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of the Polish Academy of Sciences
J. Wybickiego 7A, 31-261 Kraków, Poland
tel. +48 12 632 33 00, fax +48 12 632 35 24
e-mail: polene@min-pan.krakow.pl
www.min-pan.krakow.pl

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Natalia Pryshliak[1], Andrii Sakhno[2], Dina Tokarchuk[3], Hanna Shevchuk[4]

Peculiarities of assessing the possibilities of increasing the yield of biofuels from agricultural crops on the example of Ukraine

Abstract: The development of the modern economic system is becoming increasingly dependent on the sufficient provision of quality energy resources due to the intensification and transformation of the mechanization and automation of all industries. The growth of the energy needs of society is parallel to the awareness of the need to ensure the environmentally friendly development of society. There are a number of reasons for the search for new energy sources, including the limited reserves of traditional sources, dependence on oil-exporting countries, the greenhouse effect due to the entry of carbon dioxide into the atmosphere and air pollution by harmful gases. The biofuel sector offers the potential for both the development of national agriculture and for increasing its energy independence. Global trends in the rapid development of bioenergy in combination with the systemic crisis

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✉ Corresponding Author: Natalia Pryshliak; e-mail: natalka.vinn@gmail.com

[1] Vinnytsia National Agrarian University, Vinnytsia, Ukraine; ORCID iD: 0000-0002-0544-1441; e-mail: natalka.vinn@gmail.com

[2] Vinnytsia National Agrarian University, Vinnytsia, Ukraine; ORCID iD: 0000-0002-6135-2371; e-mail: andrijsahno@gmail.com

[3] Vinnytsia National Agrarian University, Vinnytsia, Ukraine; ORCID iD: 0000-0001-6341-4452; e-mail: tokarchyk_dina@ukr.net

[4] Vinnytsia National Agrarian University, Vinnytsia, Ukraine; ORCID iD: 0000-0001-6094-0414; e-mail: shevchykhv@gmail.com

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of the energy sector in Ukraine have necessitated a detailed study on the possibility of increasing the yield of biofuels from crops. The economic and mathematical modeling of the possibility of increasing the yield of bioethanol and vegetable oil from agricultural crops has been carried out. An economic optimization model has been formed, which made it possible to study an increase in the yield of bioethanol from sugar-containing and starch-containing crops and vegetable oil from oil crops from 1 ton per 1 hectare of area. Also, an assessment of the lost yield for the investigated crops has been carried out using the method of analysis of the functioning environment (Farrell's method).

KEYWORDS: efficiency, modeling, biofuel, agricultural crops

Introduction

There are a number of reasons for the search for new energy sources, including the limited reserves of traditional sources, dependence on oil-exporting countries, the greenhouse effect due to the entry of carbon dioxide into the atmosphere and air pollution by harmful gases.

Over recent decades, research by various scientists around the world has been actively carried out aimed at ensuring fuel economy and the partial replacement of traditional fossil hydrocarbon energy sources, the resources of which may be depleted in the foreseeable future. The constant rise in oil prices, and local and global pollution of the planet with wastes from its use have led to an active growth in the production and use of environmentally friendly biofuels.

Ukraine annually consumes about 50 million tons of oil-equivalent of energy resources, of which the largest share belongs to industry (32.2%), households (31.7%) and transport (18.8%). At the same time, according to data from State Statistics Service of Ukraine (2020), in 2020, Ukraine imported 34 million tons of oil-equivalent fuel and energy resources. Considering the high rates of imports of energy resources, Ukraine remains an energy-deficient country, as it imports 68% of the required volume of natural gas, crude oil and oil products.

According to the Yearbook of Global Energy Statistics (2020), in 2015, Ukraine had the highest energy intensity of GDP in the world (0.232). Russia (0.210) and Venezuela (0.205) were also in the top three. The energy intensity of Ukraine's GDP in the total supply of primary energy from 2008 to 2019 varied slightly (from 0.220 tons of oil equivalent/thousand international dollars in 2008 to 0.165 tons of oil equivalent/thousand international dollars in 2019), which indicates an insufficient efficiency of energy efficiency policy implementation (The official website... 2021).

According to the Energy Trilemma Index, 2020, calculated by the World Energy Council, in 2020 Ukraine, ranked 62nd out of 125 countries (in 2015, Ukraine ranked 110th) with a value of 68.9. The Energy Sustainability Index is assigned on the basis of a comparative analysis of the energy situation in the country and is based on three factors: energy security, availability of electricity for the population (Energy Equity) and environmental sustainability of the energy sector (Environmental Sustainability). Depending on the success in each direction, the country is assigned a rating from A to D. Ukraine's rating is BCD. According to the compilers of this rating, the worst thing in Ukraine is concerned with the environment, as well as with the overall efficiency of the industry. Denmark became the leader in the ranking of the energy resilience index. In addition, Switzerland, Sweden, the Netherlands, Great Britain, Slovenia, Germany, New Zealand, Norway and France were in the top ten.

According to the forecasts given in the annexes to the Energy Strategy of Ukraine for the period up to 2035 "Security, energy efficiency, competitiveness" it is planned that the import dependence of energy resources in the total primary energy supply by 2025 will continue to be less than 33%.

The main priorities of Ukraine's energy policy are energy efficiency, the use of renewable energy sources and reducing the negative impact on the environment (Kaletnik et al. 2020). One of the tools to ensure Ukraine's energy security is to expand the use of all types of renewable energy and biofuels, among which, special attention will be paid to biodiesel and bioethanol.

In the last twenty years, the biofuels industry has rapidly developed in many regions of the world. In a range of countries, the intensive development of programs for the production of biofuel from biomass as a renewable energy source can be considered as preparation for the inevitable depletion of fossil fuels. The global biofuel industry has been developed due to a wide range of measures of legislative and regulatory support for the development of bioenergy, as well as government programs aimed at increasing the production of biofuels in a particular country. Global experience from the dynamic increase in biofuel production shows that only a comprehensive and consistent government policy using legislative and economic mechanisms contributes to the effective introduction of biofuels in the market. As pointed by Saravanan et al., 2020, one of the key drivers for the development of biofuel production industries and the simultaneous dilution of biofuels in the energy market is the country's policy.

1. Literature review

Biofuel production is expected to be an intrinsic confluence in the renewable energy sector in the coming years under the European regulations for renewable energy. Key standpoints of biofuel promotions are the reduction of national carbon emissions and rural deployment (Achinas et al. 2019).

Over recent years, biomass has become an important resource for the production of biofuels, which has become an important part of the liquid fuel industry (Wasiak 2019). The challenges associated with the commercialization of biomass-derived biofuels can be overcome by the process of integration as well as the fine-tuning of various process variables affecting production (Sindhu et al. 2019).

At present, the production of liquid biofuels relies on plant biomass, which in turn depends on the photosynthetic conversion of light and CO_2 into chemical energy. Consequently, the process is renewable on a far shorter time-scale than its fossil counterpart, thus rendering the potential to reduce the environmental impact of the transportation sector. However, the global economy is not intensively pursuing this route, as the current generation of biofuel production does not meet two key criteria: (1) economic feasibility and (2) long-term sustainability (Perin and Jones 2019).

Biofuels can be differentiated according to a number of key characteristics, including feedstock type, conversion process, technical specification of the fuel and its use (Jeswani et al. 2020). The first generation of biofuels is ethanol derived from food crops rich in starch or biodiesel taken from waste animal fats such as cooking grease (Rodionova et al. 2017).

Due to the large amount of diesel fuel demands worldwide and the negative environmental and health impacts of its direct combustion, biodiesel production and consumption have been globally increasing as the best short-term substitute for mineral diesel. However, using edible and non-edible oil feedstocks for biodiesel production has led to several controversial issues, including feedstock availability and cost, greenhouse gas (GHG) emission, land use changes (LUC), and fuel vs. food/feed competition (Hajjari et al. 2018). Along with the environmental benefits, biodiesel could not be extensively applied as a complete substitute fuel for conventional diesel due to the higher cost of production. As pointed out by Gebremariam et al. 2018, the reduction of the cost of biodiesel production can be attained through improving the productivity of technologies to increase yield, reducing capital investment cost and reducing the cost of raw materials.

Bioethanol is one of the most promising alternative biofuels. Numerous biomass resources have been investigated for bioethanol production, which can broadly be classified into sugars, starch and lignocellulosic biomass (Zabed et al. 2017). As noted by Niphadkar et al. 2018, the production of bioethanol from renewable resources and the combustion advantages for greener alternatives have led scientists around the world to develop cutting-edge technologies to achieve higher biomass conversion and, consequently, industrial-level yield and purity. Vohra et al. 2014 discussed the current state of ethanol production from different feedstocks and the state of technologies involved in ethanol production from these different feedstocks.

Mathematical models have been widely used to simulate all aspects of bioenergy production systems including the growth kinetics of energy crops, conversion processes, production economics, supply logistics and environmental impacts. These models can provide powerful tools to design a bioenergy system and evaluate its technical feasibility, economics and environmental impacts (Wang et al. 2015).

The importance of biofuel development in Ukraine has been studied by various Ukrainian and world scientists. Kaletnik et al. 2021 assessed the resource potential for the production of bioethanol in Ukraine. Tokarchuk et al. 2021 emphasized that quality soil and good climatic conditions of Ukraine create favorable conditions for the development of biomass suitable for biofuel processing. As pointed out by Berezyuk et al. 2021, the residues of biomass after processing into biofuels can be used as a fertilizer for crop production. Also, the production of biofuels might have a positive socio-economic effect, predominantly in rural areas (Samborska et al. 2020).

However, the peculiarities of increasing the efficiency of biofuel yield from crops require further research. Thus, the peculiarities of assessing the possibilities of increasing the yield of biofuels from agricultural crops on the example of Ukraine have been studied.

2. Materials and methods

In the course of writing, approaches to assess the potential for increasing the yield of biofuels from crops have been proposed. In particular, to assess the efficiency of the yield of vegetable oil, the yield indicators were used for sunflower, soybeans, rapeseed, hemp, peanuts, mustard and flax seeds. To assess the efficiency of the yield of bioethanol, yield indicators were used for sugar beets, Jerusalem artichoke, corn, wheat, barley, sugar cane and cassava. The main method that was used in the research process was the method of analysis of the functioning environment, the basis of which is the calculation of technical efficiency based on the limiting indicators of "reference" cultures. The use of the method of analysis of the functioning environment made it possible to apply the following analysis methods: a graphical method – to draw a line of technical efficiency and calculate the level of efficiency of other crops; a method of coefficients in the form of ratios between production (factor) indicators and the effective indicator (yield); an analytical method – for the analysis of crops positions in the functioning environment; a comparative method – to identify patterns and deviations in all positions of the functioning environment.

The use of all these methods made it possible to carry out optimization measures through graphic transformations and design in order to achieve efficiency through an increase in the effective indicator and a decrease in factor indicators. The calculation of the optimized values was accompanied by the use of the descriptive method and the method of scientific assumptions, which made it possible, on the one hand, to explain the transformations of the functioning environment, and on the other hand, to interpret the proposals for the development of production on the basis of mathematical analytics.

3. Results and discussion

Biodiesel is an alternative fuel that is similar to conventional diesel fuel (Blum et al. 2010). According to data from OECD-FAO Agricultural Outlook (2020–2029), about 77% of world biodiesel production is based on the use of vegetable oils (37% rapeseed oil, 27% soybean oil and 9% palm oil) or waste oils (21%).

Biodiesel's biodegradability, non-toxicity, and the absence of sulfur and aromatic hydrocarbons give it an advantage over conventional petroleum diesel (Geletukha et al. 2020). When burned, biodiesel emits less air pollutants and greenhouse gases. In addition, it is safer to use and has better lubricating properties than petroleum diesel. However, despite all these environmental benefits, biodiesel is not produced on an industrial scale in Ukraine. The main reason is the higher production cost (Gebremariam and Marchetti 2018).

Reducing the cost of biodiesel production can be achieved by increasing the productivity of technologies to increase yields and reduce the cost of feedstock. This requires careful economic analysis of the available technological alternatives, catalyst alternatives, and raw material alternatives, so that the best option can be selected from an economic point of view.

The cost of biodiesel production is influenced by a number of factors: yield, cost of seeds, oil content in seeds, oil yield from seeds, efficient use of the by-products of production, cost of chemical ingredients, cost of processing equipment, quality of technological process, administrative costs, cost of electricity, wages service person.

The use of various types of feedstock is also important in terms of increasing the supply of biodiesel and socio-economic issues (Pryshliak et al. 2021). For the use of fuels which are obtained from oils, two ways are considered. One of these provides for the esterification of vegetable oils to the condition of diesel fuel and its further use in biodiesel and diesel blends. The most optimal type of biodiesel blends are blends in which the content of biodiesel fuel does not exceed 30%, and oil diesel is 70%. Adding up to 30% biodiesel to petroleum diesel fuel does not require the redesign of the engine (Shevchenko and Kurennaya 2013). The second way is to change the diesel engine in such a way that when raw oils are burned, carbon deposits are not formed in it (Knothe and Razon 2017). The second method has become quite widespread among farmers in Germany.

One of the effective ways to reduce the cost of biodiesel fuel is to increase the oil yield from 1 ton of feedstock and from 1 hectare. To calculate the possibility of increasing the yield of vegetable oil from 1 ton and 1 hectare of feedstock, we use data on the average yield of vegetable oil by pressing (Table 1), and also estimate the lost yield for the given crops. To carry out such an analysis, we propose use of the method of analysis of the functioning environment (Farrell's method), the essence of which is a nonparametric limiting assessment of the efficiency of resource use within the framework of the effective indicator.

The graphical presentation of the method for analyzing the functioning environment is presented on the basis of the interpretation of the approaches of Sakhno 2017, to the Farrell model (Farell 1957).

Using the data in Table 1, we propose taking the yield for each of the seven crops as the effective indicator (Y). Factor (resource) indicators are oil output from 1 ton (X1) and oil output from 1 ha (X2). Thus, it is possible to calculate the ratio between the yield of oil from 1 ton of feedstock and the yield and between the yield of oil from 1 hectare of area and the yield (Table 2).

As shown in Table 2, the maximum ratio between the yield of oil from 1 ton of feedstock if from flax (36.67), the least is from soybeans (9.09), while the maximum ratio between the yield of oil from 1 ha is from rapeseed (66.11), the least is from soybeans (20.00).

Table 1. Average yield of vegetable oil by pressing

Tabela 1. Średni uzysk oleju roślinnego metodą tłoczenia

Type of crop	Yield [tons/ha]	Oil content [%]	Yield of oil (liters) from 1 ton of feedstock	Oil yield from 1 ha [liters]
Sunflower	2.5	52–57	400	1000
Soybean	2.2	16–27	200	440
Rapeseed	1.8	40–45	420	1190
Hemp	1.0	30–38	340	756
Peanut	1.6	41–50	470	752
Mustard seeds	1.5	32–44	400	600
Flax	1.2	40–48	440	528

Source: formed by the author based on Kaletnik 2018; Blum et al. 2010; State Statistics Committee of Ukraine 2020.

Table 2. The yield of vegetable oil per 1 ton of crop and the ratio of the yield of vegetable oil per 1 ha of the area to the crop from this area

Tabela 2. Uzysk oleju roślinnego z 1 tony plonu oraz stosunek uzysku oleju roślinnego z 1 ha powierzchni do plonów z tej powierzchni

No.	Type of crop	X1/Y	X2/Y
1	Sunflower	16.00	40.00
2	Soybean	9.09	20.00
3	Rapeseed	23.33	66.11
4	Hemp	34.00	75.60
5	Peanut	29.37	47.00
6	Mustard seeds	26.67	40.00
7	Flax	36.67	44.00

Source: calculated by the authors.

Based on the calculated ratios, we propose constructing a diagram of the corresponding positions in the functioning environment for all cultures, where the positions (from 1 to 7) are the positions of the functioning environment. The abscissa axis shows the coefficients of the ratio between the oil yield from 1 ton of raw materials and the yield (X1/Y), the ordinate axis shows the coefficients of the ratio between the oil yield from 1 hectare of area and the yield (Fig. 1).

Using the approaches of the method of analysis of the operating environment, we define the line of technical efficiency as a line consisting of the positions of crops as close as possible to the axes of abscissa and ordinate: 3 (rape), 2 (soy), 7 (flax). The positions of these crops are technically efficient, he coefficient of their technical efficiency is equal to 1.

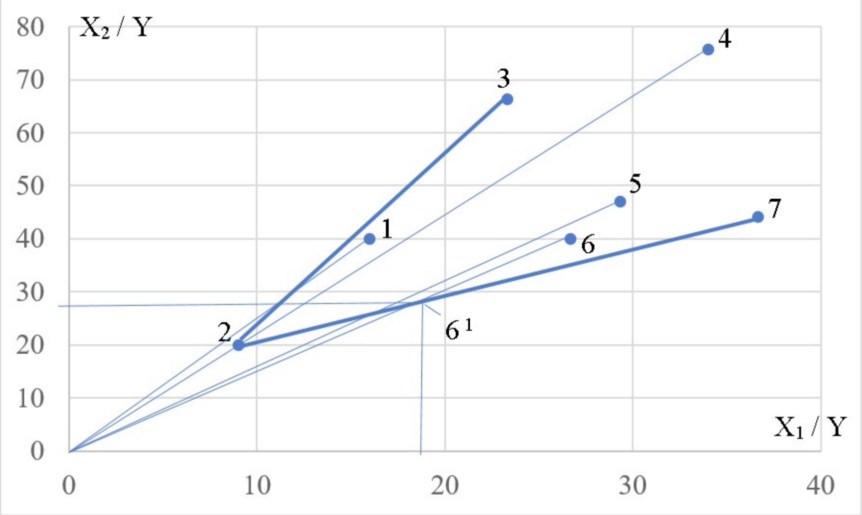

Fig. 1. Positions of the relationship by crops between the yield of vegetable oil per 1 ton of the crop and between the yield of vegetable oil per 1 ha and the crop of this area

Rys. 1. Umiejscowienie relacji według upraw między uzyskiem oleju roślinnego z 1 tony plonu oraz między uzyskiem oleju roślinnego z 1 ha powierzchni a plonem z tego obszaru

For other crops there is a technical inefficiency, as their coefficient of technical efficiency is in the range from 0 to 1 (sunflower, hemp, peanuts, mustard seeds). Distances 0–1, 0–4, 0–5, 0–6 are segments that allow you to calculate the coefficient of technical efficiency (for example, position 6 – mustard seeds: 0–61/0–6) (Table 3).

Table 3. Calculation of technical efficiency of vegetable oil yield by types of crop

Tabela 3. Obliczanie wydajności technicznej uzysku oleju roślinnego według rodzajów upraw

No.	Type of crop	Coefficient of technical efficiency
1	Sunflower	0.75
2	Soybean	1.0
3	Rapeseed	1.0
4	Hemp	0.27
5	Peanut	0.56
6	Mustard seeds	0.70
7	Flax	1.0

Source: calculated by the authors.

Thus, we can conclude that under the current conditions, it is most profitable to obtain vegetable oil from rapeseed, soybean and flax. At the same time, the use of other oils also makes economic sense, although the presence of technical inefficiencies indicates the need to optimize the operating environment by positioning (moving) positions towards the abscissa and ordinate axes.

The most efficient of the inefficient production of oil from crops is the production of vegetable oil from sunflower (0.75). The coefficient of inefficiency for oil from this plant is only 0.25 (1–0.75). The most inefficient among the inefficient production of oil from crops is the production of vegetable oil from hemp (0.27). The coefficient of inefficiency for the oil from this plant is 0.73 (1–0.27).

Since the position of each crop, the production of vegetable oil from which is ineffective, in combination with the origin forms a segment that intersects with the line of technical efficiency (for example 61), then on the line of technical efficiency at the points of intersection, new ratios are formed that make it possible to calculate the magnitude of the increase and the total oil production volume. The possibility of increasing the oil yield from 1 ton of feedstock is presented in Table 4.

TABLE 4. Evaluation of the possibility of increasing the yield of vegetable oil from 1 ton of feedstock

TABELA 4. Ocena możliwości zwiększenia uzysku oleju roślinnego z 1 tony surowca

No.	Type of crop	(X1/Y)1	Increase volume [liters]	Total oil yield [liters]
1	Sunflower	11.8	295.0	400.0 + 295.0 = 695.0
4	Hemp	9.09	90.9	340.0 + 90.9 = 430,9
5	Peanut	16.07	257.12	470.0 + 257.12 = 727.12
6	Mustard seeds	18.92	283.8	400.0 + 283.8 = 683.8

Source: calculated by the authors.

We propose assessing the possibility of increasing the oil yield from 1 ton of feedstock using the example of sunflower. Based on the calculation of the ratio between oil yield and yield, where X1/Y is used instead of X/Y, we get: 11.8 = X1/25 X1 = 11.8 * 25 = 295. Since according to the results of the reporting year, the output of oil from 1 ton of feedstock is 400 liters from 1 ton, the total volume of oil output from 1 ton of feedstock will be 400 + 295 = 695 liters from 1 ton of feedstock.

We have conducted similar actions with three other types of crops. The highest increase is observed as a result of the production of vegetable oil from peanuts: 257.12 liters from 1 ton of feedstock. As a result, the total yield of oil from peanuts could be 727.12 liters per ton. The lowest increase is observed in the production of vegetable oil from hemp – 90.9 liters from 1 ton of feedstock. Thus, the total yield of this oil can be 430.9 liters per ton.

The total increase in oil yield from 1 ton of feedstock for four crops will be 926.82 liters.

A similar algorithm is used to calculate the oil yield from 1 hectare (Table 5). In contrast to the calculation of the oil yield from 1 ton of feedstock, the calculation from 1 hectare made it possible to establish that the maximum increase in comparison with other crops is observed as a result of the production of oil from sunflower (750 liters from 1 hectare), which as a general calculation is equal to 1,750 liters from 1 hectare.

Table 5. Assessment of the possibility of increasing the yield of vegetable oil from 1 ha

Tabela 5. Ocena możliwości zwiększenia uzysku oleju roślinnego z 1 ha

No.	Type of crop	(X2 / Y)1	Increase volume [liters]	Total oil yield [liters]
1	Sunflower	30.0	750.0	1000.0 + 750.0 = 1750.0
4	Hemp	20.0	200.0	756.0 + 200.0 = 956.0
5	Peanut	25.7	411.0	752.0 + 411.0 = 1163.0
6	Mustard seeds	28.6	429.0	600.0 + 429.0 = 1029.0

Source: calculated by the authors.

In this case, the maximum increase in vegetable oil yield is observed for sunflower (750 liters per 1 ha). The total increase in vegetable oil yield will be 1,750 liters per 1 hectare. As in the assessment of the possibility of increasing the yield of oil from 1 ton of feedstock, the lowest increase in yield from 1 hectare is observed for hemp (200 liters per 1 hectare). The total volume of the possibility of increasing the yield of oil from hemp is 956 liters from 1 hectare.

The total increase in oil yield from 1 hectare of area for four crops is 1,790 liters.

Since the possibility of increasing the yield of vegetable oil from 1 hectare is 1.9 times more than from 1 ton, in this case it is more productive to increase the production of sunflower, hemp, peanuts and mustard seeds.

The assessment of the possibility of increasing the yield from 1 ton of feedstock and 1 ha of area (Table 6 and Table 7) is also based on the values of the ratios (X1/Y)1 and (X2/Y)1, respectively. For example, the estimated yield of sunflower is: 11.8 = 400 / Y. Y = 34. Since the average yield of vegetable oil from sunflower is 2.5 tons/ha, the lost yield is: 3.4 – 2.5 = 0.9 kg/ha.

According to calculations, most of the yield is lost from growing hemp. In general, the lost yield for all crops per 1 ton of feedstock and 1 ha of area was 5.5 tons/ ha.

The configuration of the line of technical efficiency indicates the possibility of optimizing the position of crops in the operating environment. The principle of such optimization is the direction of these positions in the direction of the origin and therefore to the abscissa and ordinate axes (Fig. 2).

As a procedure for optimizing the position of the ratio positions between the oil yield from 1 ton of feedstock and the yield and between the oil yield from 1 hectare of area and the yield for the crops from which vegetable oil is produced, we suggest the following:

1. The connection of the two extreme positions of the line of technical efficiency 3 (rapeseed) and 7 (flax) with the origin – the formation of segments 0–3 and 0–7.

TABLE 6. Estimation of possibility of increasing productivity from 1 ton of feedstock

TABELA 6. Oszacowanie możliwości zwiększenia wydajności z 1 tony wsadu

No.	Type of crop	(X1/Y)1	Estimated yield	Lost yield
1	Sunflower	11.8	34.0	34.0 – 25.0 = 9.0
4	Hemp	9.09	37.0	37.0 – 10.0 = 27.0
5	Peanut	16.07	29.0	29.0 – 16.0 = 13.0
6	Mustard seeds	18.92	21.0	21.0 – 15.0 = 6.0

Source: calculated by the authors.

TABLE 7. Assessment of the possibility of increasing yields from 1 hectare of area

TABELA 7. Ocena możliwości zwiększenia plonów z 1 ha powierzchni

No.	Type of crop	(X2/Y)1	Estimated yield	Lost yield
1	Sunflower	30.0	33.0	33.0 – 25.0 = 8.0
4	Hemp	20.0	38.0	38.0 – 10.0 = 28.0
5	Peanut	25.7	29.0	29.0 – 16.0 = 13.0
6	Mustard seeds	28.6	21.0	21.0 – 15.0 = 6.0

Source: calculated by the authors.

2. Formation of a vertical projection on the abscissa axis – 71 and horizontal on the y-axis – 31.

3. Formation of lines 71–74, that passed through position 71 and position 2 (csoybean) and 31–34, that passed through position 31 and position 2 (soybean), which allowed getting position 72 and 32.

4. The formation of an alternative line of technical efficiency, in particular 32–72, which does not meet the optimization requirements, because position 2 (soybean) is closer to the origin than positions 32 and 72.

5. The formation of an alternative line of technical efficiency, in particular 33–73, which meets the requirements of optimization, because position 21 is closer to the origin than position 2 (soybean).

Thus, new positions have been obtained for the relationship between the yield of oil from 1 ton of feedstock and the yield and between the yield of oil from 1 hectare of area and the yield for crops from which vegetable oil is produced, which allows, according to these positions, the planning of the cultivation of soybeans, rapeseed and flax based on the regularities of the functioning environment, where the achievement of efficiency is ensured by the optimal values of yield and an increase in the yield of oil both from 1 ton of feedstock and 1 hectare of area.

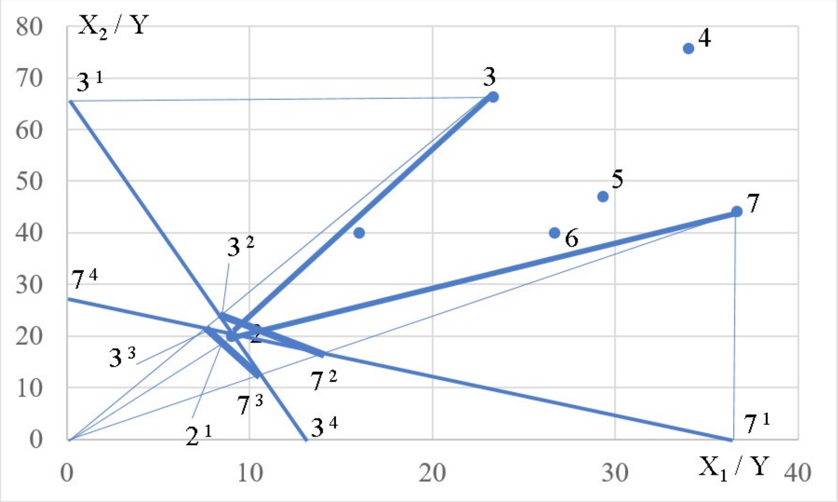

Fig. 2. The order after the optimization of the stands with crops according to the yield of vegetable oil per 1 ton of crop and between the yield of vegetable oil per 1 ha and the crop

Rys. 2. Kolejność po optymalizacji stanowisk z uprawami według uzysku oleju roślinnego z 1 tony plonu oraz między uzyskiem oleju roślinnego z 1 ha powierzchni a plonem

An important reserve for increasing the efficiency of growing oil-containing crops is maximizing the use of the potential of varieties, observing crop rotations, switching to modern growing technologies, optimizing nutrition and the water regime, using integrated systems of protection against weeds, pests and diseases, and a modern complex of machines for cultivation.

An alternative to petroleum gasoline is bioethanol. Currently, bioethanol production in the world is the most dynamic sector of the biofuel industry. It accounts for 85% of the global production of biofuels. The properties of bioethanol increase the octane number and eliminate the use of toxic antiknock agents, such as tetraethyl lead, benzene, toluene, etc. This reduces the toxicity of exhaust gases.

The indisputable advantages of bioethanol include low toxicity and the almost complete absence of CO_2 emissions from combustion products, biodegradation, the ability to increase the efficiency of agricultural resources, a reduced dependence on oil, and a reduced the greenhouse effect. The main disadvantages are the high cost of bioethanol production, unstable yields of some types of biomass, hygroscopicity and increased fuel consumption.

The feedstock for bioethanol production are sugar and starch-containing crops, as well as lignin-cellulose biomass. Currently, about 64% of bioethanol is produced from corn, 26% from sugar cane, 3% from molasses, 3% from wheat, and the rest from other raw materials, in particular, cassava and sugar beets.

Using the method of analysis of the operating environment (Farrell's method), we will calculate the approximate yield of different crops and the possible yield of bioethanol from biomaterials (Table 8).

Table 8. Estimated yield of different crops and possible yield of bioethanol from feedstock

Tabela 8. Szacunkowy plon różnych roślin i możliwy uzysk bioetanolu z surowca

Type of crop	Yield [tons/ha]	Oil content [%]	
		oil content [%]	yield of oil [liters] from 1 ton of feedstock
Sugar beet	50.0	100	5000.0
Jerusalem artichoke	30.0	87	2610.0
Corn (grain)	7.0	416	2912.0
Wheat	5.0	395	1975.0
Barley	5.8	370	2150.0
Sugar Cane	65.0	70	4550.0
Cassava	12.0	180	2160.0

Source: calculated by the authors.

In contrast to the calculations of vegetable oil ratios, the calculations of the ratio between the yield of bioethanol from 1 ton of feedstock and yield and between the yield of bioethanol from 1 ha and yield show that this level of yield exceeds the yield of bioethanol per 1 ton of bioethanol from sugar beet, Jerusalem artichoke and sugar cane (Table 9).

Table 9. The yield of bioethanol from 1 ton of crop and the ratio between the yield of bioethanol and the crop from 1 ha to the crop for particular types of crops

Tabela 9. Uzysk bioetanolu z 1 tony plonu oraz stosunek między uzyskiem bioetanolu a plonem z 1 ha do plonów dla poszczególnych rodzajów plonów

No.	Type of crop	X1/Y	X2/Y
1	Sugar beet	0.20	10.00
2	Jerusalem artichoke	0.29	8.70
3	Corn (grain)	5.94	41.60
4	Wheat	7.90	39.50
5	Barley	6.38	37.07
6	Sugar cane	0.11	7.00
7	Cassava	1.50	18.00

Source: calculated by the authors.

Using the principles of the method of analysis of the functioning environment, we can construct in the coordinate system the positions of the ratios by crops between the yield of bioethanol from 1 ton of feedstock and the yield and between the yield of bioethanol from 1 hectare of areas and the yield (Fig. 3).

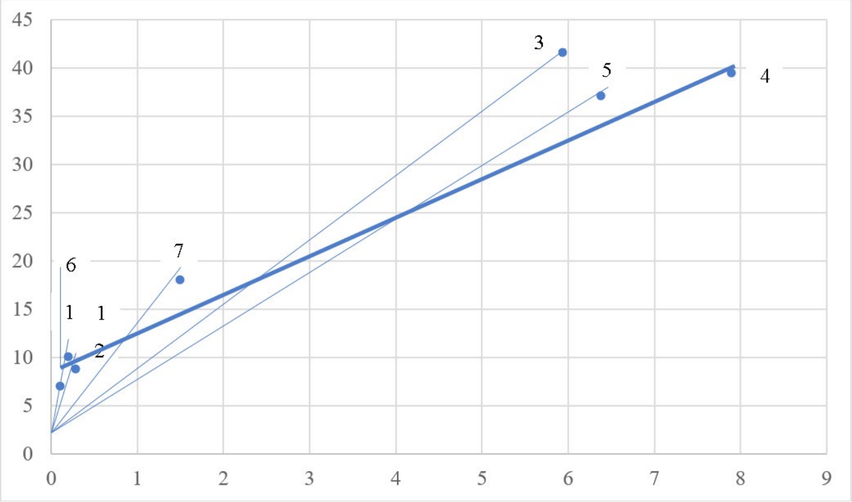

Fig. 3. Crops positions according to the yield of bioethanol per 1 ton of crop and between the yield of bioethanol per 1 ha of the area and the crop of this area

Rys. 3. Pozycje upraw według uzysku bioetanolu z 1 tony plonu a oraz między uzyskiem bioetanolu z 1 ha powierzchni a plonem z tego obszaru

In contrast to the production of vegetable oil, the technical efficiency of bioethanol production is characterized by a line of only two positions: 6 (sugar cane), 4 (wheat). Thus, according to calculations, it is technically inefficient to produce bioethanol from crops corresponding to positions 1, 2, 3, 5 and 7.

Calculation of the technical efficiency of bioethanol yield by types of crops (Table 10) shows that the most efficient production of the five ineffective is the yield from Jerusalem artichoke (0.76). The estimated inefficiency is 0.24.

Corn has the lowest efficiency in the production of bioethanol (0.38). Also, a significant inefficiency is observed when using cassava – 0.55.

The configuration of the line of technical efficiency indicates the possibility of optimizing the position of crops in the operating environment. The principle of such optimization is the direction of these positions in the direction of the origin, and therefore to the abscissa and ordinate axes (Fig. 4).

As the procedure for optimizing the placement of positions of the ratio between the yield of bioethanol from 1 ton of feedstock and the yield and between the yield of bioethanol from 1 hectare of areas and the yield for crops from which bioethanol is produced, we suggest the following:

1. We connect the extreme positions of crops, the production of bioethanol from which is inefficient with the origin: 0–1 (sugar beet) and 0–5 (barley).

2. We make a perpendicular from the position of culture 4 (wheat), the production of bioethanol from which is effective on the y-axis.

3. We mark the positions of the intersection of the perpendicular with the segments 0–1 and 0–5 as 11 and 51(41), respectively.

4. We design a new line of technical efficiency 11–51(41).

Table 10. The yield of bioethanol from 1 ton of crop and the ratio between the yield of bioethanol and the crop from 1 ha to the crop for particular types of crops

Tabela 10. Uzysk bioetanolu z 1 tony plonu oraz stosunek między uzyskiem bioetanolu a plonem z 1 ha do plonów dla odbiorcy plonów

No.	Type of crop	Coefficient of technical efficiency
1	Sugar beet	0.68
2	Jerusalem artichoke	0.88
3	Corn (grain)	0.38
4	Wheat	1.0
5	Barley	0.63
6	Sugar cane	1.0
7	Cassava	0.55

Source: calculated by the authors.

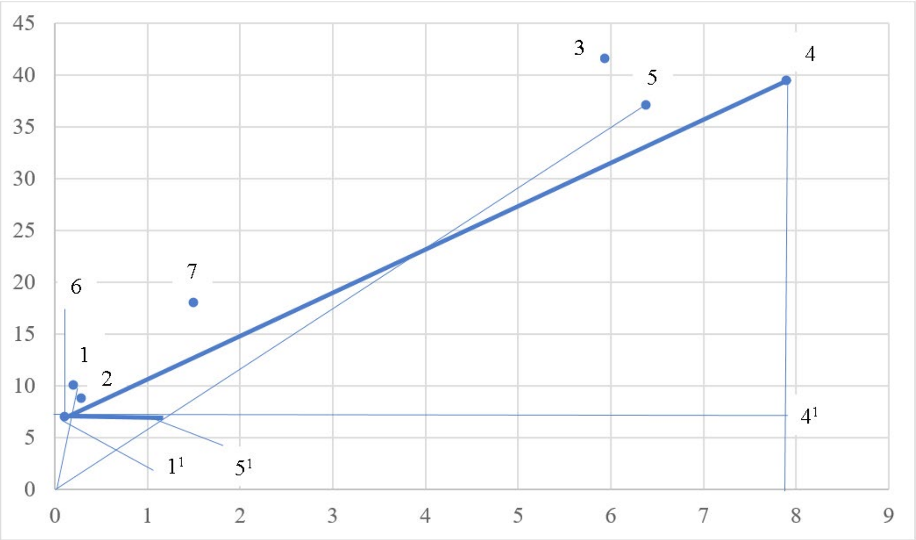

Fig. 4. The order after optimization of the positions of various cultures according to the ratio of bioethanol yield per 1 ton of crop and productivity, and between bioethanol yield per 1 ha of area and productivity

Rys. 4. Kolejność po optymalizacji stanowisk różnych kultur według stosunku uzysku bioetanolu z 1 tony plonu a produktywnością oraz między uzyskiem bioetanolu z 1 ha powierzchni a produktywnością

Thus, new positions of relations between bioethanol yield from 1 ton of feedstock and yield and between bioethanol yield from 1 ha of area and yield by crops from which bioethanol is produced are obtained.

Based on the laws of the operating environment, the best indicators of efficiency, provided by the optimal values of yield and increase the yield of bioethanol from 1 ton of feedstock and 1 ha of area were found for sugar cane and wheat. As sugar cane is not grown in the natural and climatic zones of Ukraine, wheat, corn and sugar beets remain effective crops for bioethanol production.

The peculiarity of this study is that the production of vegetable oils and bioethanol can be ensured by achieving efficiency in the use of different crops. It should be noted that the increase in production efficiency is easier to achieve with bioethanol because the comparison of two optimized lines of technical efficiency (Fig. 4 and Fig. 6) show that the ratios for this product are much closer to the coordinate axes than in the case of vegetable oils.

Conclusions

In Ukraine, the most promising feedstocks for bioethanol production are sugar beets, molasses, feed grain and corn. In terms of potential feedstock for biodiesel production, Ukraine is currently a leader in the cultivation of such oil crops as rapeseed, soybeans and sunflowers, but most of the harvested yields are exported. Thus, Ukraine has significant untapped feedstock potential for the production of both bioethanol and biodiesel. However, with today's ratio of energy and prices of feedstock, the economy of biofuel production in Ukraine is not efficient enough. It is possible to reduce the cost of biofuels by increasing the efficiency of crop production, and, as a consequence, increase the yield of oil (from oil-bearing crops) and bioethanol (from sugar-containing and starch-containing crops) from 1 ton of feedstock and from 1 ha. As a result of the economic and mathematical modeling of the possibility of increasing the yield of bioethanol and vegetable oil from crops, new positions of the relationship between oil yield per 1 ton of raw material and yield and between oil yield per 1 ha and crop yield, between bioethanol yield per 1 ton of raw material and yield, as well as between the release of bioethanol from 1 ha, which allows from these positions to start planning the cultivation of oil, sugar and starch crops, based on the laws of the operating environment, where efficiency is achieved by optimal yields and increased oil and bioethanol yield tons of raw materials and 1 hectare. Effective measures in this direction can be the increased crop yields through the introduction of intensive technologies, the use of high-yielding varieties and hybrids; development and implementation of technologies of cultivation, post-harvest processing and storage taking into account zonal features of crop production, increasing the efficiency of crop processing.

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Natalia Pryshliak, Andrii Sakhno, Dina Tokarchuk, Hanna Shevchuk

Specyfika oceny możliwości zwiększenia wydajności biopaliw z upraw rolnych na przykładzie Ukrainy

Streszczenie

Rozwój nowoczesnego systemu gospodarczego staje się coraz bardziej uzależniony od zapewnienia wystarczających zasobów energetycznych wysokiej jakości w związku z intensyfikacją i transformacją mechanizacji i automatyzacji wszystkich gałęzi przemysłu. Wzrost potrzeb energetycznych społeczeństwa idzie w parze ze świadomością konieczności zapewnienia przyjaznego środowisku rozwoju. Powodów poszukiwania nowych źródeł energii jest wiele, m.in. ograniczone zasoby źródeł tradycyjnych, uzależnienie od krajów-eksporterów ropy naftowej, efekt cieplarniany spowodowany emisją dwutlenku węgla do atmosfery, a także zanieczyszczenie powietrza szkodliwymi gazami. Sektor biopaliw oferuje potencjał zarówno dla rozwoju krajowego rolnictwa, jak i zwiększenia niezależności energetycznej kraju. Światowe trendy w szybkim rozwoju bioenergii w połączeniu z systemowym kryzysem sektora energetycznego w Ukrainie wymusiły konieczność szczegółowego zbadania możliwości zwiększenia wydajności biopaliw z upraw. Przeprowadzono modelowanie ekonomiczne i matematyczne, w którym zbadano możliwości zwiększenia wydajności bioetanolu i oleju roślinnego z upraw rolniczych. Powstał model optymalizacji ekonomicznej, który umożliwił zbadanie wzrostu uzysku bioetanolu z upraw cukrowych i skrobiowych oraz oleju roślinnego z roślin oleistych z 1 tony na 1 ha powierzchni.

Słowa kluczowe: wydajność, modelowanie, biopaliwo, uprawy rolnicze