BIOMASS USAGE IN THE EU

Lappeenranta–Lahti University of Technology LUT

School of Energy Systems

Degree Programme in Bioenergy Systems

Master's Thesis

2023

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Examiner(s): Professor, D.Sc. (Tech.), Esa Vakkilainen

D.Sc. (Tech.), Svetlana Proskurina

ABSTRACT

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Biomass is considered a key driver in the European Union's long-term prospect to achieve climate neutrality by 2050. It has a significant contribution in electricity and heat generation, and transportation across the EU. The amount of biomass consumed over the last thirty years suggests that the growth of biomass in the EU is remarkable and holds a prosperous outlook. While the EU region produces most of its biomass locally, there is a significant trade within and outside of the region. In the European energy mix, biofuels are mostly consumed in heating plants. Besides, its share in electricity generation and transportation is on the rise. Some popular forms of biomass that are being consumed are wood pellets, bioethanol, biodiesel, charcoal, torrefied biomass, and pyrolysis oil. The future of biomass depends on how sustainably it can be cultivated, and how it can compete with other renewable sources.

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Furthermore, I am delighted to get the opportunity to conduct a Master's thesis in Lappeenranta–Lahti University of Technology. I am fortunate to be a part of this university, and to study bioenergy systems where I was provided with the opportunities to develop experiences in the field of energy technology.

List of Abbreviations

EU	European Union
GHG	Greenhouse Gas
°C	Degree Celsius
EJ	Exajoule
TJ	Terajoule
GWh	Gigawatt hours
ktons	Kilo tonnes
ktoe	Kilo tonnes of oil equivalent
Mtoe	Million tonnes of oil equivalent
HC	Hydrocarbon
PM	Particulate Matters
Syn-gas	Synthetic gas
RED	Renewable Energy Directive
IEA	International Energy Agency
USDA	United States Department of Agriculture
EEB	The European Environmental Bureau

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1 Introduction

The European Union (EU) is committed to lowering its greenhouse gas (GHG) emissions and increasing renewable energy's share of the energy mix. Biomass is one of the dominant sources of renewables in the EU, and its consumption in the large power plants has been thriving in the past few decades. Biomass energy is a renewable form of energy obtained from organic materials such as wood, agricultural wastes, and municipal solid waste. Various processes, such as combustion, gasification, and anaerobic digestion, can convert biomass into energy. As a form of renewable source, biomass offers various advantages, including its availability, storage capability, minimizing greenhouse gas emission and improving waste management.

In the EU, biomass is used in a variety of ways which includes dedicated biomass power plants and co-firing power plants. Dedicated biomass power plants consume biomass as their main fuel source whereas biomass is combined with coal in the co-firing power plants (Dockerty, et al. 2012, p. 1144). Recently, the capacity and usage of biomass in power plants are escalating, especially Finland and Sweden have a large proportion of biomass in their energy mix.

There are comprehensive policies and regulatory frameworks in the EU that promote renewable technology development. The emergence of Renewable Energy Directive in 2009 has advanced EU's renewable energy consumption to 21.8% in 2021 from 12.5% in 2009. The EU's Renewable Energy Directive was revised in 2018 and implemented binding targets of reaching 32% share of renewable energy in the energy mix including heating, cooling, and transport sectors by 2030. The directive was further revisited twice in July 2021 and March 2023 to raise the target to at least 42.5% with an aim of 45% (European Commission, 2023a).

To fulfil sustainability requirements, biomass must be generated in a sustainable manner without causing any environmental or social consequences. It must fulfil sustainability definition that entails energy security and conserving natural resources for future generations at the same time. Although biomass is mostly renowned for its many advantages, it has several impacts on the environment and society. For example, biomass generation can compete with food and feed production. As a result, agricultural land may expand to

cropland, forests, wetlands, and peatlands. This extension may lead to indirect land use change which would release the stored CO_2 in trees and soil to the atmosphere. The other major drawbacks are deforestation, and soil degradation which may result in biodiversity and ecosystem loss. Therefore, biomass cultivation must follow the guidelines imposed by the Renewable Energy Directive (Proskurina & Mendoza-Martinez, 2023, pp. 7-8).

The aim of this thesis is to evaluate the role of biomass usage in the EU's energy mix. The data were mostly collected from renowned sources, such as Eurostat, International Energy Agency (IEA), Mordor Intelligence etc. The target is to present data of energy mix, biofuel trade, and different biofuels at least until 2021 as well as analyze the bioenergy perspective in the EU. Section 2 of the thesis presents the role of bioenergy in renewable energy development in the EU. Section 3 describes the role of biomass trade including solid biofuels in the EU. Section 4 shows biomass usage in different sectors in the EU, and what types of biofuels are being used in these sectors. Section 5 demonstrates modern bioenergy usage and production across biofuel types in the EU which includes wood pellet, bioethanol, biodiesel, charcoal, torrefaction plants, and pyrolysis oil plants. Section 5 also discusses trades, end-use, and feedstock of each biofuel type along with their plants' locations. Section 6 draws a perspective on future biomass usage after the birth of new policy and regulations. Finally, section 7 concludes the thesis by summing up the present and future scenario of biomass.

2 Biomass role in renewable energy development in the EU27

2.1 Electricity generation

After the Brexit event in 2020, the European Union now consists of 27 nations. In 2021, the most dominant sources for generating electricity in the EU were nuclear, natural gas and coal which made up around 60% in the energy mix. Among the renewable sources wind and hydro power are dominant. Total renewable share was 37% whereas biomass only shared 5.15% of total electricity generation. Figure 1 represents share of different sources in 2021 including breakdown of different types of biomasses (IEA, 2023a). Total energy consumption in the EU27 in 2021 was 60.11 EJ which was 10.1% of the entire world. In the same year, the amount of renewable energy consumed in EU27 was 11.16 EJ which accounts to 13.92% of the world (British Petroleum, 2022, p. 8, 9). Biomass is considered as a major renewable source in Europe due to its availability in most of the European countries. The consumption of biomass stood at 305 thousand barrels of oil equivalent per day in 2021 which is equal to 0.68 EJ in the annum. The European Union countries consumed 16.6% of global biomass production (British Petroleum, 2022, p. 49).

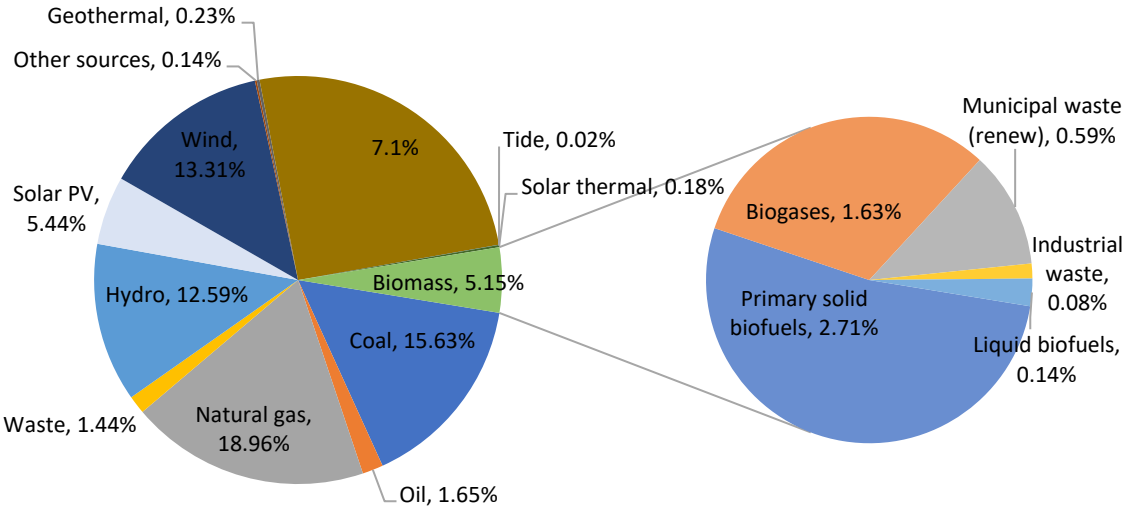

Figure 1. Percentage of various sources in electricity generation in 2021 across the EU (IEA, 2023a)

2.2 Heating and cooling

In European energy mix, heating, and cooling, including commercial and residential applications, occupy approximately 50% share of gross energy consumption. The demand of renewable energy for heating and cooling is gradually increasing in the EU which is getting supported by biomass and heat pumps. The share of renewables in heating and cooling was just above 23% in 2020 which suddenly decreased to 22.9% due to the economic recovery from COVID-19 in 2021 which results in increase of consumption of all fuels. This figure stood at only 11.7% in 2004 which depicts the quick growth of clean energy in this sector. Sweden was the leader in using renewables in heating and cooling in 2021 with an approximate figure of 68.6%, followed by Estonia, Latvia, and Finland (European Commission, 2023b) (IEA, 2023b). The share of heat generation sources in the EU except Greece, Ireland, Malta, Portugal, and Spain in 2021 is shown in Figure 2 including the breakdown of each biomass sources (IEA, 2023b).

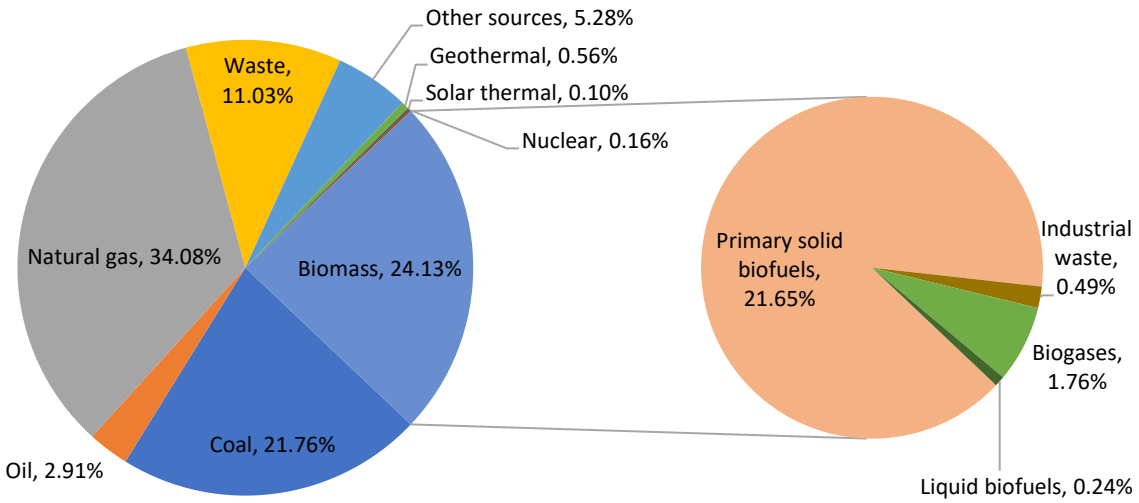

Figure 2. Percentage of various sources in heating and cooling in 2021 across the EU (IEA, 2023b)

2.3 Biomass supply

Biomass is considered a significant driver among the renewable sources in European Green Deal which is the EU's long term growth strategy to make Europe world's first climate neutral continent by 2050. According to the strategy, the EU has a binding target to reduce greenhouse gas emission by 55% by 2030, compared to 1990 levels (European Commission, 2023c).

In 2021, Germany ranked first in terms of biofuel supply. The other major users were France, Italy, Sweden, Poland, and Finland. Between 1990-2021, biomass usage has escalated in all the EU countries. Over the years, biomass usage in the energy mix increased by 4460 PJ. Total biomass supply in each country of the EU from 1990 to 2021 is shown in table 1 (IEA, 2023c) (Eurostat, 2023a).

Table 1. Total biomass supply (in TJ) in EU27 from 1990-2021 (IEA, 2023c) (Eurostat, 2023a)

Countries	1990	1995	2000	2005	2010	2015	2020	2021
Austria	104793	120910	131228	170433	261812	274101	258401	273671
Belgium	31596	37832	43367	67313	144677	149325	159957	166825
Bulgaria	7221	8878	23367	31423	38342	51691	81418	96131
Croatia	36173	44191	41974	52398	52889	55565	62761	82435
Cyprus	257	571	429	654	2167	2885	6030	4534
Czech Republic	44124	54143	64914	85840	125615	173339	200888	209079
Denmark	47723	60058	73141	111416	150371	162293	197777	237118
Estonia	7865	20623	21454	24376	34671	38408	52703	62230
Finland	191068	210177	274175	292725	347227	380325	405046	464513
France	460033	471782	450761	503352	655986	686240	706402	787872
Germany	200851	224205	329742	666089	1171020	1277310	1320038	1357896
Greece	37403	39146	42261	42485	45033	58539	49294	49738
Hungary	27487	33265	31737	68886	113009	123244	113255	116132
Ireland	4511	3844	5908	9036	15499	22100	31956	33251
Italy	39395	60977	94266	278658	529698	611017	612685	628946
Latvia	27581	42102	39696	49852	48386	59431	67837	71249
Lithuania	11916	19312	27019	35139	41647	55851	63377	72645
Luxembourg	954	1549	2122	3857	5990	8898	16095	16527

Malta	0	0	0	0	60	341	724	703.35
Netherlands	40383	49505	76484	115811	150128	148168	209336	235305
Poland	93347	192603	155753	185498	303497	348796	498522	487626
Portugal	103699	106653	115980	124222	133688	127374	137924	142899
Romania	25192	72250	119709	136922	173000	159419	175006	182511
Slovakia	7286	12052	17296	18909	37409	57669	78172	78936
Slovenia	11177	11007	23711	30164	31651	31283	29644	30043
Spain	170295	154225	172937	214168	288560	301112	316474	318242
Sweden	230579	301704	345989	365058	470892	493382	575337	582329
EU27	1962909	2353564	2725420	3684684	5372924	5858106	6427059	6802653

Figure 3 depicts that over the span of 1990-2020, Cyprus increased its biomass consumption by about 23 times more than its 1990 value which is the most. Cyprus is followed by Luxembourg and Italy which are using around 17- and 15-times biomass respectively. On the other hand, France, Portugal, and Greece observed a small improvement in their biomass usages. Overall, biomass usage in the European Union has tripled in the last 30 years.

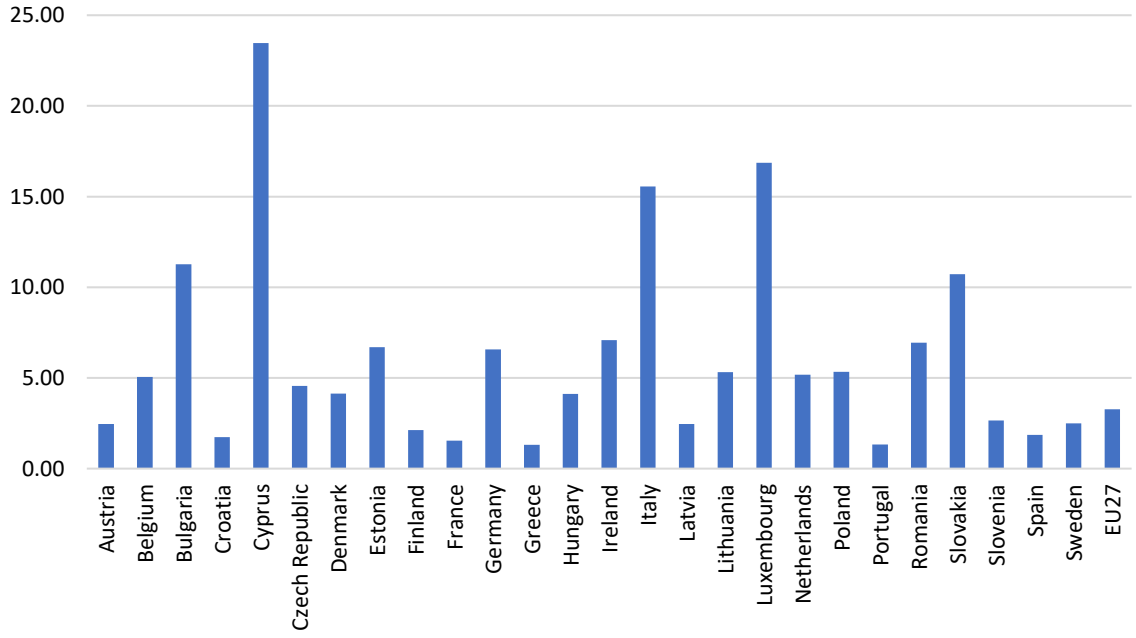

Figure 3. Growth of biomass in the EU27 from 1990-2020 (IEA, 2023c)

Table 2 illustrates that only a few countries in the EU were significant biomass users in their local energy mix in the early 90s. These countries were Finland, Portugal, Sweden, and Austria who had more than 10% share of biomass in their energy mix. However, in the last

30 years, all the EU27 nations installed significant biomass-based power plants and transportation infrastructure which has made biomass a major source of energy by the end of 2020. Currently, Latvia, Denmark, Finland, and Estonia are mostly dependent on biomass as each of them having above 30% share of biomass. However, there are still few countries that have below 10% share of biomass, such as Ireland, Greece, Spain, Cyprus, France, Belgium, and Netherlands.

Table 2. Share of biomass and waste in the energy mix (in %) of the EU27 from 1990-2021 (IEA, 2023c)

Countries	1990	1995	2000	2005	2010	2015	2020	2021
Austria	10.04	10.68	10.91	12.20	18.51	20.50	19.71	20.08
Belgium	1.57	1.71	1.80	2.80	5.78	7.05	7.62	7.11
Bulgaria	0.62	0.92	2.94	3.66	5.01	6.50	11.19	10.14
Croatia	9.73	13.97	12.39	13.38	14.03	17.23	19.70	16.28
Cyprus	0.45	0.80	0.48	0.70	2.09	3.37	6.75	4.00
Czech Republic	2.11	3.10	3.68	4.42	6.48	9.67	11.77	11.61
Denmark	6.81	7.37	9.40	14.18	18.38	24.73	32.31	34.51
Estonia	1.67	8.64	10.65	10.44	13.44	18.78	30.28	30.91
Finland	16.62	17.80	20.93	21.29	23.34	29.41	31.95	35.29
France	4.82	4.64	4.18	4.33	5.90	6.35	7.60	7.86
Germany	1.37	1.59	2.34	4.69	8.45	9.75	11.26	11.20
Greece	4.18	4.14	3.72	3.38	3.96	6.24	6.22	5.98
Hungary	2.36	3.10	3.07	5.98	10.35	12.26	10.71	10.55
Ireland	1.09	0.86	1.02	1.49	2.59	3.97	5.77	5.87
Italy	0.66	0.93	1.34	3.65	7.44	9.82	10.86	10.52
Latvia	8.69	22.84	25.77	27.41	26.07	34.57	39.15	39.35
Lithuania	1.67	5.19	9.06	9.37	15.72	21.52	22.99	25.65
Luxembourg	0.75	1.36	1.77	2.24	3.69	6.54	13.01	12.64
Malta	0.00	0.00	0.00	0.00	0.17	1.47	2.65	2.70
Netherlands	1.45	1.64	2.50	3.53	4.35	4.94	7.22	7.96
Poland	2.16	4.61	4.16	4.76	7.20	8.78	11.84	10.83
Portugal	14.76	12.66	11.30	11.47	13.72	13.97	16.46	17.57
Romania	0.98	3.70	7.87	8.43	11.77	11.80	13.10	11.72
Slovakia	0.83	1.63	2.30	2.36	5.04	8.51	11.30	10.65
Slovenia	4.61	4.23	8.53	9.53	10.03	11.34	10.72	11.10
Spain	4.51	3.67	3.41	3.61	5.38	6.07	6.95	6.61
Sweden	11.63	14.37	17.61	16.80	22.23	25.33	29.40	28.53

3 Developments of biofuels trade in the EU27

3.1 Current status

Foreign biomass or a product containing biomass can be directly used in the imported countries or processed into higher quality end products, which can subsequently be consumed locally or exported further. Imported biomass are typically used for various purposes including as a fuel in transport and power plants or as raw materials in industries. Therefore, it must identify first where the products are consumed. Biomass trade for biofuel production is a growing trend these days. Some common bioproducts that are traded globally are ethanol, vegetable oils, fuel wood, charcoal, and wood pellets. The forestry industry largely imports wood for use as raw material which is significantly consumed in energy generating application or turned into by-products for energy production purpose. For policymakers and other stakeholders, international trade of energy biomass is a significant term since biofuel market development is the key to enhance biomass energy consumption (Vakkilainen, et al. 2013, p.12).

EU countries typically utilized their locally produced biomass and waste. Around 87.5% of the biomass consumed for energy in the EU27 countries were locally produced in 2020. Only the remaining amount was imported from other countries. Belgium, Cyprus, Denmark, and Luxembourg are exceptions who mostly depends on the imports. Biofuels export from the EU still holds trivial figure. However, Latvia is exceptionally exporting above 50% of their domestic biomass production. Figure 4 demonstrates biofuel production, import and export (in Mtoe) in the EU27 in 2020 and figure 5 shows what percentage of the biofuels are locally harvested and imported (IEA, n.d.).

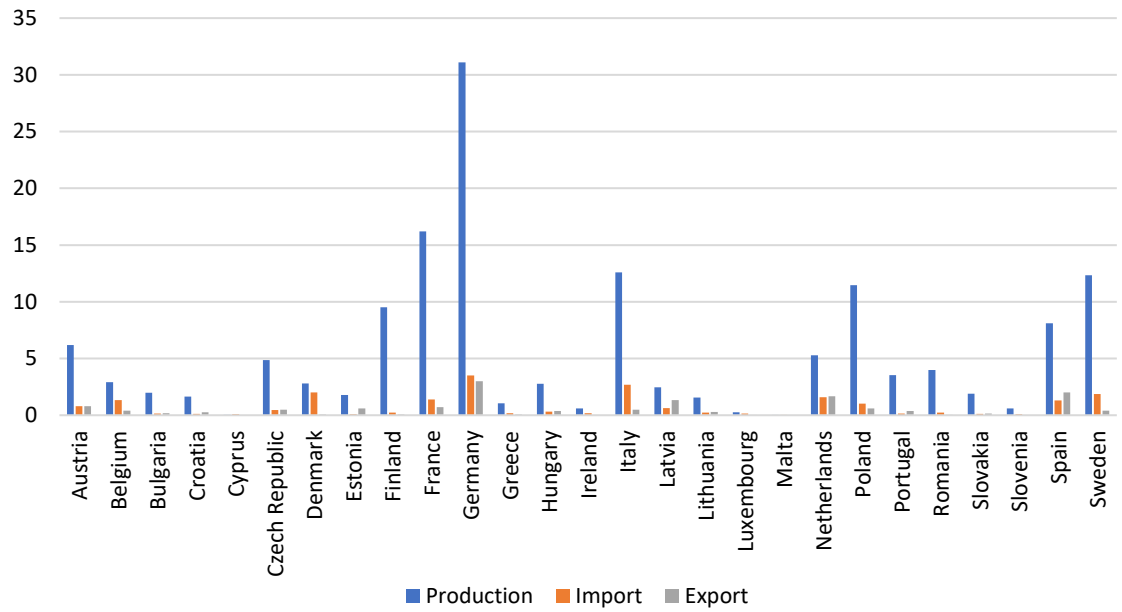

Figure 4. Biofuels and waste production, import and export (in Mtoe) in 2020 (IEA, n.d.)

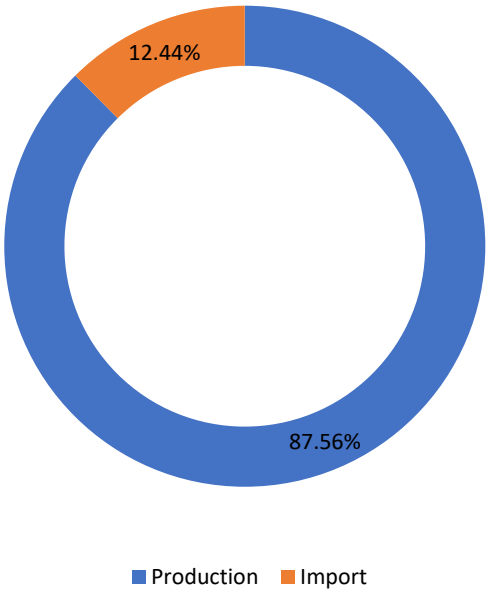

Figure 5. Percentage of Biofuels and waste production, import and export in the EU27 in 2020 (IEA, n.d.)

3.2 Import and export volumes

Biomass trade means an exchange of biofuels between nations. For this study, trade of wood pellets, biogasoline, bioethanol and biodiesel were focused since they are most significant traded solid and liquid biofuels. Biofuels import to the EU increased gradually at the end of the last decade, and import values became twice in 2021. Wood pellets and biodiesel contributed most to the skyrocketing of biofuel imports while biogasoline and bioethanol imports increased comparatively slowly. Likewise, exports of these biomass sources also rose over the years. However, biogasoline and bioethanol exports remained almost constant while wood pellets and biodiesel exports escalated significantly. In 2021, the import and export of these sources stood approximately at 28 million tonnes and 21 million tonnes respectively. Figure 6 and 7 shows the import and export volumes of solid biofuels and municipal waste (in ktons) respectively between 2015 and 2021 (Eurostat, 2023b) (Eurostat, 2023c).

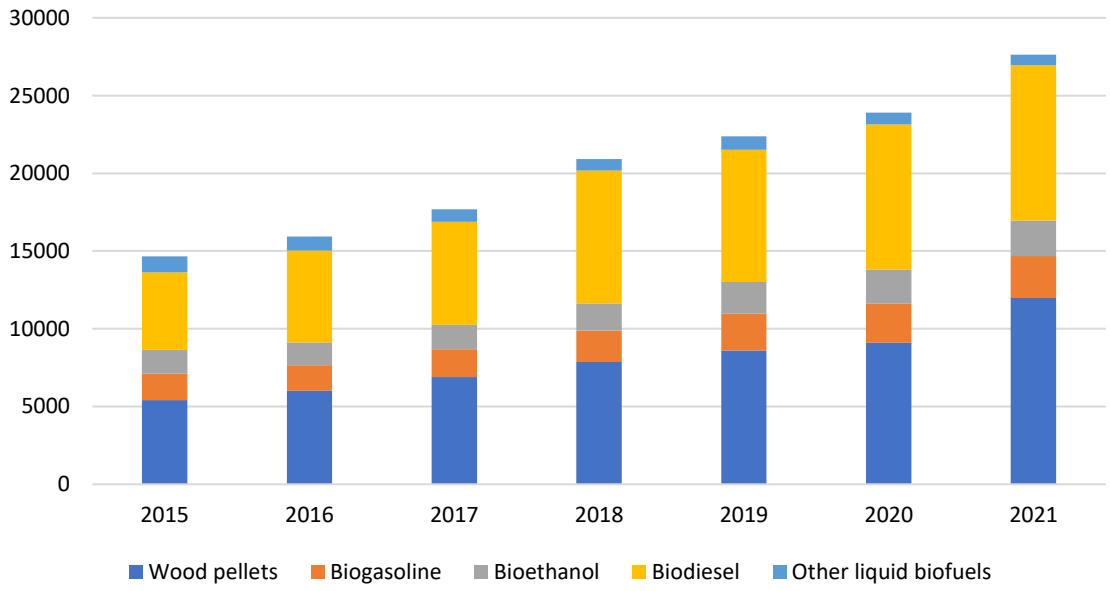

Figure 6. Import volumes of biofuels in the EU27 from 2015-2021 (in ktons) (Eurostat, 2023b)

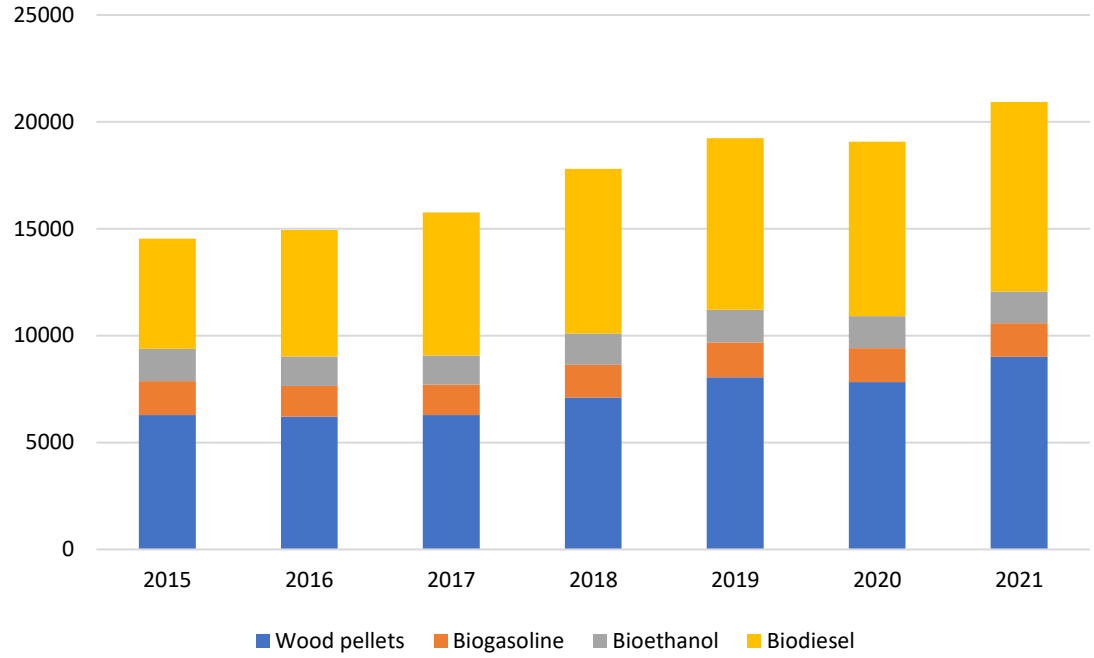

Figure 7. Export volumes of biofuels in the EU27 from 2015-2021 (in ktons) (Eurostat, 2023c)

4 Modern bioenergy usage across sectors in EU27

Biomass is dominantly used in the heating sector including residential, industrial, and commercial purposes. In 2020, heating sector used almost 74% of the total biomasses for energy, followed by transport and bioelectricity with 13.5% and 12% respectively. Residential buildings are consumers of about half of the biofuels used for heating (Geelen, 2022, p. 25, 26). In terms of transportation, road vehicles are the utmost users of biofuels while rail and maritime transportation possess a merely figure. Biofuel's share in transportation held only 6% of the total fuel usage in 2020. Oil and petroleum products were paramount in transportation with 91% of share (Calderón, et al. 2022, p.13) In EU27, biomass for electricity generation needs more extension to make Europe climate neutral by 2050. As mentioned earlier of this study, types of biomasses used for electricity generation are solid biomass, biogas, renewable municipal waste, and liquid biofuels in descending order with solid biomass and biogas comprising 55% and 31% of total biofuels (Geelen & Jossart, 2023, pp. 37, 38). Figure 8 illustrates the gross final energy consumption by bioenergy across different sectors.

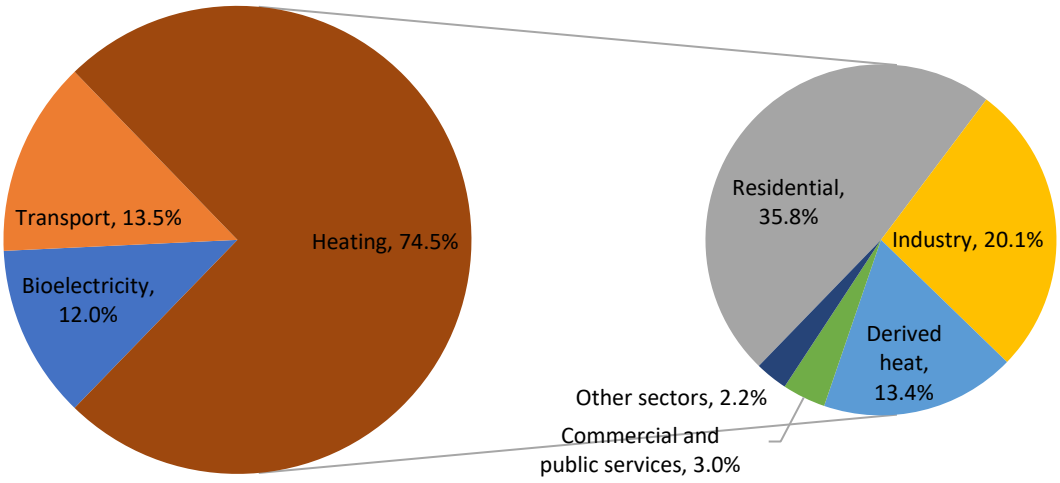

Figure 8. Biomass use for energy purposes in 2020 (Geelen, 2022)

4.1 Electricity generation

According to table 3, primary solid biofuels are the dominant source consisting of more than half of biomass in electricity generation. Most significant user of primary solid biofuels in 2021 were Finland, Germany, Sweden, Netherlands, and Denmark. Biogas was the second largest sources, excessively used by Germany. Due to Germany, Italy, Netherland, France's significant usage of municipal waste, it is also considered a major biomass source across the EU. The other two minor sources are industrial waste and liquid biofuels whereas only Italy is the main consumer of liquid biofuels (IEA, 2023d) (Eurostat, 2023d).

Table 3. Types of biofuels used in electricity generation in the EU27 in 2021 with their quantities (in GWh) (IEA, 2023d) (Eurostat, 2023d)

Countries	Primary solid biofuels	Biogases	Municipal waste	Industrial waste	Liquid biofuels
Austria	3523	602	354	182	0
Belgium	3051	959	918	371	10
Bulgaria	2372	216	0	0	0
Croatia	659	440	0	0	0
Cyprus	0	60	0	0	0
Czech Republic	2665	2592	127	16	0
Denmark	7134	607	971	0	0
Estonia	1715	15	76	0	0
Finland	12883	317	547	69	0
France	4163	2918	2104	176	5
Germany	11342	33160	5707	888	293
Greece	41	336	0	34	0
Hungary	1775	295	161	156	0
Ireland	471	170	356	0	0
Italy	4330	7593	2304	66	4045
Latvia	570	292	0	0	0
Lithuania	387	157	142	80	0
Luxembourg	285	63	43	0	0
Malta	0	7	0	0	0
Netherlands	7751	858	2146	0	0
Poland	6437	1275	212	69	2
Portugal	3214	262	342	16	0
Romania	580	73	0	0	0
Slovakia	1071	492	23	128	0
Slovenia	169	110	0	11	6
Spain	5126	928	785	227	14
Sweden	9195	27	2609	62	335
EU27	90909	54824	19927	2551	4710

4.2 Heat generation

Primary solid biofuel is widely used in the EU for heat generation. Sweden, Finland and Denmark are the three Nordic countries that utilized solid biofuels remarkably in 2021. Biogas was mainly consumed in Germany and Italy which makes it the second largest bioenergy source in the EU. The use of liquid biofuels and industrial waste were limited. Table 4 shows what amount of each source was used in the EU for heat generation in 2021. The quantity of sources in Greece, Ireland, Malta, Portugal, and Spain are excluded as they are not yet available (IEA, 2023e) (Eurostat, 2023d).

Table 4. Types of biofuels used in heat generation in the EU in 2021 with their quantities (in TJ) (IEA, 2023e) (Eurostat, 2023d)

Countries	Primary solid biofuels	Industrial waste	Biogases	Liquid biofuels
Austria	48373	902	196	0
Belgium	405	515	840	13
Bulgaria	8305	227	160	0
Croatia	4017	0	708	0
Cyprus	0	0	37	0
Czech Republic	10156	295	1153	0
Denmark	71373	0	1714	152
Estonia	15764	0	120	0
Finland	85261	471	850	15
France	56091	646	3397	0
Germany	27412	5638	19740	145
Hungary	3859	357	124	0
Italy	19757	443	10776	2066
Latvia	16824	0	818	0
Lithuania	23516	626	100	0
Luxembourg	4332	0	107	0
Malta	0	0	0	0
Netherlands	14178	0	405	0
Poland	19124	1097	846	6
Romania	3554	2	194	0
Slovakia	5969	85	708	0
Slovenia	1818	150	175	19
Sweden	94879	639	282	3457
EU	534967	12093	43450	5873

4.3 Transportation

Biodiesel, biogasoline and biogas are three major sources used in transportation, especially in road transportation. Two forms of biodiesel and biogasolines are used, including pure and blended forms. Consumption of blended biodiesel and biogasoline outweighed pure form of them. In this study, two different forms are summed together, and simply called as their common name. The proportion of biodiesel in total biomass sources in transportation were beyond 80% in 2021 with France and Germany being the key user. Biogasoline was also predominantly used by these two countries in the same year. Finally, Biogas usage is still lagging behind in transportation which is solely utilized in Sweden. Quantities of biodiesel, biogasoline and biogas used in the EU27 in 2021 are listed in table 5 (Eurostat, 2023e).

Table 5. Types of biofuels used in transportation in the EU27 in 2021 with their quantities (in ktoe) (Eurostat, 2023e)

Countries	Biodiesel	Biogasoline	Biogases
Austria	409	49	0
Belgium	612	160	0
Bulgaria	147	21	0
Croatia	90	1	0
Cyprus	24	0	0
Czech Republic	306	55	19
Denmark	175	82	2
Estonia	41	4	12
Finland	557	113	5
France	2182	710	0
Germany	2151	735	0
Greece	149	68	0
Hungary	198	87	0
Ireland	158	20	0
Italy	1388	27	0
Latvia	35	12	0
Lithuania	110	17	0
Luxembourg	120	18	0
Malta	11	0	0
Netherlands	356	233	0
Poland	912	208	0
Portugal	323	17	0
Romania	375	121	0
Slovakia	135	26	0
Slovenia	95	9	0
Spain	1289	112	0
Sweden	1255	117	79
EU27	13605	3023	118

5 Modern bioenergy usage and production across biofuels types in EU27

5.1 Biomass plants that process and refine biofuels

5.1.1 Wood pellet

Wood pellets are formed by finely powdering dry biomass and passing it through a pellet dye at high temperature and pressure. Because of the compression and high temperature, the lignin in the biomass melts, bonding the particles, which then reassemble as a solid pellet after chilling. Depending on the raw material used, the pellet production process may contain a few numbers of steps: raw material reception, screening, grinding, drying, pelletizing, chilling, sifting, and packing. Relative to wood chips, pellets have high-value and high energy density (Whittaker & Shield, 2008, p. 233).

According to a report from USDA Foreign Agricultural Service's Global Agricultural Information Network, pellet consumption in European Union was estimated 23.1 million metric tonnes in 2021. Among the EU27 countries, Italy topped the list with 3.4 million metric tons of pellet consumption in 2021. The next two major consumers were The Netherlands and Germany each consuming 2.9 million metric tons of wood pellets. The report further claimed that it is anticipated that consumption would continue rising in the following years. In the recent years, Germany is heavily burning wood pellets for their residential heating applications, and The Netherlands is focusing on co-firing of pellets with coal. As a result, pellet combustion is on the rise in the EU (Voegele, 2022a).

Wood pellet production in 2021 in the EU27 stood at 7168.51 ktoe in 2021. Germany was by far the biggest producer of the wood pellets. The other main producers were Latvia, France, Estonia and Austria who comprised approximately 57% of the wood pellet production share together with Germany. Figure 9 demonstrates the European union countries with their indigenous pellets production in 2021 (Eurostat, 2023f).

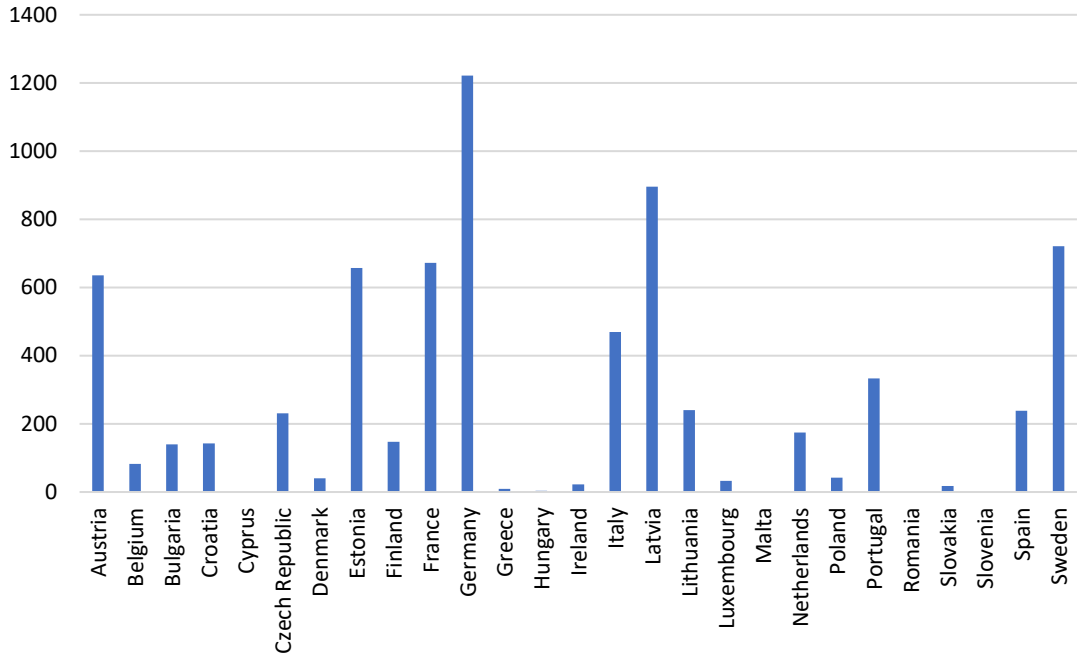

Figure 9. Wood pellet production in EU27 in 2021 (in ktoe) (Eurostat, 2023f)

This increased combustion is being supported by the biomass boiler installation and fossil fuel's excessive price. The EU's pellet production capacity was about 25.8 million metric tonnes in 2021 which was slightly higher than that of 2020. Overall, the pellet mills successfully utilized their 77.4 percent of capacity in 2021 and were aiming to reach 78.3 percent in the following year. This means pellet production figure in 2022 was expected to reach approximately 20.0 million tonnes, compared to 19.7 million tons in 2021. The imported amount accounted for 5.428 million metric tons. EU imported 1.914, 1.853 and 0.594 million metric tons of wood pellets from Russia, USA, and Belarus respectively. Total pellet exports from abroad reported for 4681 and 5428 thousand metric tonnes in 2020 and 2021 respectively. However, pellet import from Russia is restricted from April 2022. Top pellet importer countries were Denmark, Netherlands, Italy (Voegele, 2022a). Few leading pellet importers of the EU and suppliers to the EU in 2020 and 2021 are provided in Figure 10 and 11 respectively (Flach & Bolla, 2022, p.10).

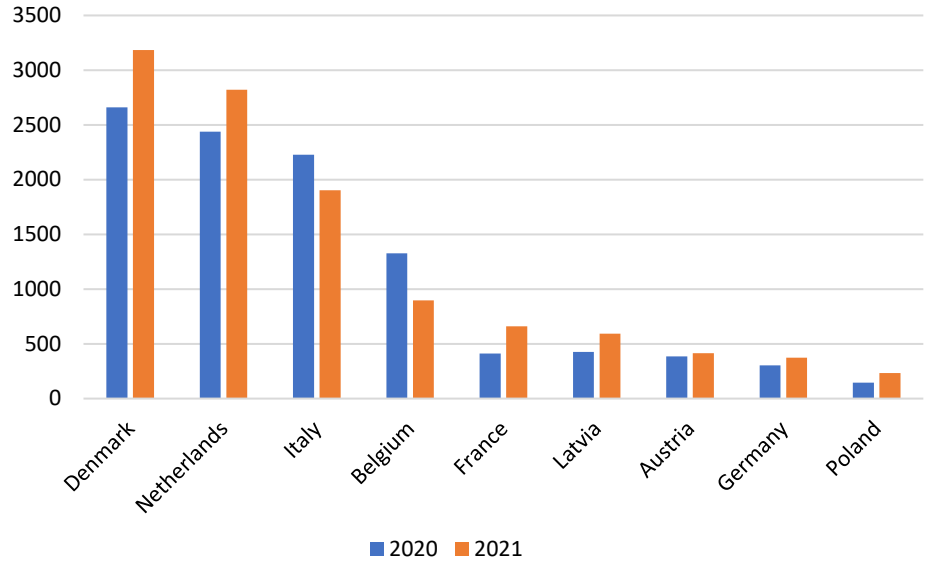

Figure 10. Wood pellet leading importers in the EU27 in 2020 and 2021 (in ktons) (Flach & Bolla, 2022, p.10)

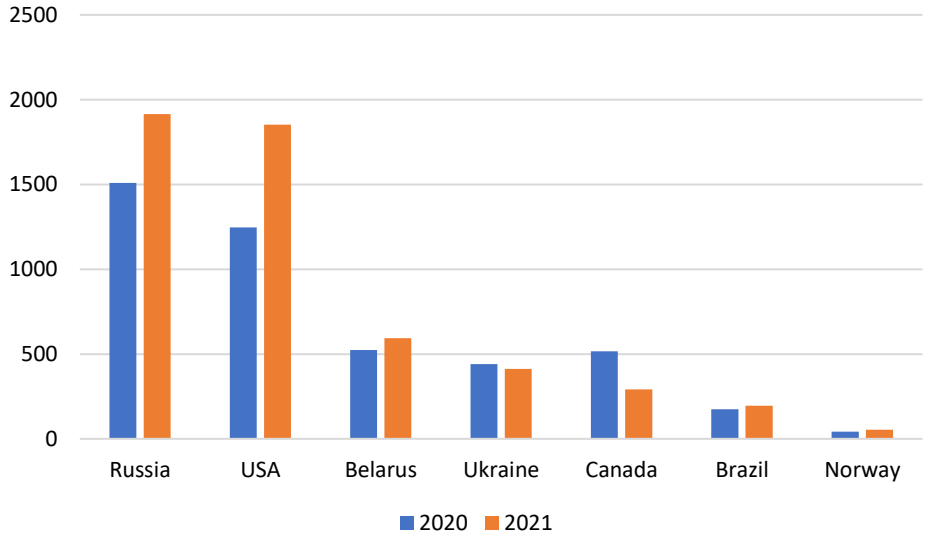

Figure 11. Wood pellet suppliers to the EU27 from outside in 2020 and 2021 (in ktons) (Flach & Bolla, 2022, p.10)

52% of the globally produced pellets were distributed in European Union in 2021. Wood pellets were consumed mostly for heating in residential and commercial buildings in that year, which accounted for around 16000 tonnes. Only electricity generation power plants

used approximately 3800 tonnes of wood pellets, and finally combined heat and power plant used 4500 tonnes of wood pellets in the EU27. Industries and residential and commercial buildings consumed almost equal amounts of wood pellets that year. Industries accounted for 17300 tonnes and residential and commercial buildings accounted for 18265 tonnes. The percentage of each end use is depicted in figure 12 (Geelen, et al. 2022, p. 31, 55)

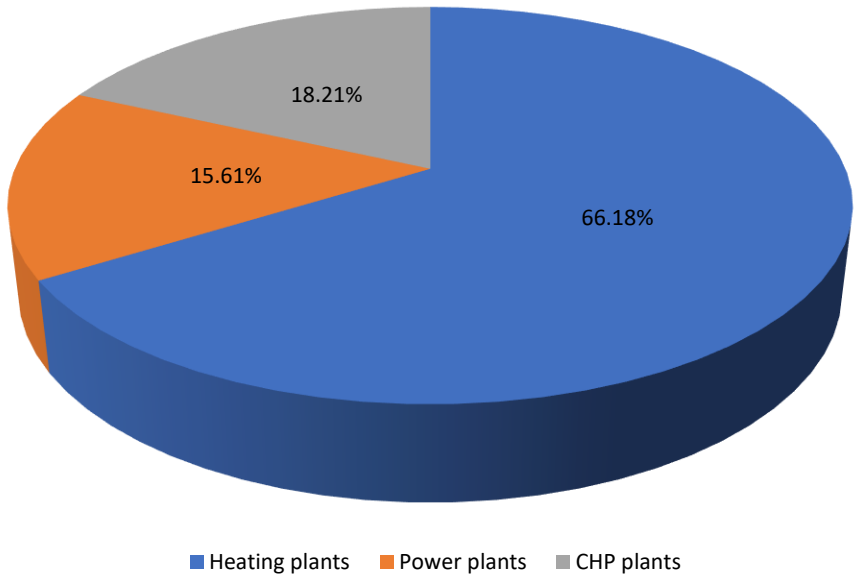

Figure 12. End use of wood pellets in 2021 (Geelen, et al. 2022, p. 31, 55)

In 2018, there were 713 pellet mills across the EU27 excluding the UK. The production capacity of these plants was 23353 tonnes, and actual production was 16879 tonnes (Calderón, et al. 2019, p. 17). In the next five years, it is predicted that pellet demand will be escalated by 30-40%. This increasing demand of pellets is creating a strong pressure on raw material markets in Europe which is leading to the creation of the new sources including forest residues, recovered wood and energy crops. Sawmill residues are the most dominant feedstock, followed by roundwood and recovered wood. The latter two feedstocks have a small share in the wood pellet industry. The share of each of the feedstocks are illustrated in figure 13.

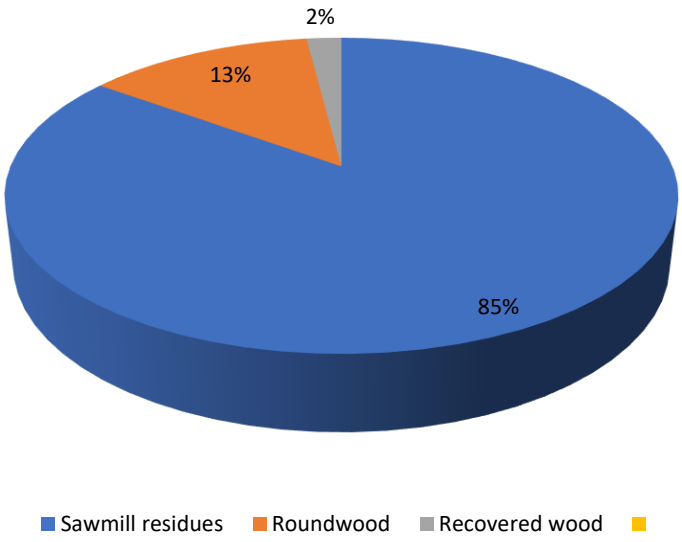

Figure 13. Feedstocks of wood pellets in 2021 (European Pellet Council, n.d)

The wood pellet market in Europe is relatively concentrated. The key players of the market are Stora Enso Oyj, Enviva Partners LP, AS Graanul Invest, Drax Group and Segezha Group PJSC (Mordor Intelligence, 2023a).

Table 6. Wood pellet market leaders in Europe with their plants' location (Stora Enso, 2023, p. 88) (Enviva, 2022, p. 5) 2700 (Graanul Invest, n.d.) (Drax, 2023, p. 7) (Segezha, 2022, pp. 128-129)

Company Name	Plant Location	Production Capacity (ktons)
Stora Enso Oyj	Ždírec, Czech Rebublic	80
	Imavere, Estonia	100
	Näpi, Estonia	25
	Launkalne, Latvia	50
	Ala, Sweden	100
	Gruvön, Sweden	100
	Total	455 (Stora Enso, 2023, p. 88)
Enviva Partners LP	Ahoskie, North Carolina	410
	Amory, Mississippi	115
	Cottondale, Florida	780
	Greenwood, South Carolina	600
	Hamlet, North Carolina	600
	Lucedale, Mississippi	750
	Northampton, North Carolina	750

	Sampson, North Carolina	600
	Southampton, Virginia	760
	Waycross, Georgia	800
	Total	6165 (Enviva, 2022, p. 5)
AS Graanul Invest	4 plants in Estonia (4)	
	6 plants in Latvia (6)	
	1 plant in USA (1)	
	1 plant in Lithuania (1)	
	Total	2700 (Graanul Invest, n.d.)
Drax Group	Smithers, British Columbia, Canada	
	Houston, British Columbia, Canada	
	Burns Lake, British Columbia, Canada	
	Meadowbank, British Columbia, Canada	
	Williams Lake, British Columbia, Canada	
	Armstrong, British Columbia, Canada	
	Lavington, British Columbia, Canada	
	Princeton, British Columbia, Canada	
	High Level, Alberta, Canada	
	Entwistle, Alberta, Canada	
	Russellville, Arkansas, USA	
	Leola, Arkansas, USA	
	Morehouse, Arkansas, USA	
	LaSalle, Arkansas, USA	
	Amite, Mississippi, USA	
	Aliceville, Alabama, USA	
	Demopolis, Alabama, USA	
	Selby, North Yorkshire, UK	
	Total	5000 (Drax, 2023, p. 7)
Segezha Group	Ksilotek – Siberia, Russia	
	Novoyeniseyskiy Wood-Chemical Complex, Russia	54
	Inter Forest Rus	
	Timber Trans, Russia	
	Tairiku- Igrima, Russia	
	Total	340 (Segezha, 2022, pp. 128-129)

5.1.2 Bioethanol

Bioethanol is a liquid biofuel generated through acetone-butanol-ethanol fermentation which can be directly used in automobiles. It has benefit of providing similar characteristics of traditional transportation fuels while having potential of reducing emissions. The feedstocks for bioethanol are corn, soyabeans, wheat straw, woodchips and microalgae. It consists of 35% oxygen which provides it high-octane rating. Bioethanol has lower volumetric energy density, requiring more quantity than conventional gasoline. The advantage of bioethanol is that it helps in achieving increased energy efficiency and performance (Dahman, et al. 2019, p.311).

Bioethanol consumption in 2021 surpassed the pre-COVID level and contributed 5.9 percent of EU gasoline. In accordance with the annual biofuels report of USDA Foreign Agricultural Service's Global Agricultural Information Network, it was forecast that this share is set to rise to 6 percent in 2022. High price of the conventional gasolines worked as a key factor of increased competitiveness of ethanol. The usage figure stood at 5.443 billion litres in 2021, and it was also predicted that it is about to reach 5.57 billion litres in 2022. In 2019 and 2020, this figure was 5.227 and 5.159 billion litres respectively. Top consumers were Germany with estimated consumption of 1.456 billion litres, followed by France (1.225 billion litres), Netherlands (500 million litres) and Poland (361 million litres) (Ethanol Producer Magazine, 2022).

In 2021, total bioethanol production capacity in the EU was just over 7.75 million litres where France, Germany, Hungary, and Netherlands were the leaders. These four countries held approximately 60 percent production capacity in 2021. The other significant producers were Belgium, Spain, Poland, and Sweden. The remaining countries have very little or no production plants capacity. Figure 14 represents bioethanol production capacity (in million litres) in the EU countries in 2021 (ePure, 2022).

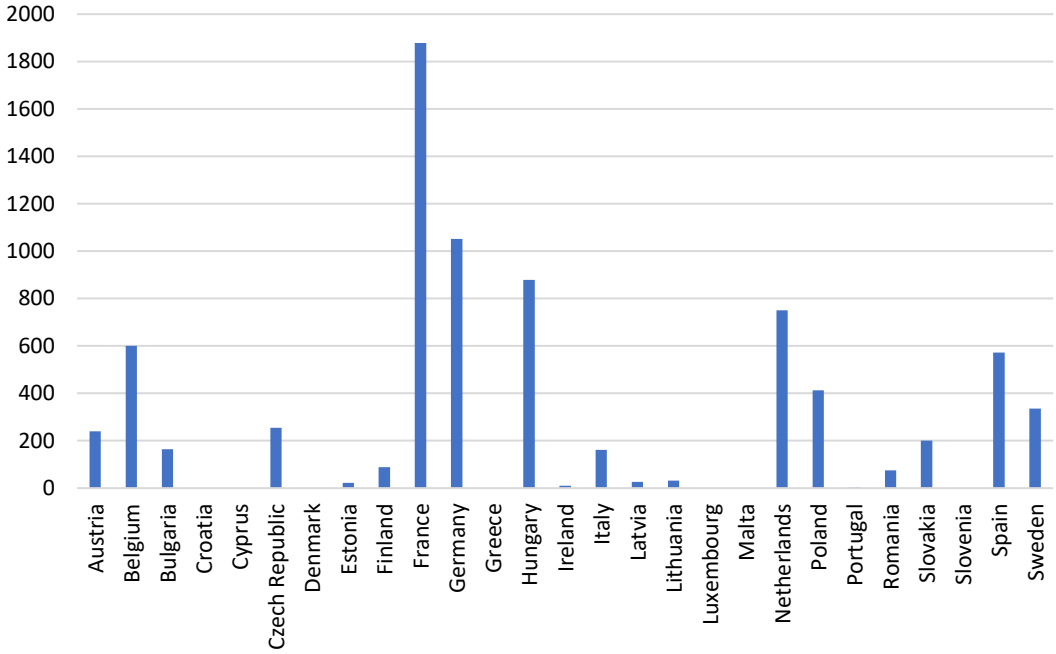

Figure 14. Bioethanol production capacity in each EU27 countries in 2021 (in million litres) (ePure, 2022)

There are several reasons behind the EU to develop its biofuel. It is a fact that all Europeans cannot afford electric cars, and there are even countries in the EU that still do not have the sufficient infrastructure to support electric automobiles. To combat climate change, biofuel including bioethanol and biodiesel are ready-made alternatives of fossil fuel in EU's transport, because biofuel requires no additional infrastructure. According to European Commission, crop-based biofuel production meets sustainability in Europe since associated environmental effects are minimal. Bioethanol from cereals produces highly digestible dried distiller grain with soluble which can be used as animal feed (EU Biofuels Chain, 2022).

In 2021, 477 million litres of bioethanol were imported to the EU, measured by annual biofuels report. This figure was less than 2019 and 2020 when the import values were 665 and 832 million litres respectively. On the other hand, bioethanol exports accounted for 342 million litres in 2021 which was decreased from 481 million litres in 2020 and 510 million litres in 2019. It was estimated to reach 354 million litres in 2022 (Ethanol Producer Magazine, 2022). Figures 15 and 16 show the leading importers and suppliers of bioethanol in 2021.

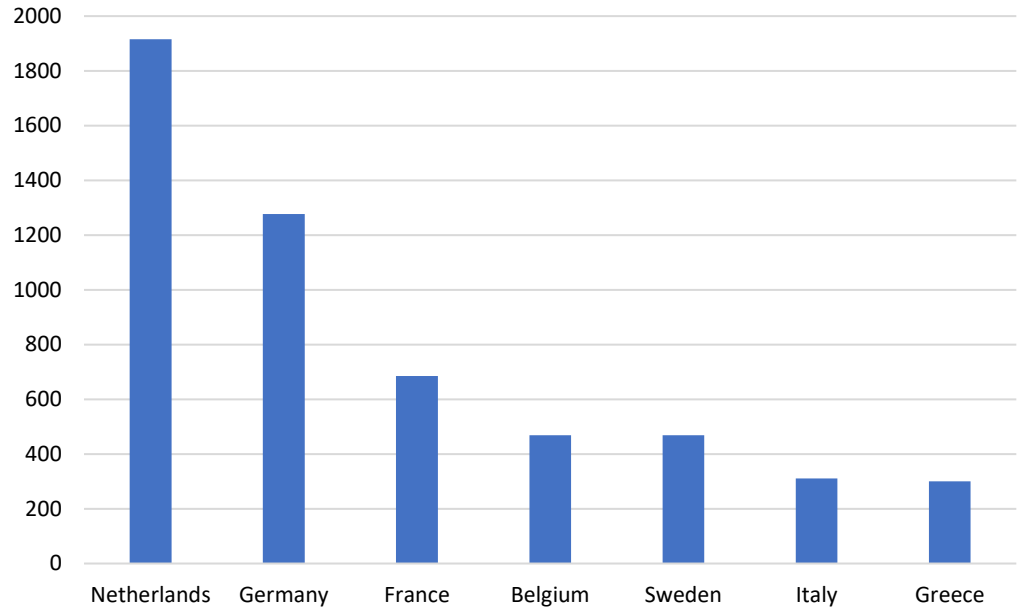

Figure 15. Bioethanol leading importers in the EU27 in 2021 (in million litres) (IndexBox, 2022)

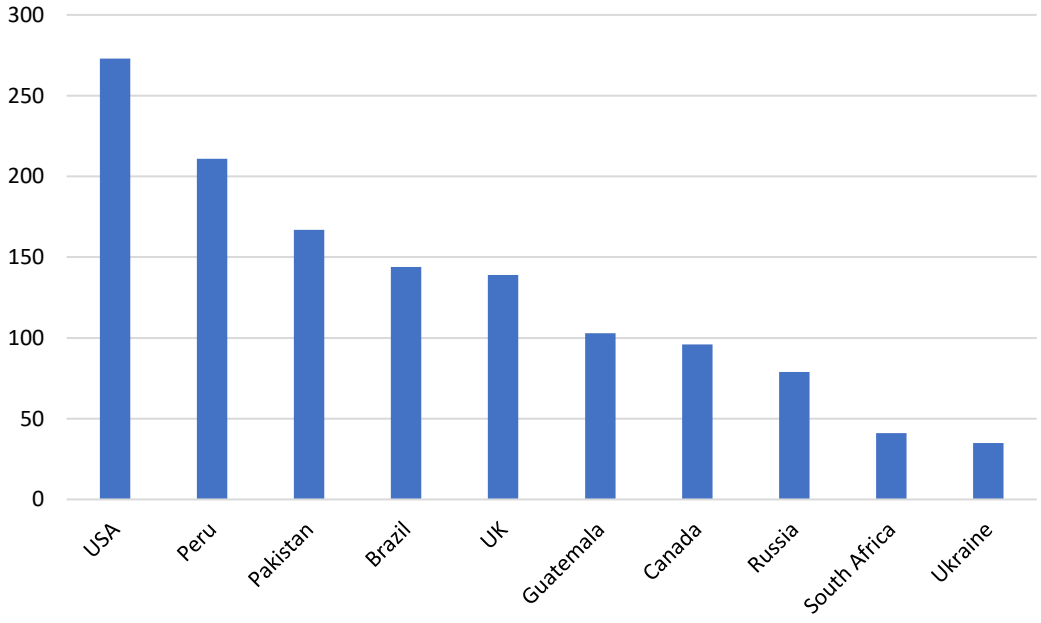

Figure 16. Bioethanol suppliers to EU27 from outside in 2021 (in million litres) (ePure, 2022)

The report from USDA also stated that there were 55 first generation ethanol biorefineries in 2022 in the EU. The capacity of these refineries was 6.42 billion litres. Operational capacity was 81 percent in 2021 which was expected to become 83 percent by 2022. Along with biorefineries the EU owned 4 cellulosic ethanol plants in 2022 whereas two of them started operation from 2021. Their gross capacity is 125 million litres. The latter two plants added 85 million litres capacity. In 2021, operational capacity stood 40%. The target was to accomplish 52% capacity by 2022 (Ethanol Producer Magazine, 2022).

The transportation sector was the dominant consumer of Bioethanol. Bioethanol as a fuel represented 84.2% in 2021 which accounted for 4.69 billion litres. The other two end users were industrial sector and food and beverages who comprised 9.4% and 6.4%. The share of end use of bioethanol is depicted in figure 17 (ePure, 2022).

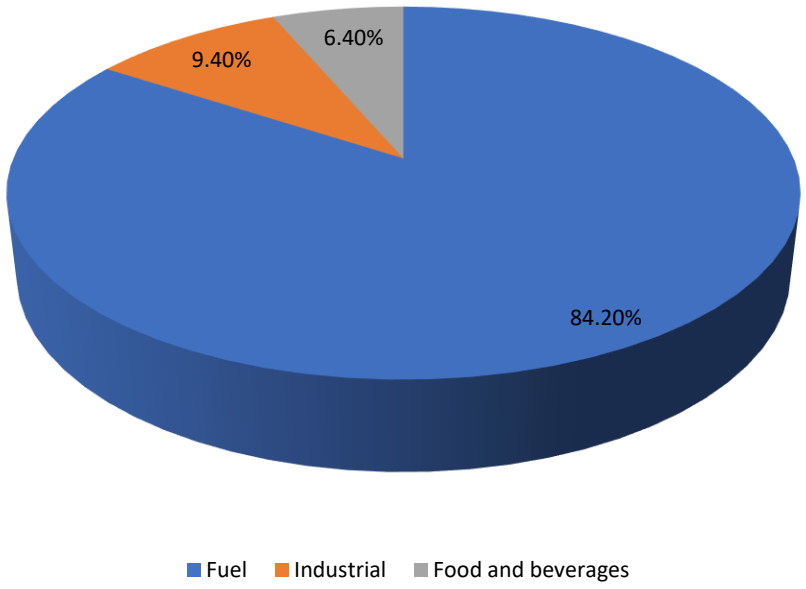

Figure 17. End use of bioethanol in 2021 (ePure, 2022)

Half of the feedstock for bioethanol production was wheat, which was accounted for 6.77 million tonnes. The amount of wheat, sugars and ligno-cellulosic used to produce ethanol were 4521.1, 1775.2 and 1404.85 million litres respectively. The percentage of each feedstock is shown in figure 18 (ePure, 2022).

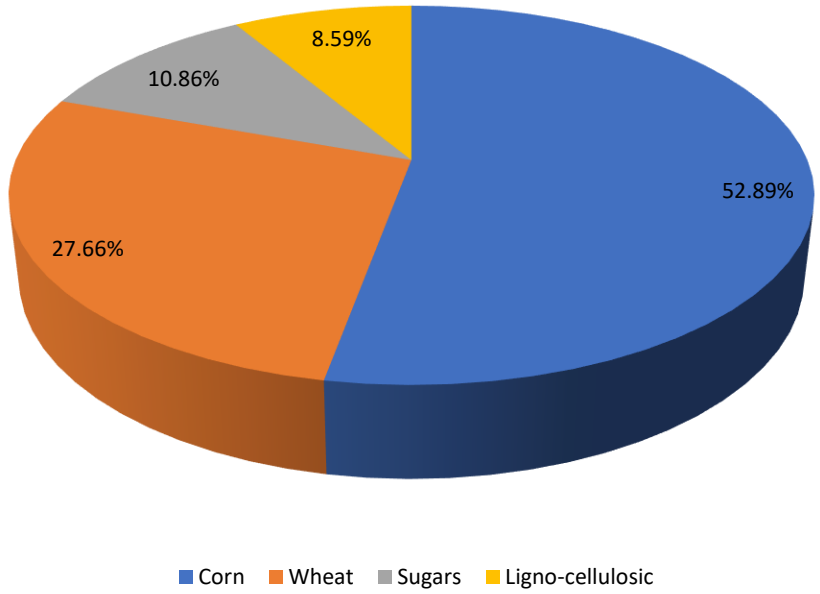

Figure 18. Feedstocks of bioethanol in 2021 (ePure, 2022)

Top 5 market leaders of bioethanol in Europe are Abengoa, Alcogroup SA, Lantmännen Agroetanol AB, Archer Daniels Midland (ADM) and Agrana Beteiligungs-AG (Mordor Intelligence, 2023b).

Table 7. Bioethanol market leaders in Europe with their plants' location (Vakkilainen, et al. 2013) (Abengoa, 2019) (De Smet, n.d.) (Lantmännen, 2023, p. 42) (Neeley, 2021) (Agrana Beteiligungs-AG, n.d.)

Company Name	Plant Location	Production Capacity (million litres)
Abengoa Bioenergy	Rotterdam, Netherlands	480
	São João da Boa Vista, São Paulo, Brazil	145
	Hugoton, Kansas, USA	95
	Madison, Illinois, USA	333
	Mt. Vernon, Indiana, USA	333
	Ravenna, Nevada	333
	Total	1719 (Vakkilainen, et al. 2013) (Abengoa, 2019)
Alco Biofuel	Ghent, Belgium	150 (De Smet, n.d.)
Lantmännen Agroetanol AB	Norrköping, Sweden	230 (Lantmännen, 2023, p. 42)
ADM	Nebraska, Iowa, Illinois and Minnesota	6057 (Neeley, 2021)
Agrana Beteiligungs-AG	Pischelsdorf, Austria	250
	Szabadegyháza, Hungary	187
	Total	437 (Agrana Beteiligungs-AG, n.d.)

5.1.3 Biodiesel

Nowadays biodiesel is considered one of the most prominent replacements of crude oil while crude oil prices are getting higher. Biodiesel is a drop-in fuel for diesel engines since its properties are similar to diesel. It is extracted from vegetable oils animal fats which consist of alkyl monoesters. Biodiesel does not include any aromatics or sulfur, and it has a higher cetane number than diesel. Additionally, it comprises 10-11% by weight of oxygen. It is produced through a chemical reaction where transesterification between a triglyceride and methanol or ethanol is performed. The reaction takes place in three phases. Firstly, diglycerides are generated from triglycerides. Secondly, diglycerides break into monoglycerides. Lastly, monoglycerides are transformed into glycerol. In each phase, esters are created as a product which is known as biodiesel. The products of the reaction are esters and glycerol. Biodiesel assists in reducing emission of carbon monoxide (CO), hydrocarbon

(HC) and particulate matter (PM) in exhaust gas. However, to consider it as a sustainable alternative, biodiesel must provide a net energy gain, be competitive in price, and be mass produced without affecting food supply (Manzanera, et al. 2008, pp. 25, 27).

Despite the COVID-19 pandemic, biodiesel and renewable diesel demand in the EU was high in 2020 and 2021. The EU biodiesel usage was enhanced by 3% post COVID-19 economic recovery. In these two years, consumptions were 17.09 billion litres and 17.611 billion litres respectively. A report from USDA Foreign Agricultural Service's Global Agricultural Information Network stated that the consumption would stagnate in 2022 and remained same of 2021. France topped the consumers list with a figure of 3.494 million litres in the EU. Germany's consumption was slightly lower than France and accounted for 3.072 million litres. The other notable users were Spain, Sweden, Italy and Poland. Together their usage reported for 72% (Flach, et al. 2022, pp. 25, 26).

Total biodiesel production in the EU reported just above 16100 million litres in 2021. Germany alone produced almost one-quarter of the EU's biodiesel in 2021. Netherlands, Spain, France and Italy made up 46% of share that year. Besides, Poland and Finland had some significant proportion in biodiesel production. Indigenous production of Biodiesel in each EU country is represented by figure 19 (Eurostat 2023).

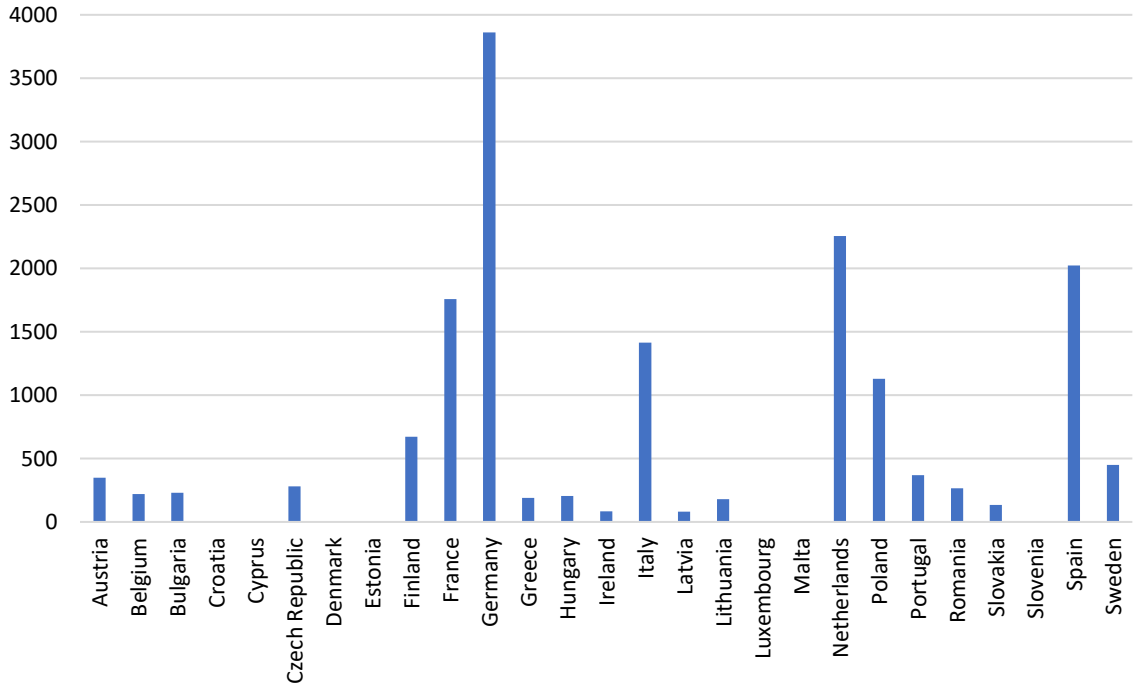

Figure 19. Biodiesel production in EU27 in 2021 (in million litres) (Eurostat 2023)

The amount of biodiesel imports to the EU countries is gradually decreasing during COVID era due to lockdown measures. The figure accounted for 3100 million litres in 2021 which was significantly lower than 4289 million litres in 2019. On the contrary, biodiesel exports also experienced decreasing trend in the last two years, accounted for 1059 million litres in 2021 and 2229 million litres in 2020. The imports and exports are predicted to recover as the COVID restrictions were lifted in 2022 (Flach, et al. 2022, pp. 22, 23). Figures 20 and 21 indicate the leading importers and suppliers of biodiesel in 2021.

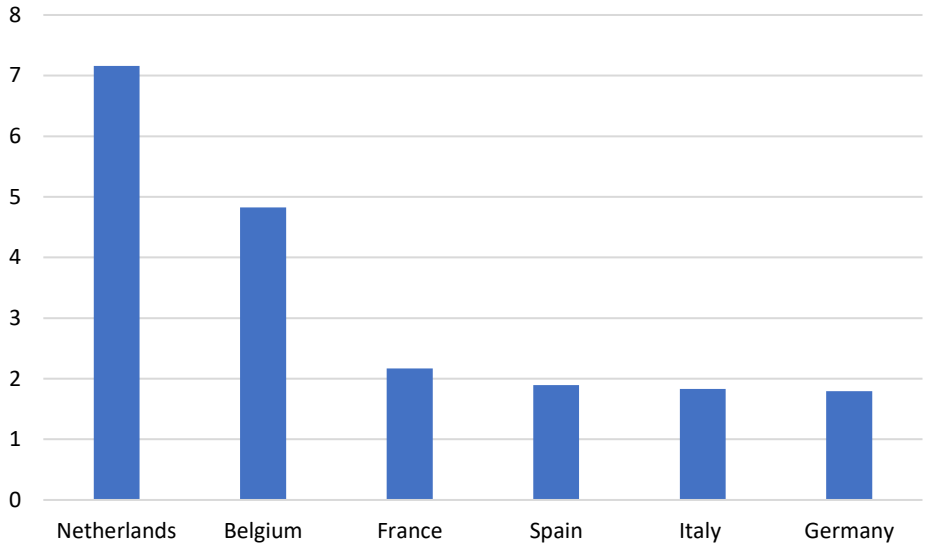

Figure 20. Biodiesel leading importers in the EU27 in 2021 (in USD) (Opportimes, 2022)

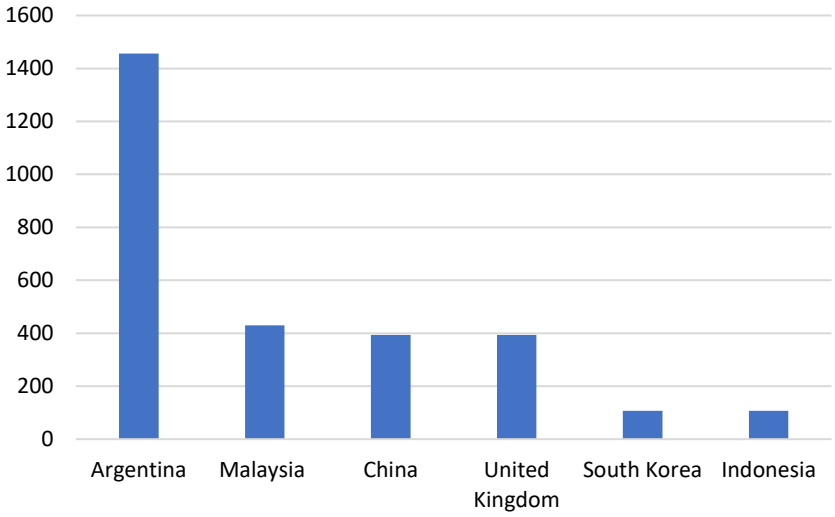

Figure 21. Biodiesel supplies to EU27 from outside in 2021 (in million litres) (Flach, et al. 2022, p. 31)

Currently, there are 170 biodiesel plants in the EU which is down from 173 in 2020. The combined capacity of these plants were 19.552 billion litres in 2021 which was slightly higher than that of 2020, compared to 19.302 billion litres. The capacity use of them were 62% and 63.1% in 2021 and 2020. Along with biodiesel plants, the EU owns 16 renewable diesel facilities. Comparing to biodiesel, renewable diesel combined capacity is small with a figure of 5.287 billion litres in 2021 and 5.399 billion litres in 2020. However, their plant operation capacity was vaguely over biodiesel's capacity, stood 66% in 2021 (Voegele, 2022b).

Virgin vegetable oils including rapeseed, palm oil and soy comprise three-quarters of the feedstocks in biodiesel production. In 2020, rapeseed oil contributed nearly 6.31 million litres, followed by palm oil and used cooking oil which contributed 5.35 million litres and 2.97 million litres respectively. Figure 22 depicts different feedstocks used for biodiesel production in the EU in 2020 (Rangaraju, 2021).

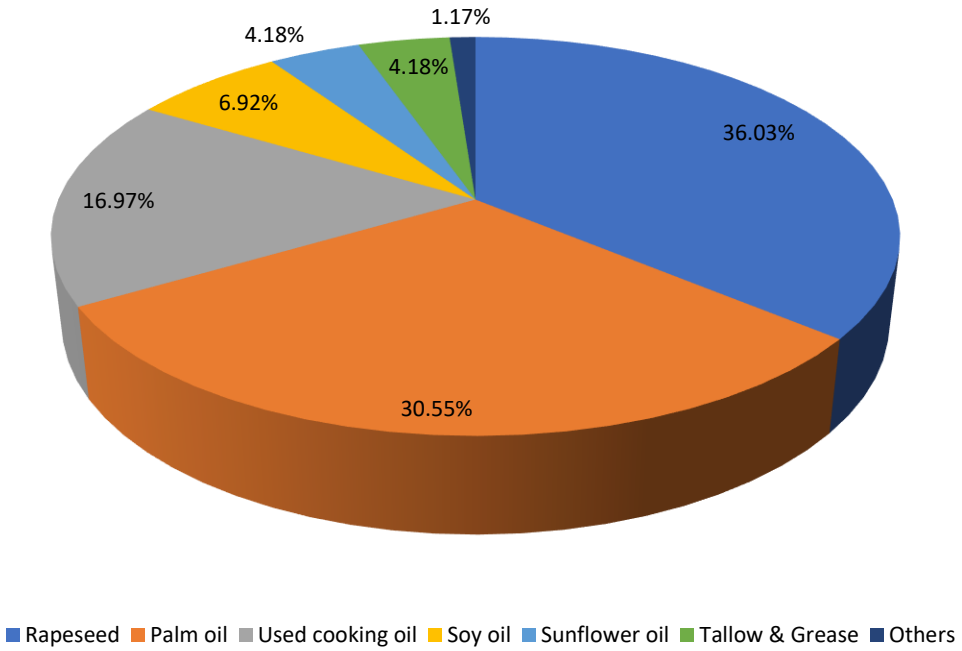

Figure 22. Feedstocks of biodiesel in 2020 (Rangaraju, 2021)

European biodiesel market is fragmented including key players, such as Neste, UPM-Kymmene Oyj, Green Fuel Nordic Oy, Svenska Cellulosa AB, Preem AB, SunPine AB, Galp Energia, SGPS, S.A., Biomethanol Chemie Nederland B.V., Beta Renewables S.p.A., Borregaard ASA etc. (Mordor Intelligence, 2023c).

Table 8. Biodiesel market leaders in Europe with their plants' location (Neste, n.d.) (Neste, 2021) (Statista, 2021) (UPM, 2023, p. 53) (BTG, n.d. a) (SCA, 2021) (Statista, 2021)

Company Name	Plant Location	Production Capacity (tonnes)
Neste	Rotterdam, Netherlands	1,400,000 (Neste, n.d.)
	Singapore	1,300,000 (Neste, n.d.)
	Porvoo, Finland	520,000
	Total	3,200,000 (Neste, 2021)
ENI	Gela, Italy	720,000
	Vence, Italy	340,000
	Total	1,060,000 (Statista, 2021)
UPM-Kymmene Oyj	Lappeenranta, Finland	130,000 (UPM, 2023, p. 53)
Green Fuel Nordic Oy	Lieska, Finland	24,000 (BTG, n.d. a)
Svenska Cellulosa AB & St1	Gothenberg, Sweden	200,000
	Östrand, Sweden	300,000
	Total	500,000 (SCA, 2021)
Preem AB	Gothenburg, Sweden	350,000
	Lysekil, Sweden	240,000
	Total	590,000 (Statista, 2021)

5.2 Other plants

5.2.1 Charcoal

Charcoal is generally considered as renewable resources, although it can be non-renewable when it is obtained through deforestation. Renewable charcoal is typically generated through tree cultivation. However, renewable charcoal can cause cultivation of single crop which may compromise biodiversity. To avoid this situation, alternate raw materials, for instance agriculture and organic waste, such as sawdust, nutshells, wheat straw etc. can be employed in charcoal production. Charcoal is mainly extracted from trees and acquired through a process known as pyrolysis, which involves heating logs under low-oxygen conditions to eliminate moisture and volatile components. Charcoal is an essential domestic energy source for low- and middle-income nations since it is extensively used as an energy resource for

cooking and smoking. Heavy industries, such as metallurgical processing also frequently burns charcoal (Gieré & Nabukalu, 2022, p. 1).

According to Data Bridge Market Research (2022), the European charcoal market will be continuously developing remarkably until 2029. The European charcoal market is predicted to reach USD 175.16 million by 2029 with a compound annual growth rate of 1.4%. Charcoal has increasing demand for its use in recreational cooking, metal manufacturing, building and construction, healthcare, industrial filtration, and pharmaceutical applications. The biggest consumers of charcoal in the EU are Germany, France, Poland, and Netherlands who mostly depend on the imports.

Every year about one million tonnes of charcoal is consumed throughout the EU. Germany alone consumed 236.7 ktons in 2018, followed by France who accounted for 147.7 ktons. Netherlands and Poland's usage figure are similar and reported for around 92.2 and 91.3 ktons respectively. Italy and Greece's consumption were just above 60 ktons separately. Portugal, Spain, and Belgium are also significant user of charcoal (Zahnen, et al. 2020, pp. 8, 12).

In 2018, the European Union countries produced approximately 243 ktons of charcoal where Poland contributed almost half of production, accounted for 106.42 ktons of production. Poland, Spain, Germany, and France constituted about 87% of the total production. The latter countries had produced 49.08, 29.82, and 26.15 ktons of charcoal. Figure 23 illustrates charcoal production in the EU countries in 2018 (Zahnen, et al. 2020, p. 12).

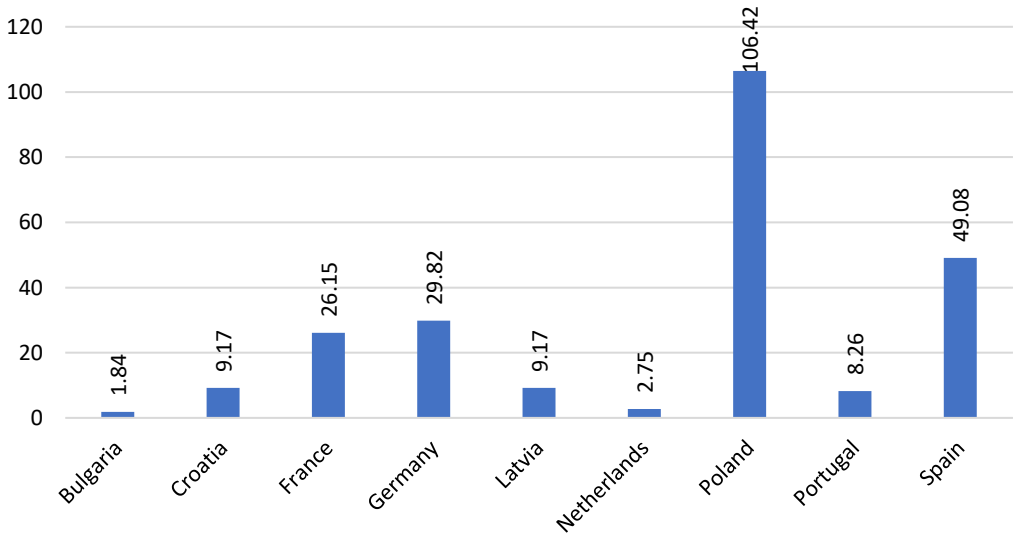

Figure 23. Charcoal production in EU27 in 2018 (in ktons) (Zahnen, et al. 2020, p. 12)

Europe mostly depends on imports for charcoal. 40% of its charcoal is imported from African countries including Nigeria, Egypt, Namibia, and South Africa. Belgium, Germany, and Poland also conduct intra-European charcoal trade with Ukraine, Lithuania, and Latvia (Nabukalu & Gieré, 2019, pp. 1, 2). Germany was the biggest importer with 233 ktons imported charcoal in 2018. The other key importers were Poland, France, Netherlands, Belgium, Italy, Greece, and Portugal. Figure 24 shows the leading charcoal importers in the EU in 2018 (Zahnen, et al. 2020, p. 12).

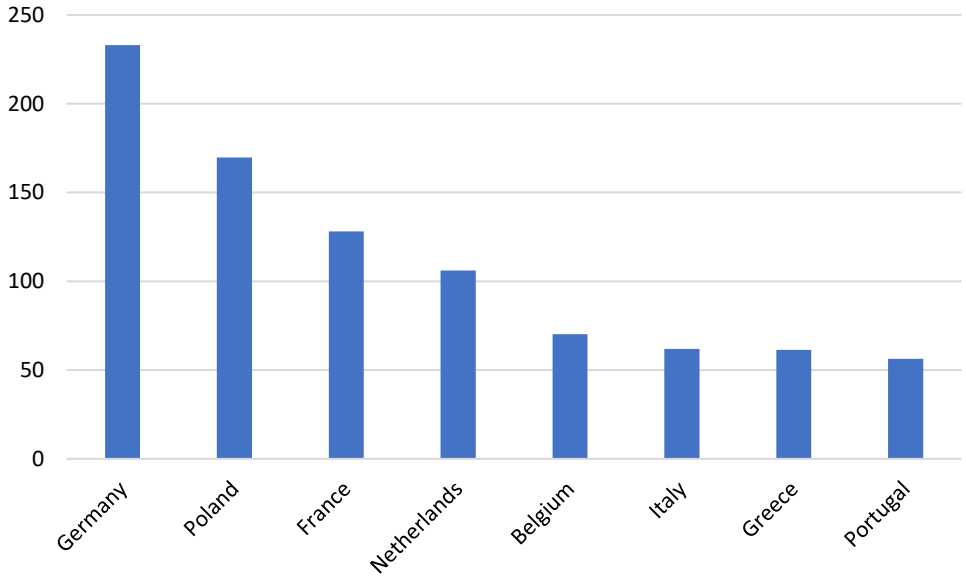

Figure 24. Charcoal leading importers in the EU27 in 2018 (in ktons) (Zahnen, et al. 2020, p. 12)

Three quarters of the consumed charcoal in the EU are imported from abroad in 2018 which was reported 747,990 tonnes. Figure 25 illustrates the countries of origin of charcoal exports to the EU in 2018 (Zahnen, et al. 2020, p. 8).

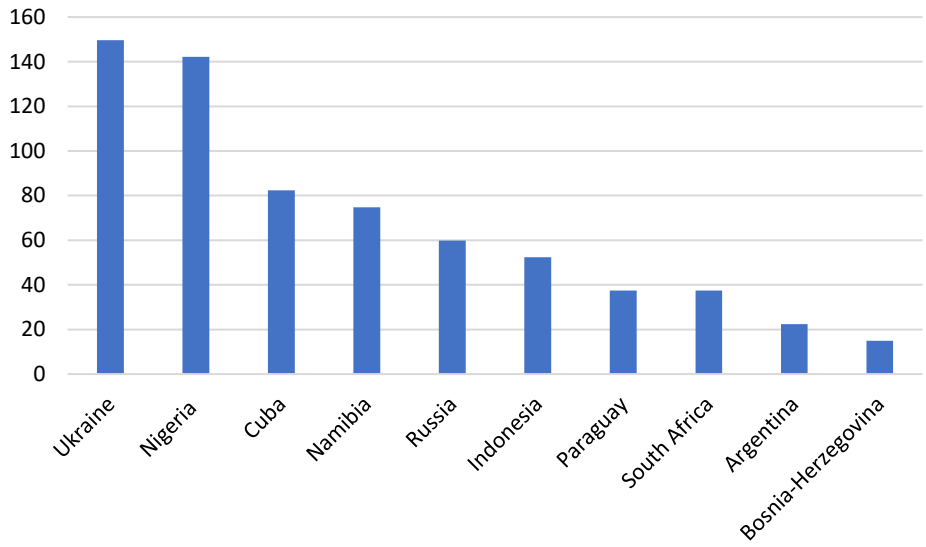

Figure 25. Charcoal supplies to EU27 from outside in 2018 (in ktons) (Zahnen, et al. 2020, p. 8)

5.2.2 Torrefaction plants

Torrefaction is a technique that thermally treats biomass, regardless of whether it is woody, agricultural biomass, biomass from energy crops, land management, or even recycled biomass, into a high-grade solid biofuel. The purpose of torrefaction is to minimize the quantity of volatile components. The torrefied biomass is suitable for combustion, gasification, and other non-energy-related uses. During the process, the biomass transforms several of the raw material's qualities into those of highly carbonized material. Torrefaction is performed at temperatures between 180-350 °C to maintain a greater proportion of the calorific content of the feedstock in the resultant solid product. The biomass is partially devitalized during torrefaction, resulting in a reduction in solid mass. However, the initial energy content of the input biomass is mostly conserved in the solid output. As a result, torrefied biomass has a greater energy density than original biomass. Torrefaction is frequently paired with pelletisation to generate a denser feedstock that can be blended with coal. It is most beneficial when long-distance shipments are required since it is a low-cost

way of converting biomass to a more stable and dense form (Wild & Calderón, 2021, p. 1) (Vakkilainen, et al. 2013, p.12).

Figure 26 represents torrefaction capacities in some of the EU countries in 2023. All the plants of these countries are commissioned as of 2023 (Wild & Calderón, 2021, p. 5).

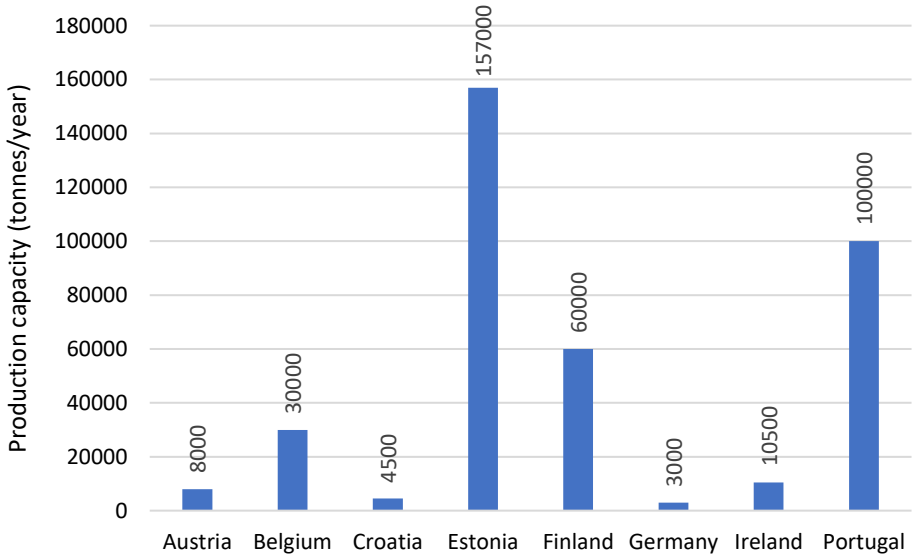

Figure 26. Torrefaction capacities in EU countries in 2023 (Wild & Calderón, 2021, p. 5)

Classified on technology and production capacity, some of the torrefaction initiatives in the EU as of 2015, are presented in table 9 (Cremers, et al., p. 24).

Table 9. Torrefaction initiatives in the EU as of 2015 (Cremers, et al., p. 24)

Developer	Technology	Location	Capacity (tonnes/year)
Horizon Bioenergy	Oscillating belt conveyor	Steenwijk, Netherlands	45,000
Topell Energy	Fluidized bed	Duiven, Netherlands	60,000
Torr-Coal B.V	Rotary drum	Dilsen-Stokkem, Netherlands	30,000
Andritz	Rotary drum	Frohnleiten, Austria	10,000
Andritz	Moving bed	Stenderup, Denmark	10,000
BioEndev	Dedicated screw reactor	Holmsund, Sweden	16,000
Grupo Lantec	Moving bed	Urnieta, Spain	20,000
LMK Energy	Moving bed	Mazingarbe, France	20,000
Torrec	Moving bed	Mikkeli, Finland	10,000
CMI NESA	Multiple Hearth	Seraing, Belgium	Undefined
Arigna Fuels	Screw reactor	County Roscommon, Ireland	Undefined
CENER	Rotary drum	Aoiz, Spain	Undefined
CEA	Multiple Hearth	Paris, France	Undefined

5.2.3 Pyrolysis oil plants

Pyrolysis oil, commonly known as bio-crude or bio-oil, is a synthetic fuel used as a petroleum alternative. Pyrolysis oil is a type of tar that includes much excessive oxygen to be called a pure hydrocarbon. The pyrolysis process is the thermal decomposition of diverse chemicals or waste materials at temperatures ranging from 400 to 800°C in an oxygen-free or extremely low-oxygen environment. Overall, the entire process includes heating, pyrolysis and subsequent cooling. In general, the results of the pyrolysis process may be classified into three groups based on their state. The major result might be gas, liquid, or char. The liquid product is the most preferrable which generally has similar properties with oil. The ratio of derived products is determined by processing variables such as temperature, heat rate etc (Crocker, 2010, p. 289) (Prurapark, et al., 2020, p. 2).

Pyrolysis plants are becoming popular in the European countries, because it is a low-carbon process that transforms waste material into clean energy fuel as well as they contribute to waste disposal methods. This means pyrolysis plants aid circular economy by promoting efficient resource usage. The EU is planning to expand its pyrolysis plants capacity to 8 million tonnes by 2030. In Europe, thermal pyrolysis has a variety of feedstock alternatives, with plastics, tires, rubber, and oil sludge being the most common. Waste oil sludge comprises contaminated soil, drill cuttings, water-based mud, oil mud, tank bottom oil sludge, coastal sludge etc. The output products of pyrolysis process are pyrolysis oil, carbon black, syn-gas and steel wire. Among them pyrolysis oil can be used as a replacement for conventional fossil fuels in heating applications and power plants, and syn-gas which is a combination of hydrogen and carbon monoxide, can be used as a fuel in electricity generation and as a chemical feedstock (Beston, n.d.) (Lux, 2021).

There are several pyrolysis plant companies operating throughout Europe. Some of the notable companies are Pyrolyze B.V, Pyrolysis, Polvax-Ukraine LLC, BTG BioLiquids - BTG Biomass Technology Group, Heat Systems, Beston Group Co., Ltd., Envigas AB, Compag Recycling und Umwelttechnik AG, Splainex Ecosystems Ltd, Dipl.-Ing. (FH) Dirk Gerlach VDI, Landfill Systems Ltd, BC Berlin-Consult GmbH, GreenPower, CTU Clean Technology Universe AG, Maskinfabrikken REKA A/S etc. Until 2021, there are five fast pyrolysis plants being operated in the EU. They are located in Finland, the Netherlands, Sweden, and Germany.

Table 10 shows their locations, feedstocks, capacities along with technologies used (BioRefineries Blog, 2019) (BTG, n.d. a) (BTG, n.d. b) (Fortum, 2013) (Dahmen, et al., 2017, p. 5) (Bailey, 2021).

Table 10. Fast pyrolysis plants in the EU27 (BioRefineries Blog, 2019)

Company	Technology	Location	Feedstock	Capacity (tonnes/year)
Twence (Empyro Project)	Rotating Cone Reactor	Hengelo, Netherlands	Wood residues	43800 (BTG, n.d. b)
Savon Voima Oyj	Fluidized Bed	Joensuu, Finland	Wood residues	50,000 (Fortum, 2013)
KIT (Bioliq project)	Twin-screw mixing reactor	Karlsruhe, Germany	Agricultural residues	4,380 (Dahmen, et al., 2017, p. 5)
Green Fuel Nordic Oy	Rotating Cone Reactor	Lieksa, Finland	Wood residues	24,000, (BTG, n.d. a)
Preem and Setra	Rotating Cone Reactor	Gävle, Sweden	Wood residues	50,000 (Bailey, 2021)

6 Perspective of future biomass usage

The revised Renewable Energy Directive imposed restrictions on crop-based biofuels and promoted advanced biofuels, for example solid and gaseous biofuels. The European Commission adopted a set of policy proposals as part of Green Deal under the “Fit-for-55” package. One proposal of it targeted usage of advanced biofuels to reach 2.2% by 2030. In accordance with the European Commission's mitigation scenario, total inland bioenergy consumption in the EU is predicted to range between 170 and 252 Mtoe by 2050. With the planned utilization of bioenergy, including agricultural residues, by-products and waste, the EU target can be accomplished (IEA, 2021, p. 3) (ETIP Bioenergy, 2020).

Biomass is dominantly used as feed and food products in the EU which accounts for around 60%. Bioenergy is the second major user of biomass before biomaterials, such as pulp and wood products. Their shares are 21% and 20% respectively. The EU is almost independent on biomass resources which is addressed by its 9% of the global biomass supply. The biomass potentiality of the EU is enough to fulfil its local market demand, including power plants, pulp and paper industry and sawmills. However, even after optimization of the entire system, some of the European countries, such as Belgium, Germany, Spain, Italy, and the Netherlands would require imported biomass (Proskurina & Mendoza-Martinez, 2023, pp. 5-6).

Mandley et al. (2020) reported that local biomass availability for energy by 2050 is projected to stay between 9 and 25 EJ annually whereas demand would be ranging from 5-19 EJ in an annum. In addition, biomass imports are forecast to escalate in the coming years. The report also claimed that imports can account 13-76% of the total biomass usage. Thus, the EU will remain the leader in biomass trade inside and beyond the EU. Proskurina et al. (2018) stated that biomass trade will be supported by bioenergy development history, resource availability, policy regulation, and sustainability. In the future, biomass supply security to the limited biomass available regions will advance biomass trade both internationally and locally. The biomass trade will further encourage in market growth in nations with underutilized biomass resources (Junginer, et al., 2019, p. 256).

In accordance with Renewable Energy Directive’s new policy (RED III), the European commission will dismay the use of wood as sustainable biomass since it contradicts present

sustainability criteria on forest feedstocks. Furthermore, solid biomass use will be shifted towards chemical industry by 2050. Sustainably obtained waste will pose key figure in ensuring circularity. In addition, first-generation biomass is European commission scheduled to be phased out by 2030 which will be replaced by second-generation biomass. Bioelectricity production may be hindered after the introduction of RED III as it will not provide any support in installation of power plants that use forest biomass. Although biomass fired power plants with carbon capture and storage are excluded from this case (EEB, 2022, p. 8).

The transport sector is the leading consumer of fossil fuels in the EU. To combat global warming, some alternative fuels, such as Compressed Natural Gas (CNG), Liquified Petroleum Gas (LPG) had been introduced in the last two decades which are however not suitable with our well-known petroleum distribution networks. In this sense, liquid biofuels can be remained as a considerable drop-in fuel in the coming years. Although according to RED III, biofuels demand in transportation is said to be halved by 2040. The target for advanced biofuels and biogas will be 2.2%, and biogas will be used only where decarbonizing is difficult in this policy. Besides, liquid synthetic fuel will be preferred over advanced biofuels (Millinger, et al., 2022, p. 2) (EEB, 2022, p.7).

Public acceptance appears to be the second main obstacle in southern and western Europe following economic feasibility of biomass. Generally, biomass usage as a fuel relatively a new concept in countries like Italy and Portugal. On the contrary, biomass is traditionally burnt in the northern and eastern countries, such as Finland, Sweden, and Baltic countries for a long time, and it is not considered an obstacle for bioenergy development in these regions. This anti-bioenergy agenda in southern and western European countries prevails although they are more likely to receive more economic profits than northern and eastern European countries. It was further identified that withdrawing energy tax for bioenergy and implementing more energy and carbon tax on fossil fuels would make bioenergy more attractive. However, with the continuous development of solar and wind power, the growth of biomass will become more challenging (Proskurina, et al, 2023, pp. 25, 30-32).

7 Conclusion

The aim of this study was to analyze status of bioenergy development in the EU27 countries and assess the future of it based on energy regulations and policies. At first, this study broke down the share of different sources, including renewables and non-renewables in electricity and heat generation. The share of biomass in 2021 in these sectors were found 5.15% and 24.13% respectively where primary solid biofuels and biogases are the main drivers in bioenergy development. In terms of biomass supply and share in each EU country between 1990 and 2021, Germany, France, Italy, Sweden, Poland, and Finland are the major user countries in descending orders. However, Germany, France, Italy, and Poland are still lagging in biomass share in total energy mix. On the contrary, Latvia, Denmark, Finland, and Estonia have significant contribution of biomass in their energy mixes, accounting for over 30%.

Next, the study demonstrates biofuels trade in each EU countries. Although 87.56% of the used biomass are locally produced, there are few countries, for instance Belgium, Cyprus, Denmark, and Luxembourg rely on imports. Unsurprisingly, Germany, France, Italy, Sweden, Poland, and Finland are the largest producers within EU. It was also observed that wood pellets and biodiesel imports have been doubled over the span of 2015-2021. Afterwards, bioenergy consumption was split into energy purposes which indicates that heating and cooling consumed about three quarters of the total used biomass. In addition, primary solid biofuels were found as the dominant biomass source in both electricity and heat generation, followed by biogas and wastes. In transportation sector, biodiesel is the foremost biofuel.

Then, several biomass forms were discussed, especially their production, consumption, trade, end-use, and feedstock. Wood pellet is largely burnt in heating plants, and some major producers are Germany, Latvia, France, Estonia, and Austria. Denmark, Netherlands, and Italy are the leading importers while the main suppliers are Russia and the USA. Bioethanol and biodiesel are trending as transportation fuels. France and Germany are the leaders in bioethanol production while Germany alone is the sole producer of 25% of European biodiesel. Netherlands, Germany, and France are the chief importers of these liquid biofuels. The USA and Argentina are the key suppliers of bioethanol and biodiesel. The consumption

of charcoal for energy purposes is still very small in the EU. Poland and Spain produce some significant amount of charcoal only in the EU. Europe mostly depends on imports, and major suppliers are Ukraine and Nigeria. Torrefaction plants are predominantly located in Estonia, Portugal, and Finland. Until 2021, there are five fast pyrolysis plants in the EU among them plants in Joensuu and Gävle are the largest each having 50,000 tonnes/year capacity.

Finally, the future perspective of biomass usage is briefly discussed. The inland bioenergy consumption by 2050 may reach 170-252 Mtoe. It is forecast that the EU will continue to be independent on biomass resources, and annual available biomass for energy will be between 9 and 25 EJ. It will surpass the demand which is predicted to be 5-19 EJ. In addition, biomass imports will continue growing which will keep EU as the leader in biomass trade. However, sustainability criteria for forest biomass are stricter in the new policy of Renewable Energy Directive that may hinder the growth of biomass. Sustainably obtained waste and second-generation biomass may play a lead role in generating electricity and heat in the coming years. Liquid biofuels' future looks promising until the electric cars become technologically feasible and economically affordable. Moreover, prediction of bioenergy future is a difficult task and includes many issues, such as public acceptance, policy regulations, environmental limitations and so on.

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