biomass for electricity production (bioelectricity) seems to have limitation since REDIII was introduced. According to REDIII bioelectricity seems less important than green heat production. In 2021, about 7% (170 TWh) of electricity was produced from bioenergy. Most of this production (61.8 TWh) is from CHPs. In the heating and cooling sector, bioenergy has 19% from total energy consumption. Biomass-base green heat generation can provide a sustainable renewable alternative to heating systems that rely on fossil fuels. In the light of REDIII bioelectricity decrease is expected. However, in general, the demand for thermal power plants is expected to increase because the increase in electrification requires a significant increase in the energy source. This can be organized by balancing other renewables rather than bioenergy [30].

Despite a lack of policy support in forest biomass use, it seems that the large decrease of bioelectricity has not happened. Residues from forest operations (e.g. tops, branches, thinning) and wood processing residues (e.g. bark, sawdust and black liquor) are actively used for bioenergy. Combustion of biomass under the right conditions creates less CO2 emission comrade with fossil fuel combustion [30]. In addition, biomass usage in CHP is well known technology and popular in many countries such as Finland and Sweden nowadays. In many countries, the future of biomass is mainly seen through medium-scale, flexible CHP units dealing with low-rank resources (e.g. Bulgaria in Section 3.1.2). This strategy encourages the efficient use of local resources, lowers losses and improves energy security.

3.2.2. Biomass resources potential

About 60% of biomass in the EU is used for feed and food products. Bioenergy is the second largest consumer of biomass with 21%, followed by biomaterials (e.g., wood products and wood pulp) with 20% of total biomass consumption. The EU has about 9% of global biomass supply. Thus, the EU is quite independent in terms of biomass resources [31]. According to Mandova et al. [32], the biomass potential of the EU-28 is sufficient to meet domestic current biomass demand from the pulp and paper industry, electricity and power generation plants, and sawmills (total 4.01 EJ year−1). Additionally, the biomass potential of the EU-28 is sufficient to meet domestic current biomass demand for woody-based feedstock from integrated steel plants (1.30 EJ year−1). If to look at the future, if the whole system will be optimized, imported biomass will be important especially for countries such as Belgium, Germany, Spain, Italy and the Netherlands [32].

Analyzing recent projections of both supply and demand dynamics for EU bioenergy to 2050, Mandley et al. (2020) [33] concluded that technical EU potential of domestically available biomass for energy is between 9 to 25 EJyr-1 and EU biomass demand is between 5 and 19 EJyr-1 by 2050. Biomass imports are expected to increase from the current 4% to 13–76%. This can be explained by the fact that not all domestic biomass resources are not of satisfaction quality or look economically inaccessible [33].

Indeed, it is expected that the biomass trade within and outside of the EU will increase. Analyzing international trade of biomass, Proskurina et al. [6] suggest that globally the EU is currently the main leader in biomass utilization and main importer of biomass product such as wood pellets, which are traded for long distance in larger volumes then others. The trade stream volumes have potential to continue their growth. Many different factors influence current biomass trade streams, such as historical bioenergy development, availability of biomass resources, policy regulations, and sustainability certification [6].

In the future new biomass trade streams can be raised and new trade streams can be created, for example, waste trade that can be mostly for short distance and within the EU. The international biomass trade is very likely to increase thanks to its advantages such as the security of supply in regions with lesser resource availability. Moreover, biomass trade can motivate local biomass usage and market development in countries that have biomass resource that are not utilized. For example, in Eastern Europe, we can see examples where export of wood chips or pellets helped to create local markets [34].

Biomass can be used for non-energy related purposes (biobased products). It seems that current non energy demand of biomass is not very large due to limited biomass use in industry (see section 3.3.2). However, by 2050 it can be more visual and will require at least 10% of the projected feedstock needed to fulfil bioenergy. Non energy demand the EU will be between 0.56 and 2.3 EJyr by 2050 [35].

The most important biomass feedstocks in the EU are residual biomass from agriculture and forest residues with availability of 8500 PJ y-1 and 3200 PJ y-1 respectively. Straw, which is used in agriculture, has availability around 3800 PJ y-1 [35]. According to Gruttola and Borello [36], countries with high agricultural residual biomass feedstock output include France, Germany, and Romania. Austria, Finland, and Sweden have large potential as regards forestry residues, and Italy, France, and the United Kingdom (non-EU since January 2020) have the highest availability of biowastes.

According to Hamelin et al. [35], 25 NUTS-3 regions (Eurostat Nomenclature of Territorial Units for Statistics) of France have a large supply of available residues (above 20 PJ y-1). Paris, for example, has high biomass concentration thanks to the availability of substantial volumes of biodegradable municipal waste. In Spain, a large volume of agro-industrial biowaste and pruning residues are available in Jaen due to the city being a major world olive oil production center. Spain has 6 regions

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with large amounts of residues. 11 regions in Sweden and Finland also have easily available residues (above 20 PJ y-1). Forest residues are also found in the Czech Republic (5 regions), Denmark (5 regions), Spain (6 regions), Hungary (2 regions), Italy (2 regions), Latvia (2regions), Poland (5 regions), Romania (1 region), Slovakia (1 region) [35].

The development of bioenergy in EU countries is impacted by the differences in biomass resource locations between EU member states. Examples of countries with abundant biomass resources and a lengthy history of biomass development are Finland and Sweden. Finland is a country with well-structured forest management and utilization [37]. In some countries with large resource potential, biomass utilization is, however, not great as it could be due to administrative, organizational, and technological challenges. For example, Bulgaria has large resource potential, but current utilization is relatively low. The country is a net exporter of biomass, rather than a producer of higher value-added products [38]. Despite biomass resource potential being largest in Finland and Sweden, Germany is the leading producer of primary energy from solid biomass across the EU (Figure 1).

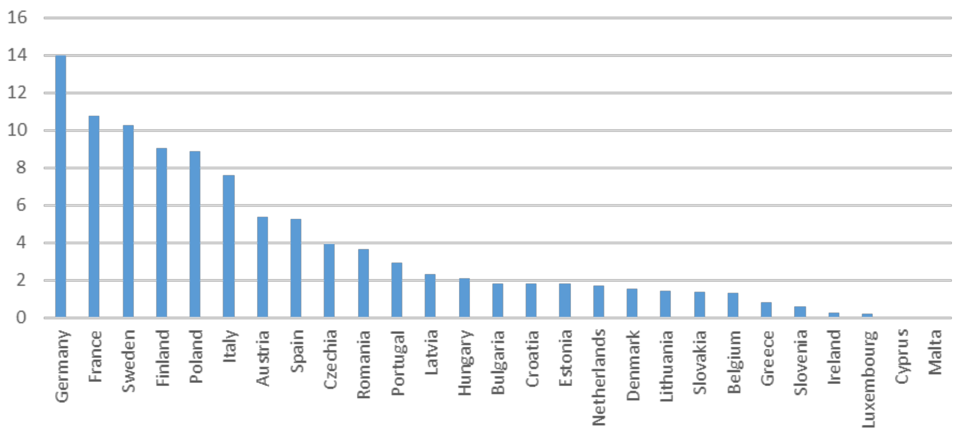

Figure 1. Primary energy production from solid biomass in the EU-27 in 2021 (in million metric tons of oil equivalent) [39].

In some countries, such as the Czech Republic, Belgium, Denmark and the Netherlands, local biomass resources are insufficient for significant bioenergy development. For example, evaluating future biomass resource potential (for 2035) in the Czech Republic, Šafařík et al. [40] find that overall forest biomass resources for energy production are inadequate to achieve the EU's objectives. In Germany, it is expected that about 25% of total bioenergy demand will be meet by local biomass resources by 2050 [41]. Thus, questions of logistics, imports, and supply of biomass are important considerations for countries without sufficient biomass production to meet their needs. As a result, there is some biomass trade within the EU [42]. Analyzing biomass trade in Belgium, Denmark, and the Netherlands, Pelkmans et al. [43] suggest that although use of local biomass should have priority, in some regions, biomass trade can facilitate local use of biomass, for example, via knowledge and infrastructure creation.

3.2.3. Biomass role in industrial sector (non-energy demand)

In 2019, the final energy consumption was 2.55 tons of oil equivalent (toe) per ca pita including non-energy use of oil, natural gas and coal in industry (Table 2). As can be seen industrial sector with no energy demand has 9% of final consumption of energy carriers and the largest consumer of fossil fuel after transport sector in the EU (Table 2) [44,45]. Although the pollution by industrial sector is decreasing in the EU, the industry is still the source of GHG emissions, air, weather and soil pollution [46]. Integration of RE in industry is significantly important in order to reach carbon neutrality. Thus, biomass usage in the industrial sector can contribute to emission reduction, diversification of raw materials and transition to a circular economy. The implementation of biomass in non-energy demand industries could also promote environmental sustainability, technological innovation and reduce the dependence on non-renewable sources. However, biomass usage and application highly depend on industrial sector processes that influence the biomass properties.

Table 2. The final energy consumption by sectors in the EU-28 [44] and EU-27 [45].

Final consumption energy carriers	Toe/capita (2019)*	% of total*	Mtoe/total (2021)**	% of total**	Solid fossil fuel consumption (2021)** (in Mtoe)
Industry (energy use)	0.58	23	240,300	35,6	11,000
Industry (non-energy use)	0.22	9	93,400		1,500
Transport	0.74	29	274,800	29,3	245,00[1]
Residental	0.62	24	261,800	27,9	6,400
Commercial and public services	0.31	12	129,400	13,7	800
Other	0.08	3		3,5	
Total	2.55				

The pulp and paper industry is one of the main biomass user in the non-energy industrial sector. The biomass share being used in the pulp and paper industry differs in different EU countries, for example, Italy has zero share, whereas in Sweden 89% of biomass is used in the pulp and paper sector [47]. Sweden and Finland are examples of countries, where biomass usage for energy purposes is well established in the pulp and paper industry [48]. Analyzing the Finnish pulp and paper industry, Lipiäinen and Vakkilainen [49] suggest that nearly carbon–neutral production can be achieved by the year 2035. Totally carbon–neutral or carbon-negative production requires negative emissions, for example, in the form of bioenergy with carbon capture and storage (BECCS). As an industry, the pulp and paper industry have room for expansion as the current decrease in paper products consumption is being compensated for by a rise in the production of packaging products. Moreover, energy is not only a commodity but also a part of the production processes in the pulp and paper sector. Thus, the sector requires new solutions for more environmentally friendly production and further increase in biomass usage can play an important role [50]. For instance, pulp mills have been investing in research and development to improve biomass consumption and utilization creating new methodologies for reducing waste and increasing water conservation. These initiatives aim to enhance the mill sustainable performance while reducing pulp mill environmental impact.

The share of solid biomass in the final energy consumption of the wood and wood products sector was over 30% (2017) in almost all EU countries, and in Belgium, Denmark, Ireland, and Luxemburg this share was above 70% [47]. The potential for increase of biomass usage for energy in this sector is limited, but there are possibilities for increases in efficiency, for example, via improving the efficiency of CHP plants and biomass gasification systems [47].

In the non-metallic minerals industry, the EU-28 has about 3% of solid biomass (mostly biochar from slow pyrolysis) in final consumption in this sector, which is relatively small. Technical possibilities exist for increasing biomass usage, for example, via a 20% substitution rate of fossil fuels by biomass in cement kilns. Torrefied biomass is technically applicable for use in this industry [51]. However, challenges connected with storage, sourcing of suitable feedstock and high capital costs create barriers for bioenergy development in the non-metallic minerals industry [47].

The EU-28 has minimal biomass usage in the chemical and petrochemical industry (about 0.5%) and no usage in the iron and steel industry. Utilization of biomass in these industries is challenging due to economic and environmental constraints [47]. Analyzing biomass usage in steel plants, Mandova et al. [32] concluded that biomass feedstock in the EU is sufficient for biomass integration to steel plants and that biomass can give benefits such as a decrease in CO2 emissions and coal usage. However, biomass usage seems limited by technical and economic issues. Discussing the role of

[1] Including liquid fossil fuels: gas oil, diesel oil, motor gasoline, fuel oil (excluding biofuels)

biomass applications in the iron and steel industry, Proskurina et al. [13] noted that the industry has attractive technical possibilities for use of torrefied biomass, and some studies have shown that theoretically full replacement of fossil fuel by torrefied biomass is technically possible. Biomass usage in the chemical industry is under active research and development. For example, gasification requires a huge amount of biomass, which requires a large space for storage. Torrefied biomass can be a good solution in such a case [13].

3.2.4. Biomass role in the transport sector

Increasing the share of bioenergy in the European energy mix is a key factor in reaching the European climate targets for 2030. Presently, the transport sector accounts for approximately one-third of the energy consumption of the OECD countries and is almost entirely supplied by fossil fuels [52]. As can be seen from Table 2, the transport sector is the main consumer of fossil fuel in the EU. In this regard, fighting global warming necessitates a shift in the energy usage profile of the transportation industry. Current market alternatives, however, present significant barriers to bioenergy utilization for transportation, with the exception of usage of biofuels. In the last two decades, various alternative fuels and automotive technologies have been the subject of much study, including electric vehicles, and the use of liquefied petroleum gas (LPG) or compressed natural gas (CNG) [53]. These technologies are incompatible with current technology used in gasoline-powered vehicles, so they result in high vehicle costs. In addition, such fuels require a separate distribution network. Faced with an uncertain market, vehicle manufacturers and fuel suppliers are reluctant to invest in many of these alternative energy sources.

In this context, liquid biofuels are a practical short-term option for reducing fossil fuel consumption in the transportation sector [54]. Liquid biofuels are compatible with current vehicles and can be distributed using the same distribution network that already exists. Achieving climate targets depends on the growth of the biofuel market, which will allow European nations to buy fuel from those with better circumstances for production, as well as the economic viability of second-generation biofuels.

Biofuels represent 89% of all renewable energy sources used in transport. The share of RE in the transport sector was 10.2% in 2020 but 9.1% in 2021. This decrease can be explained by increasing fuel consumption by the transport sector due to a lifting of COVID-19 restrictions [55]. The EU has set a target of 14% RE use in the transport sector by 2030 [56].

The production of biofuels for transport in the EU-28 increased by an average of 3.5 times between 2017 and 2018 [57]. Analyzing policy support for bioenergy in 2005–2017, Banja et al. [11] suggest that more than 95% of all measures in the transport sector were related to biofuels, with the rest being related to biogas (mainly biomethane). Most of these policy measures have been regulatory measures (e.g., biofuel quotas, compulsory blending, and sustainability promotion).

Sweden is the leading country for biomass usage in the transport sector (Figure 2). The government of Sweden supports the use of biofuels in transport via different tax exemptions, which depend on the type of biofuel (bioethanol, FAME, or HVO) and the content of the biofuel mixture. For example, the price of HVO100 is competitive with that of fossil diesel as it is totally exempt from both carbon tax and energy tax. It should be noted that usage of bioethanol has declined similar to many other countries due to competition with biodiesel, feedstock issues, fluctuating prices, and policy regulations. As regards biogas usage, Sweden has the highest biogas share relative to natural gas use at more than 23% thanks to government incentives in recent years. Sweden has set a target of 70% CO2 emissions reduction in the transport sector by 2030 [58]. The future for biogas development in Sweden seems very positive thanks to strong government support [59].

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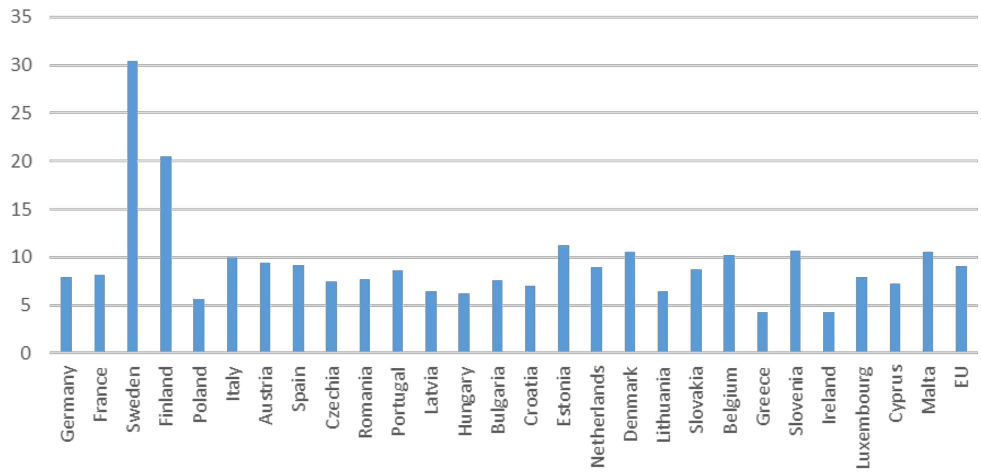

Figure 2. Share of RE in the transport sector in 2021 (in %) [60].

Sweden has a target of producing 10 TWh of biomethane by 2030. In 2020, Sweden had 70 biomethane plants, which produced a total of 1.4 TWh of biomethane, mostly for use in the transport sector. Infrastructure is slowly being developed, and in 2020, Sweden had 265 Bio-CNG (compressed biomethane) filling stations and 23 Bio-LNG filling stations (liquified biomethane). Biomethane usage in liquefied gas vehicles increased from 50% (2020) to 65% (2021) [61]. Biomethane can contribute to achieving EU targets because usage of biomethane in the transport sector can significantly reduce GHG emissions. The largest biomethane production capacity is recorded in Denmark, Italy, Estonia, and the Netherlands, and it is expected that there will be larger biomethane production and new biomethane production plants by 2030 [62].

It is forecast that biofuels and advanced biofuels will together contribute more than 17% of total energy consumption in the EU transport sector by 2050. An interesting finding is that the largest increase is expected to be in the aviation and maritime biofuels sector [63]. The main factors affecting the biofuel market in the aviation sector are the price of conventional fuel, energy security, and international pressure for emissions reduction [64]. Biofuels produce less GHG emissions than conventional jet fuels [65], and the EU has policy support for the use of biofuels in aviation, such as an ecotax on jet fuel, and a quota obligation for biofuels [66]. Implementation of the EU emissions trading system (ETS) in aviation is motivating increased use of biofuels. However, the EU ETS still faces many challenges and improvements are needed to further drive increased biofuels usage [67].

5. Conclusions

The purpose of the current study was to examine the progress of bioenergy development in the EU and evaluate the possibilities and potential of further development based on the biomass resources available and the attractiveness of biomass in the energy and non-energy sector. The study noted EU countries that had made progress in biomass utilization over the period examined. An interesting finding is that there seems to be a correlation between development of the biomass and bioenergy sector and reaching renewable energy targets by 2020. Some countries such as Nordic countries dramatically increased the RE share in total energy consumption and bioenergy at the same time. The methods used for promotion of RES differ from nation to nation depending on the bioenergy status in the country.

Poland, Sweden, the Netherlands, and Denmark are just a few of the European nations where the percentage of bioenergy has increased significantly between 2013 and 2020. With Finland, Denmark, and Sweden depending on biomass for a sizeable amount of their combined heat and power production. Biomass plays a critical role in co-generation and heating in the Nordic region. Globally, combined heat and power systems contributed significantly to the 7% of bioenergy that made up electricity production in 2021. Biomass is predominantly used in the European Union for feed and food products, followed by biomaterials and bioenergy. Moreover, the production of biofuels has significantly increased because of the EU's efforts to promote the use of renewable energy in the transportation industry, particularly through biofuels.

Study shows that non-energy demand of biomass will likely increase for the long-term perspective. It cannot be excluded from the future biomass usage potential, and it seems it will effect on the biomass demand for energy production too. Use of bioenergy in non-energy industries is relatively undeveloped, except for the pulp and paper industry. However, technical and economic factors seem to suggest that substantial progress in bioenergy use in non-energy industry related areas is unlikely in the near future. In the light of climate neutrality targets, non-energy demand of biomass can increase more raped as before, pursuing environmental goals and efficiency through sustainable forestry practices, ware reduction and energy integration.

Bioenergy including primary woody biomass will continue to count towards renewable energy targets. However, REDIII adopted amendments calling for the gradual reduction of the proportion of primary biomass counted as renewable energy. Thus, bioenergy will play an important role to achieve the new REDIII targets, creating a new field with other solutions for biomass utilization with the lack of support from primary wood biomass.

Bioenergy potential is not easy to evaluate because it varies between countries. Some countries have considerable resource podetial, such as Bulgaria and the Baltic countries, but the bioenergy sector is not as highly developed as elsewhere, for example, in Finland and Sweden, due to economical and policy issues, whereas some countries with limited resources, such as the Netherlands and Belgium, seem to have stronger policy support and greater interest in promoting bioenergy. Such countries are, however, fully dependent on trade, which makes bioenergy development in these countries a politically sensitive topic. Sustainability issues also have an impact on biomass usage because biomass can be used for multiple purposes, for example, for food production, and in the pulp and paper industry as in Sweden and Finland. However, it seems that biomass resource potential is not the main issue affecting bioenergy development in the EU, and countries such as the Netherlands are interested in developing use of bioenergy despite limited local biomass availability.

Recent global changes (e.g., Covid-19, conflict in Ukraine, EU efforts to halt the use of Russian energy resources) are creating new challenges for the energy system and EU countries are looking at possibilities to diversify energy sources and new ways of energy production. These alternatives motivated bioenergy development in the EU. Despite that it is not always linked to an increase in biomass usage. Other options such as nuclear power (e.g., Poland), and more solar and wind (Poland, Germany) are also possible solutions.

This research has thrown up many questions in need of further investigation. Further work needs to be done to establish how bioenergy will develop with less policy support for forest biomass, how second-generation biofuels can be extended and can be replace first generation biofuels, what is social aspect of bioenergy development in the EU.

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