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ASSESSMENT OF AGRICULTURAL BIOMASS POTENTIAL IN SUSTAINABLE BIOFUEL PRODUCTION

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Introduction. The depletion of fossil energy sources, climate change, and the need to strengthen energy security underscore the strategic importance of bioenergy. Ukraine's agricultural potential creates the prerequisites for transforming its agro-industrial complex to produce renewable biofuels, which is critically important for achieving energy independence, sustainable rural development, and fulfilling commitments under the European Green Deal. The need to diversify energy sources and reduce dependence on imported fossil fuels makes agricultural biomass (agribiomass) a key resource for sustainable energy production.

Aim and tasks. This study aims to comprehensively assess the raw material potential of agribiomass in Ukraine's agro-industrial complex for biofuel production, analyse projected indicators for the development of global and European biofuel markets, and determine the prospects for the integration of Ukrainian producers into the EU market.

Results. The analysis showed that Ukraine has significant agribiomass potential, particularly from agricultural waste, such as cereals, oilseeds, sugar beets, and livestock manure. An analysis of the global and European biofuel markets revealed steady growth in demand for liquid biofuels (up to 130 Mtoe globally and 21 Mtoe in the EU by 2024), biogas and biomethane (up to 52 Mtoe globally and 28 Mtoe in the EU), and solid biomass (up to 535 Mtoe globally and 58 Mtoe in the EU). An assessment of the agricultural waste potential in Ukraine for 2024 revealed a significant potential for biofuels, amounting to 134.4 thousand tons, 1.8 thousand tons of biodiesel, and 4.1 million m^3 of biogas. According to the forecast, in 2026-2030, electricity production at bioenergy plants in Ukraine will grow by 29.25%, mainly due to an increase in biomass production by 31.37%. The EU specialises in advanced biofuels and biomethane, which creates favourable export opportunities for Ukrainian producers.

Conclusions. The effective utilisation of Ukraine's agribiomass potential, combined with technological innovations and supportive government policies, will not only meet its energy needs and strengthen energy independence. It will also significantly contribute to the decarbonisation of the European economy and the strengthening of energy security. For successful integration into the EU market, Ukrainian producers should overcome barriers such as price instability, supply reliability, and biofuel quality, which requires the creation of a transparent and competitive market and harmonisation of standards.

Keywords: biofuel, biogas, agribiomass, agricultural waste, energy security, sustainable development.

1. Introduction.

Bioenergy development is gaining strategic importance in the current landscape of alternative energy source development and global challenges related to climate change, depletion of traditional fossil energy, and the imperative to strengthen energy security (Duarah et al., 2022). Ukraine's agricultural resources offer unique opportunities to transform its agro-industrial complex (AIC) for the production of renewable biofuels.

These transformations are economically feasible and important for energy-independent and sustainable rural development within the European Green Deal (EGD) framework. This can also alleviate the urgent need to reduce energy consumption and dependence on fossil fuel imports in the country.

This study aims to comprehensively assess agricultural biomass's (agribiomass) potential in Ukraine's agro-industrial complex for biofuel production, considering current trends and prospects for industry development.

This study was designed to address the following research questions (RQ):

RQ1. Analysis of the potential of agricultural biomass and its forecast indicators for use in the production of biofuels.

RQ2. Overview of agribiomass-to-biofuel production technologies for integrating energy, heat, and biofertiliser production through enterprise and community synergy.

RQ3. Analysis of the prospects for domestic Ukrainian biofuel producers to enter the EU alternative energy market.

The conducted research is relevant and important for the development of energy independence in Ukraine and the EU. It will contribute to solving the global problems of energy security and climate change. The research results will answer the posed research questions and contribute to the development of the biofuel industry in Ukraine and the EU in the context of the European Green Deal.

Thus, the results of this study will be a valuable contribution to the development of biofuel production in Ukraine (as a potential major producer of agribiomass-based biofuels). Moreover, it will facilitate the achievement of sustainable development goals and accelerated implementation of the European Green Deal.

2. Literature Review.

Despite the obvious advantages of using agricultural biomass, its comprehensive assessment and effective use face several challenges (Mignogna et al., 2024). These challenges are described by Roudneshin and Sosa (2024), covering collection technologies, transportation, storage, processing, economic feasibility and, regulation of agribiomass. This literature review aims to systematise and analyse existing scientific studies related to assessing the potential of agribiomass in the agro-industrial complex of Ukraine for producing biofuel.

Particular attention will be paid to methods for calculating available biomass, existing and promising technologies for its processing into various biofuels, their economic and environmental aspects, and an analysis of public policy and legislative frameworks that promote or hinder bioenergy development in Ukraine. The results of this review will help identify key areas for further research and the development of practical recommendations for the most effective use of agribiomass as a strategic energy resource for Ukraine.

Kaletnik and Honcharuk (2020) investigated that the reorientation of the agrarian economy towards agricultural production and the use of intensive cultivation technologies would free up significant agricultural land for energy crops.

Using special bacteria (basophilic and thermophilic) and wood biomass helps reduce pollution and support sustainable development. (Ozturk et al., 2025). In addition to producing biofuels from agricultural waste, it is expedient to cultivate energy crops for biofuel production. For instance, Mazur (2020) determined that one of the key indicators defining the value of switchgrass as a bioenergy crop is the energy yield of solid biofuels. It was concluded that optimal cultivation technologies create plant growth and development conditions, ultimately leading to higher energy yields.

In addition, corn silage has not yet been used to increase the efficiency of biogas production at existing biogas plants in Ukraine. However, selection, genetic methods and cultivation technologies have proven their effectiveness in increasing corn yields.

According to Koval et al. (2025), crop residues, manure, and food industry waste form the primary biomass sources for biogas production in Ukraine. Biogas initiatives can reduce CO_2 emissions while increasing energy-related revenues. In addition, Hontaruk et al. (2024) note that the development of biogas and fermentation production at Ukrainian sugar factories is an important step towards entering the biomethane market.

To increase the efficiency of bioethanol production, based on the research outcomes (Lohosha et al., 2024), an intensive technology for growing corn for grain and vegetable crops was developed, namely, the introduction of organic biofertiliser based on digestate into the soil in the amount of 55.0 t/ha. As a result, the Crop Factor (CF) was 3.10 (corn), 1.47 (carrots), and 2.04 (beets), which is 47.6%, 20.5%, and 22.9% more than in the control options, respectively.

At the same time, the production of biofuels from wastewater from agricultural processing enterprises is promising. Zhang et al. (2023) determined synergistic effects in co-liquefaction, where a binary mixture of wastewater sludge and wheat straw demonstrates the highest synergistic effect in biogas production.

Conversely, Pysarenko et al. (2024) justified the directions in the context of post-war recovery strategies, which include introducing environmental technologies, adapting production to the requirements of the biological economy, and creating cost-effective and efficient distribution channels.

Overall, the results of this review confirm that the development of integrated bioenergy based on agricultural biomass in Ukraine is not only economically beneficial but also a strategically necessary step to achieve energy independence, improve the environmental situation, and ensure the sustainable development of rural areas. Further research should focus on developing an integrated model for agricultural biomass management, optimising supply chains, introducing advanced conversion technologies, and developing effective public policies that promote investment in the bioenergy sector (Jahani et al., 2023; Malinov et al., 2024).

3. Materials and Methods.

This study analysed sources addressing bioenergy, agribiomass, biofuels, and sustainable development. To achieve the stated research questions (RQ1-RQ3), the following research methods were applied:

- Systematisation of information from various sources, identification of relationships between elements of the bioenergy system, and development of general conclusions.

- A bibliometric analysis was used to assess the importance of academic publications and to identify key areas of bioenergy research.

- Statistical analysis to determine the potential of agricultural biomass, which is calculated based on livestock numbers and waste generation, and solid biofuels, which are based on crop yield and by-product yield.

- expertert assessment method was used to interpret the forecast data and determine key directions for bioenergy development, considering existing challenges and opportunities. This method is justified in identifying and adapting best practices to enhance the competitiveness of Ukrainian producers, which is critically important for analysing the prospects of entering the EU market.

Based on the National Renewable Energy Action Plan until 2030 (Cabinet of Ministers of Ukraine, 2024), an analysis of the forecast indicators for the development of electricity generation in Ukraine was conducted, specifically the share of bioenergy facilities. The calculation of the volume of byproducts (straw, tops, etc.) was based on data on the production volumes of the main agricultural crops (cereals, rapeseed, sunflower, and sugar beet) for 2024 and the coefficients of byproduct yield per 1 ton of the main crop (or per 1 ha). The following approach was used:

$$V_{biogas} = V_{crop} \times K_{yield} \quad (1)$$

Where:

V_{biogas} – potential volume of by-products (thousand tons);

V_{crop} – production volume of the respective agricultural crop (thousand tons);

K_{yield} – by-product yield coefficient (t/t).

To determine the planned volume for biofuel production, the share of byproducts that are economically feasible for collection and processing was taken into account, as well as their qualitative characteristics for the respective types of biofuels (solid, liquid, and gaseous), which were considered. The calculation of biogas potential from livestock waste was based on data on the number of cattle, pigs, and poultry as of 2024, waste generation rates per head per year, and specific biogas yield from 1 ton of raw material (m³/t). The calculation formula is as follows:

$$V_{biogas} = N_{livestock} \times W_{waste} \times K_{biogas} \quad (2)$$

Where:

V_{biogas} – total biogas potential (million m³);

$N_{livestock}$ – number of livestock of the corresponding animal species (*million heads*);

W_{waste} – volume of waste generated per head per year (*t/head/year*);

K_{biogas} – volume of biogas generated from 1 ton of raw material (*m³/t*).

The share of livestock kept at industrial enterprises was also considered, as these wastes are the most accessible for centralised collection and processing at biogas plants.

This literature review is based on the available published data and official statistics. It is important to consider that precise data on agribiomass potential may vary depending on regional conditions, changes in agricultural production, and the economic feasibility of biomass collection and transportation. Bioenergy development forecasts are subject to changes in government policies, technological progress, and global energy market conditions.

4. Results.

4.1. Raw Material Potential for Biofuel and EU Integration Prospects.

The necessity for cleaner fuels in the transport sector, advances in processing technologies, and especially stricter regulations related to biofuel development ensure steady growth in biofuel production worldwide. At the same time, the EU has set a joint sub-target of 5.5% of the final energy share in transport for the development of advanced biofuels and renewable non-bio fuels (RFNBO) (European Commission, 2024).

The EU's main priority is to develop advanced biofuels to achieve a target of a 29% share of renewable energy in transport (European Commission, 2024).

This segment is the most promising for Ukrainian producers, as the raw materials for these biofuels do not compete with food (e.g. agricultural and forestry waste), which aligns with the EU's environmental and sustainability principles. In contrast, conventional biofuels (based on food crops) are strictly limited to 7% or the 2020 level, demonstrating a shift in the EU policy towards more sustainable production.

For a comprehensive assessment of the opportunities (Kożuch et al., 2024) for exporting agribiomass and biofuels to the European market, an analysis of the forecast indicators for the development of the biofuel market in the European Union is important (Dessi et al., 2023).

This analysis is based on key EU regulatory documents, such as the Renewable Energy Directive (RED III) and REPowerEU plan, which define strategic goals and priorities until 2030. The data in Table 1 emphasise that the EU has a transparent vector towards increasing the share of renewable energy sources, especially biofuels, with particular emphasis on those produced from non-food raw materials and waste (advanced biofuels and biomethane). This creates favourable conditions for Ukrainian producers who meet sustainability criteria and have access to the appropriate raw-material base.

Simultaneously, the global production of liquid biofuels (including bioethanol, biodiesel, hydrotreated vegetable oils, and Sustainable Aviation Fuel) is growing steadily, reaching approximately 130 Mtoe in 2024. This figure also showed steady growth in the EU, reaching approximately 21 Mtoe in 2024. This growth is supported by the demand for more sustainable fuels in the transportation sector, the development of refining technologies, and stricter regulatory requirements, particularly for using advanced biofuels and Sustainable Aviation Fuel (SAF). Biogas and biomethane production showed the most significant growth, particularly in 2022-2024. Globally, volumes increased from around 38 Mtoe in 2021 to 52 Mtoe in 2024.

Table 1. EU Forecasts and Targets for Biofuel Production and Use by 2030.

Biofuel category / Consumption sector	Target / Benchmark by 2030 (RED III, REPowerEU)	Notes and context for Ukraine
General objectives in the transportation sector	29% share of renewable energy in final energy consumption in transport, OR 14.5% reduction in GHG emissions intensity in transport.	Ukraine can help achieve these goals through the export of biofuels.
Advanced Biofuels (from Annex IX, Part A) and RFNBOs (Renewable Fuels of Non-Biological Origin)	5.5% share in the final consumption of all energy supplied to the transportation sector.	A priority for the EU. Ukraine, with its significant potential for non-food biomass (agricultural waste, forestry waste), has great opportunities for exporting to this segment.
Among them, for road and rail transport:	3.5% share of advanced biofuels (Annex IX, Part A).	Focus on biofuels that do not compete with food.
Biofuels from UCO (used cooking oils) and animal fats (Annex IX, Part B).	Limit to 1.7% of final energy consumption for all modes of transport.	This segment may also be of interest to Ukrainian producers, but it has limitations in terms of volume.
Conventional biofuels (based on food and feed crops).	Limit at a level not higher than the level of consumption in 2020 in each Member State, but not more than 7%.	This segment has limited growth prospects due to the EU's food-fuel policy.
Biomethane.	REPowerEU's goal: Increase production to 35 billion cubic meters (bcm).	High priority for the EU to replace natural gas imports. Ukraine has significant resources for biomethane production, primarily from animal waste and the sugar industry.
Potential for capacity expansion for advanced biofuels and biomethane in the EU.	Estimate: up to 23.6 Mtoe/year by 2030 (technically up to 58 Mtoe/year).	It shows a significant overall demand that the EU can meet both with its own production and imports.
Renewable ethanol.	Demand is projected to increase by 13% by 2030.	Ukraine is a major producer of grain, which can be a feedstock for ethanol.
Biofuels for aviation (SAF).	Significant growth, especially in biojet fuel (the largest growth among biofuels).	The EU is actively developing SAF requirements. Ukraine can invest in relevant technologies.
Biofuels for marine transportation.	Indicative target: at least 1.2% of energy from RFNBOs by 2030.	A new, promising direction for biofuels.
Total production of biofuels (all types).	More than 10 EJ (exajoules) by 2030 (in the IEA Net Zero scenario).	This goal requires an average growth rate of about 11% per year. Ukraine can contribute to this growth.

Source: based on European Union (2018; 2023).

Bioenergy has grown in the EU through the REPowerEU programme to replace natural gas and improve energy security (Table 2). Solid biomass is the leading renewable energy source in the EU, producing about 93 million tonnes of oil equivalent (Mtoe) in 2023 (Statista, 2025).

Considering the potential markets for biomass production, it is worth noting that Ukraine can become one of the leading producers and suppliers of alternative energy sources in the EU. This highlights its continuing key role in decarbonisation (Bobadilla et al., 2024).

As of the beginning of 2024, 68 biogas plants in Ukraine produced electricity with a total capacity of 135 MW. There are 24 biomass power plants with a total capacity of 178 MW that operate at a “green” tariff. Promising areas have been identified to increase the respective shares of renewable energy sources in the electricity sector under the current conditions:

- Re-equipment of existing thermal power plants (TPPs) and combined heat and power plants (CHPs) for bioenergy use.
- Using biomethane in CHP plants, and cogeneration units currently operating on natural gas.

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Table 2. Biofuels Production in the World and the EU for 2021-2024 (Mtoe).

Biofuel category	Region	2021	2022	2023	2024	Notes
Liquid biofuels (bioethanol, biodiesel, SAF)	World	108	117	125	130	Includes bioethanol, biodiesel. Growth, especially SAF.
	EU	17	19	20	21	Growth, with an emphasis on advanced and SAF.
Biogas / Biomethane	World	38	42	48	52	Increased production of biogas for electricity, heat and biomethane.
	EU	19	22	25	28	Accelerated growth of biomethane thanks to REPowerEU. Biomethane production in the EU in Q1 2024 was 6.4 billion m³ (equivalent to ~7 Mtoe/year).
Solid biomass	World	500	510	530	535	Mostly for heat and electricity.
	EU	55	57	60	58	Slight decline in consumption in 2023 due to mild winters and prices, expected to stabilise/grow.

Source: based on data from the International Energy Agency (2025) and Eurostat (2025).

The forecast data show a steady trend towards a significant increase in the total installed capacity and electricity generation in Ukraine over the analysed period. The total projected capacity will increase from 17,365 MW in 2026 to 24,058 MW in 2030, and electricity generation will increase from 30,912 GWh to 43,894 GWh. This reflects the country's strategic course to increase its energy capacity and ensure energy security (Table 3).

Table 3. Electricity Generation Forecast in Ukraine by Source, 2026–2030.

Type of source	2026		2027		2028		2029		2030	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Hydroelectric power plants	4717	8794	4721	9126	4722	9051	4725	9130	4728	8908
Geothermal energy			5	26	10	53	20	105	40	210
Solar power plants	8800	10065	9600	11360	10600	12369	11400	13275	12200	13471
Wind power plants	3285	9074	4085	12153	5085	14932	5585	16211	6214	17455
Bioenergy facilities, including:	563	2979	664	3479	747	3863	831	4304	876	3850
Biomass	328	1664	379	1930	412	2096	446	2289	475	2186
Biogas	235	1315	285	1549	335	1767	385	2015	401	1664
Total	17365	30912	19075	36144	21164	40268	22561	43025	24058	43894
Highly maneuverable capacities with quick start/stop capability	399		606		640		736		906	
Energy storage facilities	296		436		526		606		656	

Source: based on Cabinet of Ministers of Ukraine (2024).

Based on the electricity generation forecast in Ukraine, one of the primary growth drivers will be solar power plants (SPP) with an installed capacity of up to 12,200 MW in 2030 and a production of up to 13,471 GWh.

Wind power plants (WPPs) also showed significant growth. Their capacity is expected to increase from 3,285 MW to 6,214 MW, and production from 9,074 MW to 17,455 GWh over the analysed period. This indicates the growing importance of wind energy as a key renewable energy component.

Bioenergy facilities (biomass and biogas) will show stable but less intensive growth. The total capacity of bioenergy facilities is projected to increase from 563 MW to 876 MW, and production from 2,979 GWh to 3,850 GWh. This development will contribute to the diversification of energy sources and the efficient utilisation of biological resources.

Geothermal energy appears in the forecast as a new but promising direction in 2027. Its capacity will gradually increase from 5 MW in 2027 to 40 MW in 2030, and production will increase from 26 GWh to 210 GWh. This indicates the beginning of the development of this energy source.

The forecast also envisages significant development of highly manoeuvrable capacities with fast start/stop. Their capacity will increase from 399 MW in 2026 to 906 MW by 2030. This is critical for integrating large volumes of intermittent renewable energy sources (such as solar and wind power) and ensuring the stability of the power system.

Similarly, a significant increase in energy storage installation is projected. Their capacity will increase from 296 MW in 2026 to 656 MW by 2030. These installations will play a key role in accumulating excess electricity from renewable sources and supplying it to the grid during peak demand or low-generation periods.

The presented forecast demonstrates Ukraine's ambitious and targeted strategy for developing its energy sector. The main focus is decarbonisation and increasing the share of renewable energy sources in the energy mix. Solar and wind power play a dominant role in this process, which requires the appropriate development of supporting infrastructure, including highly manoeuvrable capacities and energy storage systems. The successful realisation of these forecasts will be key to achieving Ukraine's energy independence and sustainability.

As of the beginning of 2024, electricity production from biomass and biogas in Ukraine shows a slower growth rate than other renewable energy sources.

In addition, as of the beginning of 2024, 24 power generation facilities used biomass to generate electricity at the feed-in tariff, with a total capacity of 178 MW.

Although the goals of the National Renewable Energy Action Plan until 2030 (Cabinet of Ministers of Ukraine, 2024) regarding bioenergy were not fully achieved, the current National Plan envisages intensifying the development of electricity generation from biomass and biogas sources.

The total planned volume of agribiomass transfer for biofuel production is 344,550 thousand tons. This emphasises the massive potential of solid biofuels from plant waste, such as grains, sunflower straws, and sugar beet tops.

Cereals and pulses are the main sources, providing 218,000 thousand tons of waste for solid biofuels, which is approximately 63% of the total. Sunflowers also contributed significantly to 113,400 thousand tons, or approximately 33% of the total. This demonstrates the feasibility of developing pelletising and briquetting technologies for these types of biomass.

The main share of potential biodiesel production is provided by sunflowers (45,360 thousand tons) and winter rape and kola (1,822.5 thousand tons). The total biodiesel production potential is 47,182.5 thousand tons. This confirms the importance of oilseeds in the liquid biofuel segment in Ukraine.

The main source for bioethanol production is cereals and legumes, with a potential of 87,200 thousand tons. This is significant, indicating the possibility of replacing a significant share of traditional gasoline with bioethanol in the future. It should be noted that the production of bioethanol from cereals can compete with their use in the food and feed industries, which requires a balanced approach.

The most significant contribution to the potential of biogas from plant material is made by factory sugar beet (from its waste as pulp and tops), which amounts to 4.1 billion cubic meters of biogas. This emphasises the high methanogenic activity of sugar production waste. Although the table does not indicate the direct biogas potential for cereals, rapeseed, and sunflowers, their residues (straw, meal, and stover) also have significant potential for fermentation in biogas plants.

The total potential of biogas from these crops is 4,095 million m³ (excluding biogas from cereals, rapeseed, and sunflower, which can be obtained from their waste) (Table 4). Ukraine has a significant and diversified potential for plant-based agribiomass, which allows producing a wide range of biofuels: solid biofuels, biodiesel, bioethanol and biogas. Solid biofuels from grain straw and sunflower waste are the largest segment in terms of raw materials.

Table 4. Assessment of the Potential of Crop Waste for Biofuel Production in Ukraine, 2024.

Type of crop production	Production volume, 2024, mln. tons	Sown area, 2024, mln ha	Yield of by-products (straw, straw bale)		Planned volume of transfer for biofuel production, thousand tons	Yield of liquid/gaseous biofuels per 1 ton (t/m³)	Potential volume of biofuels (solid, liquid, gaseous)			
			t/ha	total, 2024, thousand tons			Solid biofuels, thousand tons	Biodiesel, thousand tons	Bioethanol, thousand tons	Biogas, million cubic meters(3)
Cereals and legumes	52.4	10.9	25	272500	218000	0.4	87200		10480	
Winter rape and kohlrabi	4.5	1.35	3	4050	4050	0.45	1822.5	1800		
Sunflower	12	5.4	21	113400	113400	0.4	45360			
Factory sugar beet	11.5	0.26	35	9100	9100	0.45				4095
Total	–						134382.5	1800	10480	4095

Source: based on the State Statistics Service of Ukraine (2025).

The development of biodiesel production from rapeseed and sunflower and bioethanol from grain is strategically important for reducing dependence on imported oil products.

Sugar beet waste is a highly efficient feedstock for biogas production, which opens up prospects for integrating bioenergy projects in sugar factories. These data confirm that the rational use of agribiomass can be one of the key factors in achieving Ukraine's energy independence and fulfilling its commitments to decarbonise its economy.

It is important to emphasise that a significant part of the agriobiomass potential is formed from livestock waste. An analysis of the distribution of cattle (the number of which directly affects the potential for biogas production) at the beginning of 2025 shows that approximately 45% of animals are kept on industrial farms (917.6 thousand animals, of which 378.5 thousand are cows), while the remaining 55% are kept in households (1 million 111.9 thousand cattle, including 799.2 thousand cows). A similar distribution is observed in the pig industry, where agricultural enterprises hold 64% of the total number of pigs and households hold 36%. It should be noted that the ongoing war has caused significant changes in the geographical distribution of the pig farms. There was a decrease in the number of livestock in the eastern regions and an increase in the western regions (Lviv, Ivano-Frankivsk), as well as in Zaporizhzhia and Kharkiv regions (Table 5).

Table 5. Potential for Biogas Production from Livestock Waste in Ukraine in 2024.

The potential of livestock waste				
Livestock products	**Number of livestock, million heads**	**Waste generation per goal per year, tons**	**Volume of biogas production from 1 ton of raw materials, m^3**	**Total potential, bcm(3)**
Cattle	2.03	20	32	1.299
Pigs	4.48	6	42	1.129
Poultry	186.42	0.112	97	2.025

Source: based on the State Statistics Service of Ukraine (2025).

Ukraine can potentially produce 4.53 billion cubic meters of biogas from livestock waste. Simultaneously, poultry offers the most significant potential for biogas production, at 2.025 billion cubic meters. This is due to the high number of livestock (186.42 million animals) and relatively high specific biogas yield per ton of feedstock (97 m^3/t), despite the lower volume of waste per animal. This emphasises the importance of poultry farms as biogas sources.

Cattle waste in Ukraine can produce 1.299 billion m^3 of biogas annually. Although the cattle population is only 2.03 million animals, it is a significant source of waste, as each head produces 20 tons of waste per year (AgroBiogas, 2020).

Pigs provide 1.129 billion cubic meters of biogas annually in Ukraine. Despite the large number of pigs (4.48 million), the lower volume of waste per head (6 tons per year) and specific biogas yield (42 m^3/t) result in a slightly lower share compared to poultry and cattle. However, decentralised solutions, efficient collection systems, and cooperation between small farms are needed to use pig and cattle waste effectively.

Livestock waste in Ukraine is a powerful but underutilised source of biogas production. Realising this potential has a double benefit: renewable energy production and efficient utilisation of organic waste, which contributes to reducing environmental pollution, improving sanitation, and reducing greenhouse gas (methane) emissions. The development of biogas projects at large livestock complexes and the creation of incentives for small farms to cooperate is key to unlocking this potential.

The main areas of increasing the share of bioenergy should be as follows:

– Modernisation of existing thermal power plants and combined heat and power plants by converting them to use bioenergy;

– The use of biomethane in new highly manoeuvrable generating plants, as well as in CHP and cogeneration systems that currently operate on natural gas;

– State support for investment projects under the Law of Ukraine (Verkhovna Rada of Ukraine, 2024) also applies to the production of bioethanol (as a fuel component), biogas, and biomethane (including liquefied or compressed).

Ukraine has significant prospects, considering the successful experience of European countries with similar bioenergy potential. Thanks to the construction and commissioning of new biogeneration facilities, electricity production from biomass could increase to 3850 GWh by 2030, corresponding to a total capacity of about 876 MW.

One of the key barriers to bioenergy development is the volatility of biofuel prices, problems with the reliability of its supply and insufficient quality. The following steps are required to address these challenges:

1. A transparent and competitive market for solid biofuels is needed, as international experience demonstrates the effectiveness of specialised platforms for biofuel trading that ensure openness and fair pricing.

2. Harmonisation of Ukrainian terminology in the field of bioenergy with the EU legislation, in particular concerning the definitions of “bio-liquid”, “biofuel”, and “biomass fuel”.

3. Implementation of European legislation on sustainability criteria and greenhouse gas emissions.

4. Implementing these measures is important to stimulate further bioenergy development in Ukraine and unlock its full potential.

5. According to the National Renewable Energy Action Plan for the period up to 2030 and the action plan for its implementation, in early 2024, the total electrical capacity of biomass and biogas facilities in Ukraine (excluding the temporarily occupied territories) will amount to 319 MW.

This indicates that the development of electricity production from biomass and biogas is still lagging behind the growth rate of other renewable energy sources (Cabinet of Ministers of Ukraine, 2024).

The following key areas are being considered to increase the share of bioenergy in the country's energy balance: Another approach is to modernise conventional generation facilities (TPPs and CHPs) by converting them to bioenergy. The use of biomethane at new highly manoeuvrable generating facilities, as well as in CHP and cogeneration plants, currently operates on natural gas. One of the key obstacles to the development of biomass energy production is the fluctuating prices of different types of biofuels, as well as logistical problems related to military operations in Ukraine and the low quality of biofuels. To solve these problems, we suggest the following steps:

– Creating a single, competitive, and transparent market for solid biofuels. International experience proves the effectiveness of the transition to specialised electronic platforms for biofuel trading, which ensures transparency, openness and competitive conditions for market pricing.

– Harmonisation of Ukrainian bioenergy terminology with EU legislation, in particular, concerning definitions such as "biofuel", "bioliquid", and "biomass fuel".

– Implementation of European legislation on sustainability criteria and greenhouse gas emission accounting.

These measures will contribute to the further sustainable development of bioenergy in Ukraine and help fully realise its significant potential (Cabinet of Ministers of Ukraine, 2024).

The expansion of Ukraine's biofuel export potential necessitates the development of strategic areas.

1. Creating a single, transparent and competitive biofuel market based on successful international experience in Ukraine will ensure fair prices and increase the sector's attractiveness for investors.

2. Attract investment to construct new biofuel production facilities (bioethanol, biogas and biomethane) that meet European standards.

3. Introduce advanced biomass processing technologies that increase biofuel productivity, improve processes and minimise environmental impact. This may include developing integrated production facilities combining energy, heat and biosecurity.

4. Create bioenergy clusters and cooperatives that unite agricultural producers, processing enterprises and research institutes to improve logistics, reduce costs and increase production efficiency.

5. Active promotion of Ukrainian biofuels in the EU market, confirmed by international sustainability and quality certificates.

The prospects for domestic biofuel producers to enter the EU market are significant, but their implementation requires coordinated efforts by the government, businesses, and scientific community. Utilising Ukraine's agricultural potential for biofuel production will not only contribute to its energy security and economic development. However, it will also position the country as a reliable and sustainable partner in the European green transformation.

The biofuel market in EU is one of the most promising for Ukrainian producers, as the EU is actively implementing a policy of decarbonisation and increasing the share of renewable energy sources. Various ways of integrating into the European energy sector are open to domestic companies (Table 6). The most obvious way to enter the EU market is through directly exporting finished biofuels, such as bioethanol, biodiesel, or biomethane (Motola et al., 2023; Sulewski et al., 2023). This route allows Ukrainian producers to obtain higher added value from their products and maximise the use of existing production capacities.

Table 6. Strategic Directions for the Integration of Ukrainian Biofuel Producers into the EU Alternative Energy Market.

№	Direction of entry into the EU market	Description and key aspects for biofuel producers	EU requirements and challenges	Features and benefits
1	Export of finished biofuels	Selling bioethanol, biodiesel, biogas (biomethane) and other biofuels directly to consumers or distributors in the EU.	RED III Directive (Renewable Energy Directive), sustainability requirements (greenhouse gas emissions, impact on biodiversity, land management), certification (ISCC, RSB, etc.), customs and non-tariff barriers, competition with local producers.	Access to a large and growing market, the possibility of obtaining higher added value, and the use of existing production facilities.
2	Joint ventures (JVs) and strategic partnerships	Establish joint ventures with European companies to produce or distribute biofuels, exchange technologies, and access to European sales networks.	The need to find reliable partners, coordinate business models, legal and corporate issues.	Reducing risks, sharing resources, access to new technologies and financing, and simplifying market entry.
3	Localisation of production in the EU	Construction or acquisition of production facilities in the EU for producing biofuels from Ukrainian raw materials or raw materials available in the EU.	High capital expenditures, regulatory approvals, access to raw materials in the EU, knowledge of local legislation and business environment.	Direct access to the market, minimisation of logistics costs, bypassing customs barriers, and the possibility of receiving subsidies and financial support from the EU.
4	Supply of raw materials for biofuel production in the EU	Export of biomass (straw, agricultural waste, forestry waste) or intermediate products (e.g., technical ethanol) for processing into biofuels in the EU.	Requirements for the quality and sustainability of raw materials, logistics, competition with other suppliers, and dependence on the demand of European processors.	Lower investment risks compared to the production of finished biofuels and the possibility of expanding the raw material base.
5	Provision of engineering and consulting services	The expertise of Ukrainian biofuel producers in developing and implementing bioenergy projects, especially in EU countries that are developing this sector.	The need for highly qualified personnel, knowledge of European standards and practices, and licensing.	Utilisation of intellectual capital, diversification of income sources, and expansion of the influence of Ukrainian companies.
6	Participation in European programs and projects	Involvement in EU research, innovation and investment projects in bioenergy (e.g. Horizon Europe, Innovation Fund).	High requirements for innovation, competition for funding, application complexity and project administration.	Access to funding, technology transfer, creation of joint R&D centres, and reputation improvement.
7	Production and export of biofuels from advanced raw materials	The focus on biofuels produced from non-food crops, waste and residues (e.g. lignocellulosic biomass, algae) is a priority in the EU.	More complex technological processes, high R&D investments, and the need to prove sustainability and compliance with EU criteria.	High added value, less competition, support from the EU, and the opportunity to become a leader in a niche segment.

The possibility of implementing bioethanol projects requires compliance with European standards, in particular, the RED III regulation (European Union, 2023) and the necessary certificates (for example, ISCC, RSB). Additional challenges include high competition from European manufacturers and tariff and non-tariff trade barriers.

The creation of joint ventures or partnerships with EU companies allows Ukrainian producers to access technology, financing, and distribution networks. Investing in localising production in the EU by building or acquiring factories gives Ukrainian companies direct market access, lowers logistics costs, and helps bypass customs barriers.

Ukraine has significant potential for biomass production, which makes the supply of raw materials (straw, agricultural waste, and forestry waste) or intermediate products (e.g. technical ethanol) for processing in the EU an attractive option. This carries lower investment risks than finished biofuel production and can become the basis for expanding Ukraine's raw material base. The key requirements are the high quality and sustainability of raw materials and efficient logistics.

Participation in European programs and projects (e.g., Horizon Europe and Innovation Fund) in bioenergy provides access to funding, knowledge, technology exchange, and the establishment of joint research centres. Although competition for funding is high and the requirements for innovation are stringent, it can significantly improve the reputation of Ukrainian companies and contribute to their technological development.

A particularly promising area is the production and export of biofuels from advanced feedstocks produced from non-food crops, waste, and residues. These biofuels are prioritised in the EU because of their lower impact on land resources and food security issues. Although the technological processes are more complex and R&D investments are higher, this segment promises high added value, less competition, and significant support from the EU, allowing Ukraine to become a leader in this niche area. Ukrainian producers must adhere to strict quality and environmental standards to enter the EU biofuel market. Simultaneously, Ukraine's energy independence is strengthened, and economic growth is stimulated due to the special chances that these regions will integrate into the global energy system.

5. Discussion.

An assessment of the potential of agricultural biomass shows that it has significant potential to increase energy independence and integration into the European energy market. This study analyses available agricultural biomass, processing technologies and current legislative measures to define ambitious bioenergy development in Ukraine in the context of the European Green Deal and post-war reconstruction.

The outcomes showed that Ukraine has enormous raw material potential for biofuel production, which is a strategic advantage (RQ1). The analysis showed that significant volumes of agribiomass, particularly grain and sunflower straw (which together account for approximately 96% of the planned transfer to solid biofuels), as well as sugar beet pulp and tops, can be efficiently converted into various types of biofuels.

Feedstock diversification is essential as it allows for flexible responses to changing market conditions and technological advances. In addition, animal manure is another powerful but underutilised source of biogas. Industrial parks with centralised waste collection are the best locations for biogas projects as they can generate 4.53 billion cubic meters of biogas from cattle, pig and chicken manure.

Simultaneously, a significant share of livestock kept in households requires the development of decentralised solutions and incentives for cooperation.

The review of agribiomass biofuel technologies (RQ2) indicates that they have the potential to integrate energy, heat, and biofertiliser production. To exploit lignocellulosic biomass (Ozturk et al. (2025) and reduce emissions (Koval et al. (2025), the production of biomethane is intensified, which can replace natural gas in highly manoeuvrable power plants and cogeneration units, which is the most important sector for increasing the energy sustainability of Ukraine (Hontaruk et al., 2024).

In addition, digestate as a bio-organic fertiliser has been shown to improve agricultural production efficiency for energy production significantly, complement the resource cycle, and enhance the sustainability of agricultural production Lohosha et al. (2024). There are several opportunities and challenges for domestic biofuel producers seeking to enter the European alternative energy market (RQ3).

Ukrainian producers must overcome barriers, including successfully integrating price fluctuations, supply stability issues and low-quality biofuels. Creating a real and competitive market for solid biofuels and aligning Ukrainian standards with European legislation is necessary.

Improving regulations is essential for expanding support for producing bioethanol, biogas, and biomethane (Pysarenko et al., 2024).

The effective use of Ukraine's agribusiness potential, combined with technological innovations and favourable government policies, will not only meet its energy needs but also significantly contribute to the decarbonisation of the European economy and strengthen the energy security of the entire continent. For this purpose, close cooperation between the government, research institutions, and the private sector and harmonisation of national legislation with European norms and standards is critical.

6. Conclusions.

This study examines the significant potential of agricultural biomass in the Ukrainian agro-industrial complex for producing biofuels. The outcomes demonstrate the strategic importance of bioenergy as a vital resource for increasing Ukraine's energy independence, sustainable growth and entry into the European energy market.

The development of bioenergy from agro-biomass has become critically important in light of global challenges related to climate change, depletion of traditional fossil fuels and the need to improve energy security, especially in light of the current geopolitical situation. The vast majority (about 96%) of the 344,550 thousand tons of expected agribiomass converted into solid biofuels comes from sunflower grain and straw, which are the primary sources of solid biofuels.

Sunflower and rapeseed are key liquid biofuels for biodiesel production. Simultaneously, cereals and legumes have significant potential for bioethanol production, which opens up opportunities to replace a significant share of traditional oil products. Livestock waste represents a powerful, albeit underutilised, source of biogas. The total potential for biogas production from these wastes in 2024 is estimated at 4.453 billion cubic meters, which is a significant indicator for supplementing the country's energy balance.

Factory sugar beet waste (pulp and tops) and poultry waste are particularly promising for biogas production, demonstrating the most significant contribution to the total biogas potential from animal waste.

Despite its significant prospects, some challenges must be overcome to integrate successfully into the European biofuels market. These include volatility of biofuel prices, problems with supply reliability and quality assurance. To solve these problems, it is critical to create a transparent and competitive market for solid biofuels, as well as to fully harmonise Ukrainian terminology and standards, including sustainability criteria and greenhouse gas emissions accounting, with European legislation.

In addition to energy production, the efficient use of agribiomass also combines the production of heat and valuable biofertilisers (digestate), which closes resource cycles, increases the sustainability of agricultural production, and effectively utilises organic waste.

To maximise this potential, further research and development of integrated agribiomass management models, optimisation of supply chains, and the introduction of advanced conversion technologies are required. The development of effective public policy that stimulates investment in the bioenergy sector, including support for R&D and the creation of bioenergy clusters and cooperatives, is key to achieving these goals.

In summary, Ukraine has all the prerequisites to become a significant player in the European biofuels market.

The successful realisation of this potential, combined with technological innovations and favourable government policies, will not only meet its energy needs but also significantly contribute to the decarbonisation of the European economy and strengthen the energy security of the entire continent. For this purpose, close cooperation between the government, research institutions, and the private sector, as well as continuous harmonisation of national legislation with European norms and standards, are critical.

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