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The monograph covers current research in the field of energy potential of biomass. The issues of world scientific and research trends in the field of biomass energy and the current state of bioenergy in the EU and Ukraine in the context of opportunities to increase the volume and improve the properties of raw materials for renewable energy based on biomass. The presented materials are intended for masters, graduate students, engineers and scientists involved in the design, testing and operation of agricultural machinery.

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CONTENTS

PREFACE

The World Economy in The Production of Electricity and Heat, is Increasingly Based on the Use of Renewable Energy Sources to Replace Partially or Totally Fossil Fuels. Biofuels Provide an Opportunity for Energy Production in Many Sectors While Maintaining Ecological Conditions.

Recently, there have been significant changes in the energy sector of Europe and Ukraine, including the use of renewable energy sources, as well as individual and district heating. Issues of energy security of countries, reduction of dependence on imported energy are becoming increasingly important. Analysis of the state of development of bioenergy in recent years has shown that the total amount of energy produced from biomass is growing.

Biomass is considered an environmentally friendly type of fuel compared to fossil solid fuels: it usually contains little sulfur, its combustion produces low emissions of nitrogen oxides, and greenhouse gas emissions correspond to the natural cycle of CO_2 uptake, storage and release.

The use of biomass reduces the amount of waste and garbage in cities, and in the case of biogas – leads to the disposal of hazardous waste from landfills, which contributes to the cleaning of littered areas, the return of biodiversity, the overall improvement of the environment.

A number of documents and programs have been adopted in the EU and Ukraine to regulate this area, in particular, “European Green Deal”, Ukraine’s energy strategy “Security, energy efficiency, competitiveness”, which will outline the strategic guidelines for the development of the fuel and energy sector until 2050 and others.

The market for energy production from biomass is a new sector of economic activity that creates new jobs, promotes the growth of regional gross domestic product and the overall “greening” of the economy.

The materials presented in this paper are designed to answer some of the most common questions in the planning and implementation of projects in the field of energy and heat supply, highlight a number of technical, economic and organizational aspects of their development and implementation, increase public awareness of energy use biomass.

The monograph shows the results of the research performed within the framework of the topic “Formation of Organizational and Economic Mechanism for Development Production Biohydrogen From Biomass – Green Hydrogen”, which was performed with support International Visegrad Fund and implemented by scientific and pedagogical staff of the educational and scientific laboratory "DAK GPS" Institute of Energy of State Agrarian and Engineering University in Podilya, drying laboratory Faculty of Production Engineering Warsaw University of Life Sciences - SGGW, laboratories of product technology and quality assessment of biofuels faculty of production and power engineering University of Agriculture in Krakow and National University of Life and Environmental Sciences of Ukraine.

Acknowledgments: We express our gratitude **International Visegrad Fund** and reviewers for a constructive review, which made it possible to improve the monograph.

With best regards, Editors

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Taras Hutsol

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CHAPTER 1

REGIONAL DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN UKRAINE

Abstract

Ukraine uses much more heat and electricity than other European countries. Prices for gas and raw materials for energy production are constantly rising, which encourages a gradual transition to alternative energy sources. Given the soil and climatic conditions of these areas and the availability of land plots unsuitable for efficient agriculture, the alternative is biomass of energy crops. These are plantations that have positive economic, energy and environmental effects.

In terms of positive environmental impact, growing energy crops prevents soil erosion and improves the environment. During the combustion of biomass from energy crops in power plants or boilers, only CO_2 is released into the atmosphere, which was absorbed by the plant during its growth.

The article presents an analysis of the problems that exist in the way of energy use of agrobiomass, and suggests possible ways to overcome them. The urgency of the topic is due to the fact that, first, Ukraine has a great potential for waste and by-products of agriculture. Secondly, without the involvement of this type of biomass in the fuel and energy balance of the country, it is impossible to achieve the bioenergy goals set by the Energy Strategy of Ukraine for the period up to 2035. The proposed recommendations for overcoming the problems take into account the best practices of the EU and the USA.

Key words: renewable energy sources, regional development, energy efficiency, fuel and energy balance, biogas, biomass, energy crops

1. Introduction

Energy efficiency is a criterion for the quality of functioning of the economic model of the state. The most acute in Ukraine at the present stage of its development are the problems of stable energy supply and efficient use of energy resources, the solution of which largely depends on the level of economic and social development of society.

Local governments need to be leaders in sustainable energy systems and help reduce the negative effects of climate change, as it is at the local level that the most tangible effects of these problems will be felt, and the energy sector will be one of the first of affected.

Ukraine still has a huge untapped potential of renewable energy sources, which allows to increase the share of renewable energy in the energy balance of the state and regions.

Consolidating the increase in the share of renewable energy sources in consumption at the legislative level is an effective method of modernizing the energy sector, reforming energy markets, improving the competitiveness of the energy sector, creating new jobs, and accelerating economic growth. Intensive use of renewable energy sources will contribute to the energy security of the state, economic diversification and sustainable development of the regions.

However, today the legislative and regulatory software for the development of renewable energy remains insufficient. Ukraine needs to adopt one major legislative act in the field of renewable energy, such as the EU program 20/20/20, which would regulate the legal relations of the actors in this sector, as well as establish clear sound indicators of the industry in the near future, ways to achieve these indicators, sources financing, transparent mechanisms for attracting foreign and domestic investment. The current Energy Strategy of Ukraine until 2030 could be considered as such, but it needs to be amended, especially to increase the indicators of renewable energy development to scientifically sound ones. Another problem is that currently the legislation in the field of renewable energy is not consistent with each other and contains different forecasts of renewable energy development in the coming years, there is no clear coordination between regulations and programs for renewable energy development at the state and regional levels. There is no single common definition of technically achievable and economically feasible potential for renewable energy sources by region. This makes it difficult to evaluate renewable energy projects. Regional development programs should pay more attention to renewable energy, because it is a way to energy independence of the region and the country, reducing harmful emissions into the atmosphere, reducing the use of fossil energy sources.

2. Theoretical background

It is expedient to use the acts and regulations of the European Union for the introduction of renewable energy at the regional level. In the European Union, the definition of renewable energy sources was enshrined in 2001 in Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal market in electricity. Renewable energy sources include renewable non-extractive energy sources (wind, solar, geothermal, wave and tidal, hydropower, biomass, organic waste gas, wastewater gas and biogas) (**e.g. Sirotyuk M.I., 2008**). The most comprehensive and detailed definition of "renewable energy" was published in 2002 by the International Energy Agency (IEA). According to the IEA classification, the following types belong to RES:

1) solid biomass and animal products, biological mass, including any materials of plant origin used directly as fuel or converted into other forms before incineration (wood, vegetable waste and animal waste; charcoal obtained from solid biomass) (**e.g. Zabolotnyy S., 2018**);

2) gas or liquid from biomass obtained in the process of anaerobic fermentation of biomass and solid waste and burned for the production of electricity or heat;

3) municipal waste - waste from the residential, commercial and public sectors, which is incinerated to produce heat and electricity;

4) industrial waste - solid and liquid materials that are incinerated directly for the production of heat and electricity at specialized enterprises;

5) hydropower - potential or kinetic energy of water converted into electrical energy by large and small hydropower plants;

6) geothermal energy - thermal energy coming from the bowels of the Earth, usually in the form of hot steam or water. Used for electricity generation or directly as a heat source for heating systems, agricultural needs, etc.;

7) solar energy - solar radiation used as thermal and electrical energy (**e.g. Bashinska Y.I., 2017**).

The European Union has a number of tariff effects on the situation with the spread of renewable energy. Among them there are:

1. "Green tariff", which provides a guarantee of connection to the grid and long-term contact for the purchase of all energy produced at a fixed rate. It is used in almost all European member countries.

2. Premium rate, applicable in only five countries of the organization. But it involves choosing between the "Green Tariff" and a fixed surcharge or premium to the market price of electricity and for a certain period of time.

3. Green certificates, commonly used by producers and suppliers of electricity. They set mandatory quotas for renewable energy sources in the total amount of electricity produced.

4. Tenders and auctions for producers of electricity from renewable energy sources and biofuels, provide a system of government bidding for the signing of contracts for the construction and operation of renewable energy projects at the lowest prices. This method of

encouragement was chosen by only four countries of the European Union (**e.g. Geletukha G.G., 2010**).

Such an incentive policy has shown the first positive changes in the first years of use. Thus, in 2010 in the European Union was saved 30 billion euros on the cost of imported fuel, and the cost of supporting renewable energy amounted to 26 billion euros. Such data indicate a clear positive impact of the introduction of alternative energy resources in the regional environment (**e.g. Geletukha G.G., 2017**).

It is also taken into account that as of 2010, renewable energy technologies were less productive compared to today's technological capabilities. The most common renewable energy sources are in Germany, which has introduced three of the four tariffs, and the program goals to achieve the rapid spread of renewable energy have proved successful. Thus, united farmers' communities and houses produce more than 46% of the country's total renewable energy. The second world leader in the introduction of renewable energy is China, which in 2010 introduced renewable energy (**e.g. Mandych O. et al., 2020**).

In Ukraine, there is a gradual transition to the use of renewable energy. This is achieved through government programs, including the "green tariff" (**e.g. Ukraine's transition to renewable energy by 2050, 2020**), as well as the development of plans for the development of this industry, such as "Plan for the development of renewable energy until 2020" and others. It is such steps that lead to the spread and development of renewable energy (**e.g. State Agency for Energy Efficiency and Energy Saving of Ukraine, 2020**).

3. Materials and Methods

The research methodology included:

– collection of information on producers and consumers of biomass from energy crops from statistics, from authorities, business support organizations and analytical companies;

– personal in-depth interviews with representatives of companies, research institutions, industry associations and market participants;

– developing and conducting a survey among the target audience;

– verification of data with market participants (in particular, on business cases and practices).

4. Research results and discussion

The role of renewable energy sources in the fuel and energy balance of Ukraine is growing from year to year, including bioenergy. However, during the preparation of this analytical study, the authors encountered a lack of relevant, standardized and reliable information on the amount of solid biomass from energy crops, its supply and consumption, species of energy plants in the study area.

Ukraine has not approved a single standardized system for measuring and accounting for solid biomass resources of forest and agricultural origin. Lack of such information, especially on energy crops, hinders the development and implementation of sustainable energy policies and projects both in a particular area and in the country as a whole. Analisys of biomass potential available for energy in Ukraine is in Table 1.

The total area of land used for growing energy crops in Ukraine is about 4.000 hectares as of August 2019. Given the large number of vacant non-agricultural lands, this number of industrial plantings of energy crops is insignificant in the state and each region (**e.g. Melnyk M.I., 2017**). In Ukraine, the economically feasible biomass potential is estimated at 27 million tons/year. Its main components are agricultural waste and energy crops (**e.g. Perederiy N.O., 2009**). According to the data of the Bioenergy Association of Ukraine presented in Table 1, provided that energy crops are grown on an area of 1 million hectares of cod and straw, they will account for 23% of the total theoretically available biomass potential in Ukraine, suitable for energy use million tons of oil (tons of oil equivalent), or 11.5 million tons of solid biofuels (**e.g. Bioenergy Association of Ukraine, 2013**).

Table 1. Biomass potential available for energy in Ukraine (2019)

<table>
<tr><th rowspan="2">Type of biomass</th><th rowspan="2">Theoretical potential, million tons</th><th colspan="2">Potential available for energy</th><th rowspan="2">%</th></tr>
<tr><th>Share of theoretical potential, %</th><th>million t.o.e</th></tr>
<tr><td>Straw of cereals</td><td>37.2</td><td>31</td><td>3.81</td><td rowspan="5">43</td></tr>
<tr><td>Rapeseed straw</td><td>2.1</td><td>41</td><td>0.29</td></tr>
<tr><td>By-products of corn production on grain (stalks, cores)</td><td>36.4</td><td>41</td><td>2.7</td></tr>
<tr><td>By-products of sunflower production (stems, baskets)</td><td>26.1</td><td>41</td><td>1.51</td></tr>
<tr><td>Secondary agricultural waste (sunflower husk)</td><td>2.0</td><td>87</td><td>0.69</td></tr>
<tr><td>Wood biomass (firewood, logging residues, wood processing waste)</td><td>6.7</td><td>95</td><td>1.56</td><td></td></tr>
<tr><td>Wood biomass (dry wood, wood from protective forest belts)</td><td>8.9</td><td>45</td><td>1.12</td><td></td></tr>
<tr><td>Biodiesel (rapeseed)</td><td>–</td><td>–</td><td>0.17</td><td></td></tr>
<tr><td>Bioethanol (from corn and sugar beet)</td><td>–</td><td>–</td><td>0.65</td><td></td></tr>
<tr><td>Biogas from waste and products of the agro-industrial complex</td><td>1.6 billion m^3 CH_4</td><td>52</td><td>0.69</td><td></td></tr>
<tr><td>Biogas from landfills for solid waste</td><td>0.6 billion m^3 CH_4</td><td>35</td><td>0.19</td><td></td></tr>
<tr><td>Biogas from sewage (industrial and municipal)</td><td>1.0 billion m^3 CH_4</td><td>24</td><td>0.20</td><td></td></tr>
<tr><td>Energy crops: willow, poplar, miscanthus (1 million hectares*)</td><td>11.5</td><td>100</td><td>4.88</td><td rowspan="2">35</td></tr>
<tr><td>Energy crops: maize for biogas (1 million hectares*)</td><td>3.0 billion m^3 CH_4</td><td>100</td><td>2.57</td></tr>
<tr><td>Peat</td><td>–</td><td>–</td><td>0.28</td><td></td></tr>
<tr><td>Total</td><td>–</td><td>–</td><td>21.22</td><td></td></tr>
</table>

Source: (**e.g. Renewable Energy Sources in Ukraine, 2019**)

According to experts, Ukraine has 15 million degraded and unproductive lands for various purposes (**e.g. State Agency for Energy Efficiency and Energy Saving of Ukraine, 2020**). Of these, at least 4 million hectares of uncultivated agricultural land are suitable for energy crops. It is quite possible to reach an area of energy crops of 1 million hectares in Ukraine (**e.g. Ukraine's energy strategy for the period up to 2030, 2020**). According to experts, there are still at least 4 million hectares of uncultivated agricultural land, of which about 1 million hectares are suitable for energy crops (**e.g. Podolets R., 2013**) (Fig. 1).

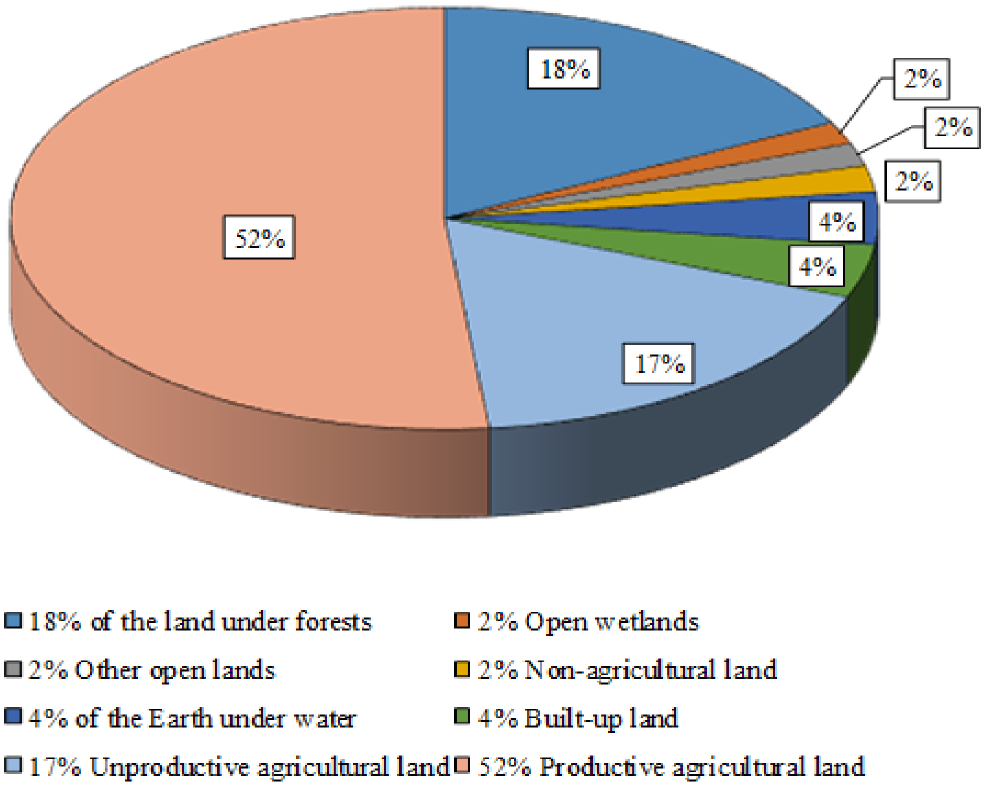

Fig. 1. The structure of land in Ukraine (**e.g. State Agency for Energy Efficiency, 2020**)

Energy crops should be grown on lands unsuitable for agriculture (**e.g. Dudyuk D.L., 2008**). Excessive levels of moisture for agriculture have a positive effect on energy crops, such as willow, poplar, miscanthus and others (**e.g. Economics, 2019**).

The northern regions of Ukraine have the most favorable climatic conditions for growing energy crops. It is observed that in five regions of Ukraine there was a significant use of renewable energy (e.g. Ministry of Regional Development of Ukraine, 2020). In particular, this was achieved in the north-western regions, as well as Dnipropetrovsk and Kharkiv regions. The rating table of the distribution of renewable energy is presented in Table 2.

Table 2. Rating table on the distribution of renewable energy in Ukraine

Regions	Location of the region by direction		Dynamics	The place of the region in terms of direction					
	2018	2019		1	2	3	4	5	6
Rivne	2	1	+1	12	5	7	10	6	1
Kharkiv	4	2	+2	8	2	2	4	4	23
Volyn	2	3	-2	7	6	14	22	3	3
Zhytomyr	7	4	+2	10	10	5	16	5	6
Dnipropetrovsk	6	5	–	26	3	3	8	7	20
Mykolaiv	4	6	-3	17	9	11	2	8	21
Kherson	2	7	-5	2	8	17	9	16	12
Vinnytsia	9	8	–	7	13	12	3	16	18
Ivano-Frankivsk	13	9	+3	21	11	10	19	12	6
Kirovohrad	6	10	-5	19	4	14	3	18	17
Khmelnytsk	2	11	-10	16	16	16	5	7	19
Zakarpattia	14	12	+1	3	7	19	–	13	9
Lviv	10	13	-4	13	19	22	11	10	14
Chernihiv	17	14	+2	13	20	12	18	14	6
Sumy	8	15	-8	15	17	21	13	19	4
Cherkasy	19	16	+2	23	18	6	7	20	9
Ternopil	18	17	–	11	15	9	25	2	12
Kyiv	15	18	-4	20	12	18	20	11	16
Chernivtsi	22	19	+2	4	21	20	15	21	14
Poltava	20	20	-1	22	14	26	17	15	11
Odesa	23	21	+1	6	22	23	14	24	24
Zaporizhzhia	25	22	+2	25	23	8	12	22	5
city Kyiv	21	23	-3	5	26	25	5	25	26
Luhansk	24	24	-1	18	23	4	24	23	22
Donetsk	25	25	–	24	25	24	21	25	25

Source: (**e.g. Monitoring of socio-economic development of regions, 2019**)

Numbers 1 to 6 indicate the following indicators:

1 - Volumes of fuel and energy resources consumed in the region during the reporting period per capita of the region, a ton of oil equivalent;

2 - The share of thermal energy produced in the region from alternative fuels or renewable energy sources for the reporting period, the percentage of total thermal energy produced in the region for the reporting period;

3 - The level of implementation of energy-saving light sources in outdoor lighting of settlements, percent to the total number of light points;

4 - The share of equipment of apartment buildings on home heat meters, interest on the total number of apartment buildings to be equipped;

5 - The share of total capacity of boilers on alternative fuels in the region, percent of the total capacity of boilers in the region;

6 - Proportion of households that have concluded loan agreements within the framework of mechanisms to support energy efficiency measures in the housing sector at the expense of the state budget, interest on the total number of households in the region (**e.g. Finance, 2013**).

Table 2 shows that Ukraine is trying to develop the sphere of renewable energy as best as possible. And some areas use the provided tariffs and investments more than others. That is why, in the further research we will pay attention to them. It should also be noted that compared to 2018, the rating table has not changed (**e.g. Socio-economic development of regions, 2020**). Except for a few areas that for some reason have sharply increased or, conversely, sharply decreased their share of renewable energy. Therefore, we will consider in more detail four regions of Ukraine: Rivne region, which ranks first among the use of renewable energy in 2019, and second place in 2018. In other categories (1, 3-5), Rivne region does not show the same good results, except for the share of households that have concluded loan agreements under the mechanisms to support energy efficiency measures in the housing sector at the expense of the state budget, through which Rivne region and won first place.

Kharkiv region took second place in 2019 and ranked fourth in 2018. Considering other indicators, it can be indicated that it occupies a leading position in two indicators: the share of thermal energy produced in the region from alternative fuels or renewable energy sources for the reporting period and the level of energy-saving light sources in outdoor lighting. With sufficient potential and attracted investments, Kharkiv region has a great chance to be a leader in the distribution of renewable energy, involving its households for the location and installation of renewable energy production stations (**Petryaev B.D., 2020**).

The third place in terms of potential use is occupied by Volyn region, which dropped to this position from the first in 2019 and respectively in 2018. Thus, the indicator of the level of introduction of energy-saving light sources in outdoor lighting of settlements, the percentage of the total number of light points and the share of equipment of apartment buildings on home heat meters, the percentage of the total number of apartment buildings to be equipped decreased to 15 in accordance. However, with stable work and capacity building, in terms of renewable energy, Volyn region has every chance to regain its first place.

And the fourth region - Zhytomyr, occupies a corresponding place in the ranking, so in 2019 compared to 2018 there was an increase in the use of renewable energy by 1.5%. However, indicators (1-2, 4) indicate a lack of great potential in this area.

We establish that a very important indicator for the development of renewable energy in regional development is the share of thermal energy, which can be seen in Table 3.

Table 3. The share of heat produced in the region from renewable energy sources for the reporting period to the total heat produced

Name of the territory	Years			Deviation 2019/2017 (+/-)
	2017	2018	2019	
Ukraine	9.8	11.5	20.42	10.62
Vinnytsia	12.8	14.6	15.82	3.02
Volyn	24.9	37.6	26.94	2.04
Dnipropetrovsk	18.3	20.4	29.68	11.38
Donetsk	0.1	1.3	0.21	0.11
Zhytomyr	14.0	17.1	18.8	4.8
Zakarpattia	1.2	2.4	21	19.8
Zaporizhzhia	0.3	1.6	3.62	3.32
Ivano-Frankivsk	11.2	14.8	16.18	4.98
Kyiv	9.8	11.6	15.99	6.19
Kirovohrad	12.1	14.3	28.89	16.79
Luhansk	2.1	5.4	4.46	2.36
Lviv	3.4	5.2	7.91	4.51
Mykolaiv	13.8	15.2	18.95	5.15
Odesa	3.3	4.5	5.55	2.25
Poltava	11.5	13.7	14.65	3.15
Rivne	14.9	17.8	28.84	13.94
Sumy	7.6	10.9	8.79	1.19
Ternopil	1.5	3.8	9.95	8.45
Kharkiv	10.8	18.5	31.43	20.63
Kherson	14.3	17.9	20.54	6.24
Khmelnytsk	7.9	12.9	9.64	1.74
Cherkasy	2.5	5.9	8.23	5.73
Chernivtsi	3.4	5	6.09	2.69
Chernihiv	3.9	5.5	7.54	3.64
city Kyiv	0.8	2.0	0	-0.8

Source: (**e.g. Monitoring of socio-economic development of regions, 2019**)

According to Table 3 it can be seen that the studied areas have quite significant indicators in this sector, and the first place among all regions is occupied by the Kharkiv region, increasing its potential in this aspect by almost one hundred percent. It should also be noted other areas that have achieved a significant breakthrough in this indicator (**e.g. Regarding the prospects for the use of alternative energy sources in eastern Ukraine, 2019**). This is Kirovohrad region, which was able to increase its potential from 14.13% to 28.89% in one year. Overall, the region managed to rise five places in the overall ranking.

The second largest region in the ranking is Dnipropetrovsk region. It should be noted that the studied areas, in addition to Kharkiv and Rivne, occupy a more indirect position in this aspect. The reasons for this are the geographical location, which limits the potential of renewable energy, as well as the predominant use of energy resources from traditional sources. Thus, Volyn region ranks first in several other areas.

Information on the share of total capacity of boilers on alternative fuels in the region is presented in Table 4. After all, the key point for us is the extraction of alternative energy itself, and not the implementation of energy efficiency measure.

Based on the presented information, it can be concluded that in Ternopil region, the largest total capacity of boilers is based on alternative fuels. As for the studied areas, they have a fairly high rate compared to others, and the pace of development is somewhat slower. Due to these trends, in the future, they may lose their positions.

Thus, summarizing the data provided by the Unified State Web Portal of Open Data, it can be argued that there is an active use of renewable energy and increase energy efficiency in the regions of Ukraine. However, a significant number of certain regions are cautiously implementing renewable energy production systems (**e.g. Socio-economic development of regions, 2020**). There are also regions that are already actively implementing similar types of energy production. This shows that local governments are actively working to promote renewable energy at the regional level by attracting projects and grants provided by the European Union, for the development of this industry significantly accelerates the work on its dissemination.

Table 4. The share of the total capacity of boilers on alternative fuels in the region to the total capacity of boilers in the region

Name of the territory	Years			Deviation 2019/2017 (+/-)
	2017	2018	2019	
Ukraine	8.7	10.4	12.8	4.1
Vinnytsia	9.2	10.5	10.9	1.7
Volyn	20.9	22.8	22.7	1.8
Dnipropetrovsk	14.6	16.8	18.4	3.8
Donetsk	0.2	1.1	1.2	1
Zhytomyr	16.4	17.5	22.3	5.9
Zakarpattia	9.7	11.1	13	3.3
Zaporizhzhia	3.8	5	3.3	-0.5
Ivano-Frankivsk	9.0	10.0	15.9	6.9
Kyiv	12.0	14.6	15	3
Kirovohrad	6.9	8.2	10.1	3.2
Luhansk	1.2	2.9	1.1	-0.1
Lviv	11.3	13.9	16.1	4.8
Mykolaiv	12.6	15.2	16.6	4
Odesa	0.3	1.2	1.3	1
Poltava	11.1	12.1	11.7	0.6
Rivne	16.3	18	20.2	3.9
Sumy	3.9	5.2	6.8	2.9
Ternopil	15.0	16.2	25	10
Kharkiv	18.8	20.1	21.2	2.4
Kherson	8.1	9	10.4	2.3
Khmelnytsk	6.4	7.1	17.8	11.4
Cherkasy	2.3	3.9	5.7	3.4
Chernivtsi	3.5	5.9	5.9	2.4
Chernihiv	6.7	8.2	12.2	5.5
city Kyiv	1.2	2.6	0	-1.2

Source: (**e.g. Monitoring of socio-economic development of regions, 2019**)

5. Conclusion

Thus, based on the study, it can be noted that the use of renewable energy at the regional level is quite relevant, as it contributes to the creation of energy exchanges to create a market environment.

The policy of regional development of renewable energy operates in foreign countries. The key role in this trend is the oriented policy of both individual countries and international organizations. The choice of the method of introduction and simplification of procedures for the implementation of regional development of renewable energy contribute to the development of this industry.

Paying attention to the Ukrainian realities, it is evident that there is a gradual transition to the use of energy resources at the regional level. This is done with the support of local governments and the support of the EU. The most negative factor influencing this industry is the socio-economic situation in Ukraine and the life of the country in terms Joint Forces Operation.

One of the main reasons why investors, both foreign and Ukrainian, are unwilling to invest in energy plantations is the unresolved issue of the land market and the low "green" tariff for energy produced from solid biomass compared to other European countries.

The lack of mechanisms for providing benefits and subsidies to companies willing to invest in the establishment of an agri-energy company creates a large investment burden for the investor at the initial stage of plantation, which in turn significantly slows down the development of such business in Ukraine.

According to market participants, there is a problem of legal support of legislative initiatives and the ambiguity of legislation concerning their activities.

Today this direction of alternative energy in Ukraine is at the stage of development. The age of industry companies does not exceed 10 years.

The available natural potential, favorable climatic conditions and large areas of land unsuitable for agriculture, which can be used for energy plantations, are not yet fully used in Ukraine.

Today, the economic and legal conditions for the development of alternative energy sources at the regional level need to be significantly improved. The outlined measures for the development of alternative energy sources in Ukraine can be grouped as follows: first, the organizational and legal direction, which should ensure the formation of a long-term strategy for the development of alternative energy sources, create a perfect legal framework, regulations and standards of production, storage and use; secondly, the financial and economic direction, which would include measures to create an attractive investment climate to attract foreign investment for the development of alternative energy sources, creating a tax holiday for both producers and consumers of alternative fuels for a certain period, giving them other preferences in the initial stages; thirdly, the technical and technological direction of state regulation should be aimed at substantiating the schemes of territorial location and establishing optimal capacities for the production of alternative energy, identifying the best technological schemes for the production of alternative energy sources; fourth, the infrastructural direction, which is aimed at creating all the additional conditions necessary for a smooth and stable process of production and consumption of alternative energy, security of resources, energy and other support. An integrated and systematic approach will create an effective system for regulating the development of alternative energy sources.

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CHAPTER 2

INFLUENCE OF AGRO-MEASURES COMPLEX ON THE BIOFUELS OUTPUT FROM SUGAR SORGHUM IN CONDITIONS OF WESTERN FOREST-STEPPE OF UKRAINE

Abstract

Finding promising raw materials for bioethanol production is an urgent task today. Sugar sorghum, which provides 90-100 t/ha of biomass with a sugar content of 18-20% at one hectare, is an effective sugar crop for its production. The publication presents the results of studying the elements of the technology of sugar sorghum cultivation and their influence on the yield of biofuels in the Western Forest-Steppe of Ukraine. In particular, the influence of plant density and different food backgrounds on the productivity of Sylosne 42, Favoryt and Troistyi varieties was studied. The best variants of technology for the production of biofuels are cultivation of the Favoryt and Troistyi varieties. These are the best variants of the technology of sugar sorghum cultivation for the production of biofuels, with a plant density of 190-200 thousand/ha on the background of the main mineral fertilizer norm $N_{60}P_{60}K_{60}$. In these variants, the yield of bio-standard was 3.11 and 3.12 t/ha, respectively, biofuels - 16.9 and 17.0 t/ha, and energy - 348 and 349 GJ. In the variant of $N_{60}P_{60}K_{60}$ application in autumn and treatment of plants with Yarylo microfertilizer (3 l/ha) in the tillering phase, sugar collection increased from 7.80 t/ha in the control to 8.68 t/ha.

Key words: sugar sorghum, biotenol, biofuel, fertilizers, technology elements, Yarylo microfertilizer

1. Introduction

In the world, more and more attention is being paid to finding ways to use energy from the rechargeable energy accumulated by living matter through photosynthesis – biofuels (**e.g. Mudryk K., 2018**). Taking into account the agrarian orientation of the Ukrainian economy, a new branch – bioenergy – becomes a promising direction for the country's development. At present, the main priority of the industry is searching cheap bio-raw materials, new technological solutions and creating the necessary infrastructure for growing bioenergy crops and processing biomass into different types of biofuels (**e.g. Khomina V. et al., 2019; Ivanyshyn V. et al., 2018; Kozina T. et al., 2018**). On the way to energy independence of Ukraine, an important factor is the transformation of photosynthesis energy into forms available for use in the economy. Bioethanol production has grown more than tripled in the last decade, mainly used as fuel mixtures to increase octane: the addition of 10% bioethanol to gasoline can reduce aerosol particulate emissions by 50%, and carbon monoxide emissions by 30% (**e.g. Geletukha H.H. et al., 2001; Kyrychenko L.V. et al., 2011; Roik M.V. et al., 2012**).

2. Theoretical background

Finding promising raw materials for bioethanol production is an urgent task today. Sugar sorghum, which provides 90-100 t/ha of biomass with a sugar content of 18-20% at one hectare, is an effective sugar crop for its production (**e.g. Roik M.V. et al., 2012**).

The technology of growing high and stable crops of sugar sorghum is based on the rational use of biological characteristics of the variety, the background of nutrition, the density of standing plants and moisture – the transpiration coefficient of it is 300 (**e.g. Gorbachenko N.I., 2013; Muliarchuk O. et al., 2020**).

Most sorghum soils provide only half of the required nutrients, so the rest needs to be replenished through fertilizers based on agrochemical soil analysis and optimal plant densities (**e.g. Hunchak T.I., 2014; Cherenkov A.V. et al., 2011**).

Combining basic fertilizer and foliar fertilization as opposed to root fertilization is the best method for introducing nutrients for plants. It timely and qualitatively regulates nutrition during the growing season of plants, in accordance with the weather conditions of the year. An important role is played by the balanced ratio of macro and micronutrients, because all the elements of nutrition are closely linked in the unified biochemical processes and the role of each of them is very important, so it is advisable to make microelements in combination with the basic elements, taking into account the biological features of the culture (**e.g. Moiseychenko V.F., 1994; Muliarchuk O.I., 2016; Muliarchuk O.I., 2017**).

The purpose of our research was to determine the influence of technology elements of sugar sorghum varieties cultivation on the processes of photosynthetic activity in plant ontogeny, formation of yields and its qualitative indicators, as well as to establish the feasibility of using micro fertilizer Yarylo.

3. Materials and Methods

The researches were carried out in accordance with the conventional methods at State Agrarian and Engineering University in Podilia during 2013-2017. Soil of the experimental field is leached black soil, low humus, on carbonate loam. The humus content in the soil layer is 0-30 cm (according to Tyurin is 3.86-4.11%; easily hydrolyzing nitrogen (according to Cornfield) - 111-121 mg/kg, mobile phosphorus and metabolic potassium (according to Chirikov) - 90 and 179 mg/kg of soil, respectively. The absorption capacity and the amount of absorbed bases vary, respectively, between 33-36 and 30-33 mg-eq/100 g of soil. Hydrolytic acidity is 0.76-0.87 mg-eq/100 g soil, the degree of saturation of the basics - 94.7-99.0%.

The solid phase density is 2.58 g/cm^3, the density of the soil structure is 1.14-1.25 g/cm^3, the total porosity is 52-59%. The maximum soil hygroscopicity is 5.2%; the lowest moisture content is 23.4%, the total field capacity is 41.2%.

The climate of the southwestern part of the Forest-Steppe of Ukraine is warm, with sufficient moisture. The average radiation balance in the region for the year is 43.3 kcal/cm^2, and for the growing season of sugar sorghum - 137.73 kJ/cm^2. Most of PAR come in June and July. In the period from May to September, 3/4 of the annual amount of heat comes to the soil surface.

Annual precipitation ranges from 550-700 mm, 3/4 of which falls during the warm season. Hydrothermal coefficient in the region is 1.4.

The weather conditions of the sugar sorghum vegetation period in the period of 2013-2017 years had the following features: with the average long-term rainfall and the sum of temperatures respectively 345 mm and 2903°C, during the years these indicators fluctuated within such limits.

During the years of research, two experiments were conducted to study the effect of the studied elements.

Experiment 1. A three-factor field experiment to study the technology elements of sugar sorghum cultivation for use in the production of biofuels was carried out according to the scheme:

Factor A - nutrition background:

1. Without fertilizers - control.
2. $N_{60}P_{60}K_{60}$.

Factor B - varieties of sorghum:

1. Sylosne 42 - control.
2. Favoryt.
3. Troisty.

Factor B - plant density:

1. 100-110 thousand/ha - control.
2. 140-150 thousand/ha.
3. 190-200 thousand/ha.

The area of the basic acreage - 108 m² (5.4 × 20 m), the accounting area - 72 m² (4.5 × 16 m), the repetition - four times. The experiment was based on the method of split plots - nutrition backgrounds - in two blocks, varieties and density of standing - sequentially in one tier.

The technology of sugar sorghum cultivation, with the exception of the studied elements, was generally accepted for the Forest-Steppe of Ukraine. Varieties of sugar sorghum were sowed with beet planter with a row spacing of 45 cm.

The varieties of sorghum (*Sorghum saccharatum* L.) studied in the experiment were created at the Institute of Grain Farming of the NAAS - Silosne 42 and Troiste, and Favoryt was created at the Selection and Genetic Institute - the National Center for Seed Science and Variety Research of the NAAS.

Experiment 2. Field experiment to study the technology elements of sugar sorghum cultivation was carried out according to the scheme:

1. Control - without fertilizers.
2. $N_{60}P_{60}K_{60}$ - introduced in autumn under plowing.
3. Microfertilizer Yarylo intensive growth - applied in the tillering phase (3 l/ha dissolved in 300 l/ha of water).
4. $N_{60}P_{60}K_{60}$ in autumn + Yarylo intensive growth in the tillering phase (3 l/ha dissolved in 300 l/ha of water).

The area of the basic planting area is 39.2 m^2 (2.8 × 14 m), the accounting area is 28 m^2 (2.8 × 10 m), the repetition rate is four times.

The area of the assimilation surface of the plants was determined by A.A. Nichiporovich (**e.g. Nichiporovich A.A., 1961**), the experimental data were analyzed by dispersion method (**e.g. Ermantraut E.R., 2007**).

Microfertilizer Yarylo intensive growth has the following composition, g/l: N - 60, P_2O_5 - 85, K_2O - 110, SO_3 - 5.3, Fe – 0.5, Mn - 2, B - 1, Zn - 0.6, Cu - 0.6, Mo - 0.05 (https://agrohim.in.ua/p924735705-mikroudobrenie-yarilo-aktivnyj.html).

The use of microfertilizer Yarilo allows to satisfy the need for culture in the nutrients, increases its resistance to diseases, pests, adverse soil and climatic and anthropogenic factors, has a positive effect on improving the processes of photosynthesis and exchange reactions in the plant, and also promotes other.

Yarylo microfertilizer promotes:

- increase of seed viability;
- stimulation of plant growth and development;
- strengthening of plant resistance to disease;
- the growth of productive shrubs;
- increase of heat resistance and drought resistance of plants;
- increase of crop yields by 10-15%,
- improving grain quality.

Microfertilizer Yarylo intensive growth provides an increase in leaf surface area and increase the net productivity of photosynthesis by 10-40%, strengthen the root system and increase the yield.

4. Research results and discussion

The studied elements of the technology of sugar sorghum cultivation affected the area of leaf surface and the net productivity of photosynthesis of sorghum plants in this way (Table 1).

According to the results of the research, there is a significant improvement in the photosynthetic activity of sugar sorghum plants due to the application of basic mineral fertilizers. Compared to the control without fertilizers, the area of leaf surface of the plant at Silosne 42, Favoryt and Troisty increased within 293 cm^2 due to their application of $N_{60}P_{60}K_{60}$ norm.

Table 1. Productivity of sugar sorghum photosynthesis, average for 2013-2017

Nutrition background	Variety	Plant density, thousand/ha		
		100-110	140-150	190-200
Area of leaf surface of one plant, cm²				
Without fertilizers - control	Silosne 42 - control	2190	2280	2290
	Favoryt	2260	2310	2325
	Troisty	2310	2370	2303
$N_{60}P_{60}K_{60}$	Silosne 42 - control	2410	2540	2560
	Favoryt	2585	2625	2645
	Troisty	2640	2680	2690
LSD_{05} of background nutrition and density of plants 87, varieties 92				
Net photosynthetic productivity, g/m² of leaf area per day				
Without fertilizers - control	Silosne 42 - control	3.32	3.41	3.46
	Favoryt	3.39	3.44	3.48
	Troisty	3.42	3.47	3.51
$N_{60}P_{60}K_{60}$	Silosne 42 - control	3.48	3.72	3.79
	Favoryt	3.60	3.74	3.79
	Troisty	3.62	3.76	3.80
LSD_{05} of background nutrition and density of plants 0.11, varieties 0.14				

By increasing the leaf surface of plants, the net productivity of photosynthesis for all studied technology elements of sugar sorghum cultivation increased: for the application of basic mineral fertilizers, use of the best varieties and optimization of the density of plant standing - by 0.25, 0.15 and 0.12 g/m², respectively of leaves surface per day.

The yield of green and dry weight of sugar sorghum under the influence of the studied technology elements of sugar sorghum cultivation varied as follows (Tables 2 and 3). Fertilizers had the greatest influence on the yield of green mass of sugar sorghum. With the application rate of $N_{60}P_{60}K_{60}$, the average yield increase compared to the control without fertilizers was 5.9 t/ha (LSD_{05} = 3.2). The yield increase between the varieties was within the error of the experiment. By optimizing of the density of sorghum plants standing by increasing it to 140-150 and 190-200 thousand/ha, the yield increase was significant only against the background of basic mineral fertilizers use according to $N_{60}P_{60}K_{60}$ (Table 2).

Table 2. Yield of green mass of sugar sorghum, t/ha (2013-2017 average)

Nutrition background	Variety	Plant density, thousand/ha			Average	± to conrol	Average	± to control
		100-110	140-150	190-200				
Without fertilizers - control	Silosne 42 - control	70.2	72.1	73.4	71.9	–	72.6	–
	Favoryt	71.7	72.7	73.5	72.6	0.7		
	Troisty	72.3	73.4	73.7	73.1	1.2		
	Average	71.4	72.7	73.5				
	Difference	–	1.3	2.1				
$N_{60}P_{60}K_{60}$	Silosne 42 - control	73.6	78.7	79.3	77.2	–	78.4	5.9
	Favoryt	76.1	79.1	81.4	78.9	1.5		
	Troisty	76.5	79.5	81.7	79.2	1.6		
	Average	75.4	79.1	80.8				
	Difference		3.7	5.4				
LSD_{05} background nutrition 3.7, plant variety and density 3.2								

Experimental studies have established (Fig. 1) that the yield of green mass of sugar sorghum is correlated with the leaf area of the plant and has a straight-line character:

y = -908.7231 + 44.4257x, correlation coefficient r = 0.94; determination coefficient R^2 = 0.88.

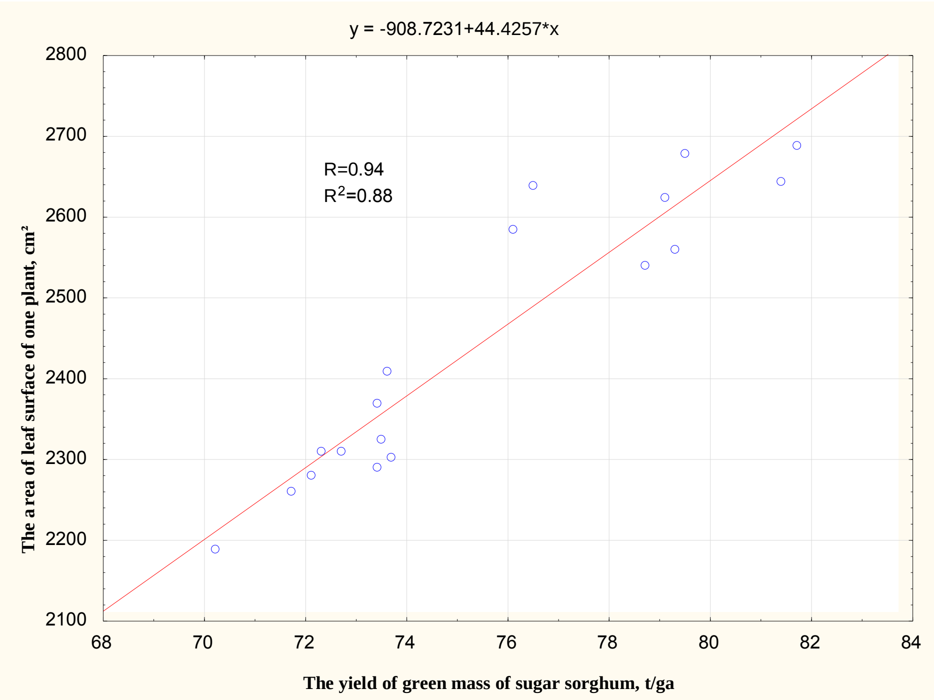

Fig. 1. The relationship between the yield of green mass of sugar sorghum and the area of leaf surface of one plant (average for 2013-2017)

The solids content on the background without fertilizers of the varieties Silosne 42, Favoryt and Troisty averaged 23, 20.5 and 22.7% respectively during the years of research, and on the background of the main application $N_{60}P_{60}K_{60}$ - respectively 24, 22 and 23.1%; the average yield of solids content is given in Table 3.

On the basis of the conducted researches the greatest increase in the solids content of the sugar sorghum varieties was with fertilizers application - compared to the control without fertilizers - 2.1 t/ha (LSD_{05} = 0.8). Compared to the variety Silosne 42, it was significant in the Favoryt and the Troisty varieties on the application background of $N_{60}P_{60}K_{60}$ - 1.5 and 1.6 t/ha. The analysis of the obtained data showed an increase in the standing density of the sugar sorghum varieties and it contributed to a significant increase in solids content yield in the variant 190-200 thousand/ha only on the application background of mineral fertilizers according to $N_{60}P_{60}K_{60}$ standard.

The correlation between the yield of dry weight of sugar sorghum and the net productivity of photosynthesis is shown in Fig. 2. It has been set by the experimental researches (Fig. 2), that the yield of dry mass of sugar sorghum is correlated with the net productivity of photosynthesis: $y = 1.8894 + 0.0984x$, the correlation coefficient $r = 0.81$; coefficient of determination $R^2 = 0.65$.

Table 3. Output of dry mass of sugar sorghum, t/ha (average for 2013-2017)

Nutrition background	Variety	Plant density, thousand/ha			Average	± to conrol	Average	± to control
		100-110	140-150	190-200				
Without fertilizers - control	Silosne 42 - control	16.1	16.6	16.9	16.5	–	16.0	
	Favoryt	14.7	14.9	15.1	14.9	-1.6		
	Troisty	16.4	16.7	16.7	16.6	0.1		
	Average	15.8	16.0	16.2				
	Difference	–	0.3	0.5				
$N_{60}P_{60}K_{60}$	Silosne 42 - control	17.7	18.9	19.0	18.5	–	18.1	2.1
	Favoryt	16.7	17.4	17.9	17.4	1.5		
	Troisty	17.7	18.4	18.9	18.3	1.6		
	Average	17.4	18.2	18.6				
	Difference	–	0.9	1.2				
LSD_{05} background nutrition 1.0, plant variety and density 0.8								

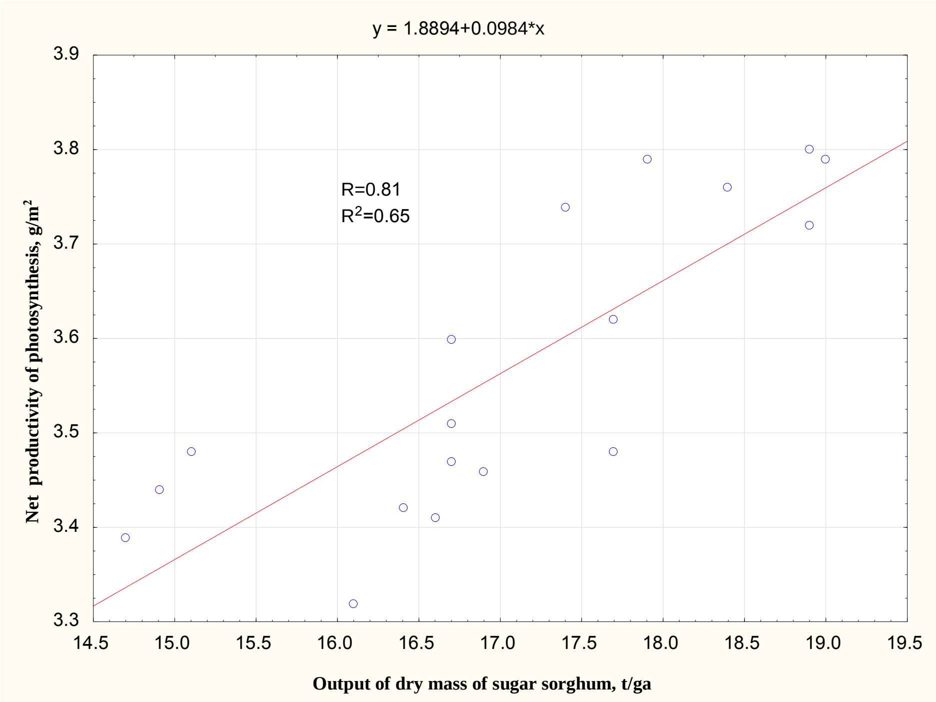

Fig. 2. Correlation between the output of dry mass of sugar sorghum and the net productivity of photosynthesis (average for 2013-2017)

The energy value of green sorghum mass, depending on the influence of the studied technology elements of cultivation is given in Table 4.

According to the research results, the Favoryt and Troisty varieties are the best variants of the technology of sugar sorghum cultivation for the production of biofuels, with a plant density of 190-200 thousand/ha on the background of the main mineral fertilizer norm $N_{60}P_{60}K_{60}$; in these variants, the yield of bio-standard was 3.11 and 3.12 t/ha, respectively, biofuels - 16.9 and 17.0 t/ha, and energy - 348 and 349 GJ.

Analyzing the data in Figure 3, it should be noted that the yield of bioethanol is correlated with the yield of green mass of sugar sorghum and is described by approximate equations:

$y_1 = -0.0141 + 0.0384x$, $y_2 = -0.0771 + 0.2069x$.

Table 4. The output of bioethanol, solid biofuels and energy depending on the use of technology elements of sugar sorghum cultivation (2013-2017 average)

Nutrition background	Variety	Plant density, thousand/ha	Bioethanol, t/ha	Solid biofuels, t/ha	Energy output, GJ
Without fertilizers - control	Silosne 42	100-110	2.68	14.6	300
		140-150	2.75	15.0	308
		190-200	2.80	15.3	313
	Favoryt	100-110	2.74	14.9	306
		140-150	2.78	15.1	310
		190-200	2.81	15.3	314
	Troisty	100-110	2.76	15.0	309
		140-150	2.80	15.3	313
		190-200	2.82	15.3	315
$N_{60}P_{60}K_{60}$	Silosne 42	100-110	2.81	15.3	314
		140-150	3.01	16.4	336
		190-200	3.03	16.5	339
	Favoryt	100-110	2.91	15.8	325
		140-150	3.02	16.4	338
		190-200	3.11	16.9	348
	Troisty	100-110	2.92	15.9	327
		140-150	3.04	16.5	339
		190-200	3,12	17.0	349

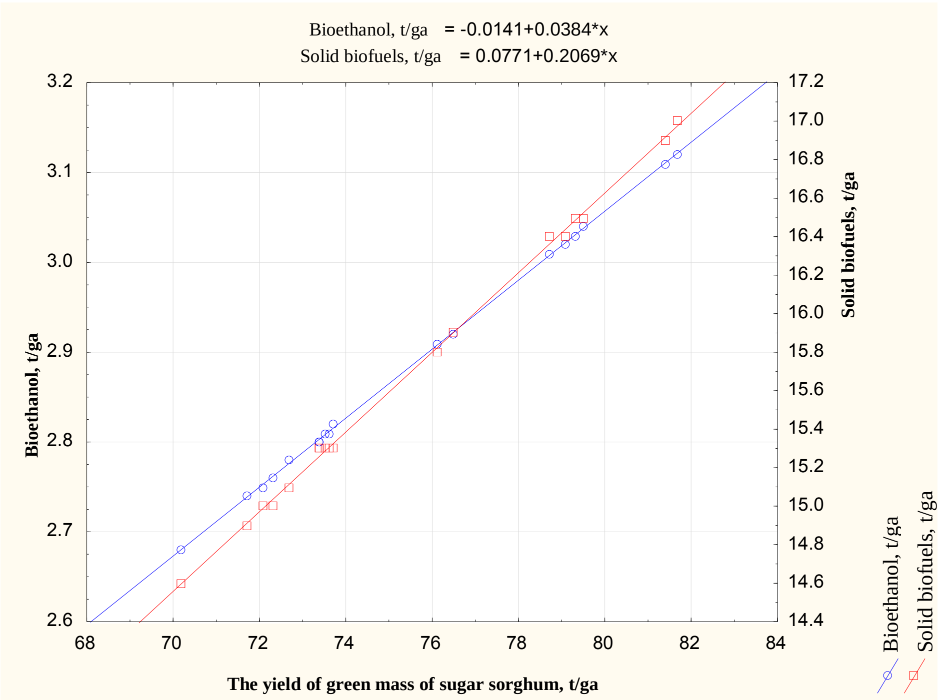

Fig. 3. Correlation dependence of bioethanol output and solid biofuels on the yield of green mass of sugar sorghum (average for 2013-2017)

The application of basic mineral fertilizers with norm N60P60K60 and microfertilizer complex Yarylo 3 l/ha during the tillering phase of sugar sorghum contributed to the extension of the growing season by 2-3 days (Table 5).

Table 5. Impact of the micro fertilizers complex on the productivity of sugar sorghum photosynthesis (average for 2014-2016)

Variant of fertilizer application	The duration of the growing season period, days	Leaf area, thousand m^2/ha	Photosynthetic potential, million m^2 days/ha	Net photosynthesis productivity, g/m^2 per day
Without fertilizers - control	138	39.6	5.46	2.23
$N_{60}P_{60}K_{60}$ - in autumn	141	47.3	6.67	4.31
Yarylo in the tillering phase (3 l/ha)	140	41.1	5.75	4.62
$N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar in the tillering phase (3 l/ha)	141	49.1	6.92	5.52
LSD_{05}	2	1.5	1.2	1.2

Studies have shown that under the influence of complete mineral fertilizers application and foliar fertilization complex of microfertilizers compared to control significantly increased the area of assimilation surface of sugar sorghum from 39.6 to 49.1 thousand m^2/ha.

Net productivity of photosynthesis of sugar sorghum plants compared to the control of full fertilizer application in autumn with the norm $N_{60}P_{60}K_{60}$ increased by 2.08 g/m^2 per day, for foliar fertilization in the stage of tillering with microfertilizer Yarylo norm of 3 l/ha - by 2.39 and for the joint application of $N_{60}P_{60}K_{60}$ in the autumn + Yarylo foliar in the tillering phase of 3 l/ha - by 3.29 g/m^2 per day.

The increase in green mass continued until the phase of waxy ripeness of grain sorghum varieties. If during the ejection phase the yield of green mass was in the range of 51.2-55.8 t/ha, then in the waxy ripeness phase it increased to 79.2-84.5 t/ha (Table 6).

Table 6. Yield and solids content harvesting by growth and development phases of sugar sorghum (average for 2014-2016)

Variant of experiment	Term of harvesting			
	Ejection phase		Wax ripeness	
	t/ha	± to control	t/ha	± to control
Green mass				
Without fertilizers - control	51.2	–	79.2	–
$N_{60}P_{60}K_{60}$ - in autumn	54.6	3.4	83.0	3.8
Yarylo in the tillering phase (3 l/ha)	52.6	1.4	81.4	2.2
$N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar in the tillering phase (3 l/ha)	55.8	4.6	84.5	5.3
LSD_{05}	–	1.3	–	1.4
Dry mass				
Without fertilizers - control	11.8	–	17.2	–
$N_{60}P_{60}K_{60}$ - in autumn	13.1	1.3	19.1	1.9
Yarylo in the tillering phase (3 l/ha)	12.6	0.8	18.7	1.5
$N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar in the tillering phase (3 l/ha)	13.4	1.6	19.4	2.2
LSD_{05}	–	0.6	–	1.1

Compared to the control without fertilizers, in the variant of basic mineral fertilizers application with the norm $N_{60}P_{60}K_{60}$ by the phases of growth and development of plants (ejection and wax ripeness) it was additionally obtained respectively 3.4 and 3.8 t/ha of green mass, in the variant of foliar nutrition of sorghum by microfertilizer Yarylo with norm of 3 l/ha in the tillering phase - respectively 1.4 and 2.2 and for application $N_{60}P_{60}K_{60}$ + in autumn tillering phase Yarylo 3 l/ha - respectively 4.6 and 5.3 t/ha.

The harvesting of solid mass was similar to that of the green mass: it also increased to the waxy ripeness of the sorghum grain. If during the ejection phase, the harvest was in the range of 11.8-13.4 t/ha, then in the wax ripeness phase it increased to 17.2-19.4 t/ha.

The application of the norm $N_{60}P_{60}K_{60}$ of mineral fertilizers in the stages of plant growth and development (ejection and waxy ripeness) in the experiments conducted in the Western Forest-Steppe of Ukraine contributed to the increase of solids content harvesting by 1.3 and 1.9 t/ha of green mass, respectively in the variant of foliar nutrition of sorghum by microfertilizer Yarylo with norm of 3 l/ha in the tillering phase - respectively by 0.8 and 1.5, and in autumn $N_{60}P_{60}K_{60}$ + in the tillering phase Yarylo 3 l/ha - respectively by 1.6 and 2.2 t/ha.

Analyzing the data of plant development by phases of growth and productivity of sugar sorghum plants, it can be noted that with sugar sorghum ripening, the sugar content in the aboveground mass increased (Table 7).

Table 7. Yields and sugar harvesting by growth and development phases of sugar sorghum (average for 2014-2016)

Variant of experiment	Term of harvesting			
	Ejection phase		Wax ripeness	
	sugar content, %	sugar harvesting, t/ha	sugar content, %	sugar harvesting, t/ha
Without fertilizers - control	14.6	4.54	16.2	7.80
$N_{60}P_{60}K_{60}$ - in autumn	14.9	4.95	16.8	8.48
Yarylo in the tillering phase (3 l/ha)	14.8	4.73	16.5	8.17
$N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar in the tillering phase (3 l/ha)	15.2	5.16	16.9	8.68
LSD_{05}	0.3	0.23	0.3	0.4

The sugar content of the sugar sorghum stems in the studied variants by phases of the grain ejection and the waxy ripeness of the grain increased significantly. If in the phase of ejection it was in the range of 14.6-15.2%, then in the phase of waxy ripeness increased to 16.2-16.9%. In the variants of the experiment, which used the application of autumn fertilizers norm $N_{60}P_{60}K_{60}$ in the phases of growth and development of plants ejection and wax ripeness sugar content in the juice increased from 14.9% to 16.8%, in the variant of foliar nutrition by microfertilizer Yarylo norm 3 l/ha in the tillering phase - from 14.8 to 16.5% and the application of $N_{60}P_{60}K_{60}$ + in autumn during the tillering phase 3 l/ha - from 15.2 to 16.9%.

According to the variants of the experiment, sugar harvesting varied as follows. In the variant of the main application of mineral fertilizers by the norm $N_{60}P_{60}K_{60}$, according to the phases of growth and development of plants ejection and waxy ripeness sugar yield increased from 4.95 to 8.48 t/ha, in the variant of the foliar nutrition of sugar sorghum varieties with microfertilizer Yarylo norm of 3 l/ha tillering phase - from 4.73 to 8.17 and in autumn $N_{60}P_{60}K_{60}$ + in the tillering phase Yarylo 3 l/ha - from 5.16 to 8.68 t/ha.

The correlation dependence calculation shows that the yield of green sugar sorghum mass had a significant effect on the yield of dry mass (Fig. 4).

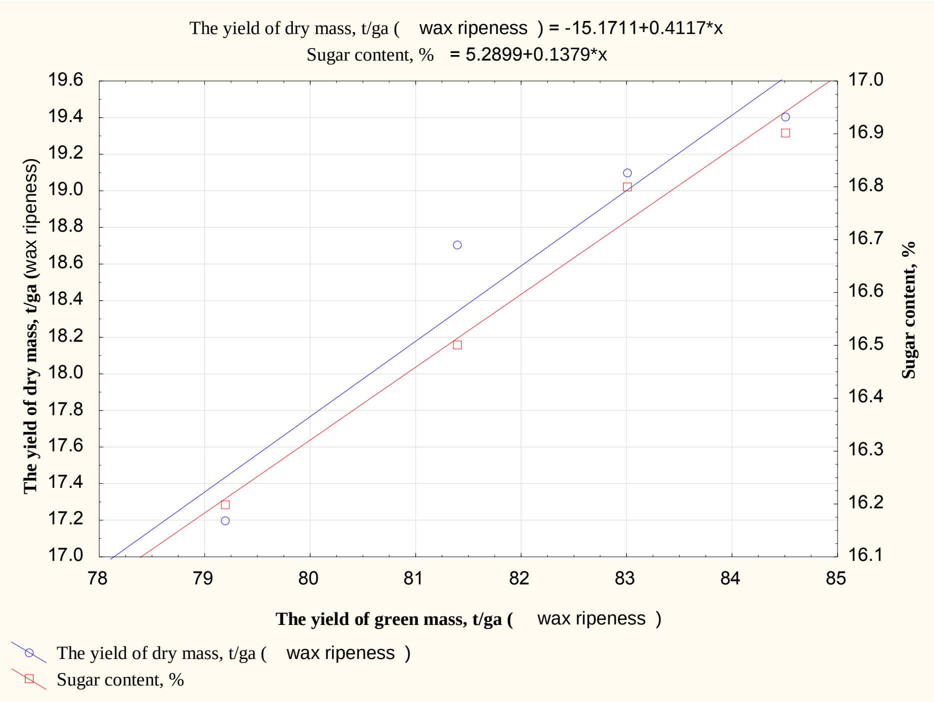

Fig. 4. Correlation dependence of the yield of dry mass and sugar content on the yield of green mass of sugar sorghum (average for 2013-2017)

The yield of bioethanol depends on the sugar content of the juice; the average proportion of stems in the green mass of sugar sorghum was 77%. Its total output is given in Table 8.

Table 8. Output of bioethanol by phases of growth and development of sugar sorghum, t/ha (2014-2016 average)

Variant of fertilizer application	Term of harvesting	
	Ejection phase	Wax ripeness
Without fertilizers - control	1.32	2.26
$N_{60}P_{60}K_{60}$ - in autumn	1.45	2.46
Yarylo in the tillering phase (3 l/ha)	1.37	2.37
$N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar in the tillering phase (3 l/ha)	1.51	2.58
LSD_{05}	0.05	0.09

It was found that the highest yield of bioethanol was obtained during harvesting of sugar sorghum in the waxy ripeness phase - in the range of 2.26 to 2.58 t/ha. The best nutritional background for varieties of sugar sorghum for the production of bioethanol is the application of complete mineral fert ilizers norm $N_{60}P_{60}K_{60}$, and in spring in the tillering phase the foliar nutrition complex with Yarylo microfertilizer (3 l/ha).

The chemical composition of sugar sorghum juice was: solids content - 16.5-18.7%, content of fermented sugars: only 14.3-16.2%, including: sucrose 8.8-9.9%, fructose 0.9-1.4%, glucose 2.3-2.7%, other monosaccharides 1.5-2.3%.

5. Conclusions

1. With fertilizer application of $N_{60}P_{60}K_{60}$ norm, the leaf area of the plant at Silosne 42, Favoryt and Troisty increased within 293 cm^2.

2. The net productivity of photosynthesis for all studied technology elements of sugar sorghum cultivation increased: for the application of basic mineral fertilizers, application of the best varieties and optimization of plant stand density - respectively by 0.25, 0.15 and 0.12 g/m^2 of leaf area per day.

3. Fertilizers had the greatest impact on the yield of sugar sorghum green mass; for $N_{60}P_{60}K_{60}$ norm of application, the average yield increase compared to the control without fertilizer was 5.9 t/ha.

4. The best variants of technology for the production of biofuels are cultivation of the Favoryt and Troisty varieties are the best variants of the technology of sugar sorghum cultivation for the production of biofuels, with a plant density of 190-200 thousand/ha on the background of the main mineral fertilizer norm $N_{60}P_{60}K_{60}$; in these variants, the yield of bio-standard was 3.11 and 3.12 t/ha, respectively, biofuels - 16.9 and 17.0 t/ha, and energy - 348 and 349 GJ.

5. Compared to the control without fertilizers, the introduction of complete mineral fertilizers and foliar fertilization with the complex of microfertilizers contributed to the increase in the area of assimilation surface of sugar sorghum plants from 39.6 to 49.1 thousand m^2/ha, the net productivity of photosynthesis for the application of mineral fertilizers by the norm $N_{60}P_{60}K_{60}$ - 2.08 g/m^2 per day, foliar nutrition in the tillering phase of microfertilizers Yarylo with norm of 3 l/ha - by 2.39 and joint application of $N_{60}P_{60}K_{60}$ from autumn + Yarylo foliar in the tillering phase of 3 l/ha - 3.29 g/m^2 per day.

6. The yield of green mass compared to the control without fertilizers in the variant of application $N_{60}P_{60}K_{60}$ by phases of growth and development of plants ejection and waxy ripeness increased respectively by 3.4 and 3.8 t/ha, in the variant of the foliar nutrition of sorghum by microfertilizer Yarylo with the norm of 3 l/ha in the tillering phase - by 1.4 and

2.2, respectively, and the introduction of $N_{60}P_{60}K_{60}$ + in the tillering phase in autumn Yarylo 3 l/ha - by 4.6 and 5.3 t/ha, respectively. Dry mass harvesting of solids content was similar to green mass yields.

7. Sugar harvesting in the variant of the main application of mineral fertilizers with the norm $N_{60}P_{60}K_{60}$ by the phases of growth and development of plants ejection and waxy ripeness increased from 4.95 to 8.48 t/ha, in the variant of the foliar nutrition of sorghum by microfertilizer Yarylo with the norm of 3 l/ha during the tillering phase - from 4.73 to 8.17 and application in autumn $N_{60}P_{60}K_{60}$ + in the tillering phase 3 l/ha - from 5.16 to 8.68 t/ha.

8. The yield of bioethanol for the sugar sorghum harvesting in the waxy ripeness phase ranged from 2.26 to 2.58 t/ha; it was the largest in the variant of the application of complete mineral fertilizers in autumn with of the norm $N_{60}P_{60}K_{60}$, and in spring - the application of foliar nutrition in the tillering phase with a complex of micro fertilizer Yarylo 3 l/ha.

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CHAPTER 3

RESEARCH TRENDS IN THE FIELD OF THE USE OF THE TORREFACTION PROCESS IN POLAND – BIBLIOMETRIC ANALYSIS IN 2011–2020

Abstract

Biomass is one of the most promising sources of RES. Biomass subjected to the torrefaction process gains physicochemical properties more favorable for energy purposes compared to unprocessed biomass. The aim of the study was to identify trends and define the main research topics in the scope of research achievements in the area of torrefaction by Polish research institutions. The main research centers dealing with selected topics are located in the south of Poland: Lower Silesian, Lesser Poland and Silesian Voivodships. Quantitative and thematic analysis shows a clear increase in the number of publications and citations after 2018. This proves the growing interest in the studied subject in Poland. The main research topics are: modeling and optimization of the torrefaction process, searching for new raw materials and studying their impact on the process, using the products of the torrefaction process in other processes (e.g. co-combustion, gasification), testing the chemical, physico-mechanical and energy properties of the torrefaction process products from different types of biomass. The indicated research topics in the field of torrefaction confirm global trends.

Key words: bibliometric analysis; research trends; research topic; scientometric; torrefaction

1. Introduction

The European Union attaches increasing importance to climate policy. This is evidenced by long-term renewable energy support strategies. An example would be "2020 climate & energy package" so-called "three 20 targets" (20% improvement in energy efficiency reduction greenhouse gas emissions, 20% of EU energy from RES, 20% improvement in energy efficiency), which sets specific goals and ways to meet them. The EU recommendation is the share of energy from RES in gross final energy consumption in Poland 15% in 2020, and 20% in 2030 (**Mudryk, Wróbel, Jewiarz, Pelczar, & Dyjakon, 2018; Wójcik, Krupa, Łapczyńska-Kondon, Francik, & Kwaśniewski, 2018**).

Numerous scientific studies show that biomass has the greatest potential of all RES sources. There is an increase in researchers' interest in issues related to the production of biofuels from biomass, e.g., from energy crops, wood biomass, agricultural waste, etc. **(Chaloupková, Ivanova, Ekrt, Kabutey, & Herák, 2018; Moiceanu et al., 2019**). Biomass can be a raw material for the production of liquid biofuel, gaseous biofuel and solid biofuels **(Adrian Knapczyk, Francik, Fraczek, & Slipek, 2019a; Moiceanu et al., 2019**).

Solid biofuels can be divided into natural (raw material) and synthetic (after processing). Another division covers processed and unprocessed biomass. Raw material for the production of solid biofuels can be divided into groups: 1) wood (coniferous and deciduous) - sawdust, shawings; fast graving trees, brances from pruning bushes and trees; trunks, thick branches; waste wood, 2) step plants (cereal straw, miscanthus, etc.), 3) peat, 4) sewage sluge, 5) wheat seeds. After processing raw material, the following types of biofuel can be obtained: pellets, briquettes, wood chips, cylindrical and rectangular bales of various sizes, wood block, wood chips, pieces of wood, chaff, loose material, granules and grain **(Adrian Knapczyk, Francik, Fraczek et al., 2019a; Zbytek & Adamczyk, 2017**).

According to the current trends in research on solid biofuels by Knapczyk et al. **(Adrian Knapczyk, Francik, Fraczek et al., 2019a**) the main groups of topics are: 1) searching for new raw materials for the production of solid biofuels - e.g. waste biomass after palm oil, sunflower husks, peanut shells etc., 2) chain optimization supply, warehouse logistics and biofuel legislation, - e.g. development of and identification system to ensure the quality of biomass, legal analysis of the international standard classification of solid biofuels etc. 3) crop optimization, performance testing physico-chemical raw materials - e.g. determinin the calorific value, chemical composition of elements and main energetic parameters in wood and bark of fast growing trees etc., 4) agglomeration process - e.g. assessment of physic-mechanical properties of agglomerate and the effect of added biochar and bio-oil etc., 5) the torrefaction process - biomass torrefaction, hydrothermal carbonization waste, wood mixtures etc. and the remaining group, in which the authors discussed such topics as: composition testing, modeling in combustion in households.

The methods of processing biofuels can be divided into: biological conversion, physical conversion, chemical conversion and thermo-chemical conversion. These methods are used to improve the physical, mechanical and chemical parameters of biofuels. As a result of processing, biofuels can either be used directly or serve as a raw material for further processing **(Adrian Knapczyk, Francik, Jewiarz, Zawiślak, & Francik, 2021**).

Thermal processing of biomass can be divided into the following processes (Fig. 1): drying (25-150°C), torrefaction (150-300°C), pyrolysis (300-600°C) and gasification (> 600°C). Each of these processes includes different products and intermediates. As the temperature increases, the energy parameters increase, but it is associated with an increase in energy inputs. Biomass subjected to the torrefaction process gains physicochemical properties more favorable for energy purposes compared to unprocessed biomass. The effect of the torrefaction process is biochar, the properties of which are similar to those of low-quality steam coals. The biochar also has favorable physical and mechanical properties, e.g. hydrophobic properties and grinding properties.

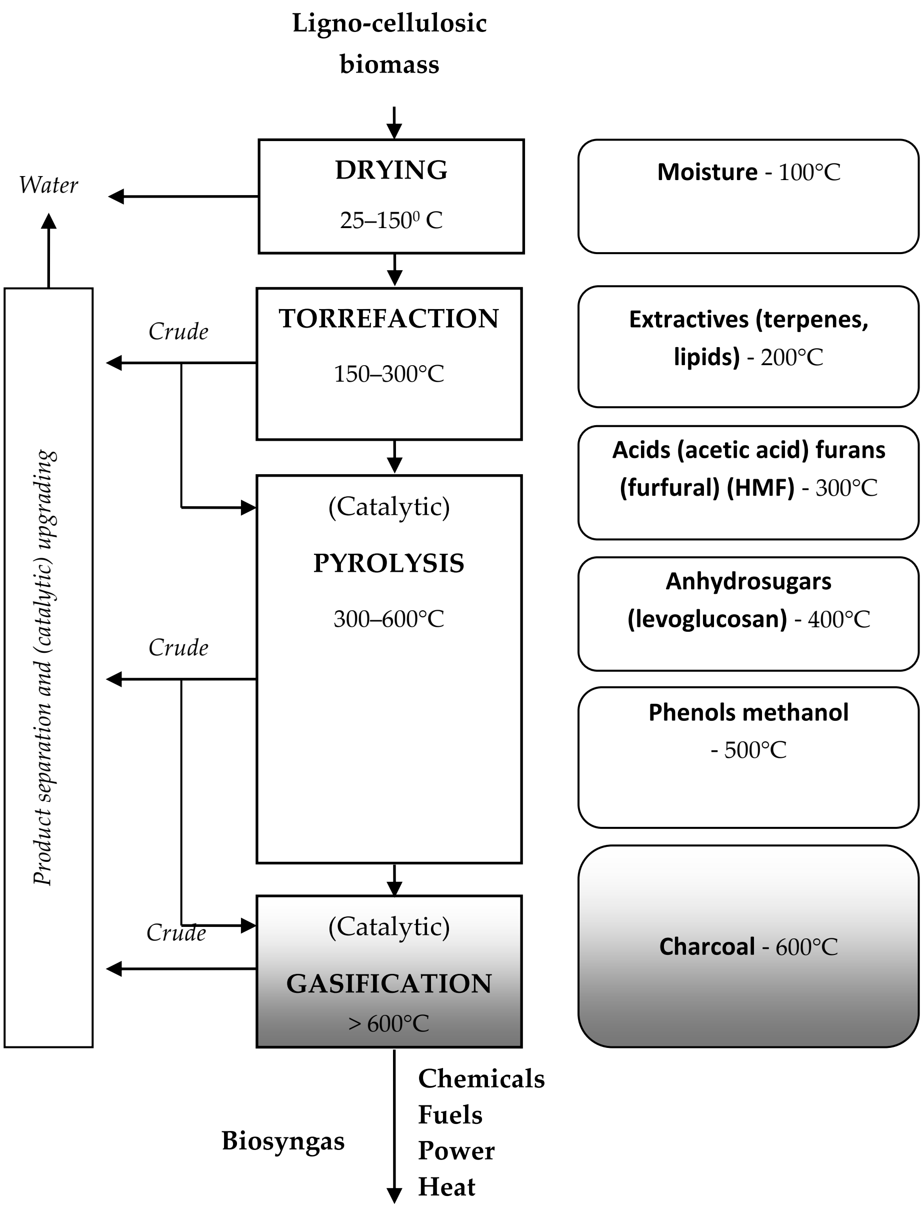


Fig. 1. Biomass thermal treatment (based on **de Wild, Uil, Reith, Kiel, & Heeres, 2009**)

The author presented the world trends in torrefaction in the publication Knapczyk (**Adrian Knapczyk et al., 2021**). It can be noticed that research on torrefaction is being discussed by scientists around the world. The main continents include: Asia (China - 318 doc., Taiwan - 95 doc., South Korea - 70 doc.), North America (USA – 288 doc., Canada - 116 doc.) And Europe (France - 72 doc. Poland - 69 associate professor and Sweden - 63 associate professor) (Fig. 2). Scientists with the largest number of publications in the area of torrefaction are: Chen W.H. (59 doc.), Skreiberg O. (23 doc.), Białowiec A. (22 doc.), Tran K.Q. (22 doc.) And Chen H.P. (21 doc.). The main organizations dealing with the subject of torrefication in the world include: National Cheng Kung University (63 doc.), United States Department of Energy DOE (40 doc.), Chinese Academy of Sciences (38 doc.), Huazhong University of Science Technology (37 doc.) and Norwegian University of Science Technology NTNU (32 doc.).

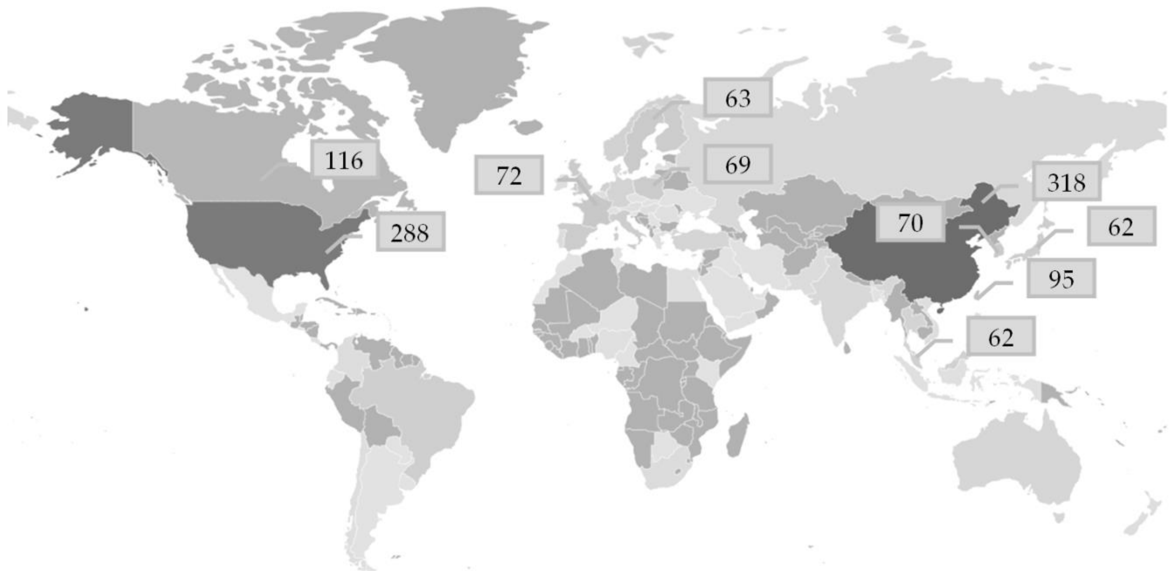


Fig. 2. Number of articles in the years indexed on WoS-CC in countries (based on **Adrian Knapczyk et al., 2021**)

By using bibliometric tools, one can objectively evaluate the scientific achievements. This field uses mathematical and statistical tools and diverse scientific bases. Bibliometry makes it possible to define current research topics (**S. Francik, Knapczyk, Frączek, & Ślipek, 2019; Adrian Knapczyk, Francik, Jewiarz, Mudryk, & Wróbel, 2019; Adrian Knapczyk, Francik, Pedryc, & Hebda, 2018**), to observe scientific trends in the world and a selected country. It enables the evaluation of research units, journals and employees on the basis of selected parameters. Using bibliometric techniques, it is also possible to indicate the network of connections between authors, countries and research topics. Data for bibliometric analysis should come from reputable and widely recognized databases of scientific publications and patents, such as Web of Science, Scopus.

Analyzes made in the publication Knapczyk (**Adrian Knapczyk et al., 2021**) indicated main thematic groups: torrefaction process, HTC process, pyrolysis process and gasification and co-combustion process. In addition to research topics related to process analysis and optimization, improvement of chemical, energetic and physical-mechanical properties of fuel, properties of raw materials and their mixtures, the authors also discussed the topics of technical and economic analysis of the torrefaction process, LCA, analysis and optimization of the supply chain and investigation into the applicability of Bond Work Index (BWI) and Hardgrove Grindability Index (HGI) tests for several biomasses.

In this work, the author continued the analysis of research topics in the field of torrefaction limited to Polish research institutions.

2. Materials and Methods

The aim of the study was to identify trends and define the main research topics in the scope of research achievements in the area of torrefaction by Polish research institutions

The work uses the proprietary methodology used in Knapczyk et al. **(Sławomir Francik, Ślipek, Frączek, & Knapczyk, 2016; A. Knapczyk & Francik, 2019; Adrian Knapczyk, Francik, Fraczek, & Slipek, 2019b; Adrian Knapczyk et al., 2021**).

The analyzes were divided into two stages (Fig. 3):

I - quantitative analysis (InCites, VOSviewer),

II - qualitative - thematic analyses.

The first stage involved searching for indexed documents in the Web of Science - Core Collection (WoS-CC). The search period covered the years 1945-2020 in English. TOPIC documents were searched: “torrefaction*”, type: article, country: Poland.

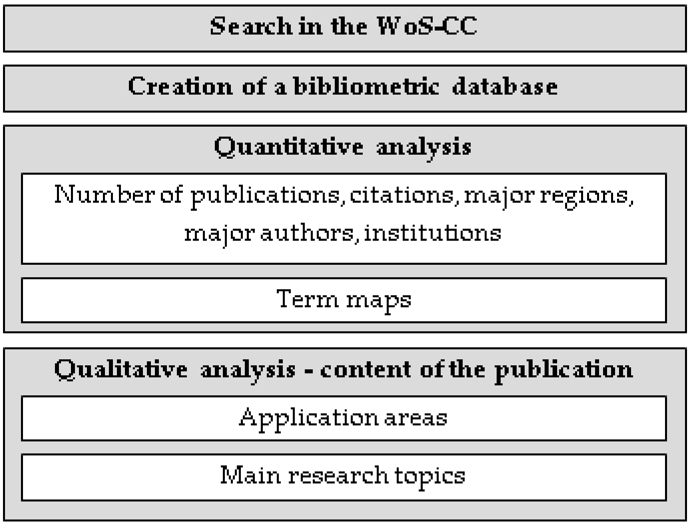


Fig. 3. Diagram of research methodology

Then bibliometric data (authors, title, year of issue, key words, additional key words, publishing house) were collected and cleaned, and then analyzed.

The first step of the analysis was loading data from the WoS-CC database into the InCites: Benchmarking & Analytics. InCites Benchmarking & Analytics software is an advanced analytical tool offered by Claritive Analytics. InCites B&A offers the possibility of creating reports on scientific achievements and activity (scientific institutions, researchers), comparing sources of funding for selected research areas or institutions, identifying trends in selected research areas and many others and analysis of selected scientific achievement indicators.

The next stage was the analysis of keywords of the authors of the publication which were analyzed in the VOSviewer program. This program is free and is used to visualize bibliometric networks. The analyses may concern authors, keywords, journals, and others. Generated thematic maps can be created on the basis of the frequency of occurrence of keywords in years, citations, networks and others. The last stage consisted of a detailed thematic analysis of the publication about Web of Science Categories: Energy fuels.

This is especially important for industry. It makes it possible to use research results and implement selected technologies processes and process parameters in production Titles, keywords, abstracts as well as full publication texts were analyzed. The goal was to indicate process parameters, materials used for torrefaction and applications of this process.

3. Research results and discussion

Quantitative analysis

Shown in Fig. 4 number of publications and citations in 2011-2020. There is a clear increase in the number of publications and citations after 2018. This proves the growing interest in the studied subject in Poland. There was an increase from the level of 13 publications (2017) to the level of 38 publications (2020).

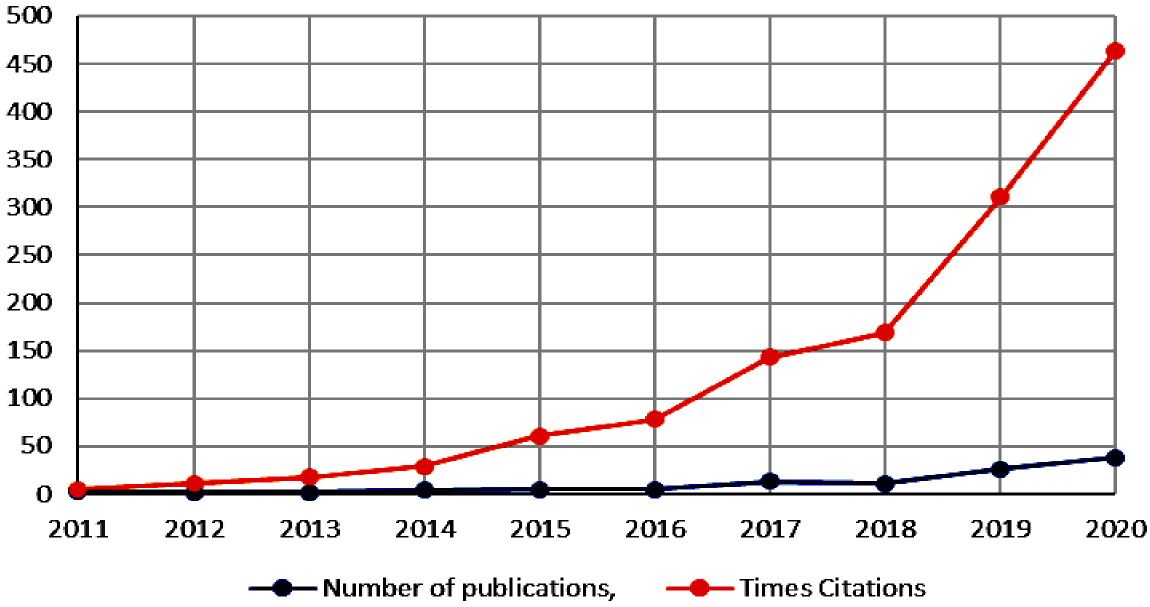


Fig. 4. Number of publications and citations in years

Presents the number of articles indexed in the WoS-CC database in individual voivodships in Poland (Fig. 5). It can be noted that the main research centers are located in the south of Poland (voivodships: Lower Silesian - 18 associate professors, Lesser Poland - 11 associate professors and Silesian - 8 associate professors.

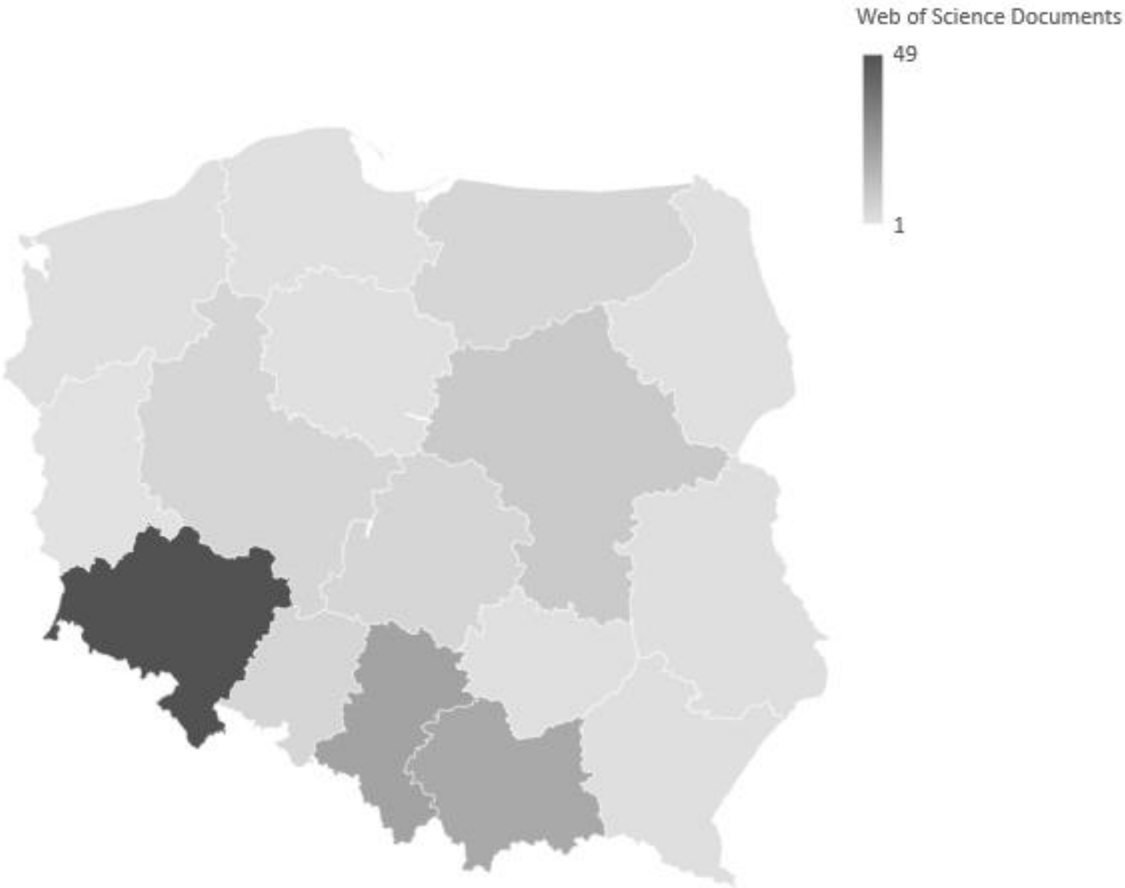


Fig. 5. Number of publications indexed in the WoS-CC database in 1980-2020 on the subject of torrefaction in Poland

Presents a ranking of 10 research institutions on a selected subject (Fig. 6). These have been referenced in a number of articles and Times Cited. The size of the circles depends on the Category Normalized Citation Impact. It can be seen that the research centers with the largest number of documents and times cited are: Wroclaw University of Science & Technology, Wrocław University of Environmental & Life Sciences, AGH University of Science & Technology and Institute for Chemical Processing of Coal.

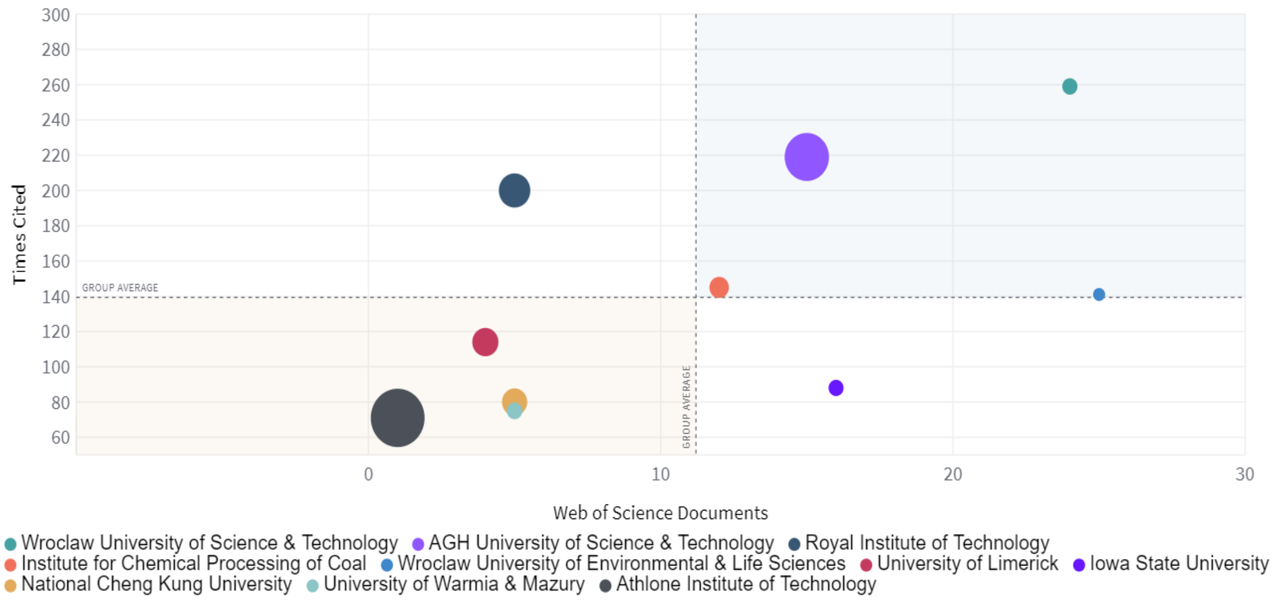


Fig. 6. Presentation of research institutions in relation to the number of documents and Times Cited

Shows the analysis of term words in years (a) and in terms of the number of citations (b). Individual years have been marked with different colors (Fig. 7).

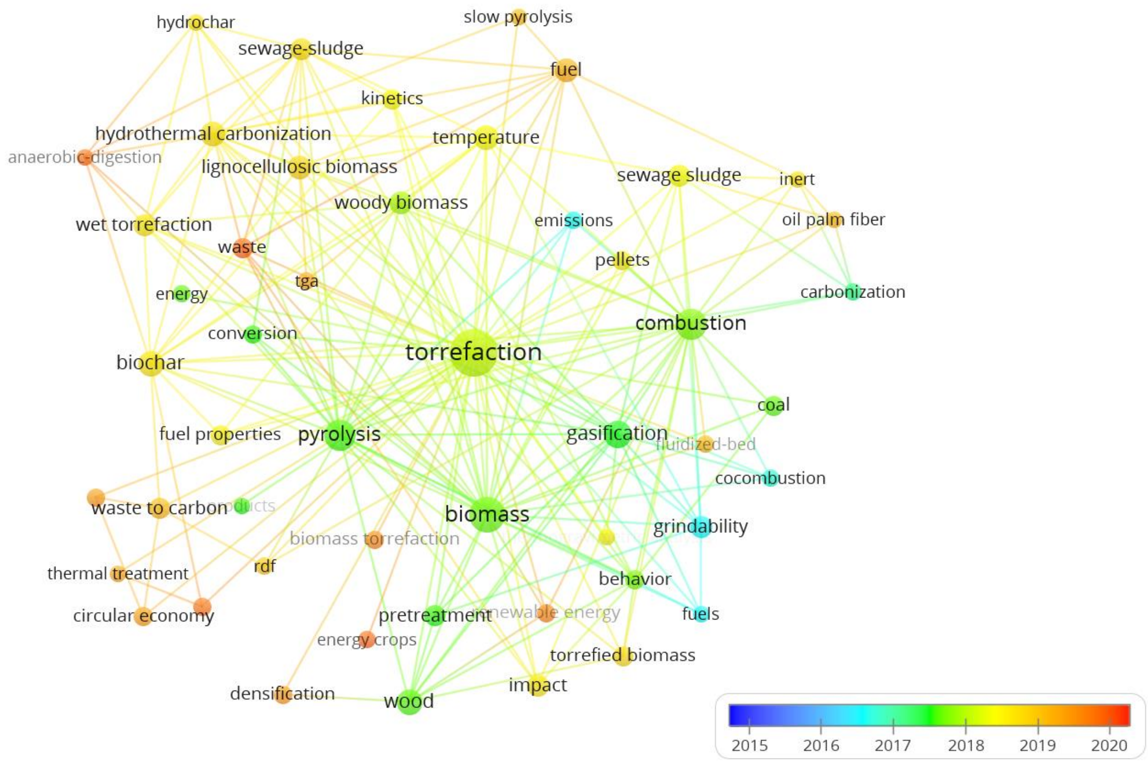
– 2015-2016 (dark blue and blue): ‘fuel’, ‘co-combustion’, ‘emissions’.

– 2017-2018 (green): ‘wood’, ‘pretreatment’, ‘biomass’, ‘pyrolysis’, ‘gasification’, ‘combustion’, ‘carbonization’.

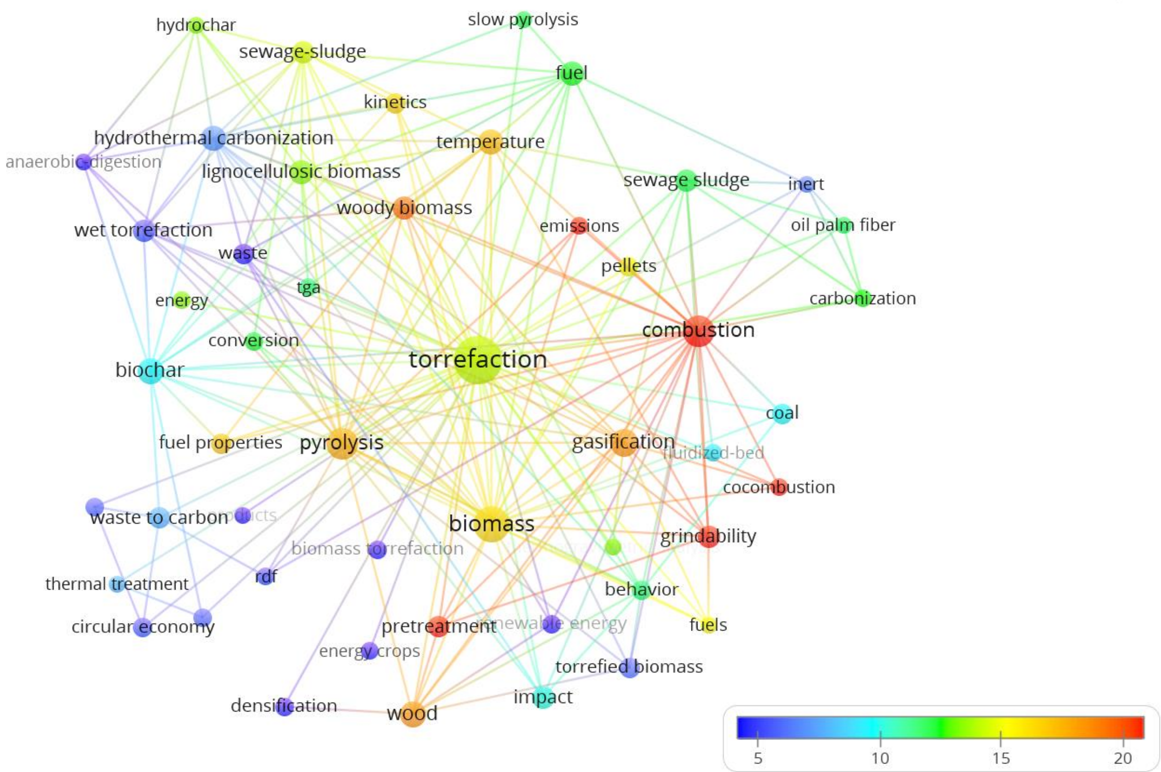
– Years 2018-2019 (yellow): ‘biochar’, ‘wet torrefaction’, ‘hydrothermal carbonization’, ‘sewage sludge’, ‘kinetics’, ‘pellets’, ‘torrefied biomass’.

– Years 2019-2020 (orange and red): ‘circular economy’, ‘thermal treatment’, ‘waste to carbon’, ‘waste’, ‘oil palm fiber’, ‘energy crops’.

The most recent research topics are (Fig. 7b): ‘combustion’, ‘co-combustion’, ‘emissions’, ‘pyrolysis’, ‘fuel properties’, ‘woody biomass’, ‘gasification’. Of less interest are: ‘sewage sludge’, ‘hydrochar’, ‘slow pyrolysis’, ‘carbonization’.



a)



b)

Fig. 7. Map of term words: (a) individual years, (b) times cited

Qualitative analysis

Presents the results of the thematic analysis of the publications. Analyzed in detail of the publication about Web of Science Categories: Energy fuels. All of them were affiliated with Polish scientific institutions. Selected publications were from the period 2011-2020 (Table 1).

The number of publications in particular years was as follows: 2011 - 1 post-doc, 2012 - 1 post-doc, 2014 - 3 post-doc, 2015 - 2 post-doc, 2016 - 2 post-doc, 2017 - 7 doc., 2018 - 6 doc., 2019 - 13 doc. and 2020 - 31 doc. A similar upward trend can be noticed as in the case of the total number of publications on the selected topic.

Main research topics in particular periods:

– 2011-2014: use of torrefaction products in gasification and co-combustion possibilities in a coal power plant

– 2015-2018: the use of the torrefaction process to process sewage sludge, optimization of process parameters, tests of chemical, physico-mechanical and energetic properties of torrefaction products from various types of biomass, modeling and optimization of the process, use of hydrothermal carbonization

– 2019-2020: research on chemical properties (e.g. reduction of mercury), physical-mechanical and energy torrefaction products from various types of biomass (agri-food processing waste, agricultural production waste, animal faeces, energy plants, etc.), Low-temperature pre-treatment of municipal solid waste, Co-Gasification of Sewage Sludge with Energetic Crops, the impact of biochar on biogas production, research on technological and economic aspects of thermal processing on selected types of biomass, studies on the impact of raw material properties on the torrefaction process, Hydrothermal carbonization (e.g. agricultural and municipal solid waste digestates), the use of torrefaction as an Additive to Organic Fertilizers, the use of torrefaction products in gasification and the possibility of co-combustion in a coal-fired power plant.

Table 1. Result of the topic analysis of publications in the period 2011-2020

Ref.	Year	Main topic
(Mokrzycki et al., 2020)	2020	to investigate black alder (*Alnus glutinosa* L. Gaertn.) waste wood chip biochar in torrefaction and pyrolysis
(Dziok, Kołodziejska, & Kołodziejska, 2020)	2020	mercury content in woody biomass and its removal in the torrefaction process
(Krochmalny et al., 2020)	2020	determination of the marker for automation of torrefaction and slow pyrolysis processes
(Rajca et al., 2020)	2020	Technological and economic aspect of Refuse Derived Fuel pyrolysis
(Kuranc, Stoma, Rydzak, & Pilipiuk, 2020)	2020	Durability Assessment of Wooden Pellets in Relation with Vibrations Occurring in a Logistic Process of the Final Product
(Trubetskaya et al., 2020)	2020	The effect of particle size, temperature and residence time on the yields and reactivity of olive stones from torrefaction
(Mączka, Pawlak-Kruczek, Niedzwiecki, Ziaja, & Chorążyczewski, 2020)	2020	Plasma Assisted Combustion as a Cost-Effective Way for Balancing of Intermittent Sources
(Zaleski & Chawla, 2020)	2020	Profitability Analysis for Two Methods of Waste Processing in Small Municipalities
(Čespiva et al., 2020)	2020	Characterization of tars from a novel, pilot scale, biomass gasifier working under low equivalence ratio regime
(Matyjewicz, Świechowski, Koziel, & Białowiec, 2020)	2020	a comprehensive description of the new approach to biomass torrefaction under high-pressure conditions
(O'Brien, Koziel, Banik, & Białowiec, 2020)	2020	Synergy of Thermochemical Treatment of Dried Distillers Grains with Solubles with Bioethanol Production for Increased Sustainability and Profitability
(Pawlak-Kruczek, Niedzwiecki, et al., 2020)	2020	Hydrothermal carbonization of agricultural and municipal solid waste digestates
(Śliz & Wilk, 2020)	2020	Energy potential of hydrochar derived from Virginia mallow
(Jewiarz, Wróbel, Mudryk, & Szufa, 2020)	2020	Impact of the Drying Temperature and Grinding Technique on Biomass Grindability
(Jagodzińska et al., 2020)	2020	Torrefaction of Agricultural Residues - Effect of Temperature and Residence Time on the Process Products Properties
(Pawlak-Kruczek, Urbanowska, et al., 2020)	2020	Industrial Process Description for the Recovery of Agricultural Water From Digestate
(Pawlak-Kruczek, Wnukowski, Niedzwiecki, Kowal, & Krochmalny, 2020)	2020	Gasification of Torrefied Sewage Sludge With the Addition of Calcium Carbonate
(Wilk, Magdziarz, Kalemba-Rec, & Szymańska-Chargot, 2020)	2020	Upgrading of green waste into carbon-rich solid biofuel by hydrothermal carbonization

Table 1 (cont.)

Ref.	Year	Main topic
(Świechowski et al., 2020)	2020	Solid Fuel Production from Biogas Plant Digestate and Sewage Sludge by Torrefaction-Process Kinetics, Fuel Properties, and Energy
(Luo et al., 2020)	2020	Influence of Torrefaction and Pelletizing of Sawdust on the Design Parameters of a Fixed Bed Gasifier
(Dyjakon & Noszczyk, 2020)	2020	Torrefaction Process of Horse Chestnuts, Oak Acorns, and Spruce Cones
(Jackowski et al., 2020)	2020	HTC of Wet Residues of the Brewing Process
(Szufa et al., 2020)	2020	Torrefaction of Straw from Oats and Maize for Use as A Fuel and Additive to Organic Fertilizers
(Wróbel, Jewiarz, Mudryk, & Knapczyk, 2020)	2020	Influence of Raw Material Drying Temperature on the Scots Pine (*Pinus sylvestris* L.) Biomass Agglomeration Process
(Sieradzka, Gao, Quan, Mlonka-Mędrala, & Magdziarz, 2020)	2020	Biomass Thermochemical Conversion via Pyrolysis with Integrated CO_2 Capture
(Tran et al., 2020)	2020	Fuel characterization and thermal degradation kinetics of biomass from phytoremediation plants
(Pawlak-Kruczek, Arora, et al., 2020)	2020	Emissions from combustion of raw and torrefied Palm Kernel shells
(Junga, Pospolita, & Niemiec, 2020)	2020	Combustion and grindability characteristics of palm kernel shells torrefied in a pilot-scale installation
(Głód et al., 2020)	2020	Investigation of Ash-Related Issues During Combustion of Maize Straw and Wood Biomass Blends in Lab-Scale Bubbling Fluidized Bed Reactor
(Urbanowska et al., 2020)	2020	Treatment of Liquid By-Products of Hydrothermal Carbonization (HTC) of Agricultural Digestate
(Gładysz, Saari, & Czarnowska, 2020)	2020	Thermo-ecological cost analysis of cogeneration and polygeneration energy systems
(Dyjakon, Noszczyk, & Smędzik, 2019)	2019	The Influence of Torrefaction Temperature on Hydrophobic Properties of Waste Biomass from Food Processing
(Stępień et al., 2019)	2019	Biocoal from Elephant Dung as New Cooking Fuel
(Jagodzińska, Czerep, Kudlek, Wnukowski, & Yang, 2019)	2019	Torrefaction of wheat-barley straw
(Stanisław Szwaja, Magdziarz, Zajemska, & Poskart, 2019)	2019	A torrefaction of Sida hermaphrodita to improve fuel properties
(Kuo et al., 2019)	2019	Low-temperature pre-treatment of municipal solid waste for efficient application in combustion systems
(Syguła, Koziel, & Białowiec, 2019)	2019	the waste mushroom spent compost treatment via torrefaction for the production of solid fuel-biocoal
(Pawlak-Kruczek, Wnukowski, Krochmalny, et al., 2019)	2019	The Staged Thermal Conversion of Sewage Sludge in the Presence of Oxygen

(Stanislaw Szwaja, Poskart, Zajemska, & Szwaja, 2019)	2019	Theoretical and Experimental Analysis on Co-Gasification of Sewage Sludge with Energetic Crops
(Dudek, Świechowski, Manczarski, Koziel, & Białowiec, 2019)	2019	The Effect of Biochar Addition on the Biogas Production Kinetics from the Anaerobic Digestion of Brewers' Spent Grain
(Huang, Li, Xiao, & Lasek, 2019)	2019	Cofiring characteristics of coal blended with torrefied Miscanthus biochar optimized with three Taguchi indexes
(Grams et al., 2019)	2019	Surface characterization of *Miscanthus ×giganteus* and Willow subjected to torrefaction
(Pulka, Manczarski, Koziel, & Białowiec, 2019)	2019	Torrefaction of Sewage Sludge - Kinetics and Fuel Properties of Biochars
(Pawlak-Kruczek, Wnukowski, Niedzwiecki, et al., 2019)	2019	Torrefaction as a Valorization Method Used Prior to the Gasification of Sewage Sludge
(Y.-H. Li, Lin, Xiao, & Lasek, 2018)	2018	Combustion behavior of coal pellets blended with Miscanthus biochar
(Bajcar, Zaguła, Saletnik, Tarapatskyy, & Puchalski, 2018)	2018	Relationship between Torrefaction Parameters and Physicochemical Properties of Torrefied Products Obtained from Selected Plant Biomass
(Białowiec, Micuda, & Koziel, 2018)	2018	Densification of Torrefied Refuse-Derived Fuel
(Pawlak-Kruczek, Krochmalny, Wnukowski, & Niedzwiecki, 2018)	2018	Slow Pyrolysis of the Sewage Sludge With Additives
(Tic et al., 2018)	2018	Novel Concept of an Installation for Sustainable Thermal Utilization of Sewage Sludge
(Botelho, Costa, Wilk, & Magdziarz, 2018)	2018	Evaluation of the combustion characteristics of raw and torrefied grape pomace
(Kopczyński, Lasek, Iluk, & Zuwała, 2017)	2017	The co-combustion of hard coal with raw and torrefied biomasses (willow *Salix viminalis*), olive oil residue and waste wood from furniture manufacturing
(Chen, Hsu, Kumar, Budzianowski, & Ong, 2017)	2017	Predictions of biochar production and torrefaction performance from sugarcane bagasse
(Wilk & Magdziarz, 2017)	2017	Hydrothermal carbonization, torrefaction and slow pyrolysis of *Miscanthus giganteus*
(Wilk et al., 2017)	2017	Combustion and kinetic parameters estimation of torrefied pine, acacia and *Miscanthus giganteus* using experimental and modelling techniques
(Sajdak, Chrubasik, & Muzyka, 2017)	2017	Chemical characterisation of tars from the thermal conversion of biomass
(Lasek, Kopczyński, Janusz, Iluk, & Zuwała, 2017)	2017	Combustion properties of torrefied biomass obtained from flue gas-enhanced reactor
(Moscicki, Niedźwiecki, Owczarek, & Wnukowski, 2017)	2017	Commoditization of wet and high ash biomass: wet torrefaction

Table 1 (cont.)

Ref.	Year	Main topic
(Lin, Chen, Budzianowski, Hsieh, & Lin, 2016)	2016	Emulsification analysis of bio-oil and diesel under various combinations of emulsifiers
(Wilk, Magdziarz, Kalemba, & Gara, 2016)	2016	Carbonisation of wood residue into charcoal during low temperature process
(Wilk, Magdziarz, & Kalemba, 2015)	2015	Characterisation of renewable fuels' torrefaction process with different instrumental techniques
(Dudyński, van Dyk, Kwiatkowski, & Sosnowska, 2015)	2015	Influence of torrefaction on syngas production and tar formation
(J. Li et al., 2014)	2014	Process simulation of co-firing torrefied biomass in a 220 MWe coal-fired power plant
(G. Xue et al., 2014)	2014	Gasification of torrefied *Miscanthus ×giganteus* in an air-blown bubbling fluidized bed gasifier
(Gang Xue et al., 2014)	2014	Impact of torrefaction on properties of *Miscanthus ×giganteus* relevant to gasification
(J. Li, Brzdekiewicz, Yang, & Blasiak, 2012)	2012	Co-firing based on biomass torrefaction in a pulverized coal boiler with aim of 100% fuel switching
(Budzianowski, 2011)	2011	Opportunities For Bioenergy In Poland: Biogas And Solid Biomass Fuelled Power Plants

4. Conclusion

The increase in the number of publications on the torrefaction process (torrefaction products and their use in the energy sector) in Poland took place after 2018.

The main research centers dealing with selected topics are located in the south of Poland: Lower Silesian, the Lesser Poland and Silesian Voivodships.

The thematic analysis of scientific publications indexed in the WoS-CC database affiliated by Polish research institutions confirms global trends. The main topics are: research, modeling and optimization of the torrefaction process, searching for new raw materials and studying their impact on the process, using the products of the torrefaction process in other processes (e.g. co-combustion, gasification), testing the chemical, physical-mechanical and energy properties of process products torrefaction from different types of biomass. Thematic analysis confirmed the global research trends in the topic under study.

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CHAPTER 4

CURRENT STATE OF MECHANIZATION OF ENERGY WILLOW PLANTING AND TRENDS IN THE USE OF PLANT AUTOMATION MEANS

Abstract

Energy willow planting process requires the use of highly effiecient and productive machines. Existing machines for planting energy crops cuttings are characterized by the low productivity because of the speed restriction to hand stowing into a plant setter. Therefore, establishment of mechanisms for the cutting auto-stowing into a plant setter is a current scientific and production task. The analysis of construction of machines for planting energy crops, forest plantations and seedlings and the processes which take place in the process of planting made it possible to systemize the accumulated experience in the design of planting machines, and highlight the most effective technical solutions. Also the research research is set against the analysis of the known planting machine constructions that are used for setting the potted plants and forest seedlings. In this research, the methods of structural and factorial analysis with regard to the mechanisms` arrangement were used, as well as peculiarities of the working processes occurring at each stage of the overall technological process of the cutting relocation from the reservoir to the land area were highlighted. The revealed features of planting machines for different types of planting material are compared with the designs of energy willow planting machines. This study found a number of characteristics and advantages of different machine types, which will ultimately lead to an increase in productivity of planting aggregates and will facilitate the work of a planter. In the issue of analysis, possible ways of different methods implementation into the technological process were singled out. This can be seen in the structural and logical scheme of the process. The promising solutions for planting automation of the energy crop cuttings were provided.

Key words: planting machine, plant setter, seedling planter, forest planters, energy crops, cutting, plant setter, feed gearing, planting head

1. Introduction

Energy willow is the most common energy crop for solid fuel production in the world. This is a plant with a very high increase in biomass (14 times larger than wild forest). The optimal planting material for the creation of energy plantations of willows are annual woody cuttings 20-30 cm long and 5-15 mm thick. This planting material is harvested from annual willow shoots (Fig. 1).

This planting material is harvested from annual willow shoots. The scheme of planting for industrial cultivation of energy willow on cuttings is as follows: deepening of cuttings - 18-19 cm, the distance between seedlings in a row - 0.60 m, between rows - 0.70 m, between strips - 1.4 m, planting density - 15 thousand pcs / hectare (**Sinchenko, 2012**). For planting of one hectare 15-20 thousand cuttings are needed, and at laying of uterine plantings - to 30 thousand.

Fig. 1. Planting material when laying energy willow plantations

This planting material takes root very quickly. During the first year after planting, seedlings require intensive protection against weeds; in subsequent years, the highly developed root system of trees inhibits the growth of weeds. After three years, the seedling develops about 30 shoots with a diameter of 2 to 4 cm (**Kravchuk, 2013**). Harvesting is carried out every 3-4 years. During this time, when the plants reach 5-6 m in height, young trees are cut in winter with the help of special equipment (Fig. 2). If the willow cultivation technology is followed, the productivity of the plantation can reach 100 t/ha, from this mass it is possible to produce 45 tons of ecological fuel (**Nov, 2009**). The plantation has been in use for over 20 years.

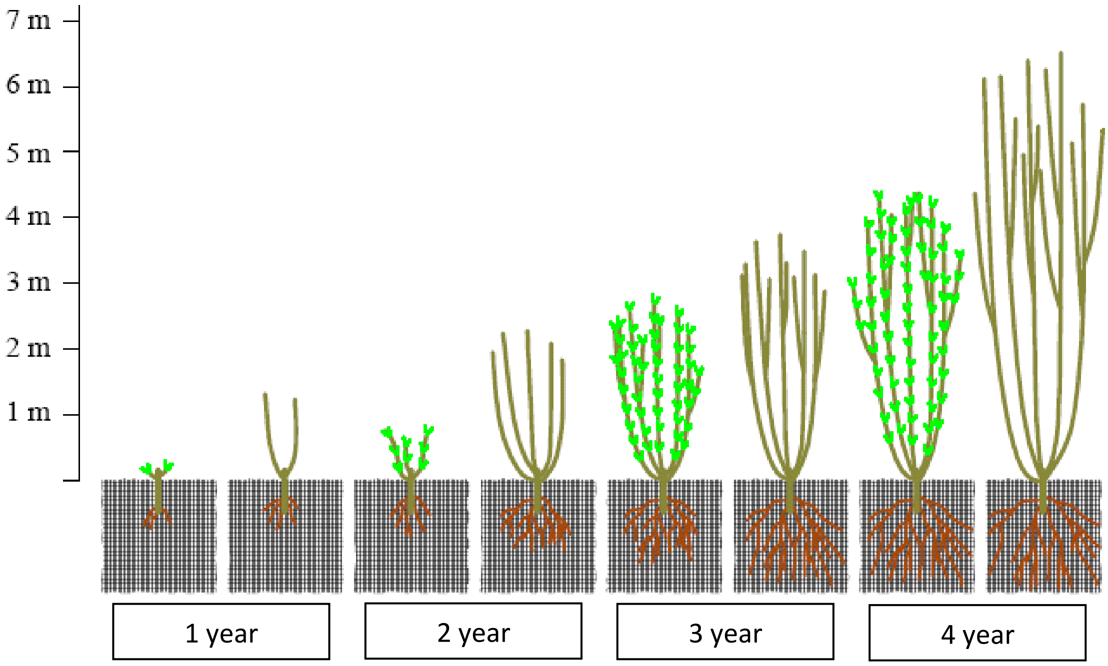


Fig. 2. Phases of willow development from its laying to the first harvest (Wrobel, Mudryk, 2018; Єрмаков, Гуцол, 2019)

The effectiveness of the introduction of technologies for the production of bioenergy from energy willow can be judged from the experience of the agro-energy company "SALIX energy". That was laid first energy plantations in Volyn in 2010. The main activity of the company is the cultivation of energy willow for biomass production. The end product is wood chips from willow energy plantations, which can be used to produce both heat and electricity (www.salix-energy.com). The accumulated experience of plantation establishment, harvesting and its processing allows allocating structure of investments in biomass production (Fig. 3).

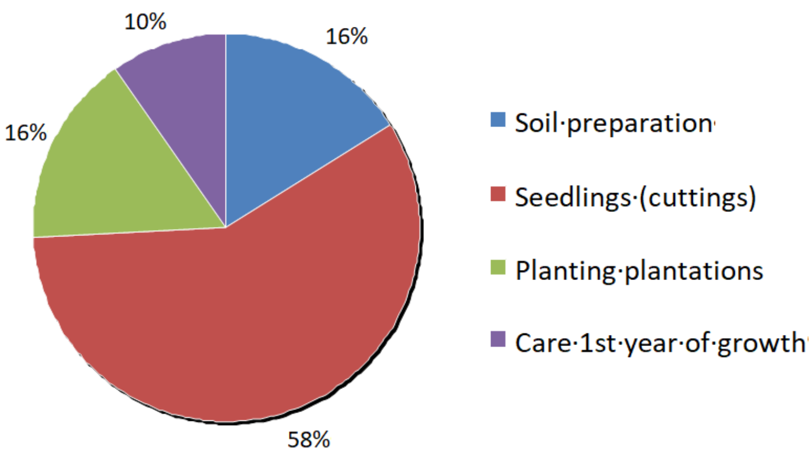


Fig. 3. Structure of investments in energy willow (according to SALIX energy)

To date, a park of machines for laying energy plantations has been created, but the use of manual labor while planting tree crops significantly reduces the productivity of the plant setters used. In addition, planting of energy crops has a lot in common with planting of some other crops, in particular in forest cultivation and seedling planting, so to find ways to further improve machines for planting energy crops, it is advisable to analyze technological and design achievements in these areas. So, the creation of highly efficient plant setters is an actual scien-tific production task.

A major barrier to further productivity improvement of the plant setters is the limited ability to feed the cuttings, only 40-60 p/min (**Bartenev, 2012**), which is equivalent to the machine translational velocity 0.8-2.1 km/h. Under these circumstances it is important to replace the operator`s work with automation equipment. This work is devoted to the search for a solution to this problem.

Taking into account the insufficient development of planting automation for energy wood crops, the goal of this project is to search for some upcoming ways and effective principles for ensuring automation of processes during the planting machines operation process. This work is aimed at identifying promising technical solutions, suitable for use in growing energy crops, which will increase the productivity of the cutting planting process. To achieve this objective, one has to accomplish the following task:

– Analyze the design of forest and seedling planters and identify typical schemes;

– Identify promising technocal solutions that are suitable for use in the machines for planting energy crops.

– Identify possible areas for improvement in the construction of planters, given the possibility of automating the entire process of planting woody cuttings, from selection from the volume to installation in the place of planting.

2. Theoretical background

Almost a century the work on the improvement issue of the complex and labor-intensive process of planting tree crops has been carries out in several ways. Starting with the separate operator bodies improvement of the plant setters and to process automation attempts that are intended to release from the manual labor and negative factors appeared after using it (the productivity cutoff of the planting material, the quality dependence from the operator`s state, etc.). First and foremost, those are the forest planters and seedling planters. Information about the structural aspects of forest planters can be found in the works of Asmolovskyi M.K., Zyma I.M., Malyutin T.T., Bartenyev I.M and others. Similar studies were also conducted by Kasymov M.G., Mun V.P., and others. But these studies are highly specialized and they do not contain examples of specific use for energy plantations.

Today, the work on improving the planting process continues. There are many works analyzing both theoretical aspects of automation (**Bartenev, 2012 Miwa, 1991; etc.**) and the automation of planting a particular plant type (**Usenko, 2010; Tarasenko, 2014; Asmolovsky, Loy, 2004, etc.**) and, even, to the introduction of robotics in the process of planting (**Kutz, 1994; Mao, Han, 2014; etc.**). However, each particular species of plants requires a specific approach. In particular, for the energy willow needs to take into account the type of planting material (cuttings in length 20-25 cm), which immediately removes a number of proposals suitable for other plants.

2.1. Technical solutions for planters for forests and seedlings and their application in seedlings of energy willow cuttings

For those machines that are used in forest cultivation, the output is seedlings, saplings and cuttings prepared in advance, and by this they are close to energy crops plant setters. Seedling planters unlike the ma-chines for planting tree crops, have a number of features resulting from the diversity of planting material species, and also agrotechnical requirements for its planting. However, it is possible to find technical solutions for the planting of energy crops among them too.

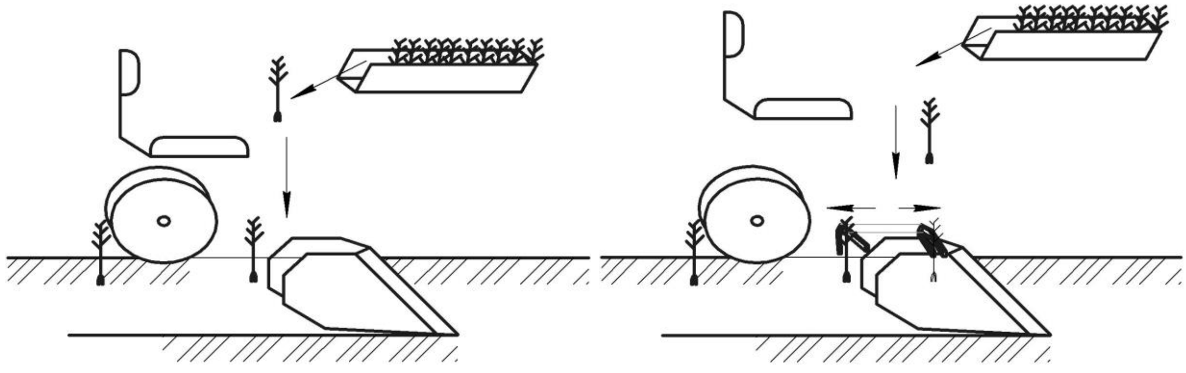
In theory, machinery for planting forests is traditionally divided into four types of planting machines: radial (Fig. 6a), disk (Fig. 8a, b), lever-slide (or coulisse) (Fig. 12a) and the conveyor (Fig. 6b) (**Asmolovskyi, Loi, 2004; Zyma, Maliutin, 2006**). Analysis of the machines for planting forests showed that about 40-50% of the known plant setters brands are equipped with the planting machines of disk type, however, according to the indicators for use in planting of energy crops the planting machines of radial type are more suitable. Approximately every fourth machine brand is equipped with it. Sometimes the machines with such devices are equipped with means of automation (for example, accessory PLA-1) (**Ермаков, Борис, 2016, Hutsol, 2018**).

In seedling planters we meet the same types (except only the lever-slide one) of planting machines, but it can be noted that large share of machines are equipped with vertical

(Fig. 10b) or gravity (Fig. 10a) planting machine, although it should be noted that such solutions are used mainly for delivering of planting material with a closed root system and therefore, given the features of design, they can hardly be recommended for use in the process of planting cuttings of energy wood crops.

Thus, having analyzed the design of forest and seedling planters, we can select ten principal schemes for the implementation of the process of "placing planting material in the planting site", which are illustrated in Fig. 4ab, 6ab, 8ab, 10ab, 12ab (**Yermakov, 2017, Hutsol, 2018**).

The easiest to implement are the plant setters with manual feed and placement of planting material directly in the place of planting (Fig. 4a). Such machines have simple design, they are of small size and, accordingly, are cheaper. Minimization of additional accessories and working elements reduces the number of possible crashes, and therefore the reliability of work is high, and the lack of friction surfaces in the process of feeding planting material provides high durability. However, in these machines there is a number of essential disadvantages associated with low level of the process mechanization and the substantial influence of the human factor on the quality of its performance, which reduces the possibilities of increasing productivity due to physiological limits of human capabilities. Under this scheme of the process implementation, the provision of ergonomic conditions of work is complicated and the working process requires a constant concentration of the planter, who performs a homogeneous, rhythmic, monotonous work, and therefore the dependence of the planting quality (verticality deviation of the planting, smoothness etc.) on the physical and mental state of a human (**Єрмаков, Борис, 2015, Hutsol, 2018**)



a b

Fig. 4. Technological schemes of planters without a planting machine:
a – manual loading of planting material in a slit or seedbed prepared by the machine;
b – loading of planting material to the mechanism of directing the seedlings over the coulter

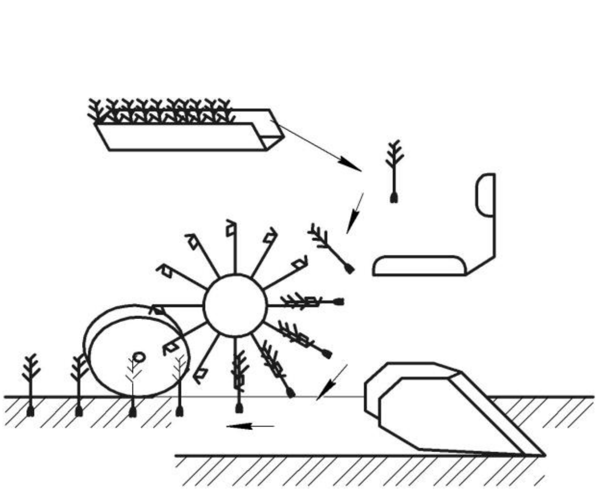
It is possible to get rid of the latter disadvantage and improve the qualitative indicators of the seedling placement if you equip the plant setter with the planting material tracking mechanism that allows you to synchronize the unit movement speed with the planting material movement by the time of fixation. The tracking mechanism can be designed in the form of a grabber that moves backward in a horizontal plane (as shown in Fig. 4b) or in the form of two rubberized transveyers. Despite the slight complexity of the design, all the benefits of manual plant setters are preserved, while most of their drawbacks retain. One may find the machines of such type amongst the seedling planters, although it is noted that they are perfect for planting cuttings.

Plant setters of such type are used in energy willow planting as well (Fig. 5).

For a real reduction in the proportion of manual labor and all srawback associated with subjective factors, machines are equipped with planting devices - mechanisms that implement the transfer of planting material to the planting site and its correct orientation.

Fig. 5. Energy willow plant setter with manual feeding of cuttings. Source: Willowpedia

Radial units with sprocket-shaped holders (Fig. 6a) showed their best in forest planters. In seedling planters such planting machines are used mainly for seedlings with an open root system, and they can be identified with radial units of the conveyer type according to the principle of their work (Fig. 6b), in which the grabbers for planting material are placed along the perimeter of the chain or tape. The advantages of such machines are conditioned by the exclusion of manual labor from the transportation process and positioning planting material in the planting site. The role of man is reduced to extracting planting material from the tanks and loading it to the planting machine grabbers. This allows you to achieve the best qualitative work indicators: to provide a stable plant spacing, orientation, accurate installation of planting material in the planting place and so on. In addition, the possibility to change the place of laying planting material (especially in conveyor ones) creates opportunities for comfortable working conditions and offers the prospects for using process automation tools. The disadvantages of the machines with radial planting units may include the need for positioning planting material with regard to the grab while the laying process, and also the range of plant spacing adjustment, which is limited with the distance between the sprocket teeth or conveyor grabs.



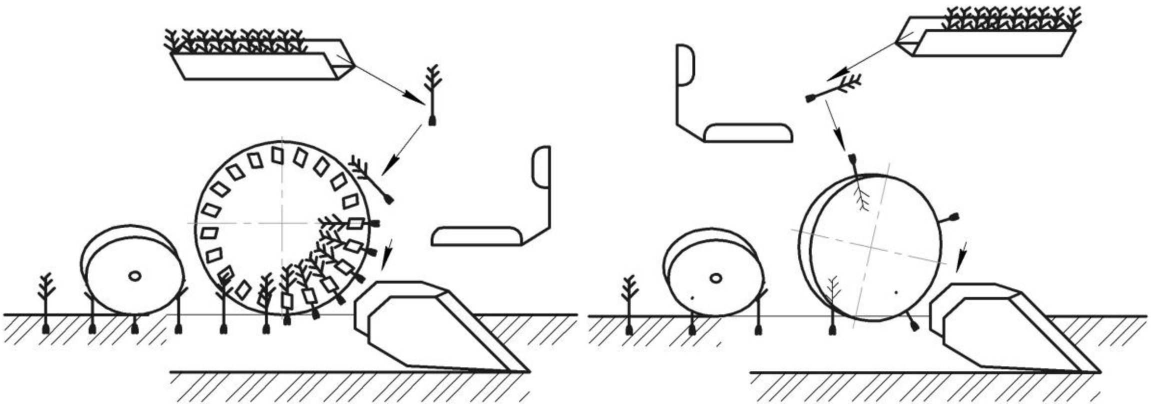
a b

Fig. 6. Technological schemes of the planting machines with radial planting units:
a – with planting units of the sprocket type; b – with conveyor planting units

Radial planting units are well adapted for automation of technological process, as the grabs are able to independently extract the planting material from the specified coordinates. Which is easy to implement when applying flexible or hard cassettes to feed plants. Such solutions can be found among the machines for planting energy willow, however, as a non-cassette version, where the cuttings are taken to grabs by the planter (Fig. 7).

Fig. 7. Plant setters with the radial planting unit with grabs. Source: BioneraVideos (screenshot from the movie)

Disk planting units are common among the design of forest planters. It should be noted that according to academic classification, disk units of rigid structure (Fig. 8a) and with elastic disks (Fig. 8b) fall into one category. In the working scheme the main difference lies in the fact that planting material is laid in the special clamps on rigid disks, and in the elastic ones - in the place where two disks meet. The advantages of machines with disk planting units of rigid design are the accuracy of placing planting material in the planting site, the accuracy of plant spacing, and the opportunity to set a small spacing. That is why they are used in planting, where it is necessary to reach the high density of plants in a row, that in the forestation finds its application for laying the shoots, and according to the initial parameters, such plantations are able to meet the requirements for planting energy crops.



a b

Fig. 8. Technological schemes of the planting machines with disk planting units:
a – with disk planting units (rigid disks); b – with elastic disk planting units

Units with elastic disks are use in the forest planting mainly for large planting material, however, they are also used in seedling planters, where they are used for planting tobacco, pepper, onions etc. The advantages of such machines are the simplicity of the planting unit, and also less danger of breakage. The disadvantages are the complexity of providing a radial location of planting material when loading it into the planting machine, and hence the precise positioning of planting material in the ground. Stable plant spacing under such a scheme depends on the competence and the condition of the planter.

Disk planting machines are implemented in planting energy willow. Such plant setters require the constant performance of planters, one per row, and the monotony of work on loading cuttings in planting machines limits the possibility of increasing their productivity.

Fig. 9. Energy willow plant setter with a disk planting machine. Source: www.probstdorfer.at

Gravity planting machine (Fig. 10a) is a guide opening (a planting tube) in which planting material is directed to the planting site. Such machine is used in simple seedling planters (i.e. Ukrainian "Rosta" manual machines (www.rosta.ua)). While using machines the device carries oscillatory motion in horizontal plane to be agreed with the speed during positioning and planting seedlings. The simplicity and durability of the gravity planting machine construction make them promising for use as the last piece combined with additional devices, i.e. revolving and circular distributor mechanisms etc. The disadvantages of such devices are upgrading difficulties, requirements to the field, possibility of seedling damage while transportation and hitting the planting machine bottom.

Machines with the vertical planting tool and circular motion or reciprocating motion devices (Fig. 10b) arrange careful transportation and potting of the planting material, so are used mainly for seedlings with the root-balled tree system into the cylindrical, conical, or pyramidal pots. There is a possibility to create ergonomic conditions in such machines, since the possibility for providing the work at the comfortable height and position, thus making the plant setter work easier. It is also possible to increase the productivity through the work of two planting pegs in one mechanism charging. Planting into the seedbeds, rather than in a gap does not create a big draught resistance of the device, but this fact provokes the necessity in the preliminary cultivation of matted and heavy soil. Such process implementation causes the construction complication and increased demands to sustain mechanism operability, especially for the reliability of the valve operation, the device stability is deteriorated with regard to the height dimensions.

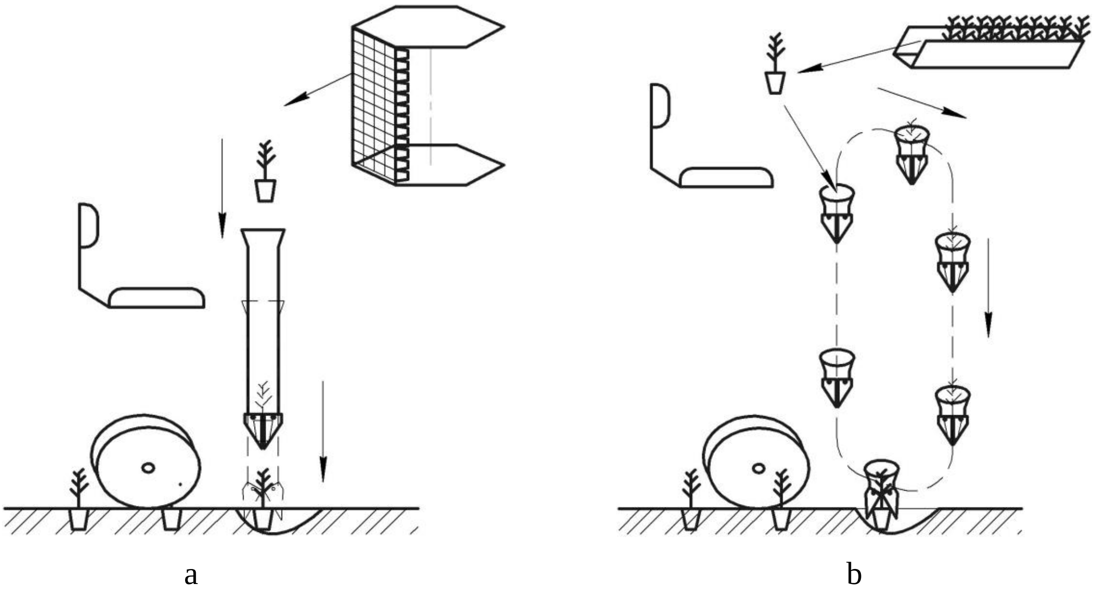


Fig. 10. Technological schemes of the planting machines with the vertical planting material movement: a – with the gravity transportation of the planting material along the planting tube; b – with the vertical planting tool and circular motion devices

For planting energy willow you can use the planting tubes as guides for rods, which are cut into cuttings of 20-30 cm immediately before the planting. Such types of plant setters can be used for planting tapioca (an important tropical tuberous plant), which is planted similar to willow.

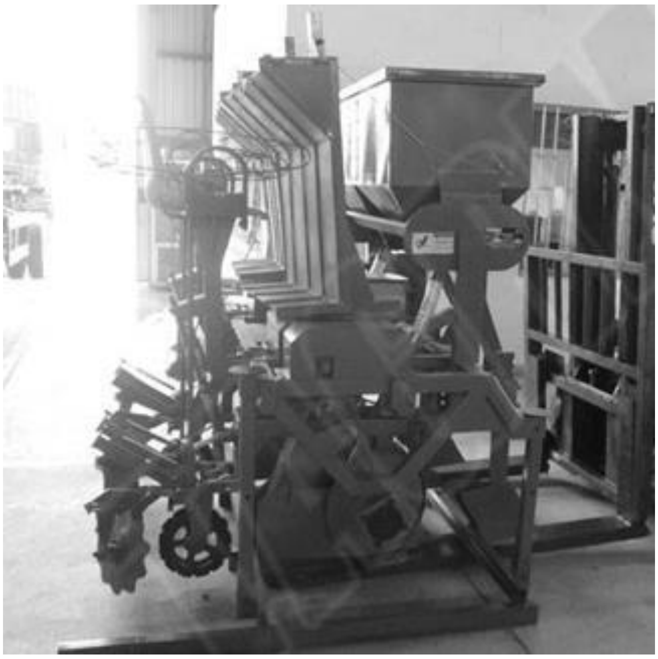
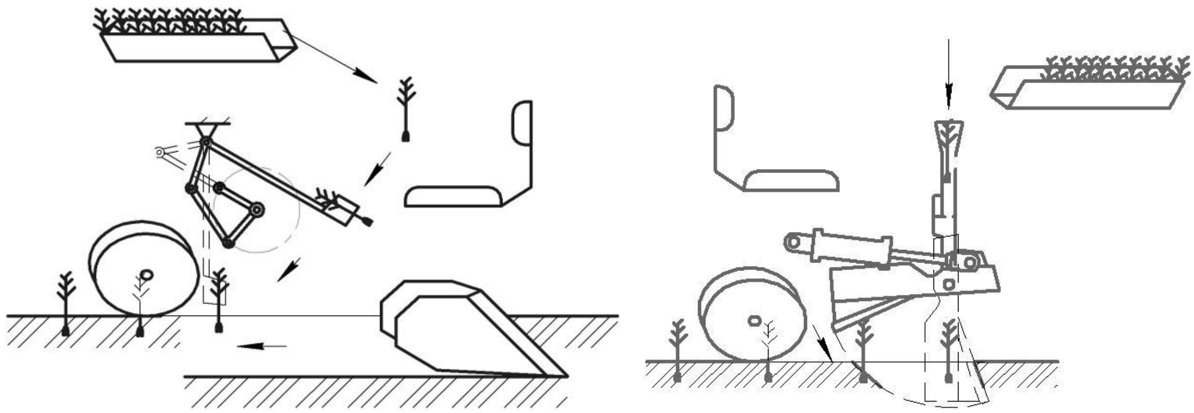


Fig. 11. STR plant setter of the Italian company Iteam. Source: internationalteam.eu

Lever-slide planting machines (Fig. 12) have not been widely used, because despite the convenient feeding of planting material to the grabs, which can be directed to the right place in the required trajectory, such units have a number of disadvantages associated primarily with reliability, since the complex design and the lever system work create complex movements with variable grabbing speed, and the number of friction nodes increases. A disadvantage is also the limited ability to regulate the plant spacing.



a b

Fig. 12. Technological schemes of planting machines with lever mechanisms:
a – with lever-slide planting unit, b – with oscillating knife coulter

Planting machines with oscillating knife coulter (Fig. 12b) are known for their use in forest planters, since they allow to plant cuttings in seedbeds created by the knife coulter with relatively low energy requirements. For energy willow, where it is important to plant with as short plant spacing as possible, such design is ineffective, that is why their use for planting energy plantations is limited (**Hutsol, 2018**).

2.2. Original technical solutions of existing energy willow planters

The general design of energy crops plant setters can be found in the brochures of the manufacturers producing the corresponding machinery, such as Egedal (Sweden), Iteam (Italy), Lignovis (Germany), Probstdorfer (Austria), wimatec MATTES GmbH (Germany), and so on, and also on videodemonstrations of these machines, that often come with the presentation materials. However, these materials give only an over-the-top picture of the processes occuring inside the plant setters. The main material for the reproduction of such crops is the one-two year old lignified cuttings. According to the generalized results of the research, it is advisable to use cuttings from 20 to 30 cm in length and a thickness in the upper section of 4 to 15 mm, although in practice they use the cutters of 8-20 mm (**Roik, Sinchenko, Fuchylo, 2015, Yermakov, 2017, Hutsol, 2018**).

There are two ways of planting such cuttings:

1 – when you plant the cuttings that have been previously prepared taking into account the proper size;

2 – when you plant long (more than 2 m) rods, and cut them directly in the plant setter.

The loading of the full-size rods, and cutting them by the working elements of the machine is used in plant setters, known as "step-planter" (Fig. 13). Such machines are equipped with an oscillating mechanism for feeding the planting material (hereinafter referred to as planting material) to coulter. When the technological process is implemented, the number of movements that the plant setter performs in order to plant reduces, that is why only one operator is able to provide high specific feed rate of cuttings, and also planting in 1 or 2 lines. His task is to select and attach the rod to the guide opening of planting machine. Such machines are specialized for dense planting of energy crops and appropriate manufacturers are responsible for their improvement (**Egedal, Iteam, Lignovis etc.).**

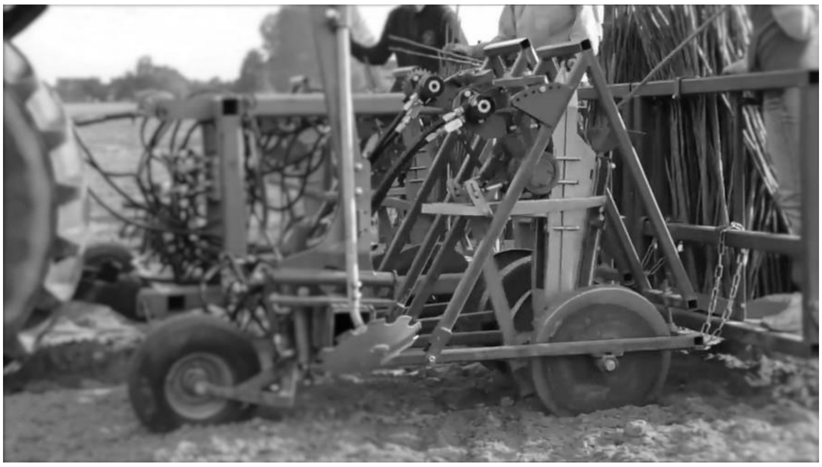


Fig. 13. Three-row plant setter of energy willow rods Step planter 3-reihig - Ernte Stemster.
Source: Lignovis

When planting previously prepared cuttings, there is no process of cutting the rods with the plant setter, that is why the design of those machines that provide such kind of planting have a great variety, and considering the fact that the information about existing models available only with presentation and advertising materials, then the analogues can be found in plant setters that perform similar processes.

In addition to these types of planting machines for planting the cuttings of energy crops the machines known as "rotor-planter" are used (Fig. 14). Plant setters look like loadbearing construction, which is a dismountable canvas of numerous pads resembling a track-laying mover. With a given plant spacing the cells for laying planting material are placed in the pads (www.lignovis.com).

Fig.14. The plant setter of energy willow with a planting unit that look like a caterpillar wimatec MATTES GmbH (Germany). Source: http://www.wimatec-mattes.de

The advantage of such machines is the high quality of placing planting material in the planting site with precise plant spacing, given laying parameters (with a projection above the ground or level with), sealing of the planting site and so on. These machines work well in the problematic areas. However, the productivity of such machines remains low, although if the plant spacing is increased, there is a possibility to attract additional workers for the laying of cuttings.

2.3. Technical achievements in the field of planting automation. Planting machines

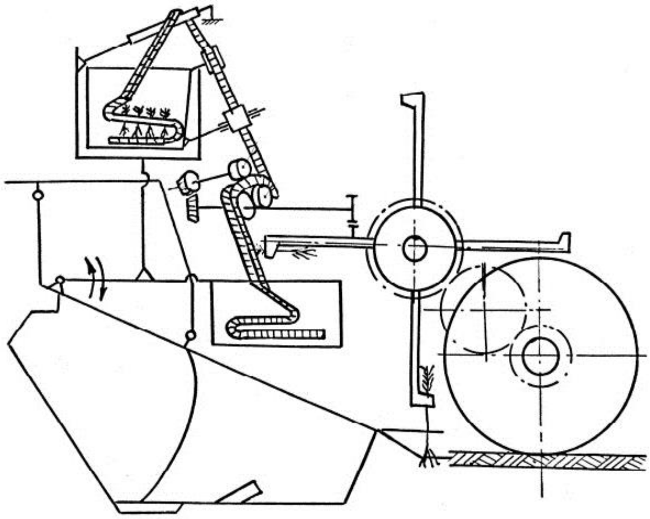
The process of planting seedlings, seedlings or cuttings has always been complex and time consuming. Scientifically, the issue of facilitating the work of workers during planting was addressed in the early twentieth century, and since then, for more than a century, there has been a constant search for ways to improve the mechanized planting process and, consequently, planting machines. Attempts to get rid of manual labor and the negative factors arising from its use (the threshold of productivity of planting material, the dependence of quality on the physiological state of the operator, etc.) have repeatedly become a cornerstone for many scientists. At that time, the whole scientific institutes of the countries, as well as individual scientists and researchers (**Verdnikov, Provotorov, Kulikov, Khiznichenko, etc.**) worked on improving the planters, offering their own constructions of mashins with automated execution of the planting process (**Usenko, 2010**). However, the first attempts to automate the planting process were reduced to the use of different feeding conveyors. In so doing, the seedlings were stowed into the special belts with slots, elastic holders or other holding devices. The belt is rolled into a cassette. While unrolling the belt is moving a step ahead and is divisible by a planting step. The seedlings are grabbed in turn from the planting machine belt and are transported to the planting place. Hence, the flow, regularity and a step of feeding the planting materials are formed and provided by means of the belt characteristics. The belt movement changes the general position as well as a spatial orientation (**Yermakov, 2018**).

In the 60s-80s of the last century, when the volume of planting work was expressed in hundreds of thousands of hectares annually, and the human factor in the person of planters was a limiting factor in increasing the working speeds and productivity of forest planting machines, LPA-1 automatic feeders (machines) were developed, APS-1, APA-1 and PLA-1 (Fig. 15) with flexible cassettes. (**Bartenev, 2017**). These devices were installed on tree-planting machines and carried out the supply of coniferous seedlings and deciduous cuttings to the grips of the planting apparatus, i.e. replaced planters.

The main drawback of such machines is the large labor-intensive characteristic of the plant stowing into the cassette, for which this operation was transferred from the main process and is fulfilled in advance before planting. Furthermore, the presence of the cassette mechanism adds complexity to the plant setters construction and their awkwardness, and also decreases the reliability of the implementation process because of such disadvantages as the belt drift of guiding rollers, operational integrity of the plant cramps in the belt.

Thus, such way to automate the process is an actual thing, in particular such cassette machines as tree planting machine PLA-1 (Fig. 16), APA-1 are well known. They are successfully used while planting seedlings of the tree crops (**Yermakov, 2018**).

The machines with rigid cassettes have the same operational peculiarities. They are designed in the shape of flat cell (LDM-21) or barrel (machine ALP-1 - Fig. 3) (**Bartieniev, 2012**). Their key difference is cassette movement along the arc on the feeding step to the place where the planting materials are selected by the planting machine grips. Here, the building of a planting material mass is determined by the characteristics of the rigid cassettes, and the movement is defined by the rotation mode.



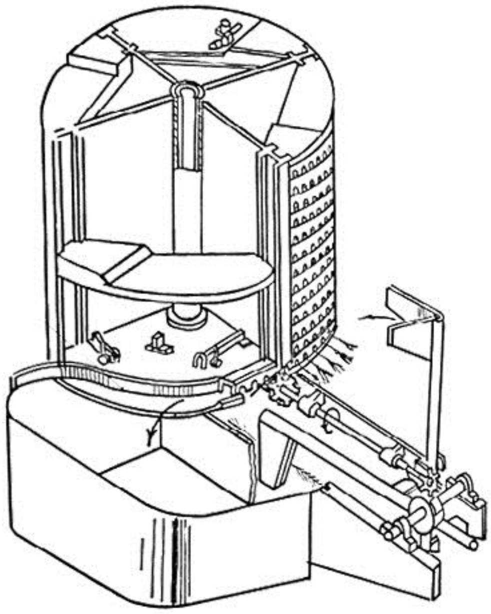


Fig. 15. Flexible cassette machine (PLA-1) Fig. 16. Rigid cassette machine (ALP-1)

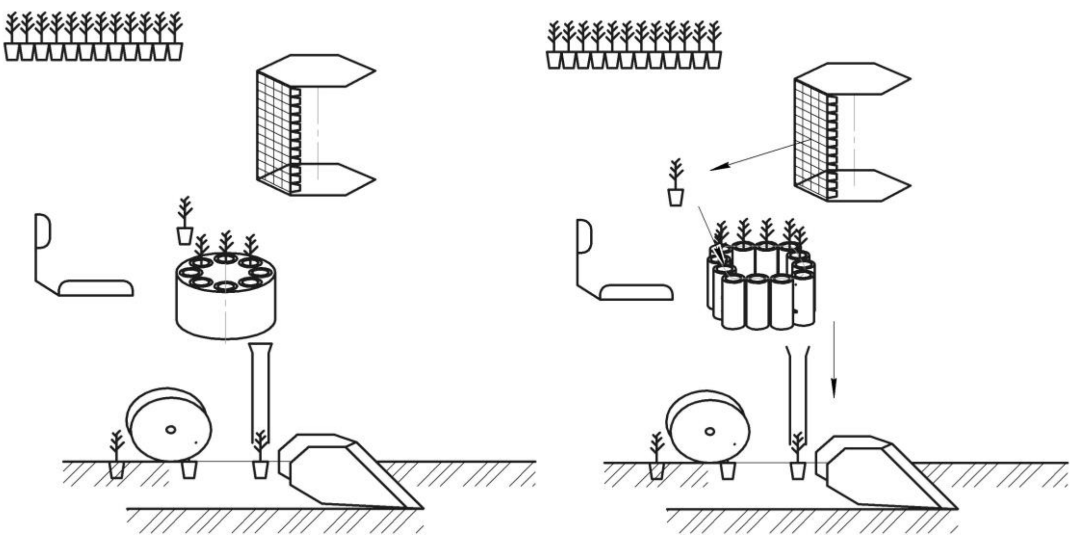
Rigid cassette machines in comparison with flexible cassette machines are more compact and they do not require any additional movement while charging the seedlings. At the same moment the cassette feeding step from the hopper to the planting machine grips and releasing the seedlings from the cassette require further study for each planting material (**Yermakov, 2018**).

As with flexible cassettes, a notable disadvantage of this method is the requirement for a preliminary cassette 'charging'. This requires the development of additional mechanisms, hence the manual charging of the belt is time-consuming, e.g. the belt charging of the German machine "Schoenherr" with the 2000 planting slots took 3.5 hours (technicamolodezhi.ru). Therefore, the total processing time for planting does not change significantly. Thus we can talk about the cassette mechanisms efficiency while feeding the plants only in the context of the direct cassette machine work.

Over exposure of the plants to the open air refers to the general disadvantages of the cassette feeding machines. This moment is important for some planting crops, in particular bare root tree system. This time must not exceed 5 minutes, otherwise the plant acceptability decreases rapidly and the growth slows down **(Bartieniev, 2012; Єрмаков, Борис, 2016, Yermakov, 2018)** Practically, before planting the plant is maintained not only during the processing time, when it is transferred from the hopper to the planting place, but also during the time related to the technical stop for the rectification measures.

A major cassette machine shortcoming is also the fact that it should be a careful seedling size selection to the total mass, root system selection and all that for their proper work. All the other seedlings are sorted out and they are planted manually. Usually, the allotment of such materials is about 50% (**Bartenev, 2012, Yermakov, Tulej, 2018**).

There is a technical automation solution of the planting process also known as potting the seedling. In this case, the seedlings are grown in special compartmented cassettes from where they are fed to the preplanned planting place. The same shape of pots directs the seedlings vertically that helps to use this property even better while charging. So, tackling quality dependency from the human capacity in the item-by-item selection (as it was mentioned early, a man can select 40-60 pieces per minute, without the proper selection homogeneousness and with the rapid fatigability because of the monotonous work), creates conditions for more suitable seedling location. For this purpose a certain planting material stock is created before the planting machine. The stock is maintained in special distributors (circular and revolving types (Fig. 17), or on slide boards (Fig. 18). At the same time, this stock is created by a human, but without any severe regularity requirements (the same amount of time between seedlings) and with the selection possibility in blocks, but not item-by-item. From there the seedlings with certain characteristics are being fed automatically into the planting machine. In the seeding planting such machines are called semi-automat. Thus, such devices can increase the productivity of the planting process significantly and improve the quality planting material flow to the planting place (exact location and coordinates). There is also a possibility to put the control mechanism under the poor seedling or its absence.



a b

Fig. 17. Planting machine of revolving (a) and circular types (b)

One more disadvantage is the construction complexity and the increase in the machine cost. In the case of slide boards it is also important to mention the possibility of plant transportation along their surface. The correct geometrical arrangement of slots allows using devices of the planting material coordinate selection. There are machines where the seedling range is pushed out by special pushers through the holes in the slide board bottom, and at the output the pots are picked up by special devices and directed to the distributors.

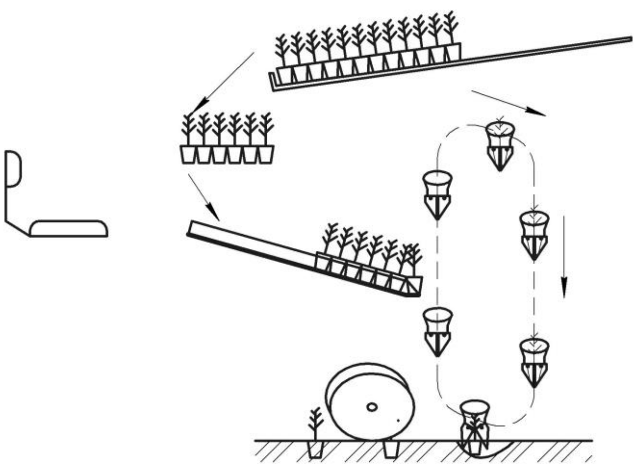


Fig. 18. Machines with the automatic feeding of seedlings on the slide boards

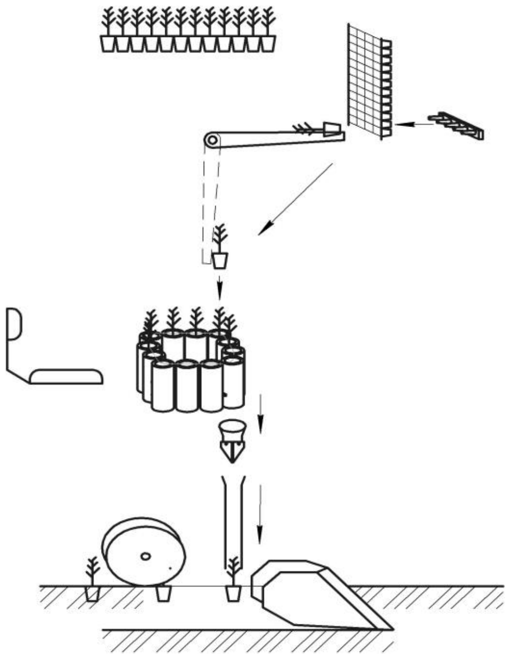


Fig. 19. Semi-automat machine for planting the seedlings

In separate machines for energy willow planting revolving distributors are marked with long rods. For setting potted plants in cassettes there are foreign machines al-ready, where a person should only monitor the timely cassettes replenishment, and all the rest happens automatically. The potted plants in these machines are pushed out of the cassettes by special pushers, which are usually preprogrammed on a coordinate cassette grid. After discharging from the cassettes the potted plants change their orien-tation to the vertical with the help of special lever devices, and are lowered into dis-tributing cradle, which being in such a position directs the seedlings to the planting site.

The labor costs for charging the cassette machines ribbons, as well as the incom-patibility of automation mechanisms for potted plants with requirements for planting seedlings and cuttings required looking for structures of cassetteless mechanisms. Their main problem is the seizure of plants from the hopper. There are many ideas still at the level of patents where this problem is solved differently, but the real design can be found in the form of a cassetteless seedling planting machine ABS-6 (Fg. 20). The main units of this machine are a hopper for seedlings in the form of a rotating cylinder with a rounded slit at the bottom for the passage of working elements of the seedlings picking mechanism, and the mechanism of seedling selection (**Zyma, Maliutin, 2006, Yermakov, 2018**).

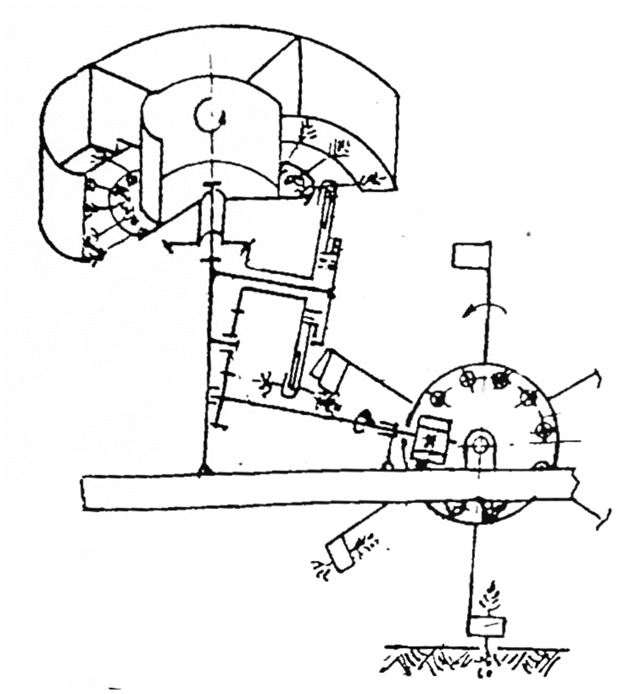


Fig. 20. Cassetteless seedling planting machine ABS-6

To ensure the proper functioning of this planting machine it is necessary to provide for a relatively well-ordered array of planting material in the hopper, that is, the initial formation of the single-piece flow of seedlings should be performed manually. While keeping orientation, grips carry them to the operation area of the planting machine grips.

2. Materials and Methods

The research was conducted on the basis of structural and factor analysis of technical solutions of existing planting machines. To distinguish the characteristic features of specific machines, we used the methods of object structuring and abstracting from those features that do not affect the research process.

Analyzing the selected schemes for the automation of planting mashins and imposing their peculiarities on the agrotechnical requirements for energy willow planting, we can develop a general algorithm for the operations necessary for automation of the process, with further recommendations on the possibility of choosing the appropriate scheme.

3. Research results and discussion

In all these machines the final result is ensured by the requirements for the installation and fixing of planting material in the ground. The main agrotechnical processes that are implemented during planting are shown in Fig. 21.

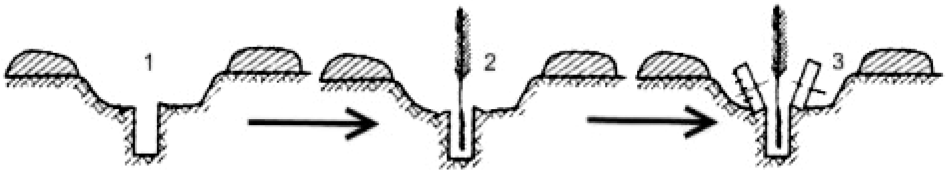


Fig. 21. The main agrotechnical processes during planting (Bartenev, 2017):
1 – the preparation of a place for planting in the form of an uninterrupted furrow or a row of seedbeds; 2 – the feed of planting material and its placement in the planting site; 3 – putting into the ground, and sealing along the line

Having analyzed the working process of existing forest and seedling planters in terms of the prospects for increasing the productivity and automation of the process implementing, let us consider process 2 (Fig. 21), since an interconnection between the initial state of planting material and its final placement into the soil takes place here, and that does not go without manual labor (**Yermakov, 2017, Hutsol, 2018**). In general, the technological process of transporting planting material from the place of accumulation to the planting site can be characterized by the implementation of the following working processes:

- extracting of planting material from working tanks;
- loading of planting material to the working element (or to the planting site at once);
- transporting of planting material to the planting site;
- fixation of planting material in the planting site (with necessary parameters).

These processes are interconnected in space and time with the general planting technology, as shown in Fig. 22.

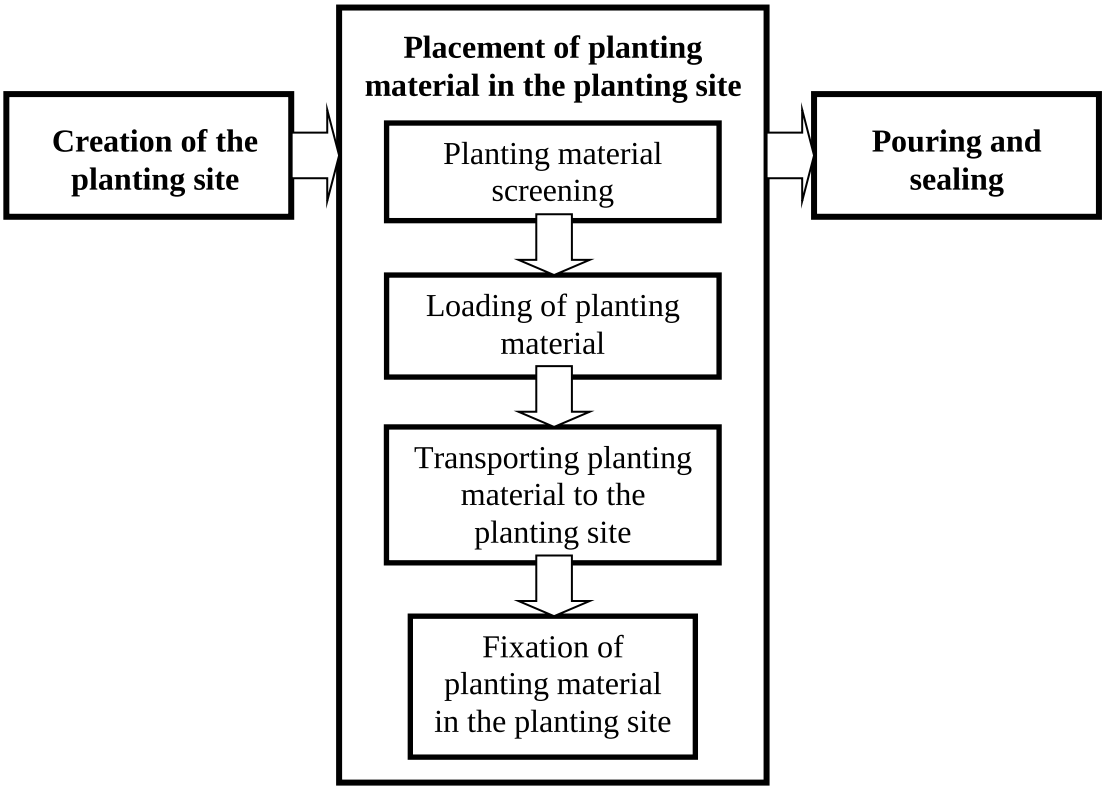


Fig. 22. Structural scheme for the planting process using forest planters and seedling planters

Analysis of working processes, that form the technological process of planting material feed and its placement in a planting site, will allow to substantiate constructive decisions what will provide the necessary parameters (speed, rhythm, etc.) of work, and find their optimal values.

Screening and transporting of planting material from working tanks is typically performed manually, which a significant obstacle to achieving the high work productivity that is needed in the planting of energy crops. Transporting of planting material to the planting site can also be performed manually, but in most cases it is solved by the equipment of plant setters with planting machines. There are several types of planting machines that can show different qualitative and quantitative indicators of the work done. That is why, while looking for possible prototypes for energy tree crops plant setters, it is important to distinguish the degree of adaptation of these or other types of planting machines to agrotechnical requirements for their planting.

The next step after determining the possibilities of using ready-made solutions for planting cuttings of energy crops is promising technological processes and operator body constructions for feeding cuttings automation in machines for planting energy crops is of current concern. This can be structurally represented by means of the following scheme (Fig. 23).

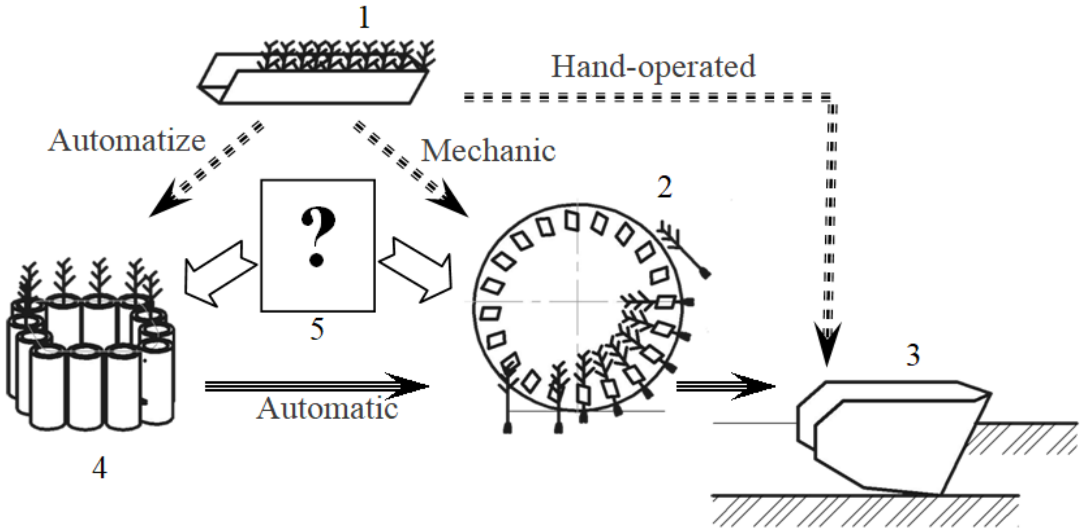


Fig. 23. Structural and logical scheme of the implementation of the energy willow planting process (**Yermakov, 2017**): 1 – seedling containers; 2 – planting machines; 3 – opening plows and deep furrow drills; 4 – seedling pool; 5 – feeding cuttings machines

In Fig. 23 the question mark is allocated the position, which is responsible for feeding the cuttings from containers with seedlings to places of planting. In modern machines for planting energy willow, this process is performed exclusively by hand. A fundamental solution to the problem of planting at higher speeds, reducing the share of manual labor for maintaining planting machines and improving working conditions is possible by transferring the functions of humans to automatic systems for the implementation and regulation of the technological process of planting (**Yermakov, 2017, Hutsol, 2018**).

Today, scientists are working on solving the problems of planting seedlings, forests, gardens and vineyards in such directions:

- Providing planting machines operation process at high speeds;
- Reducing the cost of manual labor for the planting machines maintenance;
- Improvement of working conditions.

It is possible to solve these tasks by transferring the functions of planting machines to the automatic implementation systems and regulation of technological planting process. By now, we have already accumulated some experience in the design and application of the machines that feed plants to the planting machine grabs. Automation tools can be conditionally divided into the following types:

- Pools with grain boards or distributors;
- Machines with flexible or hard cassettes;
- Cassetteless machines.

All of them have both advantages and disadvantages, but it is impossible to use these constructions for planting energy wood crops. The main distinctive factor is the type of planting material. Energy crops are planted with cuttings in the length of 20-25 cm and a diameter of 8-20 cm, which substantially differs according to its characteristics from plants with an open root system, or seedlings in the pots.

Having analyzed various designs, we came to the conclusion that in order to increase the productivity of planting machines, the process of feeding the cuttings from the containers to the planting machine needs to be improved. Also it is necessary to use intermediate cutting pools, which creates a buffer that compensates for the discrepancy between the planting machine productivity and human capabilities. But this solves the issue of productivity increasing and reducing the proportion of manual labor only partially.

Creating mechanisms for automated cutting feeding to the planting machine or directly to the planting site is an important scientific task in increasing the productivity of planting machines.

Due to the analysis of literary sources and electronic resources, the experience of some manufacturers of gardening equipment, we have synthesized the general structural and logical scheme of possible options of the technological process of feeding the cuttings (Fig. 24).

In previous studies, we have found that when the bodies are moving in the hopper, such phenomena as cluster formation, distortions in the horizontal and vertical plane, jamming and the like take place. We suggest carrying out such operations for the implementation of technological process:

– to ensure free rustling of cuttings from the hopper;
– to provide a narrowing of the flow;
– to create a single-piece flow;
– picking up cuttings from a single-piece flow;
– ensuring the correct cutting orientation during the movement.

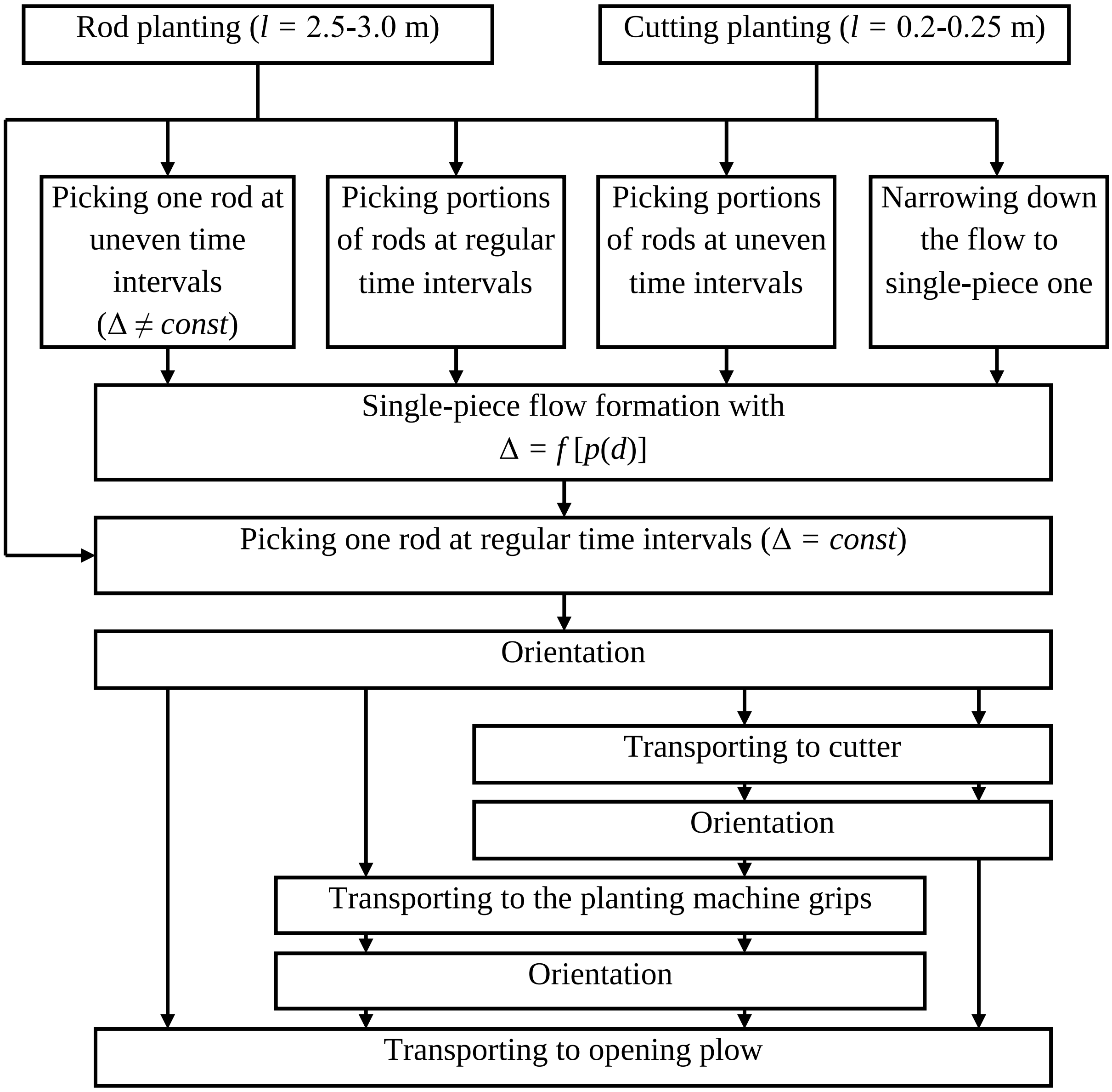


Fig. 24. Structural and logical scheme of possible options of the technological process of feeding the cuttings

4. Conclusion

Having analyzed various designs of forest planters, seedling planters, and the machines for planting the cuttings for energy crops, we came to the following conclusions, that the reason for the low productivity of forest and seedling planting machines is manual labor in the process of placing planting material in the planting site, that can partially be solved by the use of planting machines of different types.

The search for analogues in seedling and forest planting machines allows to suggest that some designs and principles of action are promising for use in the design of energy crops plant setters. In our opinion, radial, sprocket and conveyor planting machines, and also disk units of rigid design.

A promising direction is to reduce the proportion of manual labor when feeding planting material by using rods in length of 2-3 m and installation on each line of the mechanism for cutting the cuttings, however, the procurement of such material can not always be ensured due to the peculiarities of the willow itself and due to the logistics of storage, transportation, preparation of such long-lasting materials.

In order to increase the productivity when planting pre-cut cuttings, it is necessary to create mechanisms for the automatic feeding of cuttings to the planting machines or directly to the planting site.

As a result of the design analysis of existing means of planting automation and implementation methods of automated process of the planting material feeding, we managed to allocate possible ways of organizing different methods in the technological process, which is reflected in the structural and logical process scheme. The promising ways of automation of energy crops cuttings planting are singled out, which require taking into account:

– the biggest problem while creating the planting machines is the automation of planting material feeding process from the storage container to the planting site;

– it is most appropriate to look for the solution for energy crops cuttings in cassetteless machines;

– when making solutions, we encounter such problems as cluster formation, distortions, and so on;

– allocation of the process structure will allow for a systematic approach to finding a solution.

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CHAPTER 5

PROSPECTS FOR IMPLEMENTING A BIOGAS PROJECT IN UKRAINE

Abstract

The fact that such natural energy resources as oil, gas, and coal are limited has long been known to mankind. But despite this, the consumption of the above-mentioned resources to ensure living standards is constantly growing. This is typical, first of all, for developed industrial countries, which account for a large share of energy resources consumed. The continued use of fossil fuels and the impact of greenhouse gases on the environment increases interest in the production of alternative fuels from bioresources every year.

The implementation of the biogas project includes all the work, starting from the idea, planning of the installation up to its commissioning and analysis of feasibility. From the very beginning of the development and implementation of a biogas project, the initiator can, depending on his participation and available resources in the field of personnel and finances, take over the implementation of various stages of the project. The phases of finding an idea, analyzing feasibility, further preparing an investment, as well as the stages of obtaining permits and building an installation with its commissioning are discussed below.

Ukraine, like a number of other countries, considers achieving energy security as a priority goal for today, which justifies the need to develop the energy sector. The current state of the sector is most affected by the destruction of the infrastructure of the oil, gas and coal industry, the shortage of certain types of energy resources, the lack of commitment to diversify the supply of certain types of energy in the conditions of high price volatility on world markets, the high monopolization of certain segments of the energy market of Ukraine, as well as the unwillingness of industry and the consumer market to increase energy prices. Ukraine's energy dependence on energy imports is 60-70%.

Key words: renewable energy sources, biogas, biomass, bioenergy, energy crops, energy resources, carbon dioxide

1. Introduction

The amount of greenhouse gas emissions into the atmosphere is increasing, with carbon dioxide (CO_2) being the main factor. In addition, global energy demand is growing rapidly, and most of the energy currently produced is based on fossil fuels. This is primarily due to the growth of the world's population. According to the UN report "World demographic forecasts 2019: key points", it is predicted that by 2050 there will be about 9.7 billion people living on Earth. The next global factor is the limitation of natural reserves. We should only expect an increase in the consumption of these resources, which may lead to complete exhaustion of oil and natural gas in the next 25-30 years.

Moreover, the security of energy supply is a critical issue, since most of the natural energy resources (i.e., oil and gas reserves) are located in politically unstable regions. Protecting climate and resources are global challenges that require efforts to address them at the global level (**Hilpert, 2018; Ohnmacht, 2021; Kapoor, 2019; Saeed, 2019**).

Industrialized countries with a high need for fossil resources can play an important role in this process. An increasingly decisive factor in the aggravation of the problem of energy supply is the growth of industrialization and urbanization of such global giants as China, India and other Southeast Asian countries.

The consequence of these factors is a sharp increase in prices for gas, crude oil and petroleum products. If food production is prioritized, a significant contribution to solving these problems can be made by agriculture and forestry, through the provision of renewable resources for use in energy production. In this context, biogas from waste and residues can play an important role in the energy future.

2. Theoretical background

The use of alternative energy sources has a global perspective for the further successful development of civilization. In the world there are phenomena that disrupt the stability of civilized development of society: depletion of traditional energy sources, increasing the cost of their extraction, intensively polluting the environment, destroying the biosphere, generating excessive amounts of organic waste of industrial, agricultural and domestic origin. All these problems must be eliminated at an accelerated pace.

Many scientific works of economists are devoted to the development of bioenergy and the use of alternative energy sources. Among them are the works of O. Haufe, G. Geletukha, H. Lins, M., D. Spaar, O. Shpychak, H. Strubenhoff, H. Stroebel, H. Schultz, M. Trommler, S. Silva and other scientists.

The theoretical basis of the study were the works of leading domestic and foreign scientists in the development of bioenergy, namely the production of biogas.

3. Materials and Methods

For our analytical study on the prospects for the development of biohydrogen projects in Ukraine, we used materials from existing bioenergy foundations in Ukraine and Europe. Among the domestic organizations are the Bioenergy Association of Ukraine (UAIBO), which includes the well-known Scientific and Technical Center "Biomass" and the public association "Agency for Renewable Energy". We analyzed the situation in bioenergy today and the role of biohydrogen in the bioenergy development of our country and the world.

Of the special research methods used in the work are: abstract-logical - in the study and research of the development of the problem of implementation and development of bioenergy; generalization - in assessing the current state of development and use of alternative energy sources from biomass; computational and constructive, graphical, proportional dependences of indicators - in the study and identification of dependencies between the studied indicators.

4. Research results and discussion

Bioenergy is actively developing in Ukraine. In 2017, biofuels and waste account for the largest share in energy production from renewable sources - 80%. Thus, according to the Bioenergy Association of Ukraine, the total reserve of primary energy from biofuels and waste in 2017 amounted to 3046 thousand tons of oil equivalent, which is equivalent to replacing about 3.8 billion m^3 of gas.

According to the energy strategy of Ukraine, by 2035 Ukraine intends to reduce the amount of fossil fuel consumption and increase the share of renewable energy sources from 6.7% (in 2017) to 25% (in 2035) of the total primary energy supply.

There is a need to ensure efficient operation of renewable energy sources and their integration with existing energy systems. The concept of an integrated power supply system consists in combining elements of the energy infrastructure, in particular those related to providing consumers with electricity and heat.

The development of bioenergy is very important for Ukraine as it has a significant potential of biomass, which is available for energy production. Biomass in Ukraine is enough to replace imports of gas, gasoline and coal (about 23 million tons oil equivalent).

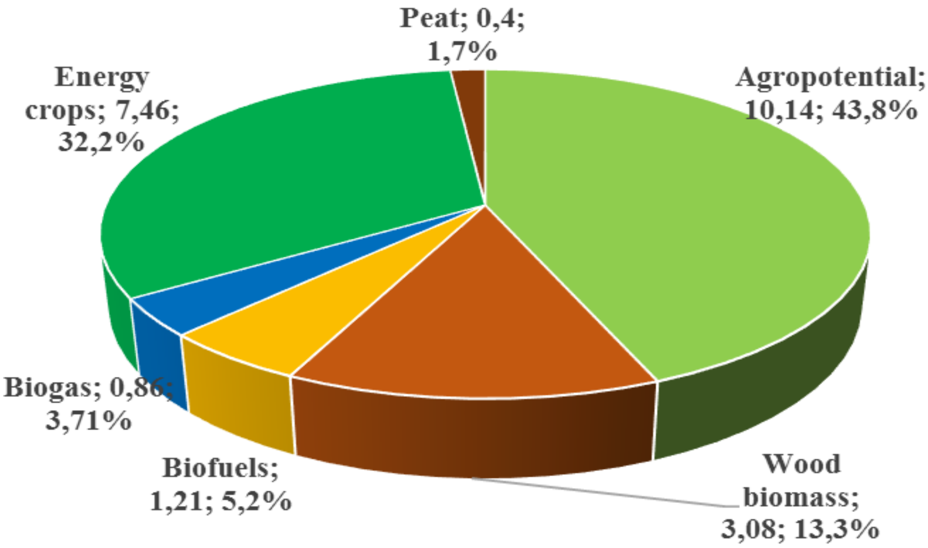

Fig. 1. Bioenergy potential of Ukraine, 2018 (million tons oil equivalent). Source: according to the Bioenergy Association of Ukraine

So, the development of the biofuel production industry in the context of a shortage of its own energy resources and significant energy consumption in Ukraine is a crucial necessity of our time, which can positively affect the development of the economy as a whole, increasing the level of output of goods with high added value. As well as to stimulate the development of related industries and agricultural production in particular. In addition, as world practice shows, a significant social effect from the development of biofuel production is represented by the creation of additional jobs and an improvement in the standard of living of the population.

The formation and rapid development of the biofuel market in Ukraine is a requirement of our time. After all, the possibility of reducing the energy dependence of our state through the production and sale of biofuels exists and has good prospects to become one of the important priorities for the development of the Ukrainian economy.

Table 1. SWOT- analysis of bioenergy production in Ukraine

Prospects	Disadvantages
- waste management; - development of agriculture; - large potential reserves; - improving the ecological state of the country; - diversity of energy crops; - recoverability; - creating new jobs; - reducing energy dependence; - great potential; - variety of applications.	- competition in the market; - soil erosion; - transportation of biomass to the processing site; - insufficient support from the state; - dependence on natural conditions.
Odds	**Threats**
- changes in legislation; - ability to export; - favorable natural conditions.	- reduction of food production volumes; - negative impact of energy crops on soils.

SWOT-analysis identifies the following key biofuel policy needs for Ukraine:

- investment in development programs and science to study this topic more deeply and develop new technologies;
- incentives to convert uncultivated land into productive land for the production of, for example, energy crops;
- tax exemption;
- investment in biofuel infrastructure;
- creation of government agencies.

The development of energy from renewable sources, especially liquid biofuels, should be the main goal of Ukraine's energy policy.

The reasons for this are:

- renewable energy plays an important role in reducing carbon dioxide (CO_2) emissions;
- increasing the share of energy from renewable sources contributes to ensuring energy security by reducing Ukraine's dependence on imported energy sources;
- in the future, renewable energy sources will become economically competitive compared to traditional sources used today;
- the contribution of energy from renewable sources contributes to the development of the agro-industrial sector, contributes to the creation of new jobs.

The most attractive strategies are those that arise at the intersection of the field of strength and opportunity:

– strategy for improving energy security, using our own organic raw materials for conversion into energy resources and using energy;
– strategy of using the existing potential of agricultural raw materials to turn into an energy resource with the subsequent sale of the resulting product and attracting additional labor resources;
– strategy of diversifying our own production program and access to new markets.

Biogas is a multi-purpose renewable energy source that can replace conventional fuel for heat and electricity generation. It can also be used as a gaseous fuel for automotive purposes. Biogas and its production technologies are an important part of sustainable energy supply (**Perederiy, 2016; Trommler, 2016**).

Ukraine has good prerequisites and sufficient potential for dynamic development of the bioenergy sector. The main drivers of this process are the constant increase in prices for traditional energy carriers and the presence of a large potential of biomass available for energy use.

This topic makes it necessary to develop the renewable energy sector, given the country's high dependence on imported energy carriers, primarily natural gas, and the large potential of biomass available for energy production.

The intensification of production and industrialization of agriculture in most countries of the world has led to a significant deterioration in the ecological state and an increase in the consumption of energy resources. In the current conditions, it is necessary to study in more detail the efficient use of alternative energy sources. The most promising tool is solar energy accumulated in biomass, which accumulates in greater quantities in agricultural production in the form of animal waste and plant residues. In addition, it should be noted that livestock farms are currently the largest sources of atmospheric pollution. Their activities are also associated with high and usually inefficient energy consumption. Therefore, the technology of anaerobic methane fermentation of organic waste is one of the options for a comprehensive solution of environmental, economic and energy problems of the agro-industrial complex. This technology is implemented in bioenergy plants and is a complex process that, on the one hand, provides fuel, liquid and solid fertilizers, and on the other, has a versatile environmental protection effect.

But the cost of their introduction and insufficient incentives from the state do not allow owners to fully assess all the positive aspects of owning a biogas plant.

This technology, implemented at bioenergy plants, eliminates bacterial and chemical pollution of the environment, allows you to obtain fertilizers enriched with potassium, nitrogen and phosphorus compounds, as well as biogas - a combustible gas based on methane, with which local issues of heat supply to enterprises can be solved.

Today, bioenergy is one of the largest sources of renewable energy, providing the need for heat, electricity, and fuel production. Energy can be obtained from wood, energy crops, biomass residues, and biogenic waste **(Kovalenko, 2020; Silva, 2017).**

These goals are achieved in the EU countries with the help of effective means of supporting and encouraging farmers to introduce biogas plants. The main element of support is the eco-tariff, under which owners of biogas complexes sell electricity to the wholesale market. Subsidies are provided from the state budget. Connecting the “green” tariff provides for a guarantee of connection to the network, a long-term contract for the purchase of all energy produced, and an increase in the cost of electricity produced.

Thus, the use of alternative energy sources and biogas technologies requires state support, especially at the stage of formation. Ukrainian legislation today has the following main mechanisms for stimulating the production of renewable energy: a “green” tariff, tax benefits, a preferential regime for connecting to the electric system, and Customs benefits.

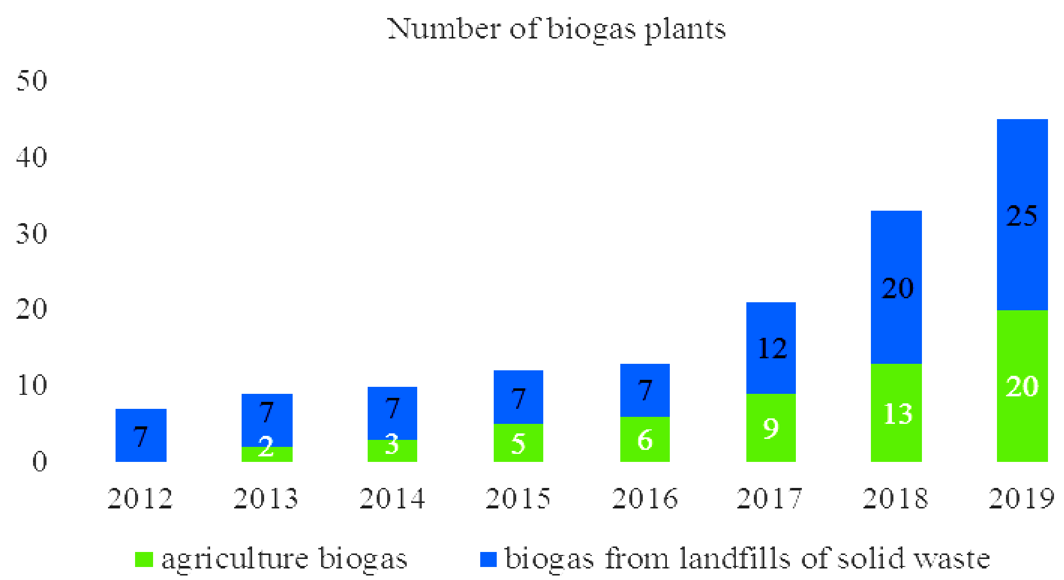

Fig. 2. Dynamics of growth of biogas capacities in Ukraine. Source: according to the Bioenergy Association of Ukraine

Currently, the best deterrent to the implementation of biogas projects in Ukraine is the almost lack of profitable long-term lending, difficulty in connecting to the electric and gas system, non-compliance of the project with the established payback periods, and the unstable political situation in the country.

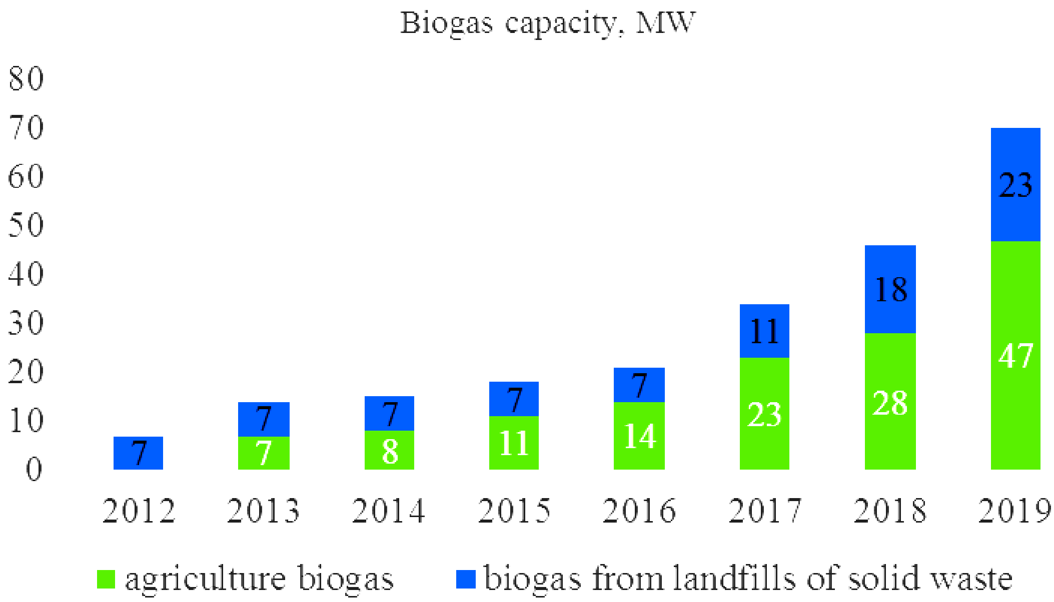

Fig. 3. Dynamics of growth of biogas capacities in Ukraine, MW. Source: according to the Bioenergy Association of Ukraine

When evaluating the efficiency of a biogas plant in other countries, such general production indicators are calculated as: the benefit of selling electricity at a "green" tariff, the benefit of selling fertilizers, and the benefit of abandoning centralized energy consumption.

A special feature of Ukrainian legislation is that the described problem makes the market for selling electricity produced at both large and individual biogas plants inaccessible to farm owners. In addition, there is still no market for biofertilizers in Ukraine, despite the fact that there has been a lot of discussion about its necessity for a long time.

Based on the above, it would be appropriate to calculate the efficiency of biogas plants in the conditions of the Ukrainian market to reduce the benefits of obtaining biogas (reducing the cost of main production, reducing funds for the purchase of mineral fertilizers, increasing the number of crop production, increasing the competitiveness of own products). In addition (**Kuzmenko, 2015; Thrän, 2020; Yermakov, 2018**), the purpose of the operation of the biogas plant is to obtain electric and thermal energy, as well as their consumption by the owner of the biogas plant.

Anaerobic cleaning of the substrate has the following positive side effects:

– Due to the biological transformation of organic matter into mineral compounds, the quality of fertilizers is improved. This makes nutrients more accessible for use in agriculture;

– Reduction of the greenhouse effect due to the replacement of fossil energy sources with biogas obtained from the substrate;

– Destruction of microbes and weed seeds;

– Use of the substrate as a high-quality fertilizer to maintain the mineral balance of agricultural land. Thus, organic materials are returned to the biological cycle.

So, anaerobic processing of biomass as a result forms high-energy biogas, improves quality and produces high-quality mineral fertilizers.

The experience of designing and operating methane fermentation plants shows that the methodology for determining the ecological and economic effect of the introduction of biogas plant should take into account the maximum possible range of positive factors, while reducing the minimum possible costs for its introduction.

Additional profit 1 from the use of biogas is that commercial biogas can be used as fuel for the needs of the economy, for electricity generation or other purposes. The biogas plant requires from 30 to 70% of the allocated biogas for its own needs (heating of incoming raw materials and compensation of methane heat losses).

Additional profit 2 determines the cost of additional crop production obtained through the use of nutrients from the released sludge.

Liquid fermented effluents after sludge separation contain a certain amount of nutrients, with appropriate organization they have their own temperature close to the temperature of methane fermentation, that is, they are a low-temperature heat carrier. Drains can be used for irrigation, as a substitute for irrigation water with simultaneous introduction of nutrients into the soil, for preheating the input material. It can also be used to remove manure with a drain or independent manure removal system, instead of industrial water, etc. Thanks to this, it is possible to get an additional profit 3 from the use of fermented mass effluents.

The cost reduction (additional profit 4) for the export of manure is due to the transportation of the liquid part of the effluent through the pipeline, instead of removal by mobile transport (in the case without division into fractions) and the reduction of waste storage costs before their use.

Thus, having all the values of the components Profit 1, Profit 2, Profit 3, Profit 4, it is possible to determine the annual ecological and economic effect:

$$E = P1 + P2 + P3 + P4 + PD - C \tag{1.1}$$

PD (preventive damage) - economic damage as a result of reducing the level of environmental pollution and improving sanitary and hygienic conditions.

Costs C include the cost of commissioning a biogas plant (capital investment) and the cost of operation (maintenance staff salaries, capital and current repairs, depreciation charges).

The analysis of calculations made using this method shows that the share of preventive damage PD in the structure of the ecological and economic effect is from 30% to 50%, but due to the lack of reliable data, all the positive factors of methane fermentation technology are not taken into account.

Positive factors include:

– destruction of weed seed germination in processing processes, which is accompanied by a reduction in the use of herbicides and an increase in yield;

– reducing the morbidity of the population due to effective disinfection of raw materials, destruction of helminth eggs and pathogenic microflora, reducing the use of mineral fertilizers, anticipating the infection of animals with helminths, given that infected animals lose weight from 10% to 15%, while consuming more feed.

It should also be noted that in addition to all these positive factors, the development of biogas technologies in Ukraine has a huge potential. The total determined capacity of biogas plant can be about 820 MW (electricity) and 1100 MW (heat).

The potential of Ukraine in the development of biogas production is huge. Our state has a well-developed agriculture, the waste from which provides an excellent raw material base. According to the state agency for energy efficiency and energy saving, the use of only 37% of waste from livestock and crop farms will produce more than 10 billion cubic meters of gas.

We especially note the importance of creating biogas stations based on livestock complexes. The common practice of storing industrial waste (manure) in open piles or lagoons leads to environmental degradation in nearby areas. Disposal of manure in huge quantities is expensive, and fines for violating sanitary standards also amount to large amounts. Obtaining biogas from manure becomes not only a way out of this situation, but also a way to get additional income from the sale of heat and electricity.

For example, here are calculations of the potential for gas production from livestock waste.

Table 2. Potential of biogas production from livestock waste in Ukraine, 2020

Animal type	Energy potential, million tons of conditional fuel		
	Theoretical	Technical	Economic
Cattle	2.21	1.68	0.09
Pigs	0.31	0.29	0.03
Poultry	0.58	0.35	0.23
Total	3.10	2.32	0.35

Source: according to Ecodevelop

To ensure stable uninterrupted operation, it is better to provide for the possibility of mixed raw materials - plant and animal. Thus, the biogas plant, which runs on agricultural waste, will be evenly loaded throughout the year, and the production of biogas will become a manageable and predictable process.

It is estimated that the potential of Ukraine in the production of biogas from waste from agricultural companies, the food industry, landfills and wastewater is up to 3.2 billion cubic meters of methane (CH_4) per year.

Having studied the regulatory framework of Ukraine on the territory of using alternative energy sources, we can conclude that, due to its imperfection, farmers do not have the motivation to use farm waste and put into operation biogas plants. In this situation, the main role should be assigned to the state. The problem of waste has also not been solved to date. Ukraine, which has a huge potential for biomass, uses renewable energy sources only by 2%. The introduction of biogas plants, if not completely solve, will at least reduce the country's energy dependence (**Kovalenko, 2020; Kuzmenko, 2015**).

The ecological and economic effect of biogas plant's work today, in our opinion, should be reduced to the calculation of the output from obtaining its own biogas and biofertilizers. It follows from the calculations that, despite the significant costs of introducing biogas plant, there is a large ecological and economic effect, which indicates the efficiency of the biogas plant.

The methane content is the main indicator of the quality of biogas. Carbon dioxide dilutes biogas and reduces its energy performance. Along with these gases, the mechanism of biochemical processes of methanogenesis also includes reactions leading to the release of hydrogen, which, in the final composition of biogas, is no more than 1%, since it interacts with CO_2 and turns into methane. One of the reasons for the increase in the CO_2 content of up to 55% in the composition of biogas may be an insufficient amount of hydrogen formed for the biochemical conversion of the CO_2 / H_2 mixture to CH_4. Therefore, an important condition for improving the efficiency of biogas production is to understand the processes and develop technologies that can increase the methane content in biogas in order to increase its energy value. A high result can be obtained in several ways: optimization of biogas production technology, selective purification from excess gases (CO_2, H_2S), additional introduction of hydrogen during methanogenesis. Recent studies show that the introduction of biologically active compounds that promote the development of methanogenic bacteria is a promising direction that increases the yield of biomethane (**Geletukha, 2013; Geletukha, 2014**).

Within the framework of the modern concept of double efficiency of production improvement - environmental and Economic, there are approaches to improving the efficiency of biogas production from agricultural waste (**Perederiy, 2013**). They include: continuous improvement of production technological parameters of biochemical processes and equipment, search, development and implementation of the best technological solutions. Improving the efficiency of biogas production from agricultural processing waste is based on the analysis of the mechanism of biochemical transformation of organic raw materials and the formation of biogas during fermentation. The process of anaerobic fermentation to form methane takes place in two main stages: methanogenic and acetogenic (acidogenic).

At the first, acidic stage, due to the hydrolytic decomposition of organic substances, acids and alcohols are formed, which is accompanied by the release of a certain amount of products: carbon dioxide, hydrogen, carbon monoxide. At the acetogenic stage, hydrogen is formed.

The concentration of hydrogen formed has a great influence on the regulation of the amount of products in the biochemical processes of methane formation. Carbon dioxide, as a result of such reactions under anaerobic conditions, forms methane molecules. Thus, with the help of microorganisms, carbon dioxide is converted to methane and used to create the cellular substance of methane bacteria. Therefore, we can conclude that carbon dioxide, which is contained in the composition of biogas, can be considered as a product of incomplete biochemical interaction of the microflora of the biogas plant with organic components.

5. Conclusion

Ensuring efficient production in agriculture, combined with the transformation of bio-raw materials, requires the interaction of a set of technological, technical, economic, organizational, managerial, social and other types of enterprise activities, diversification of production activities, entering the market of a new type of product, improving the environmental status of the enterprise location and should be the goal of management decisions on the transformation of organic raw materials.

Bioenergy is an important area for improving the competitiveness of the economy and preserving the environment, creating opportunities to ensure the balanced development of the industry.

The development of non-traditional and renewable energy sources should be considered as an important factor in improving energy security. There is no large-scale use of the potential of such energy sources in Ukraine yet. That is why increasing the number of bioenergy projects for the use of alternative (renewable) energy and fuel sources is one of the main areas of implementation of the state energy saving policy in Ukraine.

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CHAPTER 6

PROSPECTS FOR PROCESSING OF AGRICULTURAL RESIDUES OF AGRICULTURAL CROPS (BIOMASSES) AND POTENTIAL OF SOLID FUEL PRODUCTION

Abstract

Presents research aimed to determine the potential of waste biomass from. Raw material for research came from the central part of Ukraine. Studies have shown that agricultural crops residues are a valuable raw material for the production of solid biofuels in the form of briquettes or pellets. Values of quality parameters (such as calorific value, durability, density) are comparable to those found in commercial solid biofuels. The physical characteristics of the analyzed raw materials were made together with the production of pellets. The quality assessment of obtained pellets and analysis of ash fusibility were carried out. The obtained results allowed to show that the use of residues from growing crops production for the production of solid biofuels is highly justified both for agrotechnical reasons and due to the parameters of the obtained fuels. The growing interest of agricultural producers in the processing of crops in Ukraine means that the potential of these raw materials should be taken into account when balancing energy resources.

Key words: soybeans, corn, bean, buckwhheat, fennel, biomass, biofuels, energy crops, energy resources

1. Introduction

The world's projected depletion of major fossil fuels (oil and gas in the next 30-40 years) and environmental factors are prompting most developed countries to seek alternative non-traditional renewable energy sources. (**e.g. Ovcharuk, 2018**).

The catalyst for this search was a new rise in world oil prices. According to experts from the UN Development Program, the share of renewable energy sources in the global fuel and energy balance in 2050 may reach 50%, and according to the World Energy Council - up to 80-90%. At the end of this century, Germany and Sweden plan to get all 100% of their energy from renewable sources (**AEBIOM, 2011**).

The most real substitutes for petroleum fuels are solid biofuels - biomass of high-yielding perennials, as well as by-products of crop production and forestry. (**Dubrovina V.O., 2009, Havrysh V.I., 2007, e.g. Geletukha G.G., 2014, e.g. Ovcharuk, 2020**).

In the modern developed world, a lot of energy is used: for household needs, transport, industry. Fossil fuel combustion is the most common way of producing energy. However, they are released into the air CO_2, SO_2, NO, heavy metal oxides, solids and dust. Consequently, CO_2 - a major component of greenhouse gases, contributing to global warming. Acid gases SO_2, NO form acid precipitates, degrade air quality. Combustion of fossil fuels, including motor fuels, is a source of approximately 80% of pollutant emissions (e.g. Ovcharuk, 2018).

2. Theoretical background

The use of biomass for energy production already accounts for about half of all renewable energy sources in the world, reaching 70% in Europe, 64% in Sweden, 33% in Denmark and Austria. In 20 years, biomass prices will be as well calculated as coal, oil or gas. Experts expect that investments in the market for growing energy crops will grow to $25 billion by 2020 (**Publication of the European Commission, 2013, Report by AEBIOM, 2013, e.g. Melnychuk, M., 2007**).

Among renewable biofuels, solid biofuels occupy a significant share. Potential is the use of crop waste, namely untreated or with minimal preparation for incineration: sawdust, wood chips, bark, husks, husks, straw, etc. (**e.g. Kaletnik H. M., 2008, e.g. Geletukha G.G., 2014**).

Every year in Ukraine 2 million tons of conventional fuel are used for energy production. The main contribution is made by wood - about 80% of the total biomass. The energy potential of cereal straw and rapeseed is least actively used. Therefore, the search for fuel that can replace the practical properties of oil, but will not pollute the environment, is an urgent task. At least in part, this can only provide biofuels (**Dubrovina V.O., 2009, Kravchuk O., 2012**).

The European Union is successfully achieving the 2020 target of producing 20% of its energy from renewable energy sources in gross final consumption. Over the past 10 years, this figure has risen from 8% to 14%. Countries such as Sweden, Bulgaria and Estonia have already met their 2020 national target (**Report by Eur Observ'ER, December, 2013**).

Today, the volume of biomass consumption for energy production in the European Union is more than 120 million tons of oil equivalent per year, and by 2020 the gross final consumption of biomass should increase to 138 million tons of oil equivalent per year (Fig. 1).

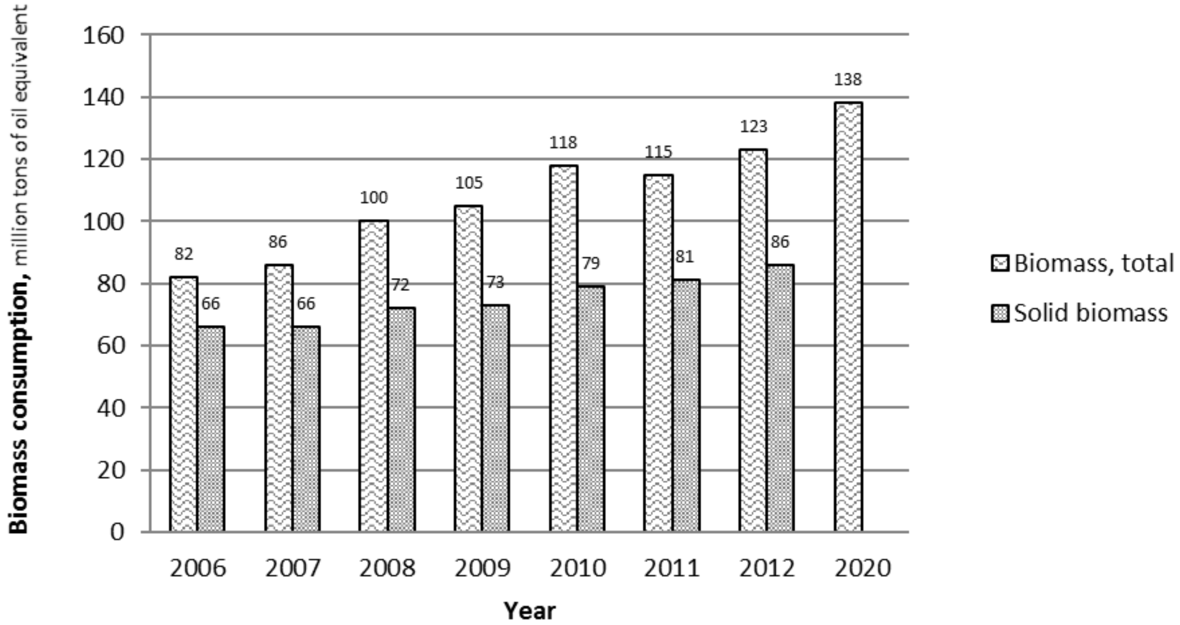

Fig. 1. Dynamics of total biomass consumption for energy production in the EU (**EU Energy in Figures, 2013, Kravchuk O., 2012**)

The main type of biomass used is solid biomass, which accounts for about 70% of total consumption. Wood remains the main type of biomass for electricity production in the EU, slightly less biogas and household waste (**AEBIOM, 2011, Kaletnik H.M., 2008, e.g. Geletukha G.G., 2014, Kravchuk O., 2012**).

From the beginning of the development of bioenergy in Ukraine for the production of biofuels preferred the use of raw materials available in agricultural production in the form of straw, plant tops, stems and rods of corn, sunflower stalks, rapeseed, wood and forestry waste (**e.g. Ivanyshyn V., 2018, e.g. Kozina**, **T., 2018, e.g. Ovcharuk O., 2020**).

At the same time, agricultural waste is a real part of the biomass potential that can be obtained in Ukraine. In addition, it was found that it is possible to predict the use of up to 30% of the theoretical potential of cereal straw and up to 40% of the theoretical potential of corn and sunflower production (**e.g. Kozina T., 2018, e.g. Ovcharuk O., 2020**).

The characteristics of such granules presented on the market of Ukraine are as follows: diameter 6-8 mm, working humidity 7.3%, ash content 2.6%, lower heat of combustion 4168 kcal/kg (17.4 MJ/kg). The cost of pellets at the end of 2015 was UAH 1,900/t including VAT. Also granular and briquetted biofuels are obtained from other parts that need to be collected from the field and delivered to the place of processing (**e.g. Geletukha G.G., 2014**).

According to the characteristics of ash melting, corn straw is close to wood biomass (for comparison: wood melting temperature of ash is about 12000°C), which provides better conditions for burning compared to straw of cereals. Also, corn straw contains less chlorine (0.2% by weight) compared to fresh ("yellow") grain straw (0.75% by weight). This is a positive factor in terms of the use of straw as a fuel, given that chlorine compounds cause corrosion of steel elements of power equipment.

In terms of elemental composition, corn straw is almost indistinguishable from cereal straw, so they have a comparable calorific value. The properties of straw strongly depend on the place of cultivation, the period of harvesting and weather, soil and fertilizers. Humidity has the greatest effect on the calorific value of corn biomass (**e.g. Ovcharuk O., 2020**).

In assessing the potential, it is extremely important to ask what share of waste (residues) of agricultural production can be used for energy needs without negatively affecting soil fertility.

Experts of the Bioenergy Association of Ukraine, having performed the relevant research, came to the conclusion that on average for Ukraine it is possible to predict the use of up to 30% of the theoretical potential of cereal straw and up to 40% of the theoretical potential of corn and sunflower waste (Table 1).

Table 1. Energy potential of biomass for solid biofuels in Ukraine (**Havrysh V., 2007**)

Type of biomass	Theoretical potential, mil. t.	The particle is available for energy, %	Economic potential, mil. t.n.
Straw of cereals	30.6	30	4.54
Rapeseed straw	4.2	40	0.84
Wastes of corn production on grain (stalks, cores of the beginnings)	40.2	40	4.39
Wastes from sunflower production (stalks, baskets)	21.0	40	1.72
Secondary waste (husk, pulp)	6.9	75	1.13

At the level of a particular agricultural enterprise or farm, this issue should be addressed individually, taking into account existing non-energy uses of straw and other vegetable waste (for example, the use of organic fertilizers, litter and livestock feed).

According to the proposed concept of development of thermal and electric biogeneration in Ukraine, the share of biomass in total heat production will be 14% in 2020 and 32% in

2030, and in electricity production - 1% and 4%, respectively. The contribution of biomass to the gross final energy consumption of the country may reach 4.3% in 2020 and 10% in 2030 (Table 2).

Table 2. The share of biomass in energy production and consumption by 2030, %

Indication	Factual 2011	Forecast	
		2025	2030
The share of biomass in gross final energy consumption	1.78	7.2	10
The share of biomass in	6	22	32
The share of biomass in	0.01	2.2	4
Substitution of natural gas, billion m^3/year	1.67	5.5	7.5

The proposed concept of bioenergy development is well consistent with the main provisions of the draft National Action Plan for Renewable Energy (**Rasporyazhenya KMU №1071 / 24.07.2013**). This Plan was developed by the State Agency for Energy Efficiency and Energy Saving of Ukraine in the framework of the country's fulfillment of its obligations as a member of the Energy Community.

At the present stage of development of society, the efficiency of production is largely determined by the limited natural resources of traditional energy sources, as well as the need to implement measures to protect the environment. Therefore, it is important to have a systematic approach to the study of the influence of natural factors on production, taking into account economic and social mechanisms of the relationship between human society and the environment in general and in agricultural production in particular. After all, agriculture itself can become a source of significant energy resources - biological raw materials. Bioraw materials must not only be grown, ie get a primary source of energy, but also converted into fuel with subsequent conversion into useful energy (**Varlamov H.B., 2003**).

That is why there is a need for environmental and economic justification of the concept of conversion of organic raw materials. It is impossible to reveal the essence of such a conversion without a detailed consideration of this process.

In the general sense of the term "conversion" (from the Latin conversio) - change, transformation, replacement of some objects of production by others or some tools to others (Diakina R., 2002). Conversion in relation to production characterizes a certain re-profiling of part of the production potential of the enterprise for the production of other products under the influence of radical changes in the market environment or global factors of economic development. This aspect involves changing the proportions of the distribution of financial, material, human resources between different sectors of the economy. However, from an economic point of view, conversion is not only the transfer of certain resources from one sector to another with the benefit of the future, but also the process of structural adjustment of the economy, and quite complex and dynamic (**e.g. Ohanian H., 2003**).

The concept of conversion in the field of agricultural production should also be considered from an environmental point of view. Ecological conversion is a condition for ensuring the right of everyone to live in an environmentally friendly environment (**e.g. Pysarenko V., 2008**). The ecological aspect of conversion is a possible transition to "waste-free" technologies, economical use of non-renewable resources, complete disposal of all types of waste before they enter the environment, and so on.

In agricultural production, the conversion requires consideration of the laws of the ecosystem. In particular, components of the agricultural ecosystem that were not previously used or returned only to the primary cycle of agricultural production should be used at least partially in the secondary cycle.

The conversion of organic raw materials is the conversion of kinetic solar energy into potential energy of organic raw materials that can be used by humans as alternative energy. The conversion of plant biomass of agricultural origin means the conversion of plant biomass into an energy resource with economic and environmental effects without negative impact on other sectors of agricultural production. A necessary condition for the rational conversion of organic raw materials is the creation of "waste-free technologies" with maximum efficiency and a reasonable direction and method of conversion.

The definition of "waste-free technology" is quite conditional, because it is impossible to create a completely waste-free production, it would be contrary to the laws of nature. However, it is necessary to minimize the amount of waste, ensure their comprehensive recycling and use environmentally friendly disposal or storage systems. We believe that the waste-free production model is a certain ideal design that can be used in research, but cannot be fully achieved in practical use.

Although the introduction of "waste-free technologies" into the production process is possible only conditionally, this concept is widely used in the scientific literature. There are several approaches to defining such technologies. The United Nations Economic Commission for Europe (according to the Declaration on Low-Waste and Non-Waste Technologies) understands non-waste technology as "the practical application of knowledge, methods and tools to ensure human needs for the most rational use of natural resources and energy and environmental protection". Ensuring "waste-free" production requires a combination of technological, technical, economic, organizational and managerial, social and other measures.

The processes of agricultural raw material production are currently being transferred to the waste-free production cycle, which is based on the integrated use of natural raw materials and waste. Recycling technology is introduced, which is a technological process in which waste from one production becomes a raw material for another (closed-loop technology) environment. (**e.g. Pysarenko V., 2008**).

However, in agricultural production, production waste should be understood as the remnants of raw materials generated in the manufacture of basic products, which at the exit of the production process have no consumer value, the latter they acquire only as a result of additional work. In agricultural production, waste-free technology is the process of production of basic products, conversion of by-products with the simultaneous restoration of fixed assets.

The achieved level of development of science and technology makes it possible to process almost all by-products and wastes of agricultural production. Thus, the reasons for the insufficient use of waste-free technologies are not so much in the absence of appropriate technologies, but in the lack of focus of agricultural enterprises on the waste-free type of production, which makes it possible to reconcile environmental and economic factors. It should be noted that ensuring "waste-free" requires additional organizational, economic and technological measures to implement the conversion of organic raw materials. Agricultural practices should take into account the above circumstances and develop effective land use and "waste-free technologies" to meet both food and energy needs. Given the shortage of traditional energy sources in Ukraine, the needs of agriculture in it can be largely met with the help of alternative energy sources (**Melnychuk M., 2007**).

The potential of biomass as a renewable energy source in Ukraine is quite large. Land resources that can be used for biomass production in Ukraine are larger than in the EU countries combined. According to the Law of Ukraine "On Alternative Fuels" biomass includes biologically renewable substance of organic origin, which undergoes biological decomposition (**Report by Eur Observ'ER, December 2013**).

In Ukraine, the potential of biomass as a renewable energy source is quite significant and amounts to 24 million tons of conventional fuel. The share of biomass in the total amount of renewable energy sources consumed in our country is about 13%. One of the main ways to reduce natural gas consumption in Ukraine may be the widespread use of energy production technologies from local types of organic raw materials, in particular, such as biomass. In addition, for many regions of Ukraine, the use of its own solid biofuel is more appropriate than coal or petroleum products, because biofuel produced from local raw materials is cheaper and does not require significant transport costs for its delivery.

Recent debates among scientists on the use of plant biomass of agricultural origin, especially in large-scale fuel production, are linked to fears that it will distract agriculture from food production. (**Ovcharuk O., 2020**).

Arguments regarding the use of straw as an energy resource should be analyzed taking into account the real situation in the world, country, region; with the provision and need for food, the level of use of agricultural potential, the dynamics of the potential of agricultural production, the advantages and disadvantages of energy production.

To determine the impact of the use of straw and stalks of cereals as fuel on the efficiency of production activities of agricultural enterprises, it is necessary to consider traditionally the main directions of their use in animal husbandry, crop production, as well as the possibility of using biofuels. In addition to these areas of attracting by-products for use in related industries of agricultural enterprises, in some cases it is burned simply in the fields.

Given that the use of biomass is based on stable, accumulated resources, we believe that the use of organic raw materials as an alternative energy resource will improve the use of natural resources in general. However, this requires increasing the energy efficiency of biomass use to obtain significant social and economic benefits in agricultural production.

Systems that use biomass for energy purposes can also ensure environmental development by reducing greenhouse gas emissions, as biomass is CO_2-neutral to the atmosphere when it is produced and used in accordance with environmental standards.

One way to release energy from biomass is through combustion. No matter how primitive this method may seem, it has not lost its relevance - because even now more than 50% of the world’s population meets their energy needs mainly through the burning of biomass. This technology is called direct combustion. This technology is simple, well studied and commercially available. In the chemical sense, combustion is the conversion of all organic materials into carbon dioxide and water in the presence of oxygen.

The heat obtained from biomass combustion can be used for heating and hot water supply, energy production, etc. One of the problems associated with the direct combustion of biomass is low energy efficiency, as when using an open fire, most of the heat is lost due to heat convection.

Combustion can be divided into 4 phases: boiling of water contained in biomass; release of gas (volatile) component; combustion of volatile gases, combustion of solid residues. The following conditions are necessary for efficient combustion: optimal combustion temperature; sufficient air; enough time for complete combustion (**Melnychuk M., 2012**).

However, in the presence of significant straw potential, direct combustion can lead to excess thermal energy, the implementation and disposal of which is difficult. In addition, there is the problem of transporting straw - due to the relatively low energy density of straw, transporting it over long distances is unprofitable. In addition, almost all types of "raw" organic raw materials decompose quite quickly, much of it is not suitable for long-term storage.

Therefore, producers need to choose and justify in advance the directions and methods of conversion of cereal straw into an energy-intensive, transportable product with the possibility of rapid implementation and improvement of the ecological state of the environment. The criterion for assessing the possible conversion of organic raw materials and the implementation of the process should be convincing economic calculations taking into account social and environmental aspects. Thus, the issue of conversion of organic raw materials becomes important economically and economically in view of reducing the shortage of raw materials and energy and restoring the environment. It is necessary to find ways to rationally use organic raw materials in general and plant biomass of agricultural origin, in particular from both economic and environmental points of view.

3. Materials and Methods

The study material was mustard residue containing both damaged seed as well as seed coat and stem fragments. The research material was obtained after processing the 2016 crops in Ukraine.

The test material was sampled and prepared according to the PN-EN 14778_2011e and PN-EN 14780_2011e standards. Based on prepared samples complex analysis of physicochemical parameters was performer. The estimated quantities were:

- Moisture content,
- Bulk density,
- Volatile matter content,

– Ash content,
– Higher and lower heating value,
– Mechanical durability of formed granulates,
– Specific density.

Moisture content M_{ar} [%] assigned according to the PN-EN ISO 18134-1:2015-11 standard. Material sample of weight aprox. 300 g placed in the dry container was dried in convective drier in 105°C ±2 for 4 h, or when mass will remain constant.

Bulk density BD [$kg \cdot m^{-3}$] of the raw material and produced pellets was measured according to the PN-EN ISO 17828:2016-02 standard based on measurement of sample mass, placed in the vessel with known volume.

Volatile matter Vd [%] determined according to the procedure proposed in PN-EN 15148_2010e standard. The dry crucible with lid filled with the test material (1 ±0.1 g), is weight (accuracy 0.0001 g) and treated in furnace for 7 min in 910 ±10°C.

Ash content [%] was determined according to the guides in PN-EN ISO 18122:2016-01 standard. The test sample was placed in the annealing dish, weighed (accuracy 0.0001 g) treated in furnace for 3 h in 550 ±10°C. Gross calorific value $q_{Vgr,ar}$ [$J \cdot g^{-1}$] and net calorific value $q_{pnet,ar}$ [$J \cdot g^{-1}$] were estimated on high class automatic, isoperibolic calorimeter C6000 produced by IKA. The measurement is made according to the PN-EN-14918:2010 standard, based on sample mass (accuracy 0.0001 g) and temperature difference.

Mechanical durability of briquettes DU [%] measurement was based on guidelines presented in PN-EN ISO 17831-2: 2016-02 standard and consisted of weighing the briquettes on the RadWag laboratory weight to the nearest 0.1 g andplacing them in tester drum. The mechanical durability test at a rotational speed of 21 rpm takes about 5 min (one test). After that briquettes were sieved through an orifice hole with a diameter of 32 mm to remove fractions created during crashing of the briquette. The prepared pellets were weighed using a laboratory scale to the nearest 0.1 g.

Mechanical durability of pellets DU [%] the test goes according to similar procedures as for briquettes in chamber appropriate shape and dimensions of the chamber in accordance with PN-EN ISO 17831-1:2016-02. The test chamber is smaller and rotates at a speed of 50 rpm. The duration of one test is 10 min. At the end of the test, the pellets are screened through an orifice hole with a hole diameter of 3.15 mm. Screening of the sample is made to remove fine fractions that have detached from the granulate during the test. The material remaining on the sieve is weighed on a laboratory scale to the nearest 0.1 g.

Specific density of the briquettes and pellets SD [kg/m^3] was assigned based on geometry measurements (height and diameter), made with use of calliper, and weight of the individual granules. The measurement was made on 10 randomly chosen granules.

Granulation of the samples to the briquettes was done using a POR ECOMEC Junior briquetting machine. It produces a briquette with a diameter of about 50 mm and a length dependent on the bulk density of the raw material (smaller density of raw material results in shorter length of briquettes and vice versa). This machine has possibility of regulation of the working pressure in the compaction chamber. When the pressure in the hydraulic system changes, the force that affects the piston changes as the pressure in the compaction chamber changes. The hydraulic pressure of the press is controlled by a sensor and could be also read on the pressure gauge. The agglomeration pressure was set at 47 MPa (the highest working pressure of Junior briquettes allowed for continuous work). Samples of pellets were made on Kovo Novak MGL 200 which is semi-industrial line for pelleting organic fractions with capacity up to 100 kg/h. According to the discernment of the market, the diameter of the designed pellet was set at 8 mm and the length of about 10-15 mm.

4. Research results and discussion

The conducted research allowed to collect important data allowing to assess the energy potential of the mustard residues and susceptibility to agglomeration processes. Table 3 shows the results of the basic material characteristics in terms of energy use. It need to be noticed that the value of the ash content over 12% suggests that there could considerable contamination of the raw material with mineral fractions (mainly soil).

Table 3. Results of qualitative assessment of raw material

Moisture content M_{ar} [%]	Ash content A_{ar} [%]	Net calorific value $q_{pnet,ar}$ [MJ·kg^{-1}]	Volotile matter V_{ar} [%]	Bulk density BD_{ar} [kg·m^{-3}]
11.2 ±0.08	12.75 ±0.4	16.48 ±0.12	68.2 ±0.56	195 ±4.6

The analysis of harvesting and post-processing technology of mustard plants showed that the source of pollution was the mineral fractions deposited on the plant during the vegetation season by atmospheric agents (rain and wind). The remaining tested parameters are satisfactory and similar to those of other recognized energy commodities such as cereal straw or miscanthus from energy crops. Raw material was then subjected to agglomerated to two forms briquettes (aprox. 50 mm diameter) and pellets (diameter 8 mm). One of the most important parameters determining the course of the process is the grain size distribution of the raw material. By analysis ofthe obtained data, it can be seen that the main fraction (35.1%) were particles that have been sieved through a screen with 8 mm holes and retained on a 3.15 mm hole sieve. The second main fraction can be distinguished by a geometry of 1.4-0.5 mm (sieved through a 1.4 mm sieve and sequentially stopped on a #1 mm perforated sieve and #0.5 mm) which together sum up to 42.1%. Such grain size distribution is proper for agglomeration processes. The contribution of both larger particles and smaller ones is essential for the proper formation of internal forces between particles, which determines agglomerates' durability (**Havrysh V., 2007**).

Conducted agglomeration tests both to form of briquettes and pellets results in good quality agglomerates. The detailed results are presented in Table 4. In both cases, high value of specific density, for pellets even above 1 g/cm^3.

Table 4. Results of qualitative assessment of granulates

Type	Mechanical durability DU [%]	Specific density SD [kg·m^{-3}]	Bulk density BD [kg·m^{-3}]
Briquette	94.3 ±0.2	936.5 ±15.8	479 ±19.5
Pellet	95.6 ±0.4	1146 ±25.1	683 ±14.4

The obtained results clearly indicate that using the classic methods of agglomeration it is possible to obtain from the tested raw material granulates with satisfactory quality parameters. The density of granules as well as their durability clearly indicate that it is possible to produce high quality granules in the form of briquettes or pellets on industrial scale, even for demanding purposes like heating plants or households usage (Table 5).

Table 5. Results of qualitative assessment of raw material

Properties of the raw material	Soybeans	Corn	Bean	Buckwhheat	Fennel
Moisture after harvest M_{ar} [%]	25.8	24.5	25.8	28.8	18.9
Bulk density after grinding BD_{ar} [$kg \cdot m^{-3}$]	12	9.1	11.7	10.6	87.3
Moisture after grinding M_{ar} [%]	132	212.4	164.3	95.4	13.5
Properties of the pellets					
Ash content A_{ar} [%]	8.9	2.7	11.5	7.3	6.6
Moisture M_{ar} [%]	11.5	7.3	11.5	8.9	10.5
Calorific vaule $q_{p.net,ar}$ [$J \cdot g^{-1}$]	15460	17174	17460	15341	17260
Bulk density BD_{ar} [$kg \cdot m^{-3}$]	594	627	614	591	548
The specific density SD [$kg \cdot m^{-3}$]	1149	1196	1189	1223	1129
Mechanical durability DU [%]	–	–	96.9	–	95.8
Properties of the briquette					
Moisture M_{ar} [%]	–	–	11.8		12.2
Bulk density BD_{ar} [$kg \cdot m^{-3}$]	–	–	484		492
The specific density SD [$kg \cdot m^{-3}$]	–	–	898		878
Calorific vaule $q_{p. net,ar}$ [$J \cdot g^{-1}$]	–	–	17460		17002
Mechanical durability DU [%]			94.6		93.6

5. Conclusions

The use of waste materials from various industries is a very important element in the energy sector economy. Raw materials often have properties imparted in processing processes that are beneficial from the point of view of their energy use (humidity, grain size, etc.). Therefore, the production of biofuels, including solid fuels, is often relatively inexpensive compared to the biomass obtained from targeted plantations. This is the case such types of raw material were examined.

Characteristics of the material predispose it to the conversion to solid fuels. Both briquetting and pelleting methods have shown great agglomeration potential. Depending on market demand (pellets, briquettes), the use of this raw material in production processes can be easily controlled. The results of our research have confirmed that in the agricultural residue sector have a high potential for fuels that can be quickly applied.

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CHAPTER 7

USE OF WASTE RAW MATERIALS FROM THE AGRI-FOOD INDUSTRY TO PRODUCE HIGH QUALITY SOLID BIOFUELS

Abstract

The production of solid biofuels is a very complex process. The quality of the pellets obtained as well as the production process itself depends significantly on the properties of the raw material. Therefore, it is very important to prepare the raw material properly so that high quality can be achieved with relatively low energy expenditure. In this study attempts were made to enrich the main raw material - sawdust of deciduous trees - with organic components acting as a binder. These raw materials were obtained as production residues from the agricultural and food sector. The results show that the addition of these components increases the mechanical strength of the pellets and reduces the energy consumption of the pelleting process.

Key words: woody biomass, fruit marc, cereal bran, brewers grains, solid biofuels, fuel quality

1. Introduction

Production of solid biofuels such as pellets, briquettes based on biomass raw materials of agricultural or forestry origin has been known for many years. These biofuels successfully replace traditional energy sources such as coal, natural gas or fuel oil. Pellet, for example, thanks to its properties (caloricity, flowability, homogeneity) has won both the retail and industrial market as a fuel for automatic energy systems. Currently, it is the fastest growing biofuel, enabling the development of many other economic sectors, e.g. the biomass machinery industry, raw material and finished product logistics, combustion equipment industry, etc. In addition, this sector directly interacts with the agri-food sector, providing additional opportunities for the use of raw materials (production residues, impaired raw materials, etc.), thus increasing the profitability of this sector. Therefore, countries where the agricultural sector is an important branch of the economy have a very large potential in the production and export of pellets to international markets. The development of fuel production based on raw materials that can be obtained from independent and dispersed sources increases the safety of their use. This translates directly into the perception of this fuel source by customers and experts as safe and stable. The development of solid biofuel production is also supported by national and European legislation related to obtaining energy from renewable sources. Currently, the use of biomass in the energy sector is significant and accounts for about 60-80% of energy production from renewable sources. Historically, biomass and solid biofuels have been a key source of energy for the developing European economy. In the EU28 countries, energy production from solid biofuels increased by 134% from 1990 to 2017 (Fig. 1). In 2017, primary energy production from solid biomass (excluding charcoal) was 3986 PJ, corresponding to 12.5% of total primary energy production and 69% of primary energy production from biomass (**Malico et al. 2019)**.

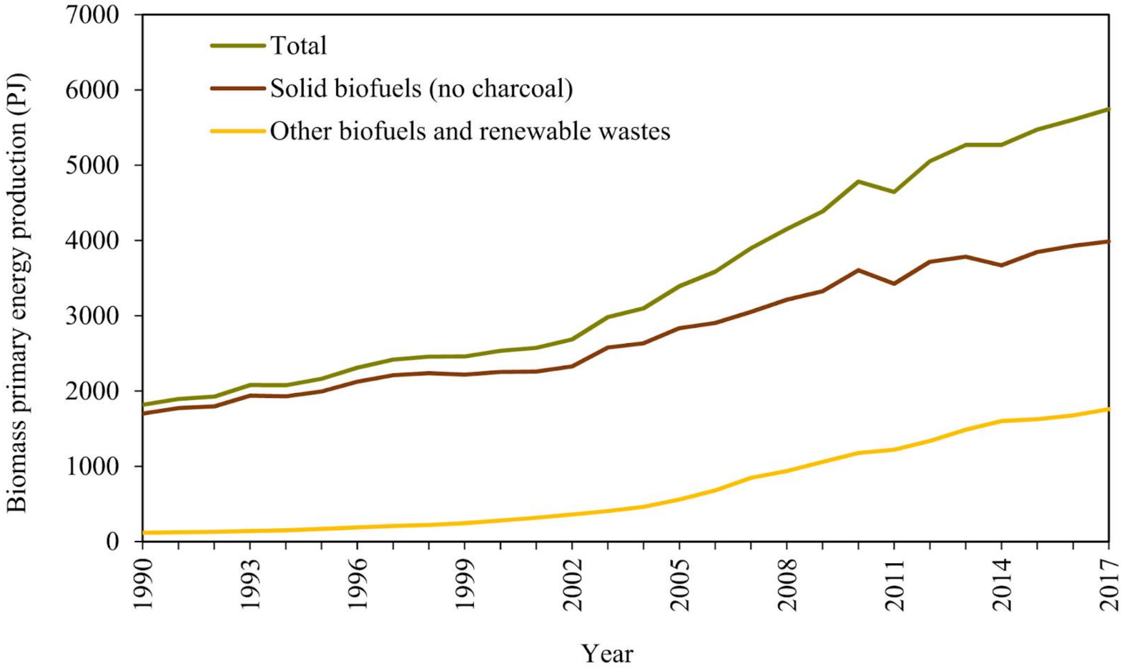


Fig. 1. Biomass primary energy production for UE28 from 1990 until 2017 (**Eurostat 2019; Malico et al. 2019**)

In 2017 22% of solid biomass energy in the EU28 corresponded to industrial final energy consumption (Fig. 2). Most solid biofuels were used in households and by the energy sector **(Eurostat 2019, Malico et al. 2019)**.

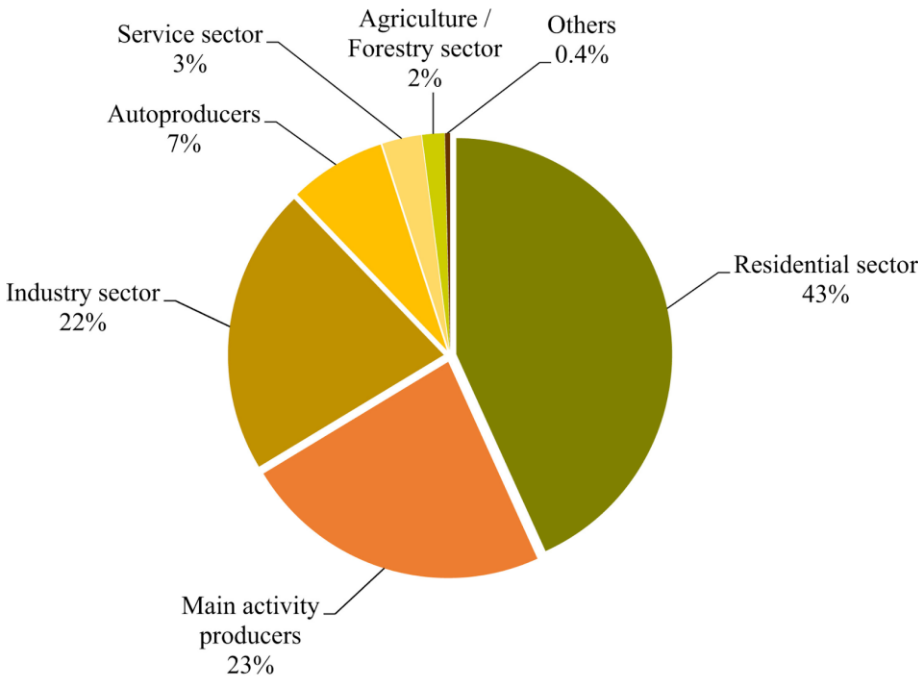


Fig. 2. Share of the different end-uses of solid biomass in EU28 in 2017 (**Eurostat 2019; Malico et al. 2019**)

Therefore, it can be concluded that European countries will continue to obtain a significant part of their energy from solid biofuels in the future. Taking into account the problem of CO_2 emissions in energy production, it is very important in the case of solid biofuels to minimize emissions in the processes of obtaining raw materials and the production and distribution of fuel. CO_2 emission in EU countries is subject to charges which, depending on the economic situation, range from EUR 25 to EUR 40 per tonne of CO_2. The main economic sector responsible for almost 75% of CO_2 emission is the power industry (Fig. 3). Therefore, the implementation of technologies and low-emission fuels is of key importance for the protection of the environment, but also will reduce emission charges.

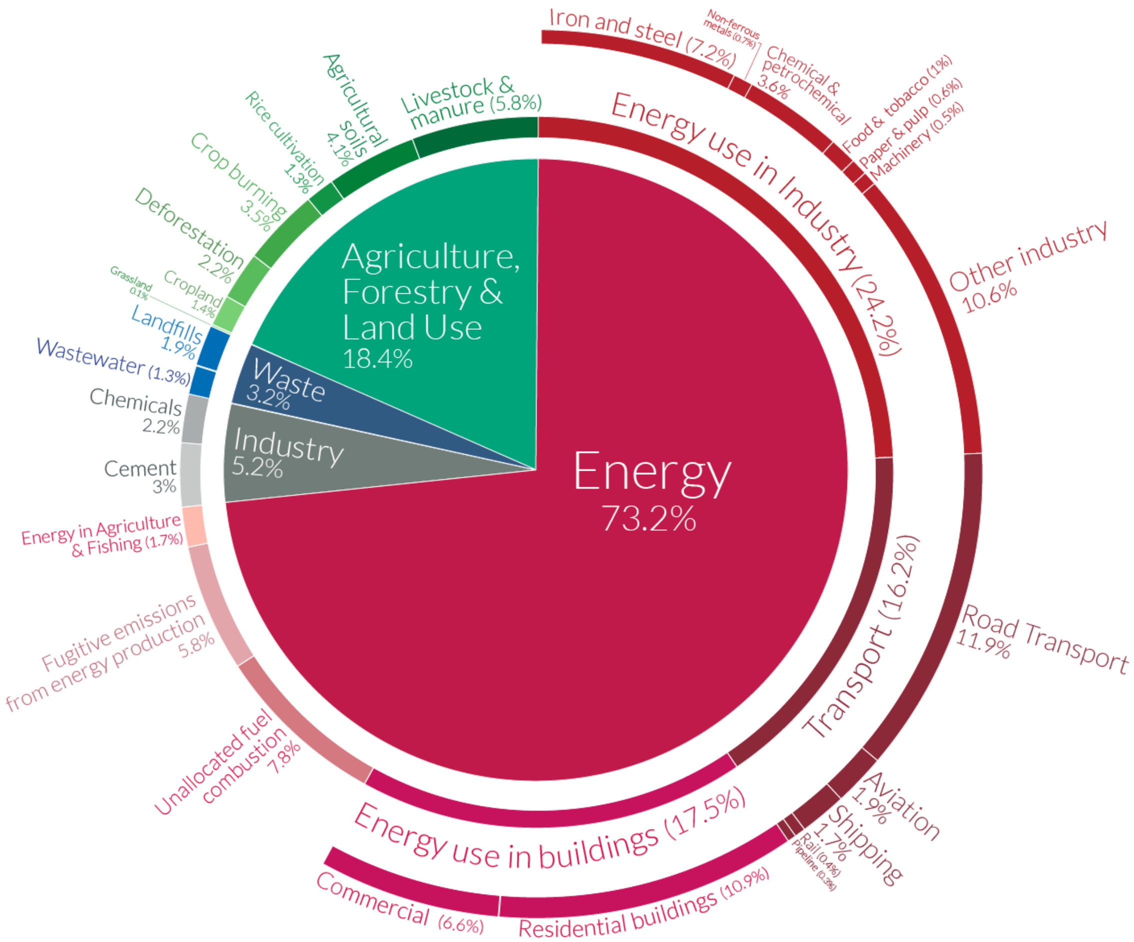


Fig. 3. CO_2 emissions by sector (**Ritchie, Roser 2020**)

Analysing the per capita CO_2 emissions for the three neighbouring countries Ukraine, Poland and Germany, it can be seen that in recent years, there has been a significant reduction in emissions, with Ukraine recording the lowest values. It should be noted that these values are significantly related to industrial production and the population of the country. Nevertheless, increasing the use of biomass raw materials in energy production on the basis of biofuels produced in Ukraine may be of key importance for the development of Central and Eastern Europe.

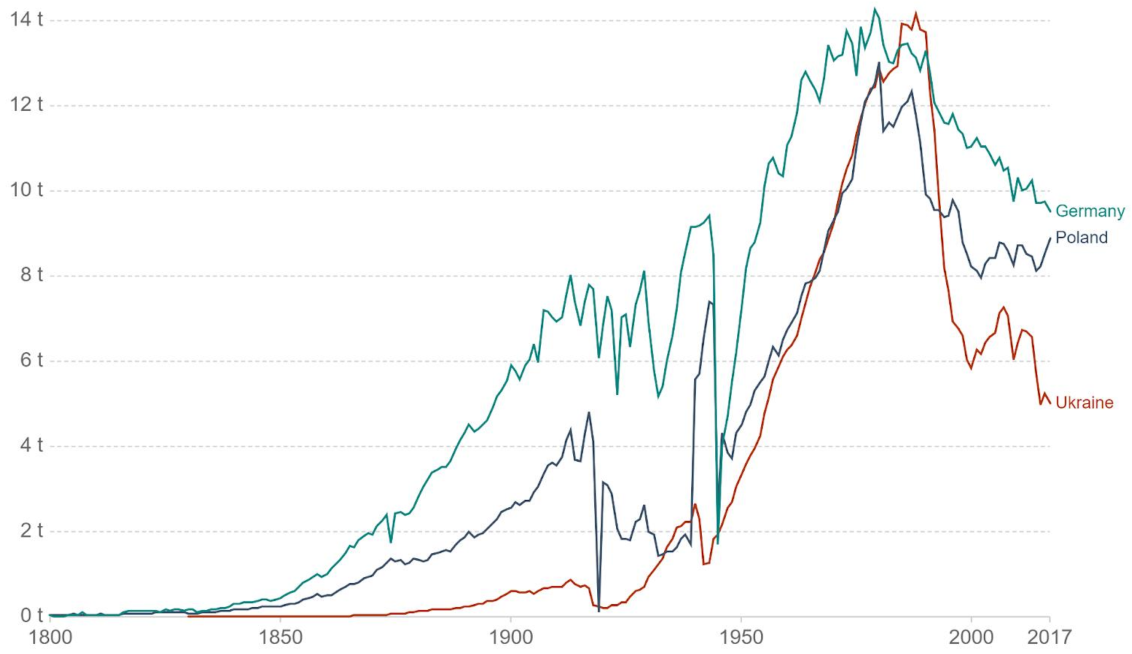
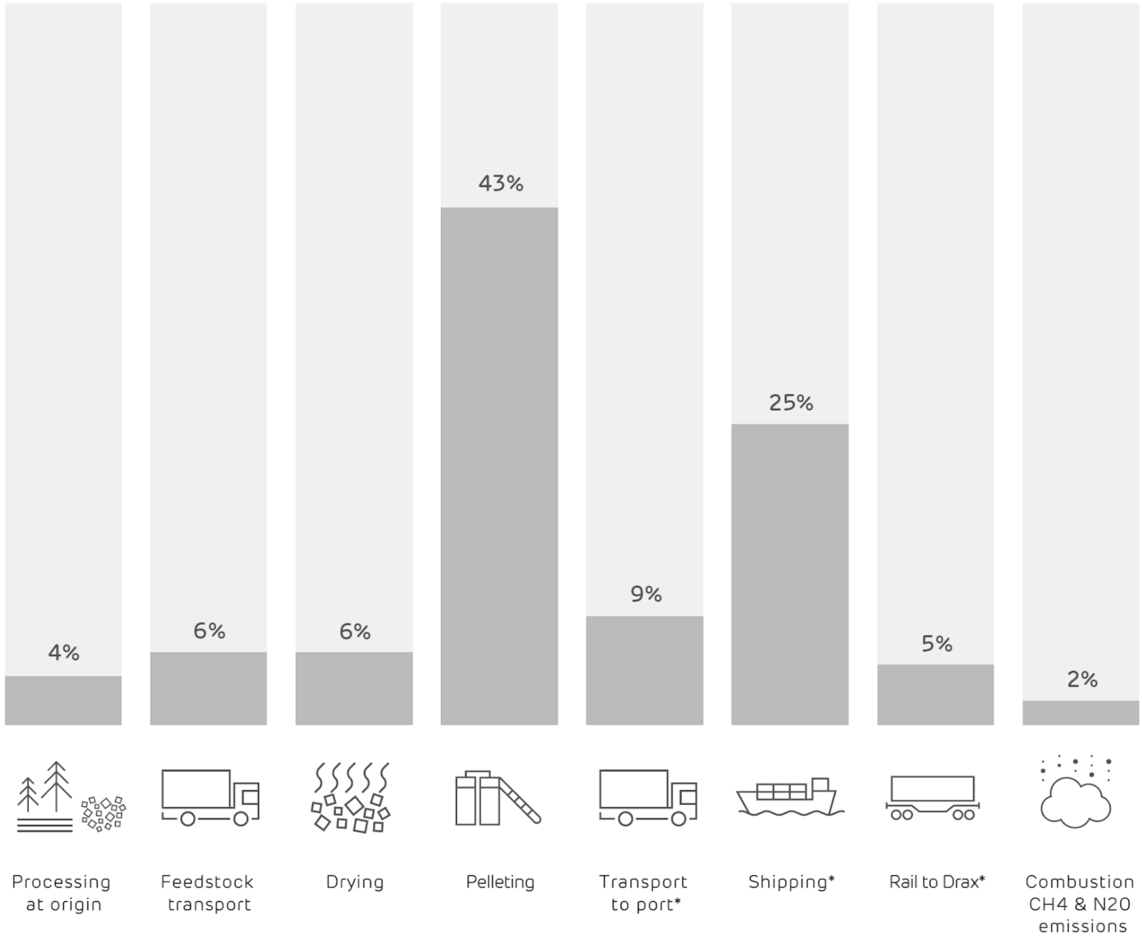


Fig. 4. Changes in per capita CO_2 emissions from fossil fuel combustion and cement production (**Ritchie, Roser 2020**)

GHG emissions expressed as CO_2 are associated with each step of the solid biofuel production process. Figure 5 shows the emission shares of each stage of the pellet biofuel production and distribution process. Noteworthy is the very significant share of CO_2 emissions from the pelletization process (about 43%) which is not entirely surprising. The pelletizing process is high-energy about 120-200 $Wh \cdot kg^{-1}$ where loose biomass is permanently formed into reproducible particles. A more interesting item is the CO_2 emissions from the rail and sea transport process. We see that the intercontinental transport process (North America - Europe) emits about 35% of the total CO_2. Therefore, it can be concluded that export over long distances makes the energy efficiency and thus the environmental effect significantly lower. Therefore, local markets for solid biofuels should be strengthened and their production from a given region (e.g. Europe) should be effectively distributed in a given country or neighbouring countries. The large raw material potential of Ukraine in solid biofuel production creates favorable conditions for international cooperation in fuel trade. These biofuels obtained in accordance with the principles of sustainable development allow to establish stable sources of fuel guaranteeing energy security of the region as well as profitable branch of industry for the Ukrainian economy.



Note: includes the biomass supply chain emissions associated with both Drax's direct operations (Pellet Production business) and third parties.
*These categories are aggregated in our Biomass Carbon Calculator (www.drax.com/sustainability/the-biomass-carbon-calculator).

Fig. 5. Power Station average biomass supply chain GHG emissions (**https://www.drax.com/annual-report/driven-by-our-purpose/#chapter-8**)

One of the most important issues in the production and application of particular biofuels is their quality and repeatability. Quality parameters determine the possibility of using particular biofuels in energy systems in an effective way. Obtaining the energy effect or proper functioning of automatic combustion systems of solid biofuels is the basis for the stable development of bioenergetics.

One of the most important parameters characterizing solid biofuels is their physical form (specific and bulk density) and mechanical strength. These parameters determine the course of logistic processes in micro (internal transport) and macro (international transport, national distribution) scales.

One of the ways to influence the quality parameters is to use natural additives with binder characteristics, which allow to increase and stabilize mechanical properties of biofuels and often also chemical properties (e.g. calorific value).

The additives used to improve the quality should be characterized by good energetic and proagglomeration properties. Such materials are residues from the agro-food industry, in particular from the processing of fruit fractions or seeds from the fat sector. Their addition of a few percent does not cause significant changes in the chemical composition of the biofuel, and allows control of mechanical properties.

The analyzed concept of energetic pellet production based on wood raw materials is based on the use of composed biomass blends allowing to control the quality of pellets obtained, as well as positively influencing the production process.

The base component of the mixture is woody biomass (coniferous) and the additives improving the quality are carefully selected raw materials obtained from the agro-food industry. These raw materials are characterized in the first place by reduced utility value in a given industry sector or have the status of the so-called production residue (economically justified product for energy use). The second very important feature is their adequate amount on the market, possible to obtain in a given period of time (this type of raw materials very often occur as seasonal products). Several components of production mixtures have been proposed, so that it is possible to carry out year-round production without significant risk of lack of their availability.

These components allow optimization of energy input while maintaining or increasing quality parameters of pellets. The quality assessment has been carried out on the basis of guidelines of European normative documents valid in Europe.

The main areas of advantage of the developed concept of technology for energy pellet production are related to the production process. It is assumed that the use of suitable components of raw material mixtures will allow to reduce energy expenses of the pellet production process, which directly allows to increase the competitiveness of this type of biofuel on the market. The second equally important area of advantage in comparison to the market products is the increase in the quality of the pellet e.g. through increased mechanical strength, which directly translates into reduction of the so-called crumbling. The occurrence of the mentioned crumbling is a disadvantageous phenomenon from the customer's point of view. Reduction of the chipping material will allow to reduce dust with biomass dust in the surroundings of the combustion installation (which will increase fire safety) as well as improve the automation of logistic processes.

The last area of advantage is the use in the production of energy pellets of raw materials that are production residues from the agri-food sector, often creating a burden for the environment through incompetent storage or use in other processes (e.g. for soil fertilization without proper preparation, etc.). The developed technology creates opportunities for appropriate management of a certain group of raw materials with proagglomeration properties.

2. Material and methods of measurement

Sawdust from deciduous trees was used as a base material in the study. This biomass represents a significant share in the balance of raw materials available in Ukraine, Poland and other neighboring countries.

Valorising additives

The following components of the raw material mixture were proposed in the conducted research:

- brewers' spent grains,
- rye and wheat bran,
- fruit pomace (apple, pear),
- middlings, rapeseed and sunflower pomace,
- residues from oilseed cleaning.

Brewers' spent grains

During the brewing process, brewers' spent grains, a very valuable by-product that is successfully used as feed, mainly for cattle, remain after the front wort has been filtered in mash tuns. Fresh brewers' spent grains contain 15-30% dry matter and are in the form of dense, moist cereal middlings, resembling moist barley groats (barley malt is usually used in beer production).

Due to the fact that the properties of brewers' spent grains depend on the type of input material (malt) and technological processes used in the brewery at the mashing stage, it is not possible to unambiguously define the expected properties, but only to give an approximate range within which the raw material may fall. In the case of granulation, a very important proagglomeration indicator is the lignin content, which is a kind of binder. For brewers' spent grains, the literature indicates values ranging from 11.9% (**Kanauchi et al. 2001**) to 27.8% (**Mussatto, Roberto 2005**). The upper value of the range is similar to that found for softwoods.

Table 1. Chemical composition and energy value of brewers' spent grains

Material	Protein [%]	Dietary fiber [%]	Fat [%]	Mineral components
Dry pulp	36.5-37.8	15.4-16.1	7.2-7.6	4.6-5.0
Wet pulp	7.4-10.3	3.1-4.4	1.4-2.1	0.9-1.3

Cereal bran

Bran - a product of cereal milling (wheat, oats, rye or rice) and buckwheat milling. Cereal bran consists mainly of the outer layer of grain, i.e. the fruit and seed layer. The main products of milling are: flour, groats and bran.

Cereal grains consist of four main components. On the outside is the fruit and seed coat, then the aleuric layer, which is directly adjacent to the main element, the endosperm and the germ. The bran is the outermost layer of the grain of cereal, rice or buckwheat and protects the endosperm. When the sacks of grain are delivered to the mills, the bran is removed from the grain and, depending on the destination (wholemeal flour, refined flour, coarse or fine groats), the aleur layer and the germ are removed or not. Thus, from the technological point of view, bran is a by-product obtained during the hulling processes of cereal grains, during the production of groats or flours of different types. In the industry of pellet manufacturers, vegetable residues, especially from the processing of cereal seeds, have been tested for many years.

Fruit pomace

Pomace - the residue of seeds, fruits, vegetables after squeezing out juice, oil, etc. They are suitable for cattle feed or for further processing as quality enhancing components.

The heat of combustion for apple pomace is about 19 $MJ \cdot kg^{-1}$ (Wojdalski, 2016).

Fruit pomace is a seasonal product and often a problem for processing plants. A big disadvantage of this raw material is its moisture content in the working state which reaches 75%. Nevertheless, the residual sugar compounds and lignin content make it an interesting substrate for blends to produce pellets for energy purposes.

Rapeseed and sunflower meal, cake

Rapeseed cake - a by-product (waste) generated during pressing of vegetable oil from rapeseed. It consists of pressing finely ground rape seeds, previously heated, using hydraulic work (deep hot pressing process). Despite the force exerted, oil remains in the material, increasing its calorific value. The cake is used primarily as a feed component and for energy purposes.

The main parameters of rapeseed cake:

- Calorific value: 20-25 $MJ \cdot kg^{-1}$,
- Protein content: 32-33%,
- Oil content: 10-11%.

Rapeseed meal - a by-product of rapeseed oil pressing combined with chemical extraction process. Produced in domestic plants, preferably from domestic rapeseed and GMO-free (does not contain genetically modified seeds). Content of total protein in middlings is stable and is about 36-38% (360-380 $g \cdot k^{-1}$) of dry matter. Fat content in middlings is 2-4% (20-40 $g \cdot kg^{-1}$) of dry matter. Crude fiber content, mainly cellulose in rapeseed feeds is: in middlings 11-14% (110-140 $g \cdot kg^{-1}$), and in rapeseed cake 9-12% (90-120 $g \cdot kg^{-1}$) of dry matter.

Residues from cleaning rapeseed

The research carried out on rapeseed harvesting process, among others by Rzepiński (2009), showed that the general level of contamination is about 1-4%, where the recipients allow 2% of contamination in the form of immature and overgrown seeds (Kachel-Jakubowska 2008).

These residues can be used in the energy sector obtaining multiple benefits. On the one hand, we obtain a high-energy biomass raw material characterized by proagglomeration properties, which can be used as a binder. On the other hand, the residues contain many weed seeds, which can be a problem when used as soil fertilizer. Thermal conversion makes it possible to carry out effective weed elimination. The calorific value depending on the fraction of seeds consisting mainly of damaged rape seeds and weeds ranges from 13.70 $MJ \cdot kg^{-1}$ to 20.89 $MJ \cdot kg^{-1}$.

To be able to properly design the raw material mixture, it is necessary to know the physicochemical properties of the individual components. Samples for analysis were taken and prepared according to the guidelines of PN-EN-ISO-14780_2017-07. The following measurements were made on the prepared samples:

- bulk density - EN ISO 17828_2015,
- moisture content - EN ISO 18134-1_2015,
- volatile matter content - EN ISO 18123_2015,
- the ash content in accordance with EN ISO 18122_2015,
- combustion heat and calorific value - EN-ISO-18125_2017.

The conducted laboratory research made it possible to determine the basic characteristics of the studied materials, which was the basis for designing fuel blends used in the production of pellets.

Table 2. Analytical results of individual fuel blend components

Raw material	Moisture content M_{ar} [%]	Ash content Ad [%]	Volatile matter content Vd [%]	Combustion heat $q_{V,gr,d}$ $[J \cdot g^{-1}]$	Calorific value $q_{p,net,d}$ $[J \cdot g^{-1}]$	Bulk density $[kg \cdot m^{-3}]$
	Reference state					
	working	dry	dry	dry	dry	dry
Wood sawdust - deciduous	47.3	0.45	75.2	19560	18895	234.5
Wheat bran	14.2	4.8	71.2	18890	17620	189.3
Fruit pomace	79.8	1.6	72.5	20620	19250	194.8
Brewers' spent grains	79.2	4.7	77.1	19876	18798	420
Rape seed post-extraction meal	8.2	6.2	67.4	20569	19576	580
Residues from cleaning rapeseed	12.2	7.2	65.2	21532	20646	395

Considering the above test results, the following fuel blends were proposed for the semi-industrial test stage (all components were stabilized at 12% water content):

– M-1-3 - 3% fruit pomace + 97% wood sawdust,
– M-1-6 - 6% fruit pomace + 93% wood sawdust,
– M-1-9 - 9% fruit pomace + 91% wood sawdust,
– M-1-12 - 12% fruit pomace + 88% wood sawdust,
– M-2-3 - 3% brewers' spent grains + 97% wood sawdust,
– M-2-6 - 6% brewers' spent grains + 93% wood sawdust,
– M-2-9 - 9% brewers' spent grains + 91% wood sawdust,
– M-2-12 - 12% brewers' spent grains + 88% wood sawdust,
– M-3-3 - 3% bran + 97% wood sawdust,
– M-3-6 - 6% bran + 93% wood sawdust,
– M-3-9 - 9% bran + 91% wood sawdust,
– M-3-12 - 12% bran + 88% wood sawdust,
– M-4-3 - 3% rapeseed pomace + 97% wood sawdust,
– M-4-6 - 6% rapeseed pomace + 93% wood sawdust,
– M-4-9 - 9% rapeseed pomace + 91% wood sawdust,
– M-4-12 - 12% rapeseed pomace + 88% wood sawdust,
– M-5-3 - 3% rapeseed residue + 97% wood sawdust,
– M-5-6 - 6% rapeseed residue + 93% wood sawdust,
– M-5-9 - 9% rapeseed residue + 91% wood sawdust,
– M-5-12 - 12% rapeseed residue + 88% wood sawdust,

The pelletization process was carried out on a laboratory installation (the manufacturer of this equipment Kovo Novak offers it as semi-industrial) MGL 200 from Kovo Novak for pelletizing organic fractions with a capacity of up to 100 $kg \cdot h^{-1}$. According to the conducted market research the diameter of the designed pellet was set at 6 mm and its length at about 8-12 mm.

3. Research findings and discussion

After preliminary tests a forming die with a channel diameter of 6 mm and a compression ratio of 4.75 was proposed. Depending on the type of pelleting machine, i.e. with a flat or annular die, the compression ratio should be determined on the basis of preliminary tests. The die is an operational element and most often it is adjusted to the given raw material but also to the technology that has been applied (type of mill, drying conditions, conditioner used, etc.). It is suggested that the output matrix should be characterized by the mentioned compression ratio i.e. 4.75.

The tests carried out on the above mentioned fuel mixtures showed that the enrichment of the wood raw material with the examined components allows for obtaining advantageous technological effects as well as for increasing the quality of the pellets obtained. Analyzing the results (Fig. 6) obtained it can be stated that the greatest influence on the analyzed parameters was obtained for the component that was the residues from rape cleaning. This component, due to the content of oily fractions, made it possible to achieve the effect of reducing the energy consumption of the pelleting process and at the same time increasing the mechanical durability.

The parametric effects of the components used are shown in Figure 6. The increase in durability of the pellets (**EN ISO 17831-1:2015**) obtained is of great practical importance to the user. This is because it translates into a reduction of dust during logistic processes. The last logistic link is the place where the pellets are fed into the combustion system, i.e. the boiler house. This is where the dust fractions from the packs cause nuisance for the equipment operators and increase the explosion risk. Therefore, achieving pellet durability above 97.5% is very desirable and can be a factor of market competition.

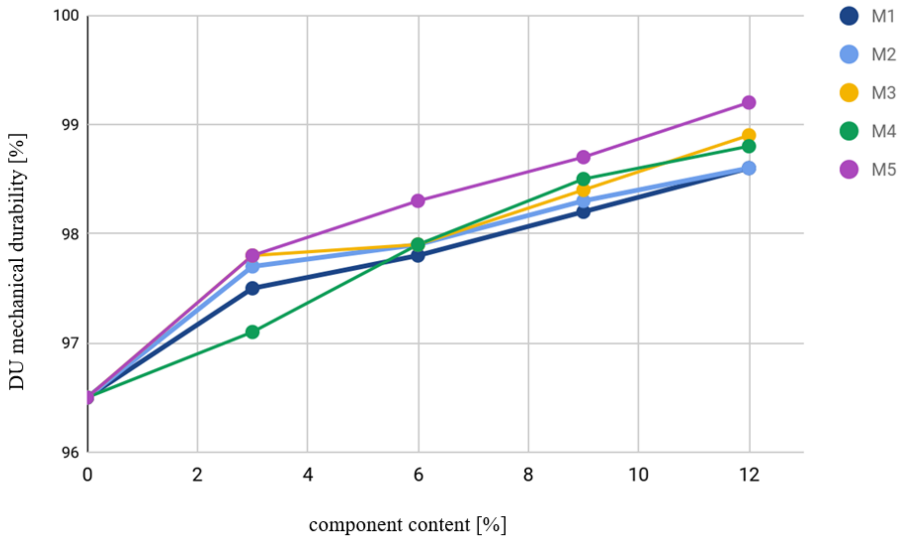


Fig. 6. Effect of tested fuel blend components on mechanical durability of pellets

Analyzing the results of the influence of the studied components on the energy consumption of the granulation proces (Fig. 7), it can be concluded that all additives to the mixtures showed a decrease in energy expenditure. Similarly as in the case of mechanical durability, the highest effect was observed for residues after sorting rapeseed. This effect is directly related to the profitability of production and also enables the producer to undertake more extensive marketing activities to promote the product on fuel markets. This few percent energy "profit" can be used to increase the quality of the pellets in order to achieve the upper quality values, which can be important in the so-called market competition.

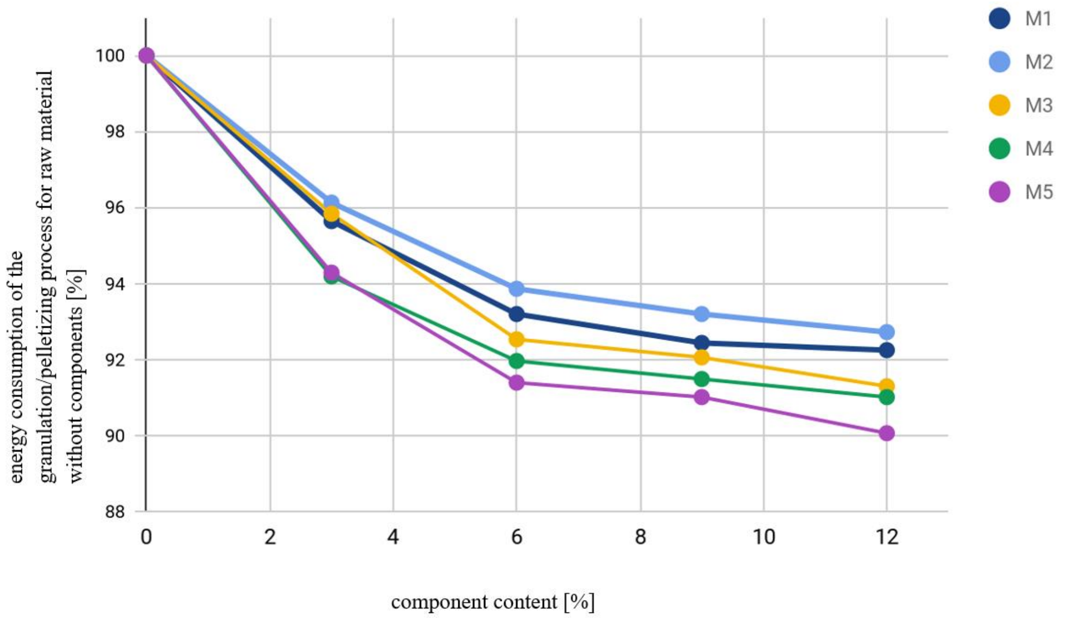


Fig. 7. Influence of the tested fuel mixture components on the energy consumption of the granulation process

Apart from the presented key process parameters as well as quality characteristics of the tested blends, tests were carried out to determine other pellet properties.

The tests of ash content showed that the base ash content in sawdust at 0.45% increased slightly. The highest increase was observed for pellets made from a mixture of sawdust and residues from rape seed cleaning. With the share of this component at 12%, the pellets were characterized by the share of ash at 1.05%. Other examined components did not cause increase in ash content above 1%, thus it can be concluded that the level of mineral fractions is very favorable for the production of high quality energy pellets.

Similarly, the calorific value, when the sawdust was enriched with the examined components did not decrease, and in most cases this parameter improved. The highest increase was observed for the component made of rapeseed cleaning residue (12% share) where the total calorific value was 19.1 MJ/kg.

The investigations conducted at this stage allow to conclude that the investigated additives allow to obtain high quality pellets that will meet the parameters of consumer pellets of EN Plus and DIN Plus quality systems (**Mudryk et al. 2021, Dyjakon et al. 2020**).

Summarizing the results obtained from the study, it can be clearly indicated that the addition of organic components can significantly affect the quality parameters important in logistics processes. The results also indicate that with the proper composition of raw materials for the production of pellets it is also possible to reduce the energy intensity of the pelleting process from 5-10%. The results of this study should be of key importance in the production of pellets exported over longer distances e.g. to neighboring countries. In addition, lowering the energy intensity reduces the emission of greenhouse gases, which could be important in the near future.

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