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PROSPECTS FOR THE DEVELOPMENT OF BIODIESEL PRODUCTION IN UKRAINE WITH CONSIDERATION OF SOCIO-ECONOMIC AND ENVIRONMENTAL EFFICIENCY

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Abstract. The article's objective is twofold: firstly, to explore the prospects for biodiesel production, and secondly, to develop a universal methodology for evaluating its efficiency. In doing so, the social, economic and environmental aspects of Ukraine will be given full consideration. *Methodology.* The research was conducted utilising the following methodologies: a cause-and-effect analysis was employed to ascertain the socio-economic and ecological efficiency of biodiesel production; statistical and economic methods were implemented for the retrieval, processing, and analysis of statistical data; and a logical generalization was employed for the formulation of conclusions. Graphical representation was employed for the creation of a diagram illustrating an algorithm for biodiesel and by-product production within an energy co-operative. The study examined the volumes of rapeseed production and highlighted the impracticality of fully exporting this crop and its oil products. The study identified leading biodiesel production technologies and substantiated their economic feasibility. The findings indicate that the organisation of biodiesel production in the form of energy co-operatives has the potential to fully meet the agricultural sector's demand for fuel and to promote the development of related industries, including animal husbandry. The research evaluates the economic feasibility, environmental impacts, and social aspects of biodiesel production. Utilising a data-driven approach, encompassing a comprehensive analysis of oilseed crop production, production costs, and market prices, a model was meticulously developed to assess socio-economic and ecological efficiency. The study identified the key advantages and barriers to the industry's development, and recommended state policy measures to stimulate biodiesel production. The need to create co-operatives to unite agricultural producers for the joint production of biodiesel is identified. The study highlights the need for scientific research to improve biodiesel production technologies, in particular by increasing the oil content of certain rapeseed varieties. The analysis shows that with rapeseed costing 14,160 UAH/t (purchase price from agricultural enterprises), transport costs of 40 UAH/t /km and processing costs of 900 UAH/t, the total production cost will be 16,260 UAH/t. The planned biodiesel production of 450 kg per tonne requires an additional investment of 2,050 UAH. By-product revenues are estimated at 5,900 UAH, resulting in biodiesel production costs of 33 UAH per kg or 28.44 UAH per litre. The research findings can be used to develop effective strategies for promoting bioenergy in Ukraine. *Practical implications.* The following practical implications of biodiesel production in Ukraine can be deduced from the conducted study: enhanced energy independence, promotion of agricultural development by means of the processing of oilseed crops, creation of new employment opportunities in rural areas, reduction of greenhouse gas emissions, increase in budget revenues, encouragement of the development of new technologies in the bioenergy sector, and establishment of scientific schools with a focus on research in bioenergy. *Value / Originality.* The study's originality lies in the development of an algorithm for the

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operation of energy co-operatives, with the objective of meeting the needs of agricultural enterprises for biodiesel and concentrated feeds. The study also includes the development of a universal methodology for assessing the socio-economic and ecological efficiency of biodiesel production.

Keywords: biodiesel, rapeseed, exports, energy independence, improvement, socio-economic and environmental efficiency.

JEL Classification: Q42, Q28, Q16

1. Introduction

In Ukraine, biodiesel production is a promising direction for energy development, combining socio-economic and environmental benefits. However, a comprehensive assessment of this process requires consideration of both its positive and negative aspects. An analysis of the economic and environmental dimensions of biodiesel production in Ukraine indicates a significant potential for this sector to contribute to the national economy and improve the environmental situation.

The annual escalation in the cost of traditional diesel fuel has a concomitant effect of increasing the cost of agricultural production. Concurrently, oil reserves – the primary raw material for diesel fuel production – are limited. With the cessation of energy imports from Russia and Belarus, the country faces a shortage of energy resources. Moreover, the use of petroleum-based fuels has a detrimental impact on the environment.

The establishment of biodiesel production in Ukraine is a matter of pressing concern, given the country's high level of energy dependence. It is the contention of the present study that the initiation of biodiesel production in Ukraine is contingent upon the establishment of collaborative relationships between agricultural producers, research institutions, and manufacturers of the requisite biodiesel production equipment. This collaboration will facilitate the design and production of bespoke equipment to meet the specific needs of customers, in addition to the provision of on-site personnel training. The commissioning of biodiesel facilities would allow agricultural enterprises to achieve partial energy independence and reduce costs for fuel and lubricants. It is imperative to acknowledge the multifaceted interplay of social, economic, and environmental factors in this context. To this end, the development of a universal methodology for calculating the socio-economic and ecological efficiency of biodiesel production is paramount.

2. Literature Review

Research by Pantsyreva et al. (2024) highlights the accelerated development of biomethane production at AIC processing facilities. Nevertheless, there is a paucity of biodiesel production projects in Ukraine.

Kaletnik (2008) asserts that, owing to a combination of objective and historical factors, Ukraine falls into the category of energy-deficient countries, with its energy consumption being nearly four times greater than that of developed nations. In the contemporary context, the diminution in conventional energy provision has transcended economic dimensions, metamorphosing into a politically charged issue.

As Zhuk (2022) have noted, statistical data on biodiesel production in Ukraine is not available, although the potential is estimated at 2 million tons per year. The raw materials for biodiesel production include technical oil, rapeseed, and soybeans – crops that Ukraine actively cultivates and exports.

The findings of earlier studies (Lohosha et al., 2023; Telekalo et al., 2022) indicate that the "Perseus" hybrid is to be preferred when producing biodiesel from rapeseed. Its methyl ester has been shown to possess a combustion heat that is 9.11% higher than that of the "Lagonda" hybrid, thereby enabling more efficient biofuel utilisation.

As posited by Khrystynchenko et al. (2023), corruption has been shown to exert a detrimental effect on the long-term well-being of citizens, security, and state stability. The study identified that corruption has the potential to erode public trust in government institutions and projects, thereby impeding the development and implementation of pivotal initiatives within the bioenergy sector.

Despite the availability of a significant amount of research and the efforts of leading scientists in the field of alternative energy production and its regulatory framework, the development of biodiesel production remains relevant. It remains an important way of ensuring the country's energy security and highlights the need to develop a methodology for assessing the efficiency of this resource.

3. Research Results

Biodiesel production helps reduce the country's energy dependence, creates new jobs, increases farmers' incomes and attracts investment. It also reduces greenhouse gas emissions, improves air quality and reduces dependence on fossil fuels.

Conversely, certain challenges must be acknowledged, including competition for land resources, impacts on food prices, high production costs, and seasonality.

The potential for biodiesel production in Ukraine is significant, yet the industry faces considerable challenges. A comprehensive approach is required, incorporating economic, environmental, and social dimensions. To successfully develop this sector, it is essential to address several issues, including high production costs, competition for land resources, and seasonal production challenges (see Table 1).

At present, rapeseed is a high-demand agricultural crop. It is an important technical and oilseed crop that is optimal for biodiesel production. The oil yield potential from one hectare of rapeseed is approximately 1,100 kg. This is in comparison to the yield of soybeans, which is approximately 310 kg per hectare, and sunflower, which is approximately 600 kg per hectare. Due to its high-fat content, rapeseed is considered a high-energy feed, containing 1.7–2.1 feed units per kilogram. Its seeds contain 40–47% oil, 20% protein, and 5.5–6.5% fibre. It has been determined that plowing post-harvesting residues of rapeseed into the soil is equivalent to applying 15 tons of organic fertilizers per hectare.

Notwithstanding the imposition of martial law in Ukraine in 2023, agricultural enterprises successfully cultivated a total of over 2.8 million hectares of crops.

Concurrently, the Research Laboratory of Bioenergy at the Educational and Scientific Center of Vinnytsia National Agrarian University is undertaking studies and practical implementation of advanced experience in biodiesel production (Kupchuk et al., 2023). Furthermore, consultations on the production and utilisation of biofuels are furnished to educational and research institutions within the region. Specialists have developed and calculated the chain for processing oilseed crops into meal and biodiesel for the internal needs of farming enterprises by creating an energy co-operative with interested agricultural producers (Figure 1).

According to the research, at a rapeseed price of 14,160 UAH/t (purchase price from agricultural enterprises), transport costs of 40 UAH/t-km and processing costs of 900 UAH/t, the total production costs are 16,260 UAH. With a planned biodiesel yield of 450 kg, additional investments of 2,050 UAH are

Table 1
Comprehensive assessment of environmental and economic aspects of biodiesel production in Ukraine

Aspect	Advantages	Disadvantages	Problem resolution
Economic	Reducing energy dependence, creating jobs, increasing farmers' incomes, and attracting investment.	High production costs, competition with traditional fuels, seasonality of production.	Government support, technological development, cluster creation, and optimisation of production processes.
Environmental	Reduction of greenhouse gas emissions, improvement of air quality, reduction of dependence on fossil fuels, and promotion of agricultural development.	Competition for land resources, impact on food prices, inefficient production.	Optimisation of land use, development of waste treatment technologies, and improvement of energy efficiency.
Social	Supporting rural areas, developing infrastructure, creating jobs, and reducing the impact on energy market pricing.	Possible negative impact on biodiversity, social inequality in income distribution.	Developing social programmes, supporting small and medium-sized businesses, ensuring transparency and accountability.

Source: authors' research

Table 2
Production volumes of major oilseeds in 2023

Crop	All agricultural holdings				Enterprises			
	Sown area, thousand hectares	Harvested area, thousand hectares	Production volume (gross harvest), thousand centners	Yield, centners per hectare of harvested area	Sown area, thousand hectares	Harvested area, thousand hectares	Production volume (gross harvest), thousand centners	Yield, centners per hectare of harvested area
Oilseed crops	8,638.3	8,608.0	218,228.8	25.4	7,741.9	7,712.1	200,440.6	26.0
including								
soybean	1,842.1	1,834.0	47,425.5	25.9	1,663.6	1,655.5	43,822.1	26.5
Winter rapeseed and colza (spring rapeseed)	1,435.6	1,431.6	41,836.5	29.2	1,428.8	1,424.8	41,671.9	29.3
Winter rapeseed	1,386.9	1,383.0	40,829.1	29.5	1,380.8	1,376.9	40,678.6	29.6

Source: The State Statistics Service of Ukraine

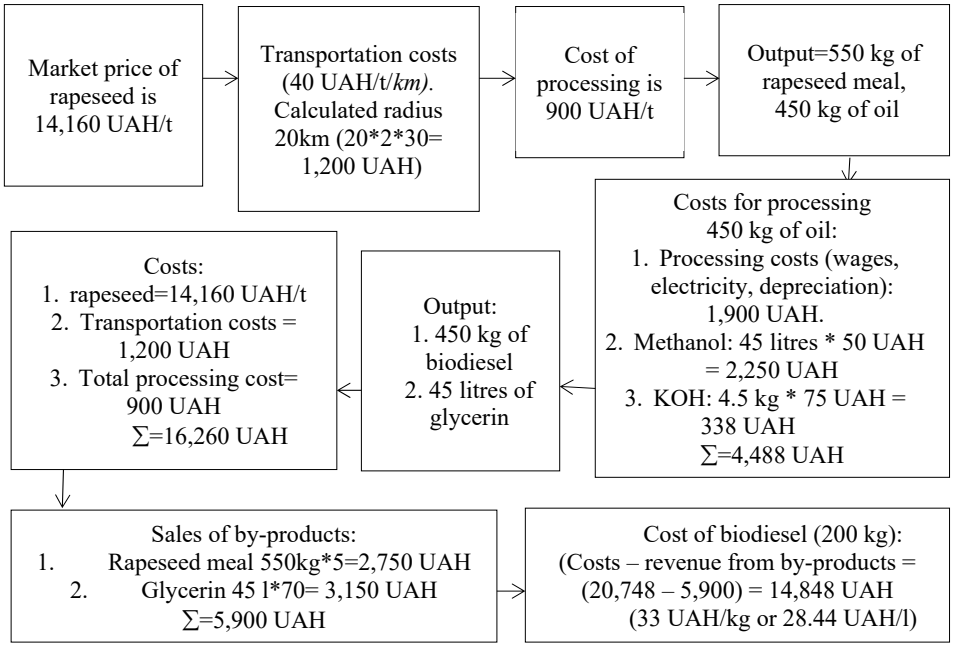

Figure 1. Calculation of the economic feasibility of rapeseed processing into biodiesel on the basis of an energy co-operative

Source: authors' research

required for production. Revenue from the sale of by-products is estimated at 5,900 UAH, resulting in a production cost of 33 UAH/kg or 28.44 UAH/litre.

In view of the prevailing costs of diesel fuel and the ongoing market deficit, the production of biodiesel is rendered highly competitive.

The scientific and practical experience of Vinnytsia National Agrarian University in biodiesel production is planned to be utilised to develop universal business plans for establishing energy co-operatives.

In order to ensure the effective development of biodiesel production, it is essential that there is close collaboration between agricultural enterprises, scientists, and equipment manufacturers. Such co-operation would facilitate the design and production of bespoke equipment, catering to the specific requirements of producers, while ensuring the training of qualified personnel. The integration of biodiesel facilities into agricultural enterprises has the potential to enhance energy independence and optimise fuel costs for farmers. The creation of co-operative associations for the processing of oilseeds into biodiesel is considered to be of paramount importance. The establishment of such co-operative networks would not only ensure the provision of biodiesel for agricultural enterprises but also facilitate the supply of concentrated animal feed to the livestock industry, in the form of rapeseed cake.

In order to enhance the properties of biofuels, hydrogen enrichment may be applied, since an increased hydrogen content has been demonstrated to increase combustion heat. A range of processing technologies, including catalytic processing, hydrogenation, and hydrogen recovery, have also been shown to enhance biofuel properties, thereby increasing combustion heat and reducing harmful emissions.

An analysis of data provided by the State Statistics Service of Ukraine indicates that the processing of rapeseed in the volume exported in 2023 has the potential to yield over 1.68 million tons of biodiesel, with a total cost estimated at over 40.3 billion UAH (based on a calculated price of 33 UAH/kg). The production of by-products would also be a consequence of this process, including 2.52 million tons of rapeseed cake with a value in excess of 12.6 billion UAH and 168,000 tons of technical glycerine with a value of 11.76 billion UAH. The total output value of these products would exceed 64.66 billion UAH, 22 billion UAH more than the value of rapeseed exports at 2023 prices (see Table 3). The aforementioned outcomes would engender socio-environmental benefits, including job creation, stabilisation of liquid fuel market prices, and a reduction in harmful emissions.

In addition to the evident economic advantages of biodiesel production, a methodology has been developed to comprehensively evaluate its efficiency, incorporating social, environmental, and economic dimensions:

$CEE_{\text{biodiesel production efficiency}} = \sum(Wi * Ii)$, where:

Wi – weight of each indicator (coefficient of importance);

Ii – index of each indicator (ranging from 0 to 1).

Table 3
Assessment of the potential for rapeseed processing into biodiesel and by-products in Ukraine (2023)

Volume of rapeseed grown, million tonnes	Exports in 2023, million tonnes	Export value in 2023 prices, billion USD	Biodiesel production, million tonnes (45%)	Cost of biodiesel production, billion UAH	Rapeseed cake yield, million tonnes (55%)	Revenue from the sale of rapeseed cake, billion UAH	Glycerin (10% of biodiesel), thousand tonnes	Glycerin sales value, billion UAH	Total revenue from biodiesel and by-products, billion UAH
4.2	3.03	1.168	1.68	40.3	2.52	12.6	168.0	11.76	64.66

Source: authors' research

Therefore, to assess the socio-economic and environmental-economic efficiency of biodiesel production, it is proposed to use the following indicators and their weight:

Efficiency = 0.2 * (jobs created (wages at biodiesel plants) + 0.6 * (income from processing oilseeds into biodiesel based on the difference in market prices for the respective crops) + 0.2 * (taxation costs for diesel – taxation costs for biodiesel)).

According to current legislation (The Law of Ukraine "On Amendments to the Tax Code of Ukraine on Implementation of the Provisions of the European Union Law on Excise Tax"), the tax rate for diesel fuel is 330 EUR per 1,000 litres, while for alternative fuels, it is 272.4 EUR per 1,000 litres.

Utilising a comprehensive assessment methodology will facilitate the evaluation of the actual impact of biodiesel production on the economy, environment, and society. The development of effective strategies for the industry's growth will be facilitated, transparency will be ensured, and accountability in decision-making processes for potential biodiesel producers will be assured.

4. Conclusions

Thus, the main directions for developing biodiesel production as a means of ensuring the state's food security should include the following:

– Implementation of a support system for agricultural producers aimed at compensating 40% of the cost of equipment purchased from Ukrainian producers for biodiesel production through transparent algorithms for the distribution of aid;
– establishment of export quotas for rapeseed and rapeseed oil at 30-40% of total production;
– development of public-private partnerships between research institutions and private investors aimed at developing rapeseed and biodiesel technologies;
– expansion of methanol production at distilleries to provide biodiesel capacity.

Implementation of these measures will significantly increase the energy independence of the national economy and promote the development of related industries that support biodiesel production.

In the medium term, the proposed measures can achieve the following results for Ukraine's energy security:

– Increasing the country's GDP by processing rapeseed into biodiesel;
– creation of additional jobs in rural areas;
– provision of concentrated feed (rapeseed cake) to the livestock sector;
– increasing the capacity of distilleries to produce methanol (a component for biodiesel production);
– reducing the cost of production of major crops by using cheaper biodiesel;
– partially meeting the needs of both agriculture and related industries for alternative fuels in the form of biodiesel;
– performing a comprehensive socio-economic and environmental assessment of biodiesel production in various forms of management;
– supply the industry with technical glycerin.

A promising area for future research involves the application of this methodology to evaluate the feasibility of biodiesel production at the scale of energy co-operatives, as well as medium and large enterprises. Further studies are required to assess the feasibility of utilising technical glycerol as a liquid furnace fuel, taking into account its energy value.

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