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Bioeconomy of resources used in biofuel production

Abstract: The main goal of the research is to develop recommendations for innovations in the field of production efficiency, processing of agricultural raw materials for alternative energy, to analyze the technological indicators of individual resources involved in the biofuel production process, to study the effectiveness of alternative technological solutions for bioenergy energy projects, and possible ways of developing bioenergy in Ukraine in the post-war period.

Significant depletion of agricultural land and, as a result, a significant decrease in the supply of humus and nutrients requires a review of the structure of the raw material base for bioenergy. It has been established that the level of energy consumption and energy income in the form of main and by-products depends on agricultural techniques for growing agricultural crops, their yield, the potential level of labor costs, fertilizers, energy carriers, and other production resources.

The results of a study of the efficiency of using organic raw materials for biofuel production and the potential for using primary and secondary products of the agro-industrial complex in biogas production were obtained. The conducted studies showed that the optimal raw material for obtaining biogas is corn and other raw materials with minimal protein content and high carbohydrate content.

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The main result of the research is the establishment of parameters of the model of the dependence of energy production volumes on the energy value of the by-products of the processing of oilseeds, grain crops, fodder, and other resources involved in the process of biogas model the efficiency of biogas production.

Keywords: biogas, alternative energy, bioresources, production efficiency, modeling

Introduction

Increasing the volume of production of agricultural products in Ukraine and the significant complication of its export require the development of an alternative strategy for the use of resources of the agro-industrial complex, in particular in the field of biofuel production. Optimizing the industry structure is another direction of rational use of plant and animal products. Considering the damage caused to the environment and climate by the war in Ukraine, there is an urgent need for a "green" reconstruction of the process of production and processing of agricultural products. Most Ukrainian and European experts are inclined to believe that after the end of the war, reconstruction with ecological sustainability at the core is necessary, as this is the only way to ensure prosperity in the long term. In particular, on September 5, 2022, the 8th meeting of the Ukraine-EU Association Council was held in Brussels, at which the need to achieve a "green" transition of Ukraine as part of reconstruction efforts was emphasized.

1. Literature review

Most of the research in the field of evaluation of food production as an alternative to obtaining biofuels has focused on the energy indicators of output from a unit of raw materials used for processing. As a result of the war in Ukraine, the area of agricultural land, abandoned by the owners and unsuitable for growing food crops, has increased significantly. Such lands can be used for biofuel production. In addition, raw materials for biofuel can be waste from agro-industrial production. This field of energy can be considered a temporary alternative to the production of biodiesel and bioethanol. The distribution of energy in Ukraine takes place between three sectors of the economy: heating and cooling (1/2), transport (1/4), and electricity generation (1/4).

The studies carried out in the conditions of the Agronomic Research Station showed that with a yield of corn hybrids VK69xG255, VK69xG255, AE801xVK13 more than 9 t/ha, it is possible to obtain 3.4–4.6 t of bioethanol, which is equivalent to 123–142 GJ/ha or use the specified raw materials for fodder production (8.6–10.8 thousand feed protein units) (Spryazhka and Zhemoyda 2022).

Ukraine has significant biomass potential, which is economically feasible for energy production. The main components of the potential include primary agricultural waste (straw, corn, and sunflower) and energy crops, the cultivation of which on an industrial scale is actively developing in the European Union (Kaletnik and Pryshliak 2019; Pryshliak 2019).

The composition of the organic matter of corn depends on a number of factors: the place of cultivation, climatic conditions, the hybrid of corn, the duration of the growing season, cultivation technology, and the method of silage of corn (Amon et al. 2007). In the EU countries, the share of use of vegetable raw materials for biogas production is 75.9%, of which 59.6% is corn silage. In addition to corn silage, sugar sorghum silage, sugar beet, clover, switchgrass, triticale, and a number of others are also used (Heiermann et al. 2009).

Due to the higher content of dry matter, the specific yield of biogas from a unit of applied silage mass of corn was higher by 33.7–50.6% compared to sugar sorghum and by 9.2–13.0% to a mixture of these crops. When calculating the yield of biogas and methane per unit area, the highest values (9.1–10.2 and 5.3–5.9 thousand m^3/ha) were obtained in variants of the joint cultivation of sugar sorghum and corn (Grabovsky 2019).

Prospects for further research in this direction will be related to the deepening of scientific developments regarding the search for new and most effective methods of using raw resources, the development of new technologies for the production and purification of biogas, gasification and methanization technologies, as well as the development of innovative projects in this vector of development (Palamarenko 2019).

The production of biogas from plant waste is an effective and investment-attractive technology due to the presence of significant raw material potential in our country, favorable natural and climatic conditions, and the low cost of this type of energy. However, Ukraine is at the initial stage of introducing the production of renewable energy sources, the scientific, technical, and economic problems of the production and use of biogas are insufficiently studied, which encourages the continuation of research in this direction (Tokarchuk et al. 2020).

The assessment of the energy potential of biomethane production in Ukraine is based on the analysis of the level of production of the main agricultural crops by agricultural enterprises, the products of the food processing industry, the available livestock, pigs and poultry at enterprises engaged in animal husbandry, as well as the volume of solid household waste and sewage of water in the communal economy. When evaluating the potential of biomethane production in Ukraine, the types of raw materials are taken into account, as well as the share of the total mass for biomethane production (Goncharuk and Vovk 2022).

Ukraine can meet its fuel needs with less than half of its own resources. A promising way to solve this problem is the use of non-traditional types of energy. The country has a great potential for biomass, namely agricultural waste, which is a cheap and accessible raw material for energy production (Resul'eva 2015).

The production of biomethane in Ukraine and the world is an innovative approach to solving the problem of energy dependence, which is characterized by more energy-efficient indicators compared to biogas (Okhota 2023). The European experience of stimulating biogas production is focused on reducing emissions of harmful gases into the atmosphere and is based on state subsidies and tax incentives. The formation of a system for the development of biogas production in Ukraine should be oriented towards the development of public-private partnerships with a focus on compensating the cost of appropriate domestically produced biogas production equipment. It is necessary to stimulate the development of biogas reactors in rural areas in order to provide biogas for personal peasant farms (Kolomiyets 2024).

Bioenergy crops are an important component of the energy potential of Ukraine, and their cultivation will have a number of positive effects, including the replacement of natural gas, which will contribute to the improvement of the balance of payments, the possibility of reducing energy tariffs for the population, land reclamation, and their restoration. Technologies for growing energy crops vary, but they are united by the ability to grow them on unproductive, degraded lands. It is expedient for enterprises to calculate the most economically advantageous option in accordance with specific business conditions and market conditions (Kaletnik and Tokarchuk 2021).

Prospective areas of research are the definition of raw materials that are appropriate to use in the production of biogas. The optimal composition, which ensures the maximum yield of biogas, has been established: 5% of a chopped mixture of vegetables, 85% of water, and 10% of cattle manure (Gatsenko and Voloshin 2019). A promising direction for improving the technology of biogas production is the use of the green mass of sugar sorghum as a raw material. The yield of sorghum hybrids can reach 82.7 t/ha and, accordingly, 7.9 thousand m^3 of biogas, which confirms the effectiveness of using this crop as a raw material for biogas production (Grabovsky 2018). In the zone of unstable moisture in the central part of the Forest Steppe of Ukraine, the highest average was for 2016–2020. The yield of biofuel and energy (up to 791.8 GJ/ha) was obtained from sorghum of the mid-late hybrid Dovista, provided that its biomass was collected in the phase of full seed maturity (Ganzhenko 2021). An alternative among energy crops is sugar sorghum, which can provide a green biomass yield of 80 t/ha, a dry matter content of 21%, and an ash content of 2%, the output of solid biofuel will be 18.5 t/ha, and energy – 301.6 GJ/ha. 0.7 m^3 of biogas with a methane content of 60% or 11.76 thousand m^3/ha can be obtained from 1 kg of dry matter of sugar sorghum, which is equivalent to 357.1 GJ/ha (Ganzhenko et al. 2020).

Sugar beet is a promising raw material for biogas production. The high content of sugar and dry matter makes it possible to obtain up to 120 m^3 of biogas (with a methane content of 55–60%) from one ton of beet mass. With a yield of root crops of 50 t/ha, the estimated yield of biogas from 1 ha of sugar beets can be 12.3 thousand m^3, which is equivalent to 268.6 GJ/ha (Ganzhenko et al. 2021). The prospects for processing and recycling sugar production waste, as well as the need for processed products, the need to minimize their impact on the environment, make this area a priority in the process of managing sugar enterprise risks (Stalinska and Khandogina 2023).

2. Aim of the research

The purpose of this study is the scientific justification of technological solutions, the development of recommendations for innovations in the field of production efficiency, processing of agricultural raw materials for alternative energy (1) to study the experience of strategy and implementation of innovations in the field of bioenergy, evaluation of alternative solutions in the field of using resources of agro-industrial production of Ukraine for production biofuel; (2) to conduct an analysis of technological indicators of individual resources involved in the biofuel production process; (3) to study the effectiveness of alternative technological solutions for energy projects of bioenergy and possible ways of development of bioenergy in Ukraine in the post-war period; (4) to summarize the theoretical and practical aspects of the efficiency of using by-products, fodder and other energy resources for obtaining biomethane.

3. Results and discussions

An important aspect of the management of biological resources of agricultural production is the development of an effective management system for their use in technological processes. In Ukraine, the main specific share in the cost structure of agricultural products (more than 80%) is made up of several biological resources (Fig. 1).

Bioeconomy in the agricultural sector of Ukraine is a process of production of plant and animal products using biotechnologies and renewable resources, and creation of favorable conditions for economic growth, environmental and social safety of production. The economic assessment of technology efficiency based on indicators of costs for the production of bioresources is an important element for making management decisions and forming effective management of the industry. Technological management of the industry involves the evaluation of alternative approaches in solving the issue of rational use of existing resources and the involvement of other resources in the production process. The dynamics and ratio of the main production resources in technological processes affect pricing, product profitability, and competitiveness.

A significant specific share of energy carriers in the structure of the cost of products and their increase in price encourage enterprises to implement innovations, evaluate management decisions regarding the selection of fertilizers, plant protection products, optimization of the structure of sown areas, and other technological solutions.

The development of renewable energy sources in Ukraine should be based on economic competition with other energy sources and the simultaneous implementation of state support for promising technologies that reflect the public interest in increasing the level of energy security. environmental cleanliness and combating global climate change.

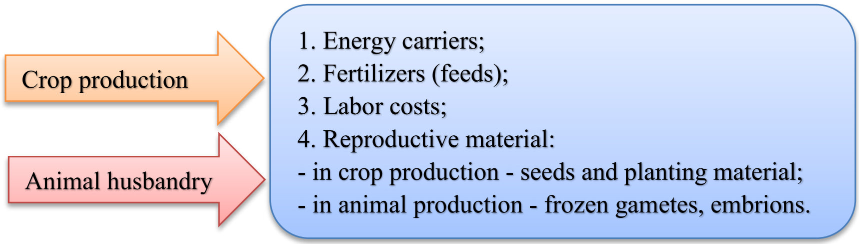

Fig. 1. Structural components of the bioeconomy of agricultural production
Source: formed by the authors

Rys. 1. Elementy strukturalne biogospodarki w produkcji rolnej

The level of use of energy resources in production is largely influenced by the natural and climatic conditions of the region. In Ukraine, the highest level of energy consumption is observed in agriculture in the northern regions (Sum, Chernihiv, Rivne, and Volyn regions).

The energy equivalent in agricultural production reflects the total energy costs required to produce products at the appropriate level of technical equipment of production, applied technology, qualifications of workers, and labor intensity in the amount of internal energy accumulated in products. Depending on the level of production intensification, the costs of obtaining a unit of production differ significantly. Research by the Research Institute "Ukragropromproduktyvnist" showed that the energy intensity when using the "No-Till technology" of growing winter wheat is 62.4% of the indicator according to the "basic technology" (Demchak et al. 2011). Costs for other agricultural crops differ even more. So, for example, the energy intensity of the sugar beet harvest is three times higher than the production of winter wheat using the "basic" technology and five times higher than the cultivation of winter wheat using the "No-Till" technology (Fig. 2).

The energy efficiency of the technology is reflected by the indicator of the total energy intensity of the products, which is determined by the ratio of the obtained products expressed in energy units to the total energy consumption for the production of the corresponding volume of products (Fig. 3).

The level of consumption of energy carriers, fertilizers, and labor costs per 1 ha of sown area in crop production is shown in the technological map. For example, when growing agricultural crops using bioadaptive technologies, the costs of production resources (fuel, fertilizers, labor costs) differ significantly for the main agricultural crops (Table 1).

Bioadaptive technology is a complex of agrobiological, technological, and ecological elements that contribute to the intensive development of plants, increasing crop productivity, reducing costs and chemical load on the environment, and adapting to the specific conditions of the region (Sinchenko and Pyrkin 2014) (Table 1).

Bioadaptive technologies for growing grain, technical and fodder crops using modern varieties and hybrids, and new types of trace elements, microbial preparations, growth regulators, and various rates of mineral fertilizers are quite effective and allow to significantly reduce the cost of production resources.

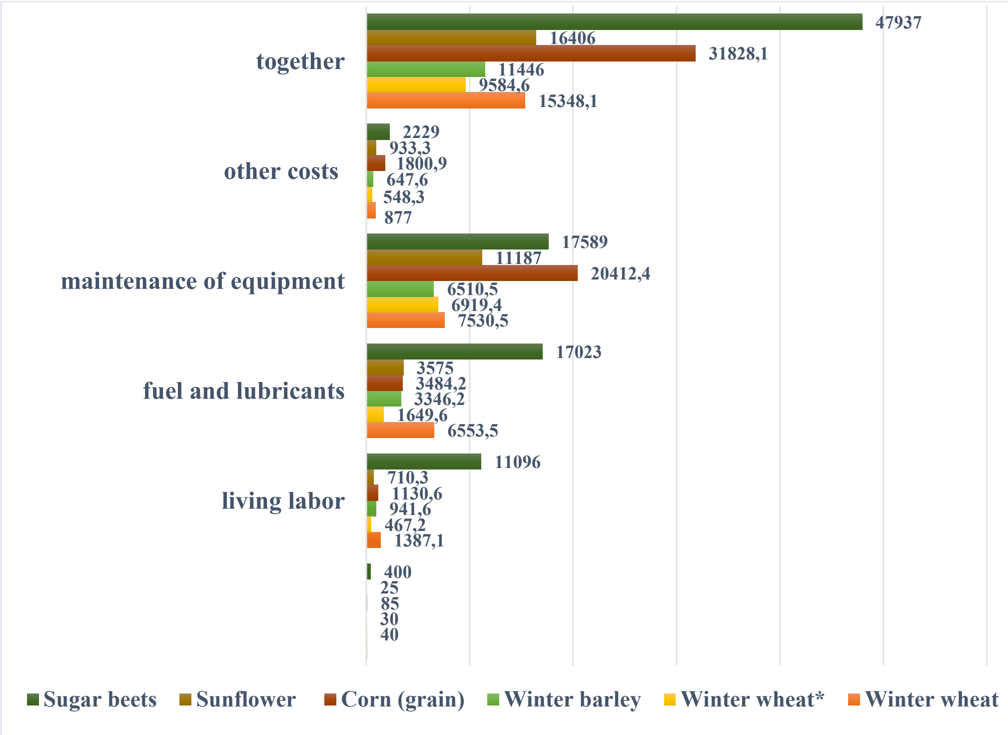

Fig. 2. Energy intensity of crop cultivation technology, basic technology [MJ/ha] (Demchak et al. 2011)
Source: formed by the authors

Rys. 2. Energochłonność technologii uprawy roślin, technologia podstawowa [MJ/ha]

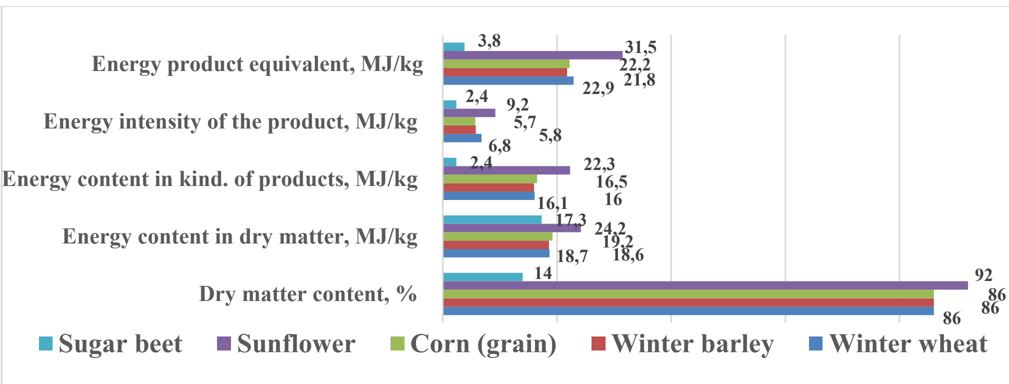

Fig. 3. Energy equivalents of crop production
Source: formed by the authors

Rys. 3. Ekwiwalenty energetyczne produkcji roślinnej

Table 1. Costs of production resources when growing agricultural crops, bioadaptive technology, per 1 ha

Tabela 1. Koszty zasobów produkcyjnych przy uprawie roślin rolniczych, technologia bioadaptacyjna, na 1 ha

Culture	Planned yield [t/ha]	Labor costs [man-hours]	Seed consumption [kg]	Fuel consumption [kg]	Mineral fertilizers [kg]** (active substance)		
					nitrogen	phosphorus	potassium
Winter wheat	60	8.64	250	51	148	15	15
Barley is hot	50	6.32	200	71	63	155	–
Corn (grain)	80	9.77	37.5	70	92	155	–
Sunflower	30	5.82	0,46 seed unit/ha	73	90	30	30
Sugar beets	500	25.98	1,5 seed unit/ha	249	133	196	15

Source: formed by the authors.

** Recommended doses of fertilizers:

- Winter wheat: nitroamofos – 100 kg + ammonium nitrate – 360 kg + urea – 20 kg;
- Spring barley: diammonium phosphate – 300 kg
- Corn for grain: diammonium phosphate – 300 kg + ammonium nitrate – 80 kg + urea – 4 kg;
- Sunflower: diammonium phosphate – 100 kg;
- Sugar beets: nitroammophos – 100 kg + diammonium phosphate – 350 kg + ammonium nitrate – 90 kg + urea – 30 kg.

Aggregate energy consumption can be calculated using the appropriate energy coefficients and reference information on the energy value of the main and secondary products (Tables 2, 3).

- 1 person-hour of qualified workers (for example, 5th grade tractor drivers) – 108 MJ;
- 1 kg of diesel fuel – 42.7 MJ;
- 1 kg of active substance of mineral fertilizers – nitrogen – 47.1 MJ; phosphorus – 15.8 MJ; potassium – 9.28 MJ.

The resulting calculations reflect the ratio of costs of the main production resources in energy units when growing the main agricultural crops of the forest-steppe zone. A significant difference in the ratio of energy consumption and energy income in the form of main and by-products indicates the peculiarities of agricultural techniques for growing certain agricultural crops in terms of their yield and the potential level of labor costs, fertilizers, energy carriers, and other production resources. For example, sugar beet with a yield of 400–600 t/ha of root crops and corresponding minimization of production resource costs is a profitable crop. The cost price of sugar beets is 2–3 times higher than the cost price of grain crops. The bioenergetic efficiency of sugar beet, with a yield of 250–300 t/ha compared to grain, is also significantly lower, depending on the total energy costs for fuel, fertilizers, protective equipment, and harvesting. The search for alternative energy sources and other production resources is one of the ways to increase the efficiency of agricultural production.

Methane is obtained as a result of the fermentation of raw materials of vegetable or animal origin. Mixtures of different compositions can be used as raw materials: manure, straw, grass,

Table 2. Energy value of the main and by-products of agricultural crops

Tabela 2. Wartość energetyczna głównych produktów i produktów ubocznych uprawy roślin rolniczych

Culture	Planned yield [centner/ha]			Energy value [MJ/kg]	
	main products /Mp/	indirect products /Ip/	coef. /Mp : Ip/	main products	by-products
Winter wheat	60	90	1.4–1.6	11.1	5.5
Barley	50	70	1.4	11.3	5.8
Spring	80	160	2.0	11.7	6.5
Corn (grain)	30	90	2–4	4.96	2.4
Sunflower	500	250	0.5	2.88	1.67

Source: formed by the authors.

Table 3. Energy consumption and energy input during the cultivation of agricultural crops, bioadaptive technology, per 1 ha

Tabela 3. Zużycie energii i nakład energii podczas uprawy roślin rolniczych, technologia bioadaptacyjna, na 1 ha

View products	Culture energy input [MJ]			Energy consumption [MJ]				Coef. En/Ev
	production main	production secondary	total /En/	labor	fuel	fertilizers	total /ev/	
Winter wheat	66 600	49 500	116 100	933.1	2 177.7	7 347.0	10 457.8	11.1
Winter barley	56 500	40 600	97 100	682.6	3 031.7	5 416.3	9 130.6	10.6
Corn (grain)	93 600	104 000	197 600	1 055.2	2 989.0	6 782.2	10 826.4	18.2
Sunflower	14 880	21 600	36 480	628.6	3 117.1	4 991.4	8 737.1	4.17
Sugar beet	144 000	41 750	185 750	2 805.8	10 632.3	9 500.3	22 938.4	8.1

Source: formed by the authors.

various wastes with a moisture content of more than 70%. The optimal raw material for the production of biogas is the green mass of grain and leguminous crops, forage grasses in the flowering phase of cereals, or in the budding phase for leguminous crops. The advantage of manure is its cheapness and availability. The disadvantage is that the quantity and quality of biogas is lower than from other types of raw materials. The production cycle will take approximately two weeks and will yield a volume of 60 m^3 with a methane content of 60%. Chicken droppings and pig manure cannot be used directly because they are toxic. To start the fermentation process, they must be mixed with silage (Ukrainian Energy 2024). The grain of cereal and leguminous crops provides several times more energy carriers compared to grasses, root crops, tuberous crops, and waste from the production of oil and other products (Table 4).

Table 4. Energy value of plant products

Tabela 4. Wartość energetyczna produktów roślinnych

View products	Based on 1 t. raw materials			Nutritional value for livestock, 1 kg	
	biogas [m^3]	electric energy [kWh]	thermal energy [kWh]	MJ/kg	digestible protein, g
Grains of cereals and legumes:					
✦ wheat	598	50	65	11.12	86
✦ triticale	597	49	64	10.29	70
✦ barley	579	49	63	11.30	76
✦ oats	501	43	56	9.04	86
✦ corn	590	50	64	11.86	64
✦ peas	581	51	66	11.21	171
✦ potatoes (fruits)	177	14	19	3.04	17
Root vegetables:					
✦ sugar beet	147	12	15	3.22	12
✦ carrot	73	6	8	1.69	11
✦ cauliflower	59	5	7	1.50	9
✦ pumpkin	51	5	6	1.17	11
✦ brewer's yeast	506	49	64	11.14	379
Oilseed processing waste:					
✦ soybean cake	552	54	70	11.08	334
✦ sunflower cake	488	48	62	11.02	358
✦ wheat bran	262	21	27	8.92	96
✦ potato mash	35	3	4	0.16	4

Source: formed by the authors.

Studies have shown a direct dependence of the production of energy carriers on the energy value of the by-products of the processing of oilseeds, grain crops, fodder, and other resources involved in the process of biogas production (Fig. 4).

For calculations of the potential volume of biogas from plant raw materials, the nutritional data of crop products, which are highlighted in the feed nutritional guides (Table 5), can be used.

$$Y = aX1 + bX2 + C \tag{1}$$

where:

Y – the amount of electrical energy [kWh/t of raw material],

a – energy value of crop production resources [MJ/kg],

b – content of digestible protein in feed resources [g/kg].

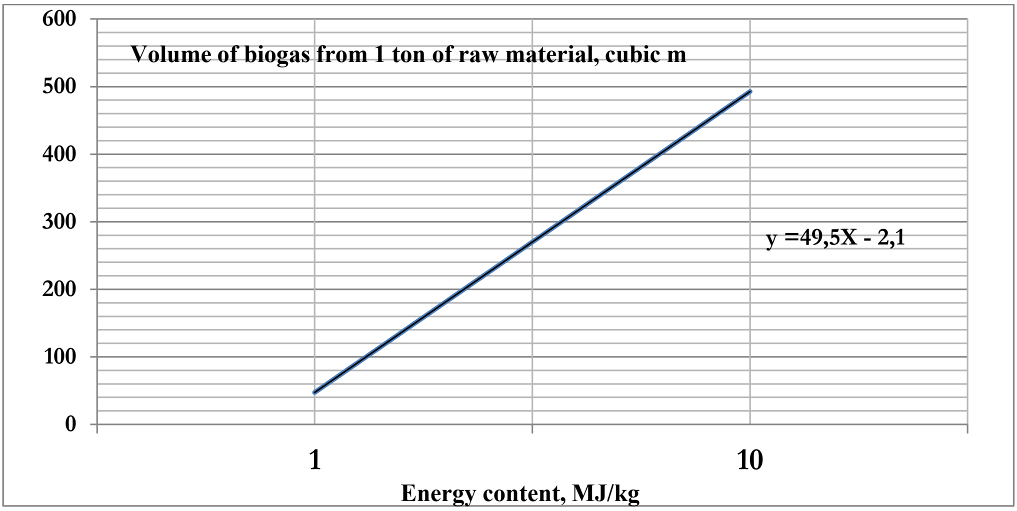

Fig. 4. Dependence of the amount of biogas production on the energy value of plant bioresources
Source: formed by the authors

Rys. 4. Zależność ilości produkowanego biogazu od wartości energetycznej roślinnych zasobów biologicznych

Table 5. Dependencies of electricity production on the energy value of bioresources

Tabela 5. Zależność produkcji energii elektrycznej od wartości energetycznej zasobów biologicznych

Regression statistics					
Correlation	0.969642				
R-squared	0.940207				
Rationed R-squared	0.931008				
Standard error	5.491478				
Observations	16				
Analysis of variance					
	df	SS	MS	F	
Regression	2	6 164.405	3 082.203	102.2075	
Remainder	13	392.0323	30.15633		
Together	15	6 556.438			
	Coef. equal regression	Standard error	t-statistics	P-meaning	Below 95%
Y-intersection	–0.63851	2.687073	–0.23762	0.815878	–6.44358
Variable Xa	4.275258	0.405499	10.5432	9.710081	3.399231
Variable Xb	0.008835	0.014246	0.620194	0.545849	–0.02194

Source: formed by the authors (Software "Data Analysis Package in Excel").

$$Y = (4.27\,X1 - 0.0088X2) - 0.638 \quad (2)$$

Studies have shown that the obtained dependences of the amount of energy on the protein content and the energy value of bioresources of plant origin can be used to model the efficiency of biogas production.

Ukraine has a modern production base that can be directed to the development of technologies for obtaining the necessary raw materials, creating favorable conditions for the processing of high-energy products, and the development of bioenergy, which allows the development of a promising energy strategy for agricultural production.

The effectiveness of alternative technologies is focused on the rational use of production resources, optimization of the cultivation of bioenergy crops, and the formation of a competitive environment for the sale of products on domestic and foreign markets. Domestic enterprises are able to increase the volume of production and sales of energy products under the conditions of using energy-saving equipment, optimization of technological operations, and timely updating of technologies for processing raw materials into biofuel.

In Ukraine, priority support is provided for the production of biofuel from the by-products of the processing of plant and animal raw materials, which do not compete with food and feed and can be used to obtain biogas and thermal energy in specified volumes (Fig. 5).

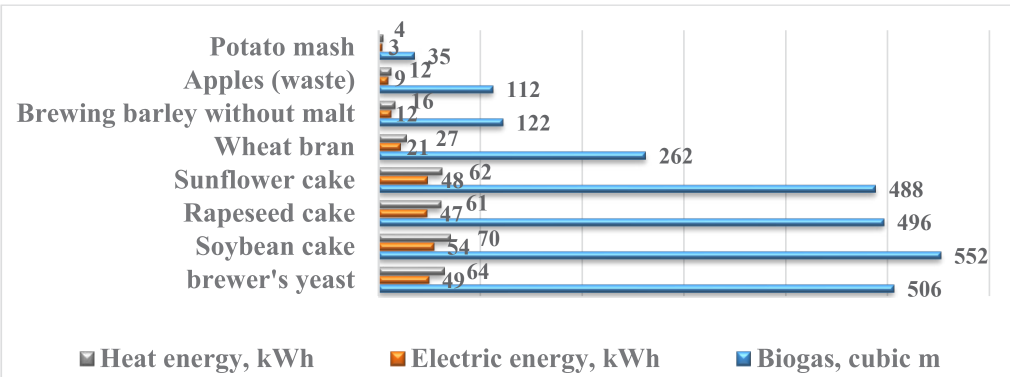

Fig. 5. The amount of energy from 1 ton of processing plant products
Source: formed by the authors (https://biteco-energy.com/ua/biogas-calculator/)

Rys. 5. Ilość energii z 1 tony produktów zakładu przetwórczego

The production of biogas from the humus of livestock litter has significant value and can contribute to the reduction of greenhouse gas emissions.

Conclusions

1. Biogas production can be developed under the conditions of the availability of alternative raw materials for food and fodder resources. In Ukraine, for a long time, the number of animals was significantly reduced, which created the prerequisites for the surplus of raw materials for fodder crops, which were used for the production of biofuel. It is unacceptable to use the main food products of crop production as raw materials for biogas plants. The expediency of using organic fertilizers (humus from bedding in animal husbandry) as a source of energy is doubtful. Significant depletion of agricultural land and, as a result, a significant decrease in the supply of humus and nutrients require a review of the structure of the raw material base for bioenergy.

2. The search for alternative energy sources and other production resources is one of the ways to improve the efficiency of agricultural production. The raw material for biogas production can be a mixture of manure, straw, grass, tops of root crops, silage, by-products, and production waste. The conducted studies showed that in order to increase the potential of using the main and by-products of crop production, the most optimal raw material for obtaining biogas is corn and other raw materials with a minimum protein content and a high carbohydrate content. The optimal raw material for the production of biogas is the green mass of grain and leguminous crops, forage grasses in the flowering phase of cereals, or in the budding phase for leguminous crops. Waste from processing enterprises, algae, and other raw materials can be used for biogas production. The disadvantage of the application is the length of the production cycle and the long fermentation cycle.

3. Calculations showed that the level of energy consumption and energy income in the form of main and by-products depends on agricultural techniques for growing agricultural crops, their yield, the potential level of labor costs, fertilizers, energy carriers, and other production resources. Studies have shown that sugar beet, with a yield of 400–600 t/ha of root crops and the corresponding minimization of the costs of production resources, is a profitable crop, and with a yield of 300 t/ha – already unprofitable at the production stage. The use of sugar beets for biogas production is not very promising.

4. Studies have shown a direct dependence of the production of energy carriers on the energy value of the by-products of the processing of oilseeds, grain crops, fodder, and other resources involved in the process of biogas production.

5. The resulting calculations of the dependence of the amount of energy that can be obtained from bioresources of plant origin with different protein content and energy value can be used to model the efficiency of biogas production.

The Authors have no conflicts of interest to declare.

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Bioekonomia zasobów wykorzystywanych do produkcji biopaliw

Streszczenie

Głównym celem badań jest opracowanie zaleceń dotyczących innowacji w zakresie wydajności produkcji, przetwarzania surowców rolniczych na alternatywne źródła energii, analiza wskaźników technologicznych poszczególnych zasobów wykorzystywanych w procesie produkcji biopaliw, badanie skuteczności alternatywnych rozwiązań technologicznych dla projektów związanych z bioenergią oraz możliwych sposobów rozwoju bioenergii w Ukrainie w okresie powojennym.

Znaczne zubożenie gruntów rolnych, a w konsekwencji znaczny spadek podaży próchnicy i składników odżywczych, wymaga przeglądu struktury bazy surowcowej dla bioenergii. Ustalono, że poziom zużycia energii i dochodów energetycznych w postaci produktów głównych i ubocznych zależy od technik rolniczych stosowanych w uprawie roślin rolniczych, ich plonów, potencjalnego poziomu kosztów pracy, nawozów, nośników energii i innych zasobów produkcyjnych.

Uzyskano wyniki badań dotyczących efektywności wykorzystania surowców ekologicznych do produkcji biopaliw oraz możliwości wykorzystania produktów pierwotnych i wtórnych kompleksu rolno-przemysłowego w produkcji biogazu. Przeprowadzone badania wykazały, że optymalnym surowcem do uzyskania biogazu jest kukurydza i inne surowce o minimalnej zawartości białka i wysokiej zawartości węglowodanów.

Głównym wynikiem badań jest ustalenie parametrów modelu zależności wielkości produkcji energii od wartości energetycznej produktów ubocznych przetwarzania nasion oleistych, zbóż, pasz i innych zasobów wykorzystywanych w procesie produkcji biogazu modelowania wydajności produkcji biogazu.

Słowa kluczowe: biogaz, energia alternatywna, zasoby biologiczne, wydajność produkcji, modelowanie