Journal of Sustainable Bioenergy Systems, 2023, 13, 16-39
https://www.scirp.org/journal/jsbs
ISSN Online: 2165-4018
ISSN Print: 2165-400X

Bioenergy Perspectives in the EU Regions: Carbon Neutrality Pathway

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How to cite this paper: Proskurina, S., Stolarski, M.J. and Vakkilainen, E. (2023) Bioenergy Perspectives in the EU Regions: Carbon Neutrality Pathway. *Journal of Sustainable Bioenergy Systems*, **13**, 16-39.
https://doi.org/10.4236/jsbs.2023.131002

Received: December 22, 2022
Accepted: March 4, 2023
Published: March 7, 2023

Abstract

Bioenergy plays an important role in the climate neutrality targets of the EU. However, the status of bioenergy implementation varies greatly across the EU. The aim of this paper is to assess the role of bioenergy in different EU countries using EU experts' opinions of bioenergy implementation in their own country. The paper identifies leading and lagging countries in biomass development by focusing on the current share of bioenergy in the total energy supply. The study shows differences in bioenergy development between Southern and Western EU countries with Northern and Eastern EU countries. The anti-bioenergy movement and continuing political support for the fossil fuel industry are important barriers inhibiting biomass development in many EU countries, especially in Southern Europe and Western Europe. Our analysis finds that the EU needs more factual bioenergy information and improved promotion of bioenergy throughout society, especially in southern and western parts of the EU. Bioenergy development in the EU can be looked at optimistically, especially in Northern and Eastern Europe. The experience of societal acceptance of bioenergy in countries such as Finland and Sweden is applicable to countries that have thus far seen less progress in bioenergy implementation such as Poland and the Netherlands.

Keywords

Bioenergy, Bioeconomy, Renewable Energy, EU Targets, Carbon Neutrality

1. Introduction

Renewable energy sources have grown in importance in the world's energy mix because of increasing demand for low-carbon energy as a response to climate change, to address environmental concerns such as air-pollution emissions, and

from a desire to decrease dependence on fossil fuels [1] [2]. Renewable energy has benefits. First, in comparison with fossil fuel, renewable energy creates less CO_2 emissions than fossil fuel, that allows to decrease global warming. Secondly, Fossil fuel impacts the water and air pollution, that affect on the people health. Thus, using RE can improve public health via less water and air pollution. Thirdly, it is renewable that means wind, sun, water, heat from earth, growing plants can create constantly replenished supply of energy. Fourthly, RE helps to increase economy. RE provides many jobs from academia to employees on the sites. Finally, RE can stabilize energy prices in the future [3].

Renewable energy plays a vital role in EU energy markets, and the importance of RE is set to grow further [4]. In addition to benefits related to greenhouse gas (GHG) emissions reduction, renewable energy can contribute to energy security and stimulate economic growth. Furthermore, the transition from traditional energy sources to renewable energy can combat growing environmental degradation [5] and allows sustainable mitigation of environmental pollution and associated health risks [6]. The European Commission has thus set a target that the EU is climate neutral by 2050, which means that the EU economy should attain net-zero GHG emissions [7]. According to the Renewable Energy Directive (RED II), which sets out policy measures for the development of RE in the EU, the EU aims to reach a level of 32% energy generation from renewable energy sources by 2030 [4].

Moreover, European Green Deal [8] sets a target to reach zero net GHG emissions by 2050. The current global changes (the Ukraine War initiated by Russia) raise the question about independency from Russian fossil fuels. It means achieving fossil fuel replacement by renewable energy is more urgent than before. In May 2022, European Commission introduced REPowerEU Plan, which is aiming to fast forward the green transition to make rapid reduction on Russian fossil fuels a reality.

The share of renewable energy in EU energy consumption was 22.1% in 2020, of which bioenergy accounted for about 60% of generated renewable energy [9]. About 75% of all bioenergy is consumed by large-scale users in the heating and cooling sectors. EU bioenergy power plants operated only at about 50% of their total capacity in 2021 [10]. Of the bioenergy sources available, solid biomass remains the most important renewable energy source in terms of energy production, and solid biomass is the dominant fuel for bioelectricity production in most EU countries, with the exception of Germany Italy and Croatia, where bioelectricity is mainly produced from biogas [11].

In this study, EU countries in Eastern and Northern Europe were compared with EU countries in Southern and Western Europe in terms of bioenergy status and the challenges faced. This regional division was chosen for comparison because based on an initial assessment, we consider eastern and northern parts of the EU as having more developed bioenergy sectors. Other parts of the EU (Southern and Western EU countries) have seen less development in bioenergy

and have a different bioenergy status. The objective of the study was to investigate the problems and perspectives of bioenergy development in different regions in the EU and to examine the role of bioenergy development in attaining climate neutrality targets by 2050. The main research questions considered are: Firstly, what are the differences in bioenergy development in different regions of the EU? Secondly, what are the main factors inhibiting bioenergy development in EU regions? And finally, what can we expect for the future of bioenergy development in different EU regions?

2. Literature Review and Contributions

It is important to understand the social, economic and environmental differences in different EU regions and the different challenges facing bioenergy development. Understanding of the differences between Northern and Eastern EU countries and Western and Southern EU countries will help to improve the status of bioenergy in the EU by enabling effective transfer of knowledge based on the experiences of leading countries in bioenergy to countries with less well developed bioenergy sectors. Moreover, better understanding of regional differences can enhance decision making in the areas of bioenergy development and bioenergy policy.

2.1. Bioenergy in EU: Comparison of East and North with South and West

Various studies have assessed the status of bioenergy in Europe, for example, [9] [12] [13] [14]. Eastern and northern regions of the EU seem to have more developed bioenergy sectors than other EU states, and Northern European countries (Sweden, Finland, Denmark, and Ireland) and Baltic countries (Estonia, Lithuania, and Latvia) are particularly active in bioenergy development. Currently, the Nordic nations are leading countries in the bioenergy sector, and they account for 19% of total bioenergy usage in the EU-28 [9]. Finland and Sweden have large biomass resources and a long history of biomass usage for energy purposes. Consequently, Finland, for example, has a high percentage of the population employed in bioenergy-related work with 23,700 jobs in the solid biomass sector for a population of 5.5 million. Finland, Germany and Sweden have the highest solid biomass turnover of €4.4 billion, €4.3 billion and €4.1 billion, respectively, for populations of 5.5 million, 83 million and 10 million. Denmark, a country of 5.8 million inhabitants, is a significant player in biofuels research, and, in 2015, the country had the most private research and development (R&D) investment in biofuels in the EU (210 million euros) [12].

Denmark, Estonia, Sweden, and Finland as examples that have made significant progress in the replacement of fossil fuels by biomass for centralized heat production, and biomass has an important share in district heating in all four nations [11]. Denmark, Sweden, and Finland have implemented CO_2 taxes on fossil fuels, which has been an important driver for industries (and heat produc-

ers) to move from fossil fuels to bioenergy [11]. Elsewhere in Northern Europe, Latvia has the highest bioenergy share in heating and cooling in the final energy consumption, and Lithuania, together with Sweden, has the highest rate of total biomass in total derived heat production. Moreover, these countries have large potential for both biomass resources and bioenergy technologies development [13]. Lithuania has plans for a large increase in biomass usage in the heating sector with a planned increase from 70% in 2019 to 90% by 2030. These plans can partly be explained by the price of biomass, which is 2 - 3 times lower than that of natural gas [14]. In electricity production, bioenergy represents more than 15%, mostly in the form of combined heat and power (CHP) production, in Denmark, Finland and Estonia. In the transport sector, Sweden and Finland have shares of 21% and more than 10% for renewable energy, respectively, which are the largest figures in the EU [11].

The status of bioenergy in southern and western parts of the EU varies considerably. Szarka *et al.* [15] suggest that Germany is an example of a country where bioenergy is developing rapidly. Germany is one of the leaders in terms of the amount of bioenergy produced in multiple sectors, *i.e.*, solid biomass, biogas, renewable energy from municipal waste, and liquid biofuels. The country has the largest number of biogas plants and greatest experience in this sector in the EU. Additionally, Germany has highest solid biomass turnover (€4.3 billion) (after Finland) and a large number of employees in the bioenergy sector with 35,400 biomass-related jobs. Germany also has the second largest volume of investments (after Denmark) in R&D in the bioenergy sector with 212.3 million euros in 2015. Other countries have lower investment figures, for example, France invested 90.2 million euros and the Netherlands 74 million euros in bioenergy development [12]. The energy context of these two countries plays a clear role: the Netherlands has large natural gas consumption and France has a strong nuclear energy sector [11].

Describing the status of bioenergy in Poland, Stolarski *et al.* [13] note that the country ranks second in terms of the number of biogas plants, installed biofuel capacity and primary production, and the number of pellet plants. According to data of the Energy Regulatory Office in Poland, the installed capacity of biogas and biomass installations at the end of 2020 was 255.7 MW and 1512 MW respectively [16]. On the other hand, the amount of electricity generated from renewable energy sources (RES), confirmed by certificates of origin, in installations using biogas and installations using biomass was 635.5 MWh and 2295.9 MWh, respectively [17]. In turn, the amount of electricity generated from RES in installations using co-combustion of biomass, bioliquids, biogas or agricultural biogas with other fuels was 702.3 MWh. Thus, it should be noted that the amount of electricity generated in installations using biomass was over 3 times higher than in co-firing technologies, which should be considered a positive phenomenon, particularly since until 2012 the situation was reversed.

Anca-Couce *et al.* [18] discuss the large bioenergy usage in the heating sector

in Austria, where Austrian manufacturers of boilers and stoves have a strong position, exporting most of their production. The most common bioenergy application in Austria is bioheat with 170 PJ in 2017 mainly obtained from woody biomass combustion, followed by biofuels with 21 PJ and bioelectricity with 17 PJ [18]. Biomass also plays an important role in the heating system in Spain, where it accounts for 90% of renewable heat production [19]. Analyzing the role of biomass in the heating system in Italy, Caputo *et al.* [20] suggest that Italy has a room for further biomass development.

2.2. Bioenergy Challenges

Despite the importance of bioenergy and its growing share of energy production, there are several factors that hinder greater development of the biomass sector. For example, usage of biomass is related to food production and there are no separate markets for biomass for food or feed use and for energy material use [21]. Bioenergy is also a source of GHG emissions, and the amount of GHG emitted depends on many factors such as logistics organization and technology used. [22]. Furthermore, ensuring the sustainability of biofuels has raised many difficult issues from the levels of both GHG and non-GHG emissions to biodiversity protection, ecosystem benefits and drawbacks, and the social impacts of bioenergy [23]. However, comparing fossil fuels with renewables, Pehl *et al.* [24] note that cumulative emissions attributable to upscaling low-carbon power (excluding hydropower) are relatively small in comparison with direct sectoral fossil fuel emissions and the total carbon budget.

Bioenergy development is connected with economic and political factors such as energy security, dependence on imported fossil fuels, and diversification of renewable energy sources, and social factors linked to employment and the revitalization of rural areas [25]. Sustainability criteria for solid biomass have already been implemented in Belgium, Denmark, and the Netherlands. Despite some uncertainties, such as the limited consideration of socio economic criteria and possible socio-economic conflicts in RED II, the renewable energy directive is a step forward in safeguarding the sustainability of the bioenergy supply [26].

Although some issues related to sustainability and technology development remain to be fully resolved, bioenergy has an important role to play in the future EU energy mix [27]. However, bioenergy is influenced by multiple factors, including economic and environmental issues specific to individual countries, and bioenergy development thus depends not only on policy but also many other issues related to the economic, environmental and social context [28]. Comparing future energy transition in France and Sweden, Millot *et al.* [29] suggest that France faces greater challenges reaching carbon neutrality due to its large use of fossil fuel. Historically, France has focused on electricity production and nuclear energy, while Sweden has focused on biomass usage in heating.

Summarizing studies on bioenergy in different countries and bioenergy challenges, it is evident that there is considerable variability in bioenergy discussions in the EU. One of the reasons for the diversity of debate is the different status of

bioenergy in different countries and regions and different attitudes to bioenergy development. To our knowledge, previous studies have not presented regional comparisons examining the complex challenges involved but have tended to focus on only one or a few aspects.

3. Materials and Methods

The study is based on a literature review combined with the results of a questionnaire. The questionnaire based survey makes this paper unique because it creates new insights that are not found in the literature. The study is interested in discovering how the status of bioenergy varies between EU regions and what similarities there are. To address the research questions in the study, the 27 EU member countries were divided into two groups. The division of the countries is described below.

3.1. Countries Division

The division is based on the share of bioenergy as a percentage of total energy supply. This methodology is partly adopted from [30] [31] with leading and lagging countries. The intermediate group presented in [30] [31] is excluded from the study because the focus of the paper is comparison of regions rather than countries. The data in **Table 1**, which is mostly from Eurostat [32], was used as a basis for defining the country groups. The EU member states with up to 20% of bioenergy in total energy supply in 2019 were ranked as Group 1 (leading countries). Countries with a bioenergy share in total energy supply of less than 20% were ranked as Group 2 (lagging countries). An interesting finding was that the first group (leading countries) includes countries from the East and North of the EU (excluding Ireland). Other countries belong to the second group (lagging countries) and are in Southern and Western Europe. Thus, in our study, Group 1(leading) comprises Northern and Eastern countries and includes Nordic countries (Sweden, Finland, Denmark and Ireland) and Baltic countries (Estonia, Lithuania and Latvia). Group 2 (lagging) is Southern and Western countries and includes: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, France, Germany, Greece, Hungary, Italy, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia and Spain.

This research extends a previous study [30] [31] which compare different countries in terms of bioenergy status. Here, we focus on inhibiting factors to bioenergy development in regions rather than focusing on environmental issues and bioenergy targets as presented by Sikkema *et al.* [31] and Proskurina *et al.* [30] respectively. Moreover, our study includes survey results, which allows for deeper analysis and improves on the method presented in Proskurina *et al.* [30].

3.2. Survey Explanation

This study is based on a survey of expert opinions. The survey was carried out as it was expected to give a comprehensive view of current and future bioenergy in

Table 1. Countries group division [32].

	Total Energy Supply (TES) in PJ	Fossil energy in PJ (%from TES)	Renewables and biofuels in PJ (% from TES)	Bioenergy in PJ (%from TES)	Bioenergy changes from 2015 in PJ
Up to 20% leading Northern and Eastern countries of the EU (Group 1)					
Latvia	188.1	109.8 (58)	76.3 (41)	68.7 (37)	10.7
Finland	1398.2	583.3 (42)	511.7 (37)	434 (31)	53.6
Denmark	681.1	413 (61)	252.3 (37)	179.5 (26)	28.3
Sweden	2043.5	565.2 (28)	890.8 (44)	505.5 (25)	43.6
Estonia	199.1	147.6 (74)	49.4 (24)	47.9 (24)	11.7
Lithuania	321.4	214.7 (67)	66.5 (21)	63.2 (20)	5.8
Below 20% lagging Southern and western countries of the EU (Group 2)					
Croatia	359.7	255.6 (71)	89.4 (25)	61.2 (17)	5.5
Austria	1412.8	971.2 (69)	432.6 (31)	230.4 (16)	−18.4
Portugal	940.2	679.8 (72)	253.7 (27)	127.9 (14)	6.5
Romania	1379.7	1005.5 (73)	251.7 (18)	163.2 (12)	7
Slovakia	710.8	444.3 (63)	92.2 (13)	72.4 (10)	22.2
Slovenia	280.3	175.7 (63)	47.8 (17)	27.8 (10)	−1.9
Czech R.	1782.6	1282.4 (72)	205.7 (12)	175.6 (10)	16.5
Bulgaria	778.9	504.4 (65)	103.5 (13)	75.2 (10)	24.5
Hungary	1106.5	788.1 (71)	118.4 (11)	105.1 (9)	−16.1
Italy	6341.5	5049.3 (80)	1235.6 (19)	581.6 (9)	7.2
Germany	12387.1	9736.8 (79)	1903.5 (15)	1105.3 (9)	19.6
Luxemburg	164.9	133.2 (81)	13.4 (8)	14.5 (9)	5.9
Poland	4307.9	3886.2 (90)	414.7 (10)	337.7 (8)	10.9
France	10271.5	4909.9 (48)	1191.9 (12)	675.6 (7)	61.6
Spain	5111.2	3668.3 (72)	790.8 (15)	324 (6)	37.2
Cyprus	97.1	86.6 (89)	10.3 (11)	5.5 (6)	3.1
Belgium	2305.8	1639.5 (71)	183.1 (8)	125.5 (5)	−0.5
Greece	938.7	794.1 (85)	132.7 (14)	49.8 (5)	−5.4
Netherlands	3012.8	2736.1 (91)	227.4 (8)	150.5 (5)	35.7
Ireland*	579.7	510.8 (88)	68 (12)	26 (4)	8.1
Malta	30.9	28.5 (92)	2.1 (7)	0.6 (2)	0.2
EU-28	59132	41,320.2 (70)	9615.5 (16)	6321.2 (10.7)	550.1

the regions, and it would extend currently available data in the literature. The aim of the survey questionnaire was to collect information about inhibitors to bioenergy development in the EU and how they differ between regions. In the paper, we focus on the second aim of the survey. The structure and contents of the questionnaire are described in Figure 1.

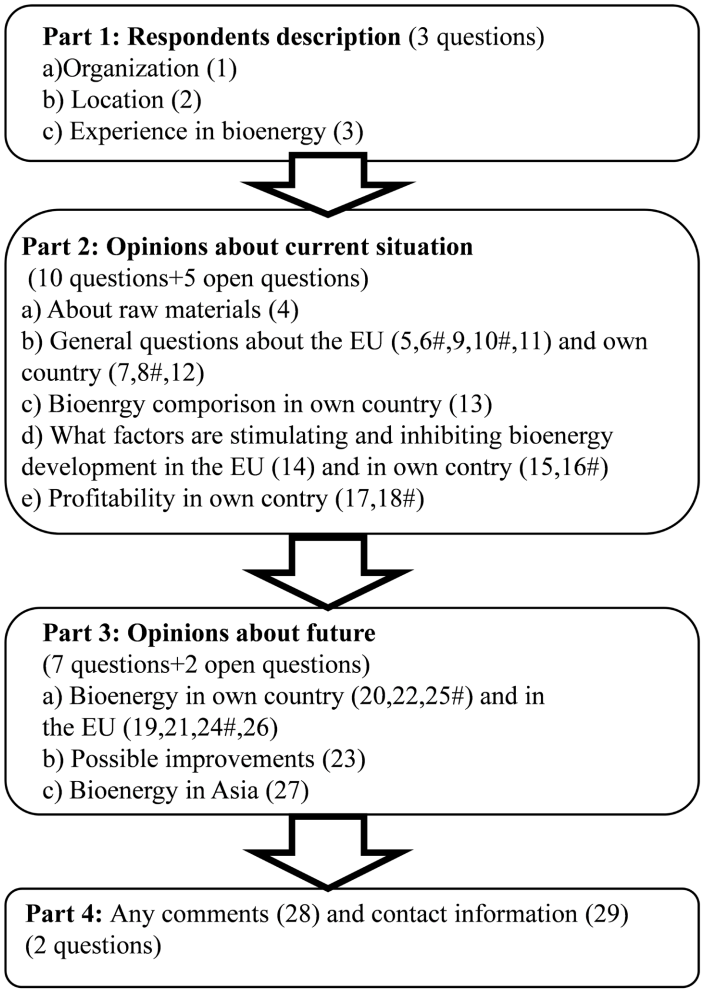

Figure 1. Key structure and contents of the questionnaire. # open question as a space for comments.

The survey was conducted via the Internet using the online Webropol software tool from 20 October 2020 to 18 January 2021. The questionnaire was sent to experts of different organizations working in the area of EU bioenergy such as Bioenergy International, World Bioenergy Association (WBA), International Energy Agency (IEA) Bioenergy, European Commission, Bioenergy Association of Ukraine (UABIO), AEBIOM, Sveaskog, Luke, Svebio and companies such as Sekab, Vapo, Versowood, Metsä, Mondi, Graanulinvest, Biomatec and AC Boilers. The questionnaire was posted on the FNR website, the Biovoices social platform and the LinkedIn website (bioenergy related groups), from which every registered expert could participate in the survey. Additionally, several respon-

dents shared the questionnaire with colleagues who are familiar with bioenergy development in the EU.

Respondents had the opportunity to respond anonymously. However, most respondents left personal contact information as they wished to receive a summary of the survey results by e-mail, indicating interest in the future of bioenergy development in the EU. The total number of experts who responded to the questionnaire was 72, of which 42 respondents were from Northern and Eastern countries and 29 respondents from Southern and Western countries. One respondent's location was outside of the EU, which was not taken into consideration in the study. The questions of the survey were written and administered in English.

3.3. Reliability and Limitations

To the best of our knowledge, this study is a first attempt to map the bioenergy status of two regions and examine bioenergy from different regional perspectives. Naturally, bioenergy is a very large and complex topic and some aspects, such as biomass resource availability and environmental issues, are outside the scope of this study. Moreover, the study does not consider detailed policy issues, such as policy for advancing biodiversity or LULUCF.

The main advantages of the questionnaire approach used are as follows: firstly, the respondents are very familiar with bioenergy and so they possess valuable information that is not available, for example, in conventional literature; secondly, the respondents' answers are given based on the current situation of bioenergy in the EU; and finally, the anonymity of the approach helps allay concerns about confidentiality and allows open discussion of the subject. The results of the questionnaire are mainly presented in terms of percentiles.

For more reliable and comprehensive data, the study uses different sources of information including a survey. In survey method approaches, interpretation of results and drawing of conclusions is nontrivial, and the validity, reliability and generalizability of the conclusions are not always easily ensured. To increase the reliability of this research, the first two questions were about the participants themselves and provided an overview of the background of the respondents and their familiarity with bioenergy. This information helped ensure the validity of the answers. The data collection method used can be considered accurate and reliable. To avoid missing answers, all questions were compulsory for respondents.

4. Results and Discussion

4.1. Organizations and Experience of the Respondents

Figure 2 and Figure 3 present information about the profile of the respondents. Figure 2 categorizes the 72 respondents based on the organization that they represent. Respondents in the category "others" represented various organizations involved in the timber products business such as forest owners, engineering and consulting, and non-governmental organizations such as bioenergy, trade, industrial and business associations, and policy makers, for example, in-

terest organizations, trade unions, EU public administration (policy), energy agencies (Ministry) and other interest groups, as well as independent experts. Industry representatives can be involved not only with biofuels production (e.g., large wood pellet producers) but also with other products (e.g., pulp and paper).

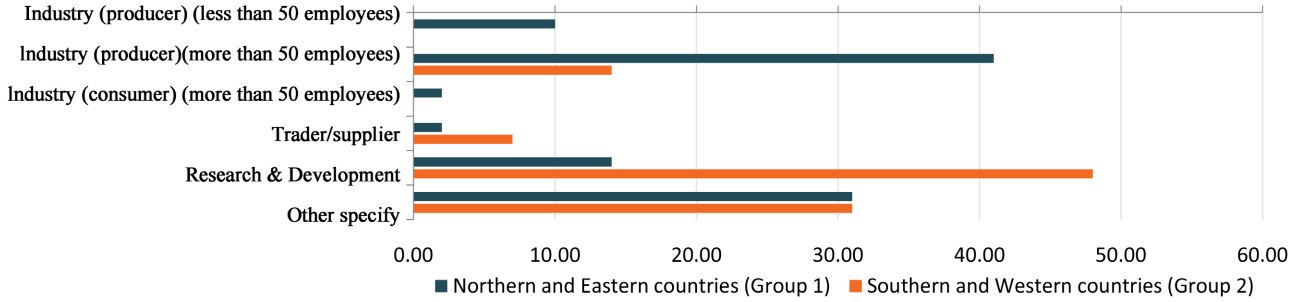

Figure 2. Organization represented by the respondents (in %).

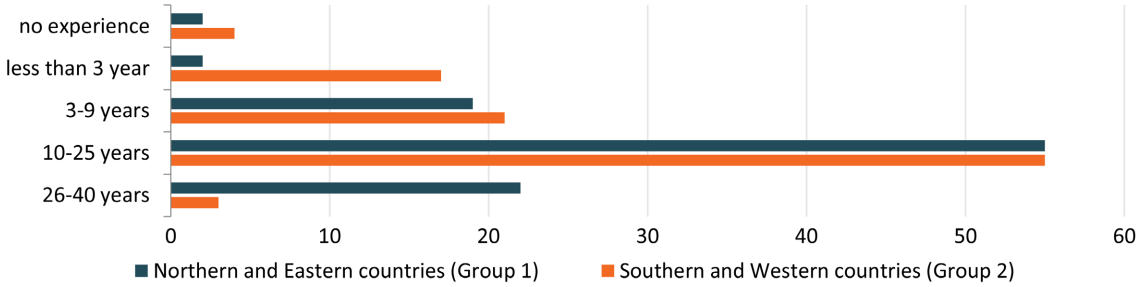

Figure 3. Respondents' experience in the bioenergy field (in %).

4.2. Factors Inhibiting Bioenergy Development

Figure 4 shows how respondents from different regions perceive the role of bioenergy in the EU. The main factors inhibiting the bioenergy development are policy, investments and competition with other renewables in both studied groups (**Figure 5**). In this study we focus mainly on these aspects. For example, the study does not contain detailed discussion of environmental aspects and biomass raw materials as such discussion would make the study unwieldy.

Respondents from Group 1 comment about the role of policy different ways. In Denmark and Sweden, for example, respondents suggest that policy support including the exemption from energy tax for bioenergy and taxes on fossil fuels make bioenergy very competitive and without a carbon tax, greater use of bioenergy would not happen. Respondents also mention conflicting policy instruments that favor the use of fossil fuels. In addition, they highlight those delays to RED II implementation, anti-bioenergy attitudes and local media intensify pressure on policy makers. It is felt that especially non-governmental organizations (NGOs) such as Greenpeace, and World Wildlife Fund (WWF) are lobbying against bioenergy.

Respondents note that Sweden has problems with EU regulations trying to cap the use of crop-based biofuels and promoting the use carbon pricing in this sector due to the EU Commission's interpretation of state aid regulations.

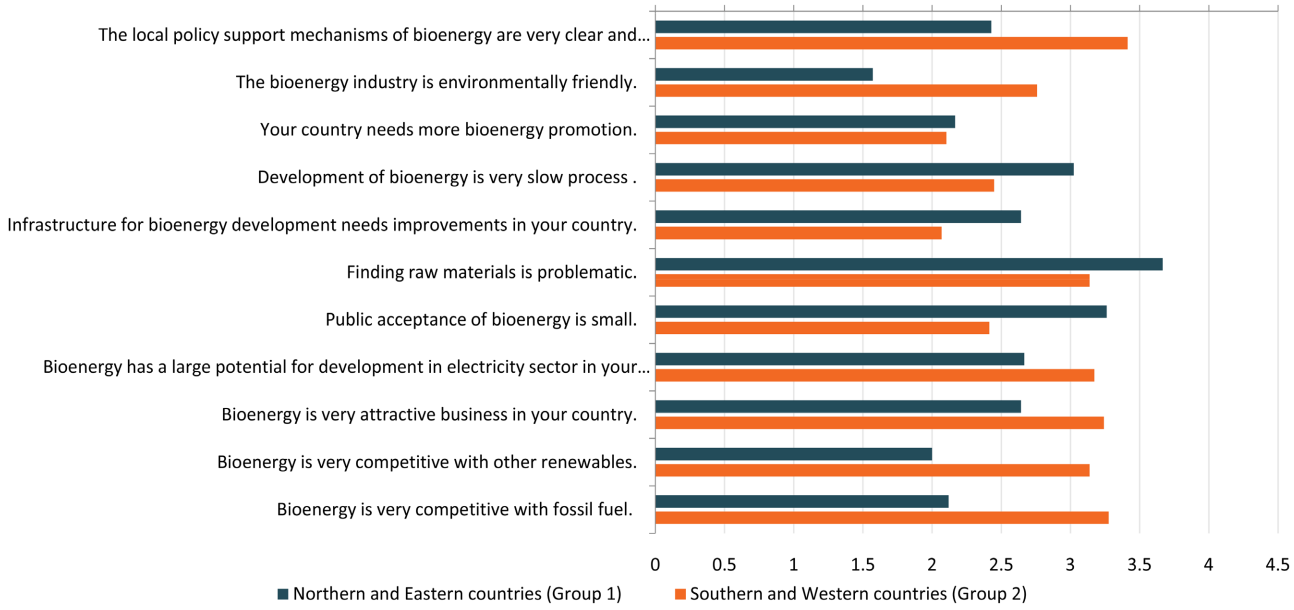

Figure 4. Respondents opinion about their own country, where 4.5 is maxim of agree with statement.

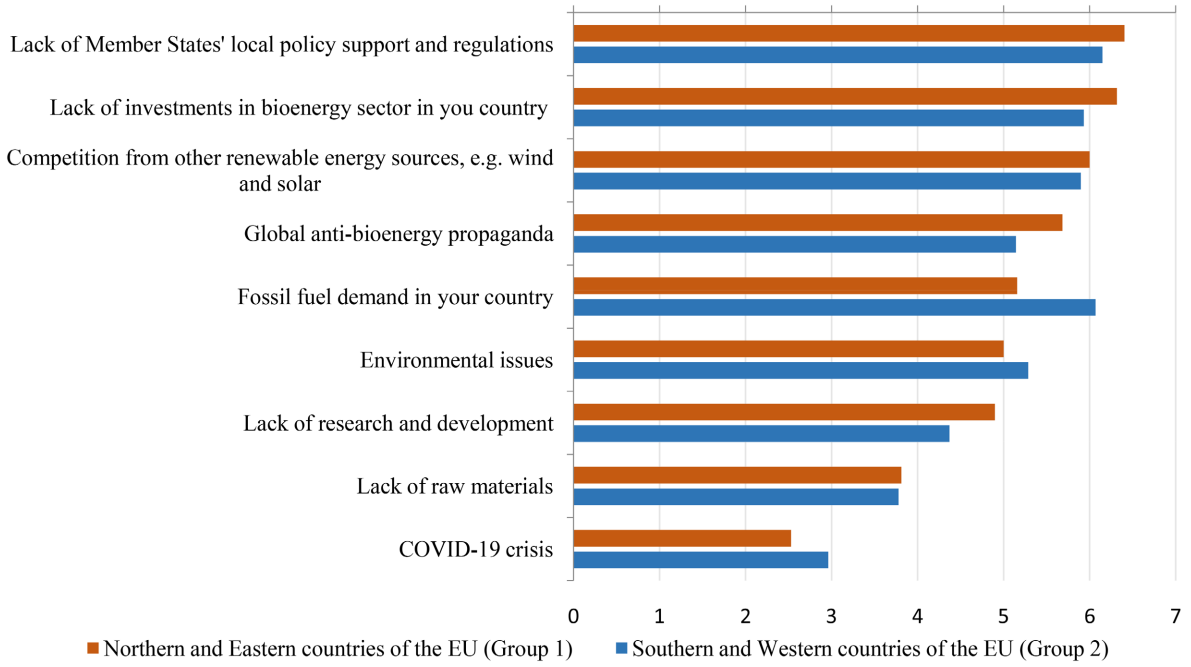

Figure 5. Factors inhibiting bioenergy development, where 0 is least important and 7 is great important.

"I personally bought a new Volvo diesel car that I run solely on renewable HVO100-diesel. Still the government makes me pay a malus tax on €1000/year as they claim I use fossil diesel in it. The data shows that my car emits less CO_2 over its lifetime than an electrical car running on wind power, still I have to pay the malus - bad for the climate. Also the Energy Taxation Directive is stopping the use of high blend renewables, as the state aid rules." "HVO-diesel can directly make a diesel car an environmental car. With modern engines, the emission is not longer a health issue." (Respondent from Sweden)

"The EU should either introduce a high carbon tax or decide on how to phase out fossil energy. It would be possible to decide the fossil fuel volumes that could be used for each year to come and restrict the use to this volume. Companies would solve their energy need with other solutions. Carbon tax is a very good option, introduce a common carbon tax outside the EU ETS (energy trading system). EU ETS is also working well from now on. Secure that the price of emissions remains high in the EU ETS. The commission does hinder the development by pointing out certain technologies. It would be better to use general incentives to phase out fossils and let all solutions contribute instead of just putting a lot of money on for example hydrogen that we cannot know if it is going to work or not. Get rid of subsidies and create markets and demand." (Respondent from Sweden)

Respondents from France suggest that France needs a more developed infrastructure for biomass harvest and collection of residues, more communication about and incentives for organic waste sorting and collecting from manufacturers, as well as agricultural biomass and residues collection from farmers and foresters.

Respondents from Sweden note high surplus production and the difficulties of finding additional extra customers that can create a reasonable price on the market and motivate development of the bioenergy industry. Also, electricity production from biomass is considered problematic due to low electricity prices and high surplus production. In comparison, the heating business is seen as profitable.

Respondents mention particular concerns regarding Sweden:

"EU regulations, like the cap on "food and feed" biofuels, and the implementation of state aid regulation, that has forced the Swedish government to impose taxes on ethanol and biodiesel from time to time! For a long time, low ambition and low carbon prices in ETS was also and inhibiting factor, but the prices now have increased somewhat. Too much focus on electrification may be an inhibiting factor in the coming years."

"Stop focusing so hard on wind and solar power. The powergrid becomes very vulnerable if we want to distribute alle our energy as electricity" "The energy market should have an electric price incentive for local bioenergy heat and power plants. This would help bioenergy electricity production at the main cities and remove capacity problems in electricity distribution cross the country." "Deregulation of the energy market to allow all sources of renewable energy to enjoy the same support and allow free market dynamics to prevail. For instance, in my country small scale hydropower and wind power are not allowed to sell electricity to the grid. There is no technical limitation but policies that only allow large companies to produce and sell electricity."

One respondent suggests about Belgium: *"Belgium is a small and densely populated countries, where the availability of bioenergy is a constrain vis a vis to other countries. Additionally, Belgium is highly dependent on fossil fuels and its climate ambition is not at the level of its economy. Therefore, supporting mobilisation of bioenergy from residues and byproducts from forestry and agriculture together with increased renewables target and a carbon price would increase*

bioenergy contribution."

"It's mainly the stigma surrounding bioenergy and that it is not as environmentally friendly as other renewable energy sources. Citizens of my country also feel like they are already doing a lot, while our share of renewable energy is one of the lowest in the EU." (Anonymous answer)

Respondents from Southern and Western countries of the EU (Group 2) also raise concerns about policy support, or even the lack of it, and suggest improvements. According to respondents, in Southern and Western countries of the EU, it is felt that policy should have a clear regulatory framework to counteract the low price of fossil fuels, CO_2 taxes should be introduced, and more support given to local authorities. Policy should focus on all sectors of bioenergy, not only electricity but also heat and transport, and should aim to stimulate the development of advanced sectors of the bio-based economy, as well as the mobilization of underutilized sources. In addition, strategy is important to unify biodiversity and bioenergy development concerns, including an associated legal framework for bioenergy promotion.

In the Netherlands, respondents note that the existing well-developed energy infrastructure will pose challenges during the transition to new biobased economy sectors, and the current support framework will create a 'bumpy ride' towards long term targets. In addition, a respondent suggests that there is a need for clear policy support and support for new companies that want to enter to the bioenergy market. It was also felt that there exists a need for more information about the benefits of bioenergy and varied use of biofuels as it is not only burning biomass from wood that is heavily debated in the Netherlands.

In Austria, a lack of awareness of government priorities and excess availability of hydropower is inhibiting bioenergy development. For Austria, a respondent suggests promotion and stimulation of carbon capture and utilization (CCU) in the production of chemicals and fuels from bio-renewables.

In addition to the factors presented (**Figure 3**), respondents mention the lack of CO_2 pricing, a lack of examples of positive tradeoffs with the Sustainable Development Goals (SDGs), and a lack of integration with the broader bioeconomy.

In contrast with Group 1, respondents mention limited awareness of bioenergy and a lack of financing for R & D. Bioenergy opportunities should be widely debated, and the public, companies, NGOs and others societal actors should be better-informed about bioenergy. For example, in Austria, a lack of awareness of government priorities and excess availability of hydropower is inhibiting bioenergy development. For Austria, a respondent suggests promotion and stimulation of carbon capture and utilization (CCU) in the production of chemicals and fuels from bio-renewables.

4.3. Role of Fossil Fuel Industry

Bioenergy is one way of reducing fossil fuel usage and it seems significantly important not only in Northern and Eastern EU countries but also in Western and

Eastern countries. The Netherlands is an example of a country with gas resources that should be switched to renewables as part of plans for a low-carbon economy by 2050. Most of the country's natural gas is extracted from the Groningen field near Slochteren, in the north of the Netherlands. Earthquakes in Groningen during gas extraction led to public protest, particularly in the affected communities, and national policy aims to shut down gas extraction entirely by 2030. The perceived need to reduce dependency on natural gas from Russia makes using renewables even more important [33].

The replacement of fossil fuel by bioenergy requires investments, for example, to address the technical challenges of replacing fossil fuels. Bioenergy can only be co-combusted to a limited extent in coal boilers, although it is easier to increase the proportion of wood fuels in fluidized bed boilers using peat. However, in Finland, for example, there are approximately 50 peat-burning plants where full peat replacement is not possible without additional investment. Furthermore, replacing oil with bioenergy often requires investing in a new boiler that is suitable for biofuels [34].

Discussing bioenergy development in the Nordic countries, Cross *et al.* [35] note that increasing natural gas consumption is shown to have a significant positive relationship with bioenergy generation in Sweden, but a negative relationship with bioenergy in the UK and Finland. This finding can be explained by different strategies to develop the energy sector and prioritize and incentivize different technologies and renewable energy generation. Furthermore, when considering security of supply, wood biomass storability, which is weaker than that of coal and peat, creates some difficulties for fossil fuel replacement by bioenergy [36]. Indeed, in Finland, a few respondents stated that bioenergy is not very competitive due to low fossil fuel price. However, the sharp rise in fossil fuel prices currently observed has changed the situation. In 2019, fossil fuel with peat accounted for 38% of total energy consumption in Finland [36].

In Southern and Western Europe, many countries use coal as an energy source, and countries such as the Netherlands, Germany, and France have coal fired power plants. Belgium became the first EU country to phase out coal in 2016 and France is planning to do so by 2023. However, there are still some EU countries that will miss the 2030 deadline for a coal phase-out laid out in the Paris Agreement. Germany is looking at 2038, while Poland, Romania and Bulgaria have no phase-out planned, and the Czech Republic and Slovenia are still considering dates [37].

Carbon neutrality targets and global changes such as the need for independence from Russian natural gas and other fossil fuels are motivating EU countries to develop renewables including bioenergy. For Northern and Eastern countries, development of bioenergy seems more straightforward, whereas it seems more difficult for Southern and Western countries. France, Poland, Czech Republic and Hungary face some challenges reaching carbon neutrality, although there has recently been much discussion of the issue also in these countries. For example, the document "Energy Policy of Poland until 2040" [38] was adopted

in Poland, which assumes, inter alia, an increase in the share of RES in all sectors and technologies. This document states that in 2030 the share of RES in gross final energy consumption is to be at least 23%. In turn, the share of coal in electricity generation will not exceed 56%. However, by 2040, efforts will be made to ensure that about half of electricity production comes from renewable energy. In addition to the further development of wind and solar power, it is also crucial to support sources that use hydropower, biomass and biogas.

4.4. Bioenergy as a Business

Investment in bioenergy seems more attractive in Group 1 countries (**Figure 6**). However, respondents note that bioenergy needs a more stable investment environment. In Finland, for example, a respondent notes that the country could also more effectively mobilize certain parts of its bioenergy potential, such as non-harvested young stands. In Baltic countries, there is a need to increase the technological potential of bioenergy production. For example, Lithuania needs introduction of new technologies of biomass gasification with production of synthetic hydrocarbons for transport fuels production.

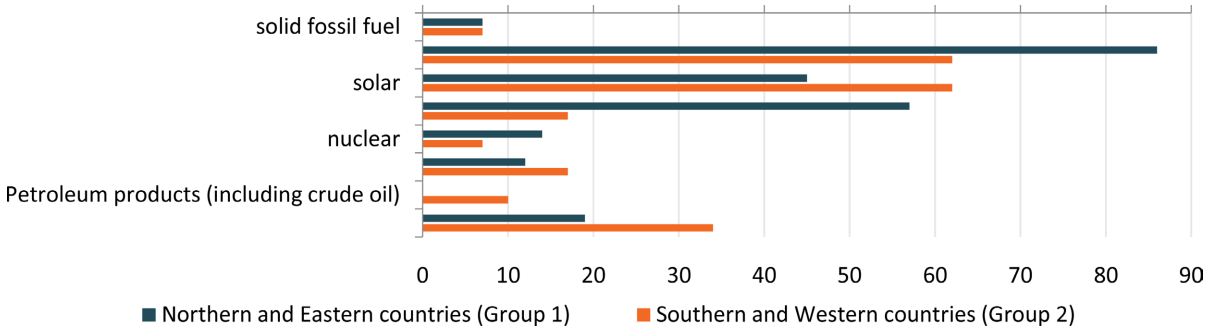

Figure 6. Investment attractiveness of fuels in the respondent's own country (in %).

Currently, bioenergy does not seem to be competitive with solar, wind and natural gas in Group 2 countries (**Figure 6**). Southern and Western countries need more economic profitability incentives for bioenergy consumption, including a lower market price. For example, Italy, a country with a regular demographic distribution, needs more investment in the bioenergy sector especially for small communities. Bioenergy is more profitable as a business in Group 1 countries, where bioenergy seems a profitable business for large scale consumers, forest industries and large producers, than in Group 2 countries (**Figure 7**).

In Group 1, respondents comment that all parties involved in the local wood industry benefit from bioenergy including equipment suppliers. Households get relatively cheap heat from district heating using biomass and municipal waste. Finland and Sweden are leading countries in the pulp and paper industry and they benefit from bioenergy. Combined heat and power (CHP) plants are also seen as benefitting from bioenergy in Group 1 countries, which is understandable as CHP plants in Nordic countries often utilize biomass. For example, wood chips, which are the most popular biomass source in Finland [39], are actively

utilized in large CHP plants.

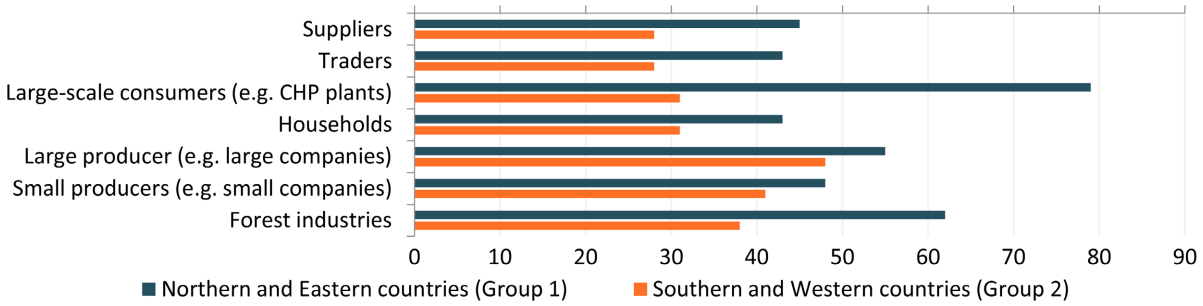

Figure 7. Profitability of bioenergy business (in %).

Respondents from Group 1 countries comment that there is a need to increase investment in bioenergy by creation of a better economic environmental climate for investments through investment in storage facilities and terminals, and the promotion of more steady demand across the seasons. It was also noted that bioenergy has a long payback time and there is a lack of a clear path forward, *i.e.*, an ever changing investment environment. One respondent suggests that bioenergy is adequately profitable.

In addition to the previously mentioned factors inhibiting bioenergy development in Northern and Eastern European countries, peat, which is an important source of heat and power in the region, is widely used. As an alternative, peat can be replaced by (or mixed with) other materials such as charcoal, which may be very beneficial for bioenergy development [40]. The change that is underway to reduce peat usage is a slow process and subject to much public debate. In Finland, for example, according to current forecasts, the main energy use of peat will end in the 2030s due to peat taxation and an increase in the price of emissions allowances [34]. However, there is some dissatisfaction in society regarding the Finnish government's target of decreasing peat utilization, although it should be noted that opinion is divided, and some people would rather place peat in the category of renewable energy [36].

4.5. Global Anti-Bioenergy Agenda and Future Perspectives

The most important aspect hindering bioenergy development in both studied groups is the challenge of making bioenergy economically profitable. An interesting finding is that in Group 2 countries the second most important obstacle to bioenergy development is public acceptance, whereas in Group 1 countries this issue is considered less important (**Figure 8**). The result can be explained by the history of biomass utilization in the respective countries. In Finland, Sweden and the Baltic countries, the use of biomass has a long tradition, but for Group 2, countries such as Italy and Portugal, the use of biomass for energy purposes is relatively new. Public acceptance has not been a systematic barrier for bioenergy development in Nordic countries (Sweden and Denmark [37]; Finland [41]). However, one respondent from Sweden noted that the country has little public

awareness rather than great public acceptance.

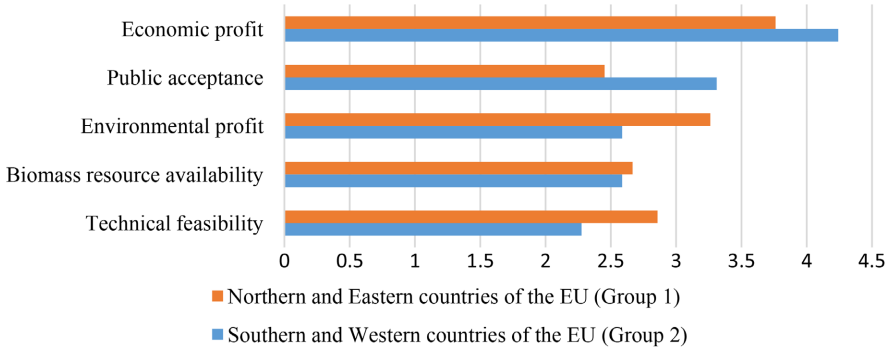

Figure 8. Respondents to the question what main aspects influence the bioenergy development in own country, were 0 is least importance and 4.5 is greatest importance.

In both studied groups, half of the respondents agree that countries need more bioenergy promotion (**Figure 4**). Many respondents mention the global anti-bioenergy movement, which is considered to significantly affect bioenergy development. In our results, the anti-bioenergy lobby is in the 4th and 6th position of factors inhibiting bioenergy development (see section 3.2).

Regarding the future perspectives of bioenergy development, despite the challenges and restrictions presented in previous sections, respondents are very optimistic about the future of bioenergy in the EU (**Figure 9** and **Figure 10**). An interesting finding is that when considering the long-term perspectives, respondents from Group 2 are the more optimistic, whereas respondents in Group 1 countries express optimism about bioenergy development more for the short term.

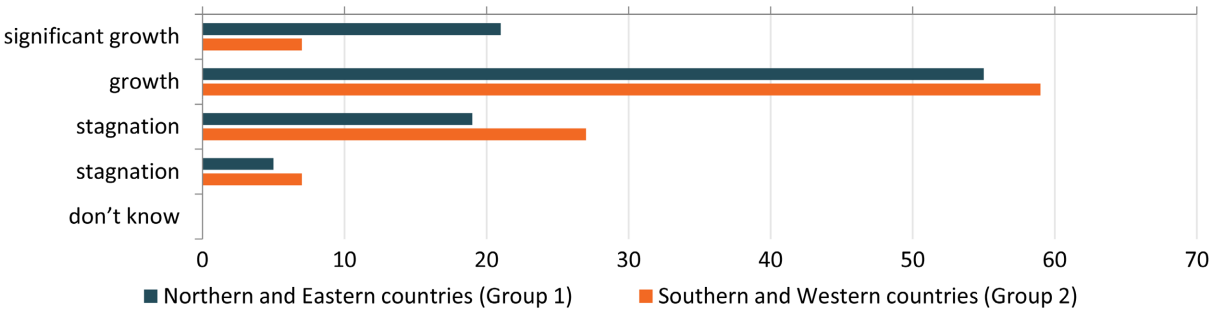

Figure 9. Opinions about future of bioenergy over next 5 - 10 years (in %).

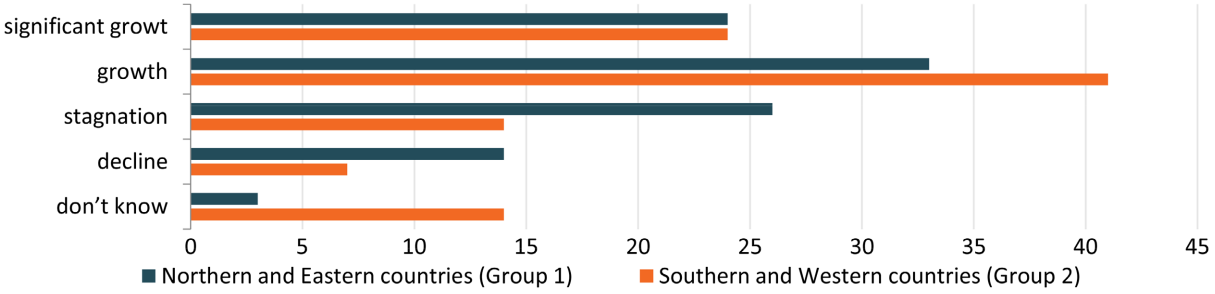

Figure 10. Opinions about future of bioenergy over 50 years (in %).

Regarding social aspects of bioenergy development, it is felt that bioenergy should have more promotion. Green activists filed a lawsuit against the EU's recognition of biomass as a renewable energy source, mainly because bioenergyis not fully environmentally friendly, although the EU Court of Justice dismissed the lawsuit in 2020 [42]. In Eastern and Western countries of the EU we can see considerable skepticism towards bioenergy in many parts of civil society. For example, the Netherlands has had ten years of public debate about bioenergy, and in 2020, the public was critical of bioenergy support by Dutch Government, which had reserved an additional EUR 11.4 billion for biomass installations. Despite sustainability criteria, the public continues to be concerned about greenhouse gas emissions, air pollution, resource inefficiency, subsidy-dependency, biomass's limited place in a long-term energy transition, and the need to protect biodiversity [43]. Public opinion obstructing bioenergy development in the Netherlands also exists in Germany. In addition to fossil fuel companies' popularity, the German media have adopted a negative tone towards biomass [37]. This attitude might reflect the relative lack of forests in Germany and its high population density, which makes green spaces more valuable than in the Nordic countries.

Global anti-bioenergy movements mainly focus on highlighting problems related to the lack of food on a global scale and the allocation of agricultural land for the cultivation of energy crops. Combined with the growth in world population and increasing food prices, these issues generate aversion to bioenergy. However, it is often forgotten in this discussion that bioenergy includes various types of bio-based raw materials, including production residues and wastes, and not only energy crops grown on agricultural land [13] [44] [45]. Use of production residues, waste and energy crops grown on marginal land can bring measurable effects in the volume of biomass obtained, and thus bioenergy produced. Such comprehensive activities in this field can bring tangible economic, environmental, social and economic benefits. Related to land use is the effects of photovoltaic farms on agricultural land, which has received little media attention. The land used for such photovoltaic facilities is, at least temporarily, excluded from food production. When comparing discussion of energy production and land usage, and its link to food prices, it is interesting that the cultivation of energy crops has been highlighted, but the occupation of such land for photovoltaic farms does not seem to raise the same doubts, or at least they are not aired.

To reach the target of climate neutrality, the idea of combining different RES is considered important in both studied groups. It seems that EU countries should focus on the question: how bioenergy can develop along with other fuels and technologies. For example, an Austrian study [18] suggests that to achieve the country's plan to be climate neutral in 2040, including the planned phase-out of fossil fuels, bioheat production should be combined with other renewables such as heat pumps. Cooling production will see increasing demand in the next years, and it can be provided to a certain extent with combinations of bioenergy and heat pumps.

5. Conclusions

The purpose of the current study was to investigate the difference in the challenges of introducing greater bioenergy use between EU countries in Northern and Eastern Europe (Group 1) and Southern and Western Europe (Group 2) and to examine how biomass can support attainment of the target of climate neutrality by 2050. It is evident that bioenergy will continue to play an important role in future energy targets in the majority of EU countries. Moreover, for countries with less developed bioenergy sectors, such as France and the Netherlands, biomass development seems important to enable them to reach their climate neutrality targets by 2050. This study notes that many countries are emphasizing the need to reach climate neutrality targets. At present, it seems that reaching climate neutrality targets is not as challenging for Northern and Eastern EU countries (Group 1) as it is for some countries in South Europe and West Europe (Group 2).

This study has shown that investment and policy play a crucial role in both studied groups. There is a need for more investment in the bioenergy sector, as well as local and national promotion about unused biomass capacity. Economic support from the EU is also required. Phasing out natural gas or fossil energy should be a priority. Although bioenergy is well developed in northern parts of the EU, some improvements are still required. For example, increased attention to bioenergy in the transport sector requires more policy support and regulations need adjustment as seen in the example of Sweden.

Bioenergy as a business seems more attractive in Northern and Eastern countries of the EU and Southern and Western countries need to do a lot of work to improve its business attractiveness. In Southern and Western Europe, natural gas, wind and solar seem more attractive than bioenergy. This means that these countries need more economic profitability incentives to drive bioenergy consumption forward. The profitability of bioenergy is mostly found in the area of forest industries and large producers in Northern and Eastern countries, where CHP using bioenergy is very well developed.

The study has shown that public opinion is very sensitive and public attitudes have had a negative impact on bioenergy development, especially in the Southern and Western countries of the EU (e.g., the Netherlands and Germany). It seems that in parts of the EU, society is not fully ready to accept bioenergy. Moreover, these countries have several anti-bioenergy movements that negatively color the opinions of different stakeholders. More information about bioenergy, including barriers and possible solutions, is required to facilitate a change in public attitudes, and countries in the south and west of the EU should increase public awareness by actively promoting bioenergy.

The fossil fuel industry also has an effect on bioenergy development. The opinions of respondents to this survey confirm that in some cases fossil fuels seem a more attractive option than fuels from biomass. This situation is more common in Southern and Western countries than in Northern and Eastern countries. Countries in the South and West of the EU have less developed bioenergy sec-

tors and have greater fossil fuel consumption (e.g., Poland and the Netherlands). In addition, the looming end of peat use will stimulate bioenergy development in some countries, for example in Finland.

Despite the challenges and barriers, the bioenergy sector can generally approach the future optimistically. Interestingly, respondents from the Southern and Western European countries were more optimistic about the long term, *i.e.*, over 50 years, than the short term. This view was not shared by respondents from Northern and Eastern countries, who expressed greater optimism for the next 5 - 10 years.

All countries from both studied groups are mostly committed to developing bioenergy. The results of the survey have shown that bioenergy will continue to grow, with significant growth forecast for Northern and Eastern EU countries over the next 50 years. In the short term, however, *i.e.*, the next 5 - 10 years, growth in bioenergy is not expected to be significant in either of the groups of countries studied. To reduce dependance on fossil fuels, countries will increase existing energy production in ways other than increased use of bioenergy, so France is likely to increase nuclear energy usage and Finland peat usage. In the long-term, however, it appears evident that countries will refocus on renewables including biomass usage.

The experience of bioenergy development in countries such as Finland and Sweden is applicable to countries whose bioenergy is less well developed like Poland and the Netherlands. Countries with a strong bioenergy sector can serve as examples of the benefits of bioenergy and their example can drive an increase in the overall share of bioenergy in the EU.

Based on the results, the study recommends that Southern and Western European countries increase promotion of bioenergy by providing additional information about the advantages and disadvantages of bioenergy in order to reduce the negative image of bioenergy and increase public acceptance. These countries should develop flexible use of bioenergy for successful integration into the EU power grid, support the use of biomass for electricity production, make bioenergy more attractive for investment, and support the integration of bioenergy with other renewables such as solar energy. In Northern and Eastern countries, it is important that the bioenergy sector continues its positive development. Although, the profitability of bioenergy in Northern and Eastern countries of the EU is higher than in Southern and Western Europe, countries should also pay attention to the issue of the attractiveness of the bioenergy sector. The environmental benefits of bioenergy and the economic profits available should be increased.

The results of the study can be utilized by policy and decision makers in the bioenergy sector both within and outside the EU. This study focused on the EU. A similar study using similar methods for other regions could be very interesting. For example, bioenergy perspectives in Africa, Canada, Latin America, and US may be very different from Europe and would thus be an attractive option for future research. The question of how the experience of bioenergy develop-

ment progress in countries with highly developed bioenergy sectors can be applicable to countries with slow bioenergy development may also be a fruitful area for future research, particularly as regards technological development.

Acknowledgements

We gratefully acknowledge the time and effort put in by the bioenergy experts who responded to the questionnaire. We would like to thank Wibke Baumgarten (FNR) for sharing the survey and making valuable comments. We would also like to thank Eeva-Lotta Apajalahti and Peter Jones from LUT University for their comments and assistance with the English language respectively.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] IEA (2017) Bioenergy and Biofuels. https://www.iea.org/topics/renewables/bioenergy

[2] Proskurina, S., Junginger, M., Heinimö, J. and Tekinel, B. (2019) Global Biomass Trade for Energy—Part 2: Production and Trade Streams of Wood Pellets, Liquid Biofuels, Charcoal, Industrial Roundwood and Emerging Energy Biomass. *Biofuels, Bioproducts and Biorefining*, **13**, 371-387. https://doi.org/10.1002/bbb.1858

[3] Union of Concerned Scientist (2008) Benefits of Renewable Energy Use. https://www.ucsusa.org/resources/benefits-renewable-energy-use

[4] European Commission (2021) Renewable Energy—Recast to 2030 (RED II). https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

[5] Adedoyin, F.F., Bekun, F.V. and Alola, A.A. (2020) Growth Impact of Transition from Non-Renewable to Renewable Energy in the EU: The Role of Research and Development Expenditure. *Renewable Energy*, **159**, 1139-1145. https://doi.org/10.1016/j.renene.2020.06.015

[6] Akadiri, S.S., Alola, A.A., Akadiri, A.C. and Alola, U.U. (2019) Renewable Energy Consumption in EU-28 Countries: Policy toward Pollution Mitigation and Economic Sustainability. *Energy Policy*, **132**, 803-810. https://doi.org/10.1016/j.enpol.2019.06.040

[7] European Commission (2021) 2050 Long-Term Strategy. https://ec.europa.eu/clima/policies/strategies/2050_en

[8] European Commission (2021) A European Green Deal, 2021. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[9] Ranta, T., Laihanen, M. and Karhunen, A. (2020) Development of the Bioenergy as a Part of Renewable Energy in the Nordic Countries: A Comparative Analysis. *Journal of Sustainable Bioenergy Systems*, **10**, 92. https://doi.org/10.4236/jsbs.2020.103008

[10] IEA (2022) A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas. https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas

[11] IEA (2021) IEA Bioenergy Countries' Report—Update 2021. https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountriesReport2021_final.pdf

[12] 19th EurObserv'ER Report (2019) The State of Renewable Energies in Europe, European Barometer.

[13] Stolarski, M.J., Warmiński, K., Krzyżaniak, M., Olba-Zięty, E. and Akincza, M. (2020) Bioenergy Technologies and Biomass Potential Vary in Northern European Countries. *Renewable and Sustainable Energy Reviews*, **133**, Article ID: 110238. https://doi.org/10.1016/j.rser.2020.110238

[14] Litbioma (2021) WBA Webinar Series—National Experiences with Bioenergy Deployment. https://www.worldbioenergy.org/news/604/47/WBA-Webinar-Series-National-experiences-with-bioenergy-deployment

[15] Szarka, N., Haufe, H., Lange, N., Schier, F., Weimar, H., Banse, M., *et al.* (2021) Biomass Flow in Bioeconomy: Overview for Germany. *Renewable and Sustainable Energy Reviews*, **150**, Article ID: 111449. https://doi.org/10.1016/j.rser.2021.111449

[16] ERO, Energy Regulatory Office (2021). https://www.ure.gov.pl/pl/oze/potencjal-krajowy-oze/5753,Moc-zainstalowana-MW.html

[17] ERO, Energy Regulatory Office (2021). https://www.ure.gov.pl/pl/oze/potencjal-krajowy-oze/5755,Ilosc-energii-elektrycznej-wytworzonej-z-OZE-w-latach-2005-2020-potwierdzonej-wy.html

[18] Anca-Couce, A., Hochenauer, C. and Scharler, R. (2021) Bioenergy Technologies, Uses, Market and Future Trends with Austria as a Case Study. *Renewable and Sustainable Energy Reviews*, **135**, Article ID: 110237. https://doi.org/10.1016/j.rser.2020.110237

[19] Paredes-Sánchez, J.P., López-Ochoa, L.M., López-González, L.M., Las-Heras-Casas, J. and Xiberta-Bernat, J. (2019) Evolution and Perspectives of the Bioenergy Applications in Spain. *Journal of Cleaner Production*, **213**, 553-568. https://doi.org/10.1016/j.jclepro.2018.12.112

[20] Caputo, P., Ferla, G. and Ferrari, S. (2019) Evaluation of Environmental and Energy Effects of Biomass District Heating by a Wide Survey Based on Operational Conditions in Italy. *Energy*, **174**, 1210-1218. https://doi.org/10.1016/j.energy.2019.03.073

[21] Sturm, V. and Banse, M. (2021) Transition Paths towards a Bio-Based Economy in Germany: A Model-Based Analysis. *Biomass and Bioenergy*, **148**, Article ID: 106002. https://doi.org/10.1016/j.biombioe.2021.106002

[22] Giuntoli, J., Agostini, A., Edwards, R. and Marelli, L. (2017) Solid and Gaseous Bioenergy Pathways: Input Values and GHG Emissions: Calculated According to the Methodology Set in COM(2016) 767, Version 2. Report EUR 27215 EN, European Commission, Joint Research Centre, Institute for Energy and Transport, Ispra 226 p.

[23] Zimakov, A.V. (2020) Bioenergy in EU: Problems and Prospects. *Mirovaia Ekonomika i Mezhdunarodnye Otnosheniia*, **64**, 81-90. https://doi.org/10.20542/0131-2227-2020-64-8-81-90

[24] Pehl, M., Arvesen, A., Humpenöder, F., Popp, A., Hertwitch, E.G. and Luderer, G. (2017) Understanding Future Emissions from Low-Carbon Power Systems by Integration of Life-Cycle Assessment and Integrated Energy Modelling. *Nature Energy*, **2**, 171-182. https://doi.org/10.1038/s41560-017-0032-9

[25] Azevedo, S.G., Sequeira, T., Santos, M. and Mendes, L. (2019) Biomass-Related Sustainability: A Review of the Literature and Interpretive Structural Modeling. *Energy*, **171**, 1107-1125. https://doi.org/10.1016/j.energy.2019.01.068

[26] Mai-Moulin, T., Hoefnagels, R., Grundmann, P. and Junginger, M. (2021) Effective Sustainability Criteria for Bioenergy: Towards the Implementation of the European Renewable Directive II. *Renewable and Sustainable Energy Reviews*, **138**, Article ID: 110645. https://doi.org/10.1016/j.rser.2020.110645

[27] Mandley, S.J., Daioglou, V., Junginger, M., van Vuuren, D.P. and Wicke, B. (2020) EU Bioenergy Development to 2050. *Renewable and Sustainable Energy Reviews*, **127**, Article ID: 109858. https://doi.org/10.1016/j.rser.2020.109858

[28] Gross, S., Welfle, A.J., Thornley, P., Syri, S. and Mikaelssom, M. (2021) Bioenergy Development in the UK & Nordic Countries: A Comparison of Effectiveness of Support Policies for Sustainable Development of the Bioenergy Sector. *Biomass and Bioenergy*, **144**, Article ID: 105887. https://doi.org/10.1016/j.biombioe.2020.105887

[29] Millot, A., Krook-Riekkola, A. and Maïzi, N. (2020) Guiding the Future Energy Transition to Net-Zero Emissions: Lessons from Exploring the Differences between France and Sweden. *Energy Policy*, **139**, Article ID: 111358. https://doi.org/10.1016/j.enpol.2020.111358

[30] Proskurina, S., Sikkema, R., Heinimö, J. and Vakkilainen, E. (2016) Five Years Left—How Are the EU Member States Contributing to the 20% Target for EU's Renewable Energy Consumption; the Role of Woody Biomass. *Biomass and Bioenergy*, **95**, 64-77. https://doi.org/10.1016/j.biombioe.2016.09.016

[31] Sikkema, R., Proskurina, S., Banja, M. and Vakkilainen, E. (2021) How Can Solid Biomass Contribute to the EU's Renewable Energy Targets in 2020, 2030 and What Are the GHG Drivers and Safeguards in Energy and Forestry Sectors? *Renewable Energy*, **165**, 758-772. https://doi.org/10.1016/j.renene.2020.11.047

[32] Eurostat 2021 (2021). https://ec.europa.eu/eurostat/data/database

[33] Rapid Transition Alliance (2021) The Dash Away from Gas: How the Netherlands Kicked a Big Fossil Fuel Habit. https://www.rapidtransition.org/stories/the-dash-away-from-gas-how-the-netherlands-kicked-a-big-fossil-fuel-habit

[34] Ranta, T., Laihanen, M. and Karhunen, A. (2021) The Role of Bioenergy in Achieving the Carbon Neutrality Target in Finland by 2035—A Case Study of Student Surveyed at University in Finland. *Journal of Sustainable Bioenergy Systems*, **11**, 61-81. https://doi.org/10.4236/jsbs.2021.112005

[35] Cross, S., Welfle, A.J., Thornley, P., Syri, S. and Mikaelsson, M. (2021) Bioenergy Development in the UK & Nordic Countries: A Comparison of Effectiveness of Support Policies for Sustainable Development of the Bioenergy Sector. *Biomass and Bioenergy*, **144**, Article ID: 105887. https://doi.org/10.1016/j.biombioe.2020.105887

[36] yle.fi. (2021) Peat Producers Protest Government Energy Policy. https://yle.fi/uutiset/osasto/news/peat_producers_protest_government_energy_policy/11909062

[37] Ulrici, P. (2019) Bioenergy Adoption Barriers across 7 EU Countries. https://www.diva-portal.org/smash/get/diva2:1335410/FULLTEXT01.pdf

[38] Ministry of Climate and Environment (2021) Energy Policy of Poland until 2040. https://www.gov.pl/web/climate/energy-policy-of-poland-until-2040-epp2040

[39] Proskurina, S., Alakangas, E., Heinimö, J., Mikkilä, M. and Vakkilainen, E. (2017) A Survey Analysis of the Wood Pellet Industry in Finland: Future Perspectives. *Energy*, **118**, 692-704. https://doi.org/10.1016/j.energy.2016.10.102

[40] Kern, J., Tammeorg, P., Shanskiy, M., Sakrabani, R., Knicker, H., Kammann, C., *et al.* (2017) Synergistic Use of Peat and Charred Material in Growing Media—An Option to Reduce the Pressure on Peatlands? *Journal of Environmental Engineering and Landscape Management*, **25**, 160-174. https://doi.org/10.3846/16486897.2017.1284665

[41] Halder, P. (2011) Bioenergy Knowledge, Perceptions, and Attitudes among Young Citizens—From Cross-National Surveys to Conceptual Model. Ph.D. Thesis, University of Eastern Finland, Kuopio. https://doi.org/10.14214/df.135

[42] Euractiv.com (2020) EU Plans Sweeping Bioenergy Review by End 2020. https://www.euractiv.com/section/biomass/news/eu-plans-sweeping-bioenergy-review-by-end-2020

[43] Fern.org (2020) Public Debate on Biomass Reaches Critical Mass in the Netherlands. https://www.fern.org/publications-insight/public-debate-on-biomass-reaches-critical-mass-in-the-netherlands-2179

[44] Von Cossel, M., Lewandowski, I., Elbersen, B., Staritsky, I., Van Eupen, M., Iqbal, Y., *et al.* (2019) Marginal Agricultural Land Low-Input Systems for Biomass Production. *Energies*, **12**, 3123. https://doi.org/10.3390/en12163123

[45] Stolarski, M.J., Szczukowski, S., Tworkowski, J. and Krzyżaniak, M. (2019) Extensive Willow Biomass Production on Marginal Land. *Polish Journal of Environmental Studies*, **28**, 4359-4367. https://doi.org/10.15244/pjoes/94812