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AN OVERVIEW OF BIOFUEL POTENTIAL FROM ENERGY CROPS WASTE BIOMASS

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Abstract. In order to mitigate climate change, reduce greenhouse gas emissions, and ensure the security of energy independence, it is important to expand immediately the energy crop waste biomass utilization in the agricultural sector. The aim of the study is to assess the potential of energy crop waste biomass with particular focus on biofuels in the case of Lithuania. The posed research question is: what type of energy crop waste biomass is considerable for the consumption of biofuel production. The results of analysis showed that the dominant position was associated with biodiesel production in Lithuania's transport sector, followed by bioethanol production. Biogas production has taken the lowest position in the biofuel industry. It was determined that the highest potential of biofuel was associated with four based energy crops. Unfortunately, the biofuel potential is still not used by utilization of other energy crops. The recommendation is to promote the cultivation of energy crops, such as miscanthus, hemp, switchgrass, reed canary grass, and others energy crops in the agricultural sector of Lithuania.

Key words: biofuel, agricultural, waste biomass, perennial crops.

JEL code: Q1, Q2, Q3, and Q4

Introduction

European Union's attention is paid to developing biofuel potential from energy crop waste biomass. The expansion of energy crop waste biomass resources is important for reducing climate change and ensuring energy sector's security in Lithuania. The expansion of energy crop waste biomass resources is important for reducing climate change and increasing energy sector's security. One of the priorities of the National Energy Independence Strategy is to ensure the security of energy in Lithuania's state. The main purpose is to use renewable sources for not less than 80 percent of the energy needs' production of the country (International Energy Agency, 2015). The measures that are now provided for in the legislation make it possible to save energy, but the main problem that is associated with increasing energy productivity remains. Hence, the changing part of the energy produced from fossil fuels to energy produced from energy crop waste biomass sources can ensure energy efficiency and seek to contribute to the implementation of climate change mitigation (Gaigalis V., Skema R., 2017; John S., 2004). Biomass waste of energy crops can supplement biofuel potential in Lithuania. Produced biofuel is suitable for the use in internal combustion engines as fuel, and its use reduces environmental pollution. Biofuel can be produced from energy crops waste biomass, mixed with conventional fuel for transport, domestic or industrial use. It is the only renewable resource that replaces the use of fossil fuels in the transport sector. The main types of biofuels used in Lithuania are: *bioethanol*, produced from raw materials containing sugar (sugarcane, sugar beet) and starch (potatoes, grains), and *biodiesel*, produced from vegetable oil (rapeseed, linseed, soybean, rye, wheat, triticale, sunflower). Biodiesel can be used as a fuel in conventional diesel engines. Bioethanol is used in internal combustion engines, replacing part of gasoline with it. However, the possibility of using bioethanol in a diesel engine is recently being explored. This is aimed at expanding the base of raw materials and increasing the share of renewable energy in diesel fuel (Katinas V., Savickas J., 2012). Another type of biofuel is biogas. Energy crop waste biomass waste generated in agriculture can be efficiently used to produce biogas. Waste biomass of energy crops, such as straw of rapeseed or wheat can replace or partially complement traditional types of energy and water and wind energy resources. The energy crops waste biomass utilization for biofuel production should be a top priority for the sustainable bioeconomy. It is economically beneficial and ensures absolute independence of the supply of primary energy resources.

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Lithuania has an unexploited energy crop waste biomass potential in the agricultural industry (Hagen K., 2016; Marciukaitis M. et al., 2016).

According to the EU directive 2015/1513, as a priority, it is planned to promote to use of biofuel-biomethane production in the transport sector. However, in recent years, biogas is increasingly being used to produce electricity. The biofuel production from energy crop waste biomass is important in helping Lithuania to meet its greenhouse gas reduction targets. Typically, it is proposed to use biofuel production in other agricultural lands, which are not suitable for growing food or feed. This study applied analysis of three main biofuel families: biodiesel, bioethanol, and biogas production.

The aim of the study is to assess the potential of energy crop waste biomass with particular focus on biofuels in the case of Lithuania.

Research question: What type of energy crop waste biomass is considerable for the consumption of biofuel production?

Tasks of the research:

1) to perform the analysis of energy crop waste biomass prepared according to statistical data;
2) to estimate the biofuel potential of energy crop waste biomass by indicating the role of waste biomass consumption for biofuel production.

The novelty of this study includes significant aspects of research: it combines an assessment potential of energy crop waste biomass with biofuel consumption efficiency and addresses the need to increase the use of more kinds of agricultural resources.

Research methods. Statistical analysis was applied by collecting the data from the database of the International Energy Agency, Biomass Energy Europe, the European Commission and others. Literature analysis was conducted by general methods: systematization, grouping, graphical presentation, summarization and others.

Research results and discussion

Energy crops biomass has an important role to play in helping to achieve the renewable energy targets. The classification of energy crops biomass for production of biofuels is shown in Table 1.

Table 1

Classification of energy crops biomass for production of biofuels

Oil crops	Solid energy crops	Cereals	Starch and sugar crops	Cellulose crops
Oilseed rape, linseed, field mustard, hemp, sunflower, safflower, castor oil, olive, palm, coconut and groundnut	Cardoon, sorghum, kenaf, prickly pear, whole crop maize, reed canary grass, miscanthus, willow, poplar and eucalyptus	Barley, Buckwheat triticale wheat, oats, maize, rye	Potato, sugar beet, Jerusalem artichoke, sugarcane	Straw, wood, short rotation coppice (SRC)

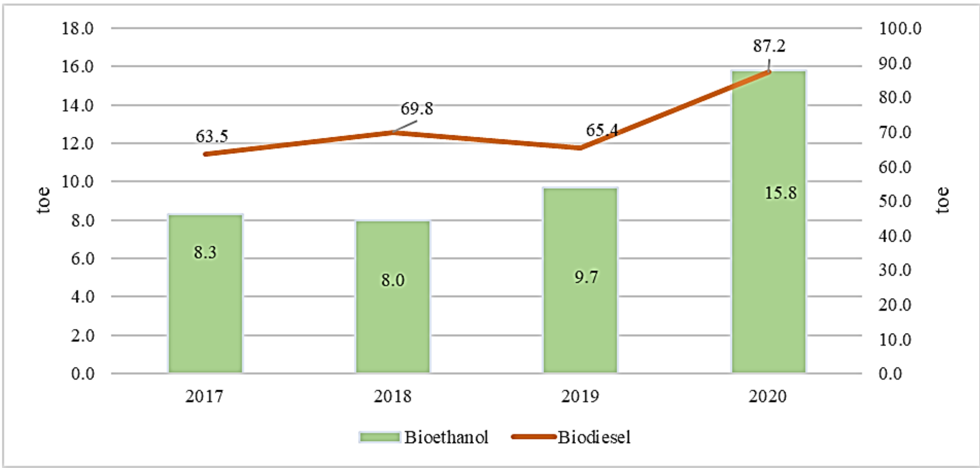
Source: Sims R.H. et al., 2006; Koçar G., Civaş N., 2013

There are many kinds of energy crop biomass that can produce three kinds of biofuels, such as emp (both oil and solid biomass) and cereals (ethanol and solid biomass from straw). Cereals can be used to produce ethanol, for example, barley, wheat, oats, maize and rye. Also, the straw of these cereals can be used as a solid fuel. Starch and sugar crops make used for the production of ethanol, such as potato, sugar beet, Jerusalem artichoke and sugarcane. Oil crops can be used directly as heating fuels or refined to transport biofuels such as biodiesel esters. Cellulose crops can be reduced to sugar by acid or hydrolysis and then fermented to produce ethanol (Kosar G., Civas N., 2013).

Energy crop waste biomass can be used in many ways. First, the utilization of crop residue provides many kinds of products, such as starch, sugar, cellulose, and oil. Second, this waste biomass can be used for biogas production to generate heat/electricity. Third, for biofuel production which incorporates ethanol, methanol, biodiesel, and their derivatives (Demirbas A., 2001). In Lithuania, the most developed biofuels are the ones that belong to the first generation, which is produced from food or fodder plants. Bioethanol made from wheat and rye is added to gasoline, and biofuels made from various vegetable oils (rape grains, rapeseed oil, and other vegetable oils) are added to diesel. However, the future belongs to the second-generation biofuels, which are produced from agricultural and other waste biomass such as straw, manure and sewage raw materials (Miezys A., 2016). In the world, there are already produced fourth-generation biofuels – genetically modified microorganisms, for example, microalgae, yeast, fungi or cyanobacteria (Alalwan H., Alminshid A., Aljaafari H., 2019).

According to the Sustainable Transport Fund's report submitted to the European Commission, second-generation biofuels, which can replace diesel, are currently only in the development stage, and it will take at least 5 years to develop reliable technologies that will allow the commercialization of scientists' inventions to the point where businesses can start investing in them. Some of these technologies will likely take more than 5 years to develop and will have a negligible impact on greenhouse gas emissions by 2030 (Biofuels Association, 2023). To reach 7 percent, in 2020, an indicator of biofuel consumption, 200 thousand hectares of rapeseed and cereal area would be enough for Lithuania or 5% agricultural land. 2019 was the first year in Lithuania when production of second-generation fuel started. This will encourage increasing the share of renewable resources in the transport sector and the obligation to offer even less polluting fuels (Energetics, 2019).

Based on statistical data, the increasing trend of biofuels' consumption for transport in Lithuania from 2017 to 2020 is shown in Figure 1.



Source: author's calculations based on the European Commission reports, 2020 and 2022

Fig. 1. **Bioethanol and Biodiesel consumption for transport in Lithuania**

In 2020, Lithuania bioethanol consumption in transport increased to reach 7.5 ton of oil equivalent (toe) in 2017 (90.4%); compared to 7.8 toe in 2018 (97.5%); compared to 6.1 toe in 2019 (63%). In 2020 biodiesel consumption in transport made growth to reach 23.7 toe in 2017 (37.3%); compared to 17.4 toe in 2018 (25%); compared 21.8 toe in 2019 (33.3%). The comparative analysis shows that the use of bioethanol and biodiesel in the transport sector has the potential to grow in Lithuania.

Based on recast Renewable Energy – Recast to 2030 (RED II), the overall EU target for Renewable Energy Sources consumption by 2030 has been raised to 32% (Directive (EU) 2018/2001). Hence, the European biogas association suggests that two specific targets should be integrated into the amended

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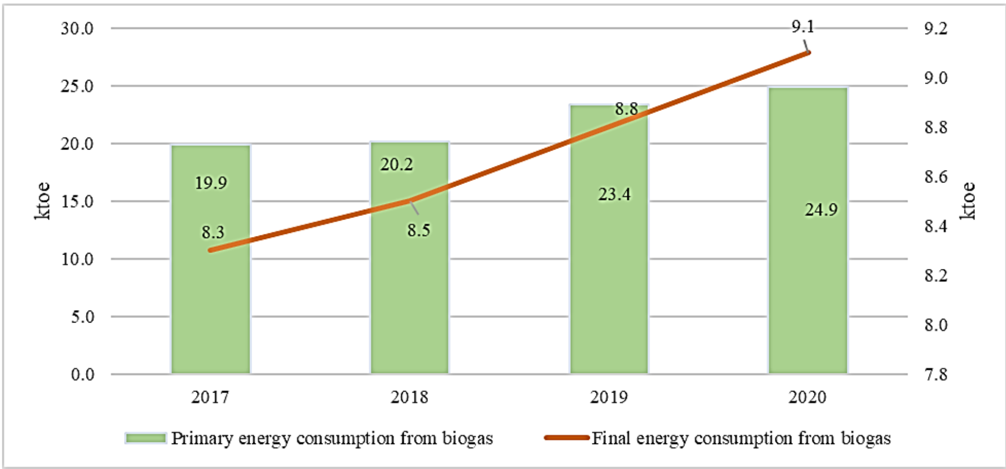
RED II: a target on the consumption of renewable gas of at least 11% in terms of energy content by 2030 and a target to reduce the greenhouse gas emission intensity of gas consumption by at least 20% compared to 2018 levels by 2030. In Europe, primary energy output growth has steadily declined ever since it peaked in 2011 (with a year-on-year rise of 21.9%). The main reason for this stagnation is the growing apprehension about the use of food crops as energy crops (European Commission, 2021). The situation of Lithuania with regard to biogas consumption is shown in Figure 2. Primary energy output from biogas in Lithuania has remained stable. According to the data, it rose to 24.9 kilo tonnes of oil equivalent (ktoe) in 2020, from 19.9 ktoe in 2017 (25%). Yet, biogas still enjoyed good growth, for example in 2019 (17.6%, with output at 23.4 ktoe). In 2018, biogas output increased, but it happened at a slower pace (1.5%, from 19.5 ktoe to 20.25 ktoe).



Source: author's calculations based on the European Commission reports, 2020 and 2022

Fig. 2. **Primary energy and final energy consumption from biogas in Lithuania**

In 2020, concerning final energy consumption directly used in industry and other sectors, it increased from 8.3 ktoe to 9.1 ktoe (9.6%) compared to 6% in 2019 and 2.4% in 2018. The summarized data lead to the conclusion that distribution between them is heavily dominated by the biodiesel sector, which has approximately 90% share compared to 37% for bioethanol and 25% for the biogas fuel sectors respectively. Biogas can also be purified to be transformed into biomethane. It can then either be injected into the network after purification and valued in the same way as can be natural gas, in the form of electricity and or heat, or either be used by natural gas vehicles. However, in Lithuania, there is still no biogas plant, which would transform biogas into biomethane. It is expected, that the first biogas plant should start to work at end of 2023. Lithuania's gross electricity increased the most in 2019 (by 154.4 Gigawatt hours (GWh)) primarily because of the build-up of biogas production from thermal processes (Figure 3).

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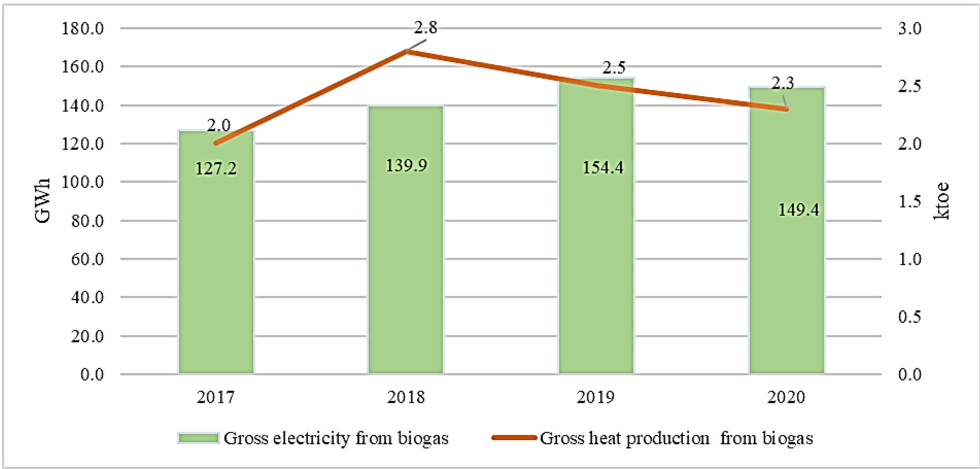
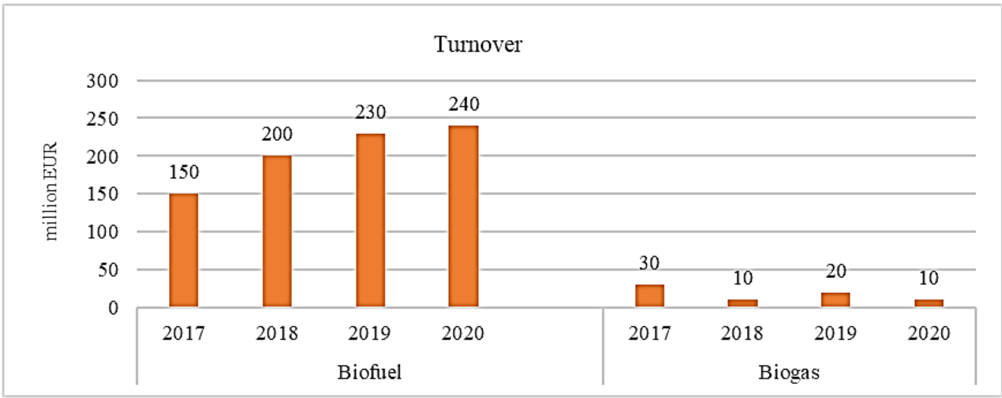


Source: author's calculations based on the European Commission reports, 2020 and 2022

Fig. 3. **Gross electricity and heat production from biogas in Lithuania**

As revealed in Figure 3, biogas produced in 2020 by biogas plants amounted to 22.2 GWh of gross electrical energy, or by 17.5 percent more than in 2017. Gross electricity production from biogas increased to reach 27.2 GWh in 2019 compared to 2017 (21.4%); compared to 12,7 GWh in 2018 (10%). However, biogas electricity output contracted slightly (by 3.2%) between 2019 and 2020, from 154.4 to 149.4 GWh. Gross heat production from biogas made growth to reach 0,3 ktoe in 2020 compared to 2017 (15%). However, biogas heat output contracted slightly (by 17.9%) between 2018 and 2020, from 2.8 to 2.3 ktoe and (by 8%) between 2019 and 2020, from 2.5 to 2.3 ktoe. The Lithuania's biofuels sector subsumes biodiesel and bioethanol for transport, and the biofuels technologies saw the biggest turnover rise in 2020 (60%). The biogas sector, which applies electricity and heat in the biogas technologies, saw the highest turnover decrease in 2020 (67%) (Figure 4).



Source: author's calculations based on the European Commission reports, 2020 and 2022

Fig. 4. **Biofuel and biogas turnover in Lithuania**

The economic volume of the biofuel industry is estimated at around 240 million euros, and the employment level increased to considerable number – 4800 persons (in 2020). The turnover of the biogas industry amounted to 10 million euros, and the employment level decreased to 200 persons (2020) (Figure 5).

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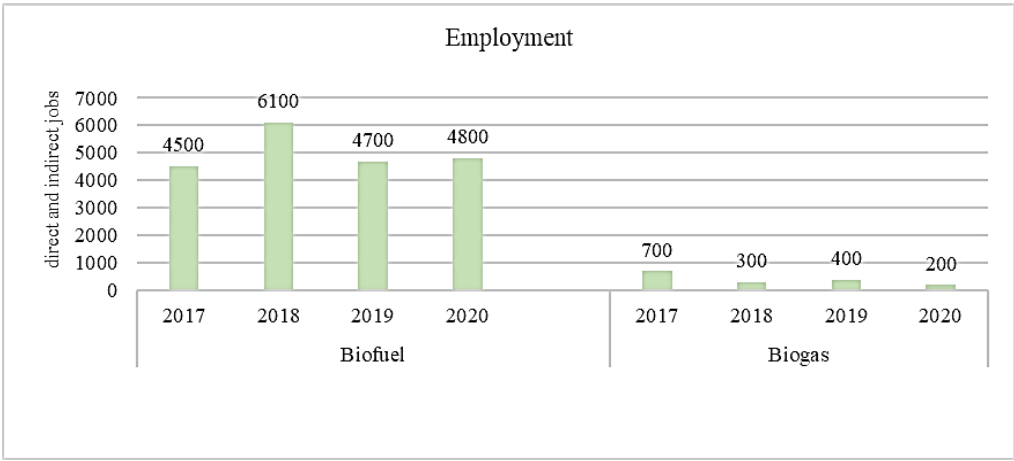

Source: author's calculations based on the European Commission reports, 2020 and 2022

Fig. 5. **Biofuel and biogas sectors' employment in Lithuania**

As revealed in Figures 4 and 5, the biofuel industry turnover and employment in 2020 increased to 90 million euro and 300 employees more than in 2017, respectively. The biogas industry turnover and employment in 2020 decreased to 20 million euro and 500 employees less than in 2017, respectively.

Determining the potential of energy crop biomass waste involves many limitations factors, such as the complexity of production and consumption, difficulty in determining the energy sources of biomass, the sustainability of long-term productivity and economic aspects of production (Papilo P., Kusumanto I., Kunaifi K., 2017). Also, there are more factors limiting the access of energy crop biomass: topography, law or local regulation, and local traditions. The potential of energy crop biomass can be measured by conducting three main methods of geospatial technology, field surveys, and modelling. Geospatial technology is used to estimate the growth of biomass and productivity estimates. The field survey is used to collect data as part of an evaluation of a specific location. Currently, the field survey in the assessment of biomass resources is used when other methods are not effective or when the ability to use other methods does not exist. A model is a framework that is simplified and designed to visualize a system or process. Both static (analytical) and dynamic (simulation) models are used in the assessment of biomass resources, for several variables such as crop production, the resulting residues, labour costs, and the price (chemical, fertilizer, fuel, and planting (Rosillo-Calle F. et al., 2015).

The area of land dedicated to biomass and energy crop growth is a fundamental driver in determining the potential availability of the grown resources. Because bioenergy crop production is not allowed to compete with food crops, only surplus agricultural land and land that is not suitable for food or feed production are considered. To avoid the competition between energy crops which are used both for food and renewable energy, it is preferred to use less fertile and other land located near roads and polluting objects for the cultivation of agricultural products intended for the biomass of energy crops. In Lithuania, for these crops it would be possible to allocate from 10% to 15% of agricultural land (Kadziuliene Z. et. al., 2013). In Lithuania, maize, sorghum, rye, wheat, sugar beet, Jerusalem artichoke, and reed canary grass are the most suitable for biogas production. Maize, wheat, rye, sugar beet, and rapeseed are suitable for biodiesel production. Bioethanol is usually produced from starchy (triticale, rye, winter wheat, potatoes) and sugary (sugar beet) energy crops. A significant part of biofuels in the world is also produced from the waste biomass of food crops - cereals, beets, soybeans, sugar cane, rapeseed, palm trees etc. (Styps E. et al., 2016). The theoretical potential of energy crops waste biomass might be calculated referred to the guidelines developed by Biomass Energy (Biomass Energy Europe, 2010):

$$THP\_PAR = \sum(CAixAPixPtRixAvi) \tag{1}$$

Where:

THP_PAR - theoretical potential of agricultural residues (e.g., straw, stalks), in tons;

CAi – the cultivated area for i-th crop, in hectares (ha);

APi – the agricultural residue for the i-th crop, in tons per hectare (t ha^{-1});

$PtRi$ – ratio of agricultural residue for i-th crop;

Avi – the availability of residues for i-th crop.

Each agricultural residue can be converted into energy units 60% of the waste values of the total energy crops biomass, using a low heating value of 13.63 to 14.63 GJ t^{-1} with a water content of about 15%. Energy units were converted from tons of agricultural residues by multiplying the lower calorific value of a particular residue. The ratio of agricultural residue is shown in Table 2. The availability of residues for each crop according to the current harvesting system was assumed to equal 1 (Papilo P. et al., 2017). This study assumed that energy crops waste biomass belongs to used 60% of biofuel production in 2022. The data on cultivation of energy crops waste biomass is shown in Table 2.

Table 2

Data of cultivation of energy crops waste biomass

Sources	Residue ratio	Cultivated area (ha)	Harvesting yield (t/ha)
Oil crops			
Oilseed rape	2	352 249	2
Linseed	0.3	809	1.35
Field mustard	1	4 559	13.5
Hemp	1	5 334	5
Sunflower	1.5	242	2.6
Solid energy crop			
Sorghum	2.5	183	6
Maize	2.5	52 859	6
Clover	1	36 572	14
Miscanthus	1	6	11
Sainfoin	1	262	16
Switchgrass	1	737	11.3
Lucerne	2	15 060	6
Meadow of perennial energy crops till 5 years	1	159 799	20
Cereals			
Wheat	1.4	940 514	4.4
Barley	1.1	136 480	3.8
Oats	1.3	81 901	2.6
Rye	1.8	29 722	2.1
Triticale	1.2	64 021	3.3
Starch and sugar crops			
Sugar beet	0.6	11 843	58
Jerusalem artichoke	1	37	11.7

Source: author's calculations based on Wright et al., 2009; Clarke et al., 2011 Sakalauskas, 2012; Iye, Bilsborrow, 2013; Papilo et al., 2017; Alhassan et al., 2019

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Table 2 shows the data for the study which was used for calculating potential energy crop waste biomass. The data include the kind of sources, residue ratio of waste calculation, the cultivation area of energy crops and their harvesting yield. Potential energies yield from energy crops waste biomass is shown in Table 3. Additionally, the results of energy crop waste biomass by type classification are shown in Figure 6.

Table 3

Potential energies yield from energy crops waste biomass for 2022 year

Sources	Energy crops waste thsd. t/ha	Energies yield thsd. GJ/ha 13.63	Energies yield thsd. GJ/ha 14.63
Oil crops, total:	***899.1***	***14088.6***	***15124.5***
Oilseed rape	845.4	13247.1	14221.2
Linseed	0.2	3.1	3.3
Field mustard	36.9	578.7	621.3
Hemp	16.0	250.8	269.2
Sunflower	0.6	8.9	9.5
Solid energy crops, total:	***2818.2***	***44159.8***	***47406.8***
Sorghum	1.6	25.8	27.7
Maize	475.7	7454.6	8002.8
Clover	307.2	4813.9	5167.8
Miscanthus	0.04	0.6	0.7
Sainfoin	2.5	39.4	42.3
Switchgrass	5.0	78.3	84.0
Lucerne	108.4	1699.1	1824.0
Meadow of perennial energy crops	1917.6	30048.1	32257.5
Cereals, total:	***4204.0***	***65876.2***	***70720.1***
Wheat	3476.1	54470.1	58475.3
Barley	342.3	5363.6	5758.0
Oats	166.1	2602.6	2794.0
Rye	67.4	1056.3	1134.0
Triticale	152.1	2383.6	2558.8
Starch and sugar crops, total:	***247.5***	***3878.8***	***4164.0***
Sugar beet	247.3	3874.7	4159.6
Jerusalem artichoke	0.3	4.1	4.4

Source: author's calculations based on the data of Lithuanian Department of Statistics

The results show, that the highest potential of energy crop waste biomass was determined in cereals, ranging from 14089 to 15125 thsd. GJ/ha (51.5%); followed by solid energy crops and oil crops, ranging from 44160 to 47407 thsd. GJ/ha (34.5%) and from 65876 to 70720 thsd. GJ/ha (11%), respectively. The lowest potential of energy crop waste biomass amounted to starch and sugar crops, ranging from 3879 to 4164 thsd. GJ/ha (3%).

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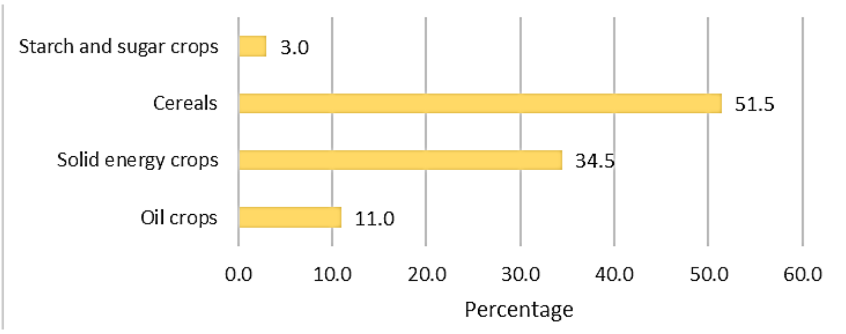
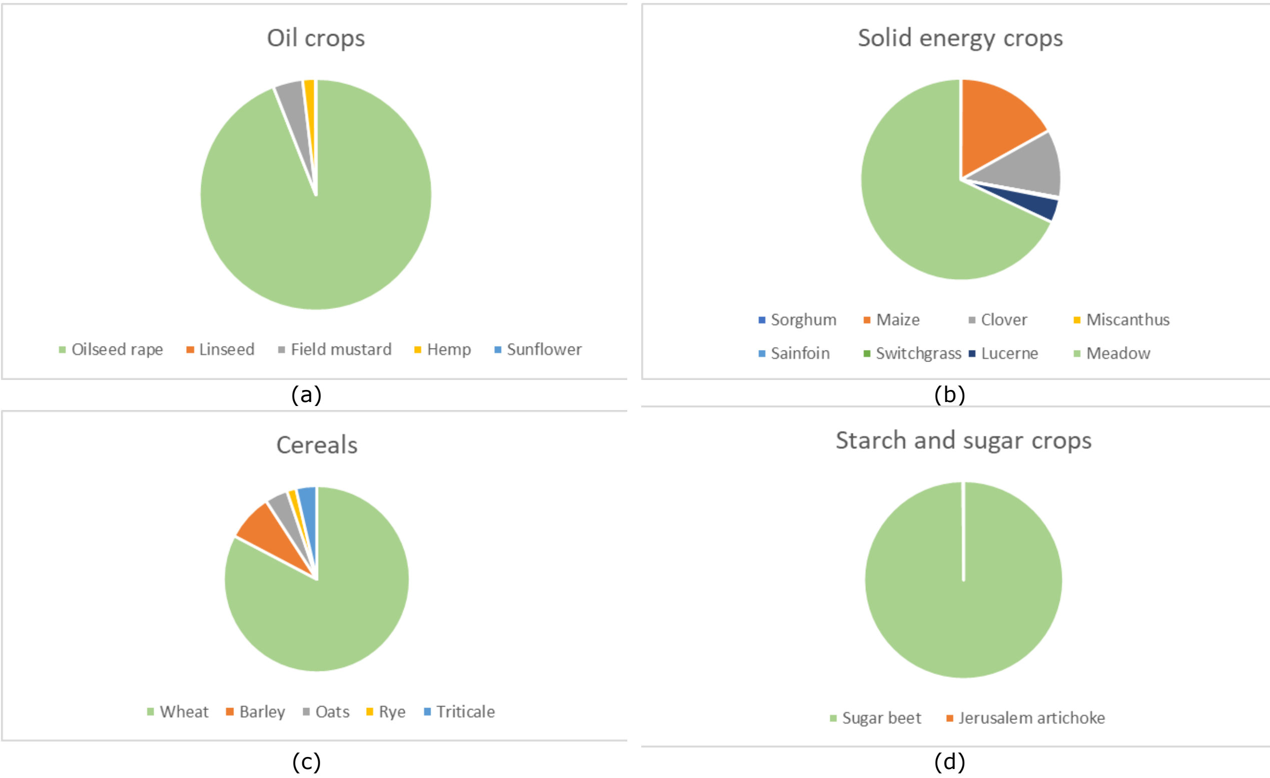


Source: author's calculations based on the data of Lithuanian Department of Statistics

Fig. 6. **The results of energy crops waste biomass by type classification, percentage**

According to the results of various kinds of energy crop waste biomass, it can be noticed that four energy crops have a significant role in the agriculture of Lithuania (Figure 7).



Source: author's calculations based on the data of Lithuanian Department of Statistics

Fig. 7. **The results of energy crops waste biomass, percentage: a) Oil crops; (b) Solid energy crops; (c) Cereals; (d) Starch and sugar crops**

Based on the data on the structure of the waste biomass related to perennial energy crops, the first highest potential of energy crops amounted to sugar beet (99.8%), followed by oilseed rape (94.9%), wheat (82.7%) and meadow (68.1%). The second lowest potential of energy crops was identified as maize (17%), clover (11%), barley (8.2%), field mustard (4.1%), lucerne, oats and triticale (4%). The smallest significance in the agricultural role have the cultivation of energy crops of hemp and rye (2%); followed by linseed, sunflower, sorghum, miscanthus, sainfoin, switchgrass and Jerusalem artichoke, ranging from 0.001 to 0.06%.

Conclusions

1) The analysis of energy crop waste biomass according to statistical data revealed that bioethanol and biodiesel utilization for the transport sector still has a possibility to increase in Lithuania. The reason is the need to find a balance between the use of food crops and energy crops. The statistical results

showed that biogas production is still insufficiently used for gross heat production. Additionally, biogas production includes the lowest energy production compared to biodiesel and bioethanol. The dominant position was taken by biodiesel production in the transport sector. The economic volume (turnover) and employment level in the biogas sector were smaller than in the biofuels industry, as well.

2) The estimation of the biofuel potential of energy crops disclosed that in the biofuel industry there might be included different types of energy crop waste biomass. The highest position applied to cereal crops, followed by solid energy crops and oil crops. The lowest position applied to starch and sugar crops. Also, it was determined that sugar beet, oilseed rape, wheat, and meadows have an important role in the agriculture of Lithuania. There is still an untapped biofuel potential energy for perennial crops, such as hemp, rye, linseed, sunflower, sorghum, miscanthus, sainfoin, switchgrass and Jerusalem artichoke.

Recommendations

According to the results, it would be sensible to cultivate energy perennial crops such as miscanthus, reed canary grass, switchgrass, sorghum, sainfoin and other energy crops, which are suitable for biofuel production. It is necessary to encourage farmers to use uncultivated lands to cultivate the aforementioned energy-perennial crops. For this reason, it is necessary to activate appropriate financial and educational mechanisms.

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