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BIORESOURCES IN THE TRANSFORMATION OF UKRAINE'S ENERGY SYSTEM

The growing volatility of global energy prices increases energy insecurity in importing countries, necessitating the development of adaptive strategies that consider local resource potential. In Ukraine, which is facing the consequences of war and partial destruction of its energy infrastructure, the development of bioenergy has become particularly relevant as an alternative path to strengthening energy security. The hypothesis of the research assumes that rising global prices for conventional energy carriers enhance the economic feasibility of local bioenergy projects, provided there is a sufficient resource base, regional support mechanisms, and effective tariff regulation.

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БИОРЕСУРСЫ У ТРАНСФОРМАЦИИ ЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ УКРАИНЫ

Зростання волатильності світових цін на енергоносії зумовлює нові виклики для енергетичної безпеки країн, що залежать від імпорту. В Україні, яка перебуває під впливом зовнішніх загроз та внутрішніх інфраструктурних втрат внаслідок повномасштабного вторгнення росії, особливої актуальності набувають локальні енергетичні рішення. Розглянуто потенціал біоенергетики як ефективний інструмент диверсифікації джерел енергії, підвищення енергетичної стійкості регіонів та зменшення залежності від традиційних енергоносіїв. Гіпотезою дослідження є припущення, що глобальні цінові коливання стимулюють зростання економічної доцільності реалізації



The research methodology is based on a combination of comparative analysis, expert assessments, a cost-element approach to energy pricing, and indicative ranking of biofuel alternatives using techno-economic criteria: cost, calorific value, profitability, and payback period. Using the Polissia region as a case study, the paper evaluates the potential of wood-based, agricultural, and peat biomass. The findings reveal that baled straw and wood chips are the most balanced heat sources in terms of cost-effectiveness, availability, and supply stability. A technical and economic comparison of various energy sources is provided, and key barriers to scaling bioenergy solutions are identified. Particular attention is paid to limitations in the current tariff policy and investment incentives. The research results are relevant for shaping regional energy transition strategies, supporting investment initiatives in the renewable energy sector, and advancing national decarbonization goals. Bioenergy is therefore positioned as a critical component of Ukraine's pathway toward energy autonomy and sustainable economic development in the context of global energy price fluctuations.

Keywords: bioenergy, price volatility, biomass, thermal energy, investment feasibility, energy policy.

JEL Classification: E30, F29, Q42.

місцевих біоенергетичних проєктів за умов наявності стабільної ресурсної бази та помірного рівня інвестицій. Методологія дослідження базується на поєднанні порівняльного аналізу, експертного оцінювання, індикативного ранжування альтернативних джерел тепла за критеріями собівартості, теплотворної здатності, інвестиційних витрат, терміну окупності та рентабельності. У ході дослідження проаналізовано ситуацію Поліського регіону, зокрема Житомирської області, яка має сприятливі умови для використання біомаси деревного, аграрного та торф'яного походження. На основі узагальнення результатів дослідження встановлено, що тюкована солома та деревна тріска є найбільш збалансованими джерелами з погляду ефективності, доступності й тарифної конкурентоспроможності. Водночас виявлено інституційні бар'єри, зокрема недосконалість тарифного регулювання, які стримують впровадження відповідних проєктів. Результати дослідження можуть бути використані при формуванні регіональних стратегій енергетичної трансформації, залученні інвестицій у відновлювану енергетику та підтримці цілей декарбонізації економіки України.

Ключові слова: біоенергетика, коливання цін, біомаса, теплова енергія, інвестиційна доцільність, енергетична політика.

Introduction

Global energy markets are experiencing periods of increasing instability, accompanied by high price volatility, which affects international energy trade and the energy security of states, creating new challenges for countries with a high level of import dependence. In conditions of external instability, especially during Russia's military aggression against Ukraine and the partial destruction of its energy infrastructure, there is an objective need to adopt adaptive local solutions aimed at strengthening energy self-sufficiency. One such solution is a reorientation to renewable energy sources, in particular to biomass, which can become a real tool for increasing the energy sustainability of regions.

The relevance of the research is due to the need for a systematic analysis of the relationship between global fluctuations in energy prices and the adoption of economically sound decisions in the field of bioenergy. Despite numerous initiatives to develop renewable energy, most of the existing solutions in Ukraine remain reactive, do not rely on a deep economic assessment of the efficiency of biomass use and do not take into account the broader global context. While in the European Union countries bioenergy is actively integrated into energy policy, thanks to predictable targets and stable incentives, in Ukraine fragmented regional projects dominate, requiring strategic rethinking in the face of global price pressure.

The scientific basis for analyzing the potential of bioenergy and its role in the energy transition is the subject of active research in a number of scientific works; in particular Scarlat et al. (2015) consider bioenergy as a central component of the EU energy transformation through an interdisciplinary approach. In the domestic discourse, important developments are the studies of Geletukha et al. (2023), as well as Oliynyk (2024), who carried out a thorough analysis of the potential of biomass, barriers to its use, and the economics of biofuels. At the same time, the issue of adapting local energy strategies under the influence of global price fluctuations, taking into accounts the technical and economic characteristics and investment attractiveness of alternative energy sources, remains insufficiently covered.

The aim of the research is to substantiate bioenergy solutions in the context of global fluctuations in world energy prices. The research focuses on analyzing the impact of international price volatility on local technical and economic decisions regarding the use of biomass as a source of thermal energy. Special emphasis is placed on substantiating the conditions and prospects for implementing bioenergy projects in regions of Ukraine with an existing raw material base, in particular on the example of Polissia.

The hypothesis of the research is the assumption that fluctuations in world prices for traditional energy carriers create the prerequisites for increasing the attractiveness of bioenergy solutions at the local level, especially in the presence of a stable resource base and moderate investment costs for equipment installation.

The methodological basis of the research is analytical and comparative methods, the expert assessment method, an elemental approach to calculating the cost of energy, as well as an indicative ranking of solutions according to the criteria of cost, efficiency, payback period and profitability. The information base was made up of statistical data from the State Statistics Service of Ukraine, official tariffs of the National Commission for the Regulation of Energy and Utilities of Ukraine, analytical reports of the Bioenergy Association of Ukraine, scientific publications from the international Scopus database and technical and economic parameters of implemented projects in the Zhytomyr region. The limitations of the research are due to the instability of the energy market, the lack of systematic accounting of agricultural waste at the local level, and the complexity of predicting changes in the regulatory and tariff environment.

The article consists of three main sections. The first section examines the dynamics of global wood and natural gas markets and their impact on local solutions. The second section analyzes the resource potential of biomass in Ukraine using the example of the Polissia region, taking into account technical capabilities, raw material base and operating enterprises. In the third section, a technical and economic comparison of thermal energy sources (wood chips, straw, pellets, natural gas, and electricity) is carried out with an assessment of investment feasibility, tariff efficiency and payback periods.

At the final stage, the results are summarized and recommendations are proposed for the formation of local policies to support bioenergy projects in the context of global energy pressure.

1. Global price fluctuations in the energy market

The global energy market over the past decade has been characterized by increased volatility, due to the influence of a wide range of geopolitical, economic, climatic and technological factors. The process of forming the price environment is influenced by the complex interaction of supply and demand, existing infrastructure constraints, as well as the regulatory policy of leading market participants. Additional determinants of price fluctuations have been the global crises of recent years, in particular the COVID-19 pandemic, the energy shock caused by the full-scale military aggression of the Russian Federation against Ukraine, as well as the sanctions policy of the EU and the USA, which significantly affected the transformation of the current pricing mechanisms. In these conditions, the analysis of the dynamics of world prices for key energy carriers, namely: natural gas, coal and oil, acquires particular importance. Identification of key price trends makes it possible to identify critical factors influencing local energy strategies, taking into account decisions on the development of renewable energy, including the use of biomass as an alternative source of thermal energy.

1.1. Dynamics of world prices in the natural gas market

In view of the holistic diagnosis of the price situation on the global energy market, it is important to analyze the situation and quotation trends on the natural gas market, which remains a key element of the global thermal energy architecture. In order to ensure the purposefulness, comprehensiveness and systematicity of the assessment, information and analytical data from leading exchange platforms that perform the function of global indicators of the price for natural gas were used. The main representatives of the exchange infrastructure that form guidelines for price positioning for gas include:

- gas hub Title Transfer Facility (hereinafter referred to as TTF);
- London Stock Exchange ICE (Intercontinental Exchange);
- New York Mercantile Exchange NYMEX (New York Mercantile Exchange).

Each of the above market infrastructure entities trades in its own currency and specific units of measurement of natural gas (Ministry of Finance, p. 11).

One of the largest gas hubs, the TTF, located in the Netherlands, is a key European trading center where prices are set in a freely convertible currency and are considered an indicator of the formation of free market prices for gas in Europe, measured in euros per megawatt hour (MWh). The

correspondence between energy and volume indicators is: 1 MWh = 95.31 m³ of natural gas, or 1000 m³ = 10.49 MWh. The London ICE exchange as a regulatory quotation platform, where the exchange price level is set in the national currency of Great Britain (GB p/thm), is 1/100 of a pound sterling per Therm, which approximately corresponds to 2.7933 m³ of natural gas, or 1000 m³ $\approx$ 358 Therms. The NYMEX futures market is an indicator of gas prices in the Western Hemisphere, where natural gas is traded in US dollars per Henry Hub, a benchmark gas grade in MMBtu = 1 million Btu = 1.000.000 Btu = 27.933 m³. A Btu is a British thermal unit (BTU), which is 252 cal, or 1.055 J. A BTU is the amount of heat required to raise the temperature of 1 pound of water (a mass of water equal to 0.45359 kg) by 1° Fahrenheit (Department of Finance, 2025).

The price situation in the natural gas market demonstrates similar trends among the three main exchange platforms that form global quotes (Figure 1).

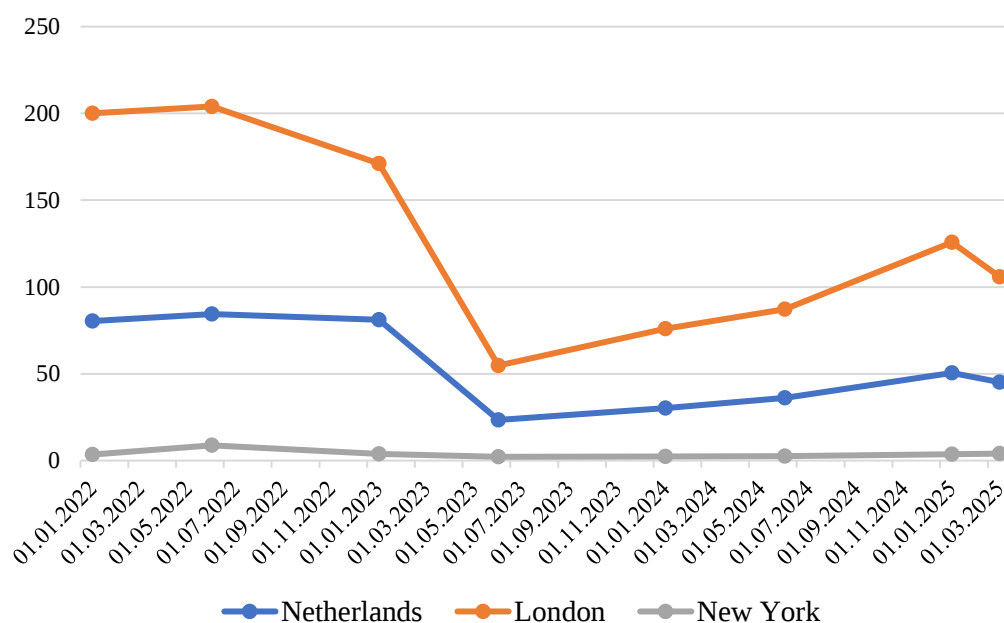


Figure 1. Dynamics of world prices for natural gas, USD per ton

Note: units of measurement: Netherlands (Gas Hub) – EUR/MWh; London Stock Exchange – pence/Therm; New York Mercantile Exchange – USD/million BTU.

Source: compiled by the authors based on (Ministry of Finance, n. d.).

The highest price level was recorded in March–May 2022. Subsequently, a gradual decline was observed, reaching a minimum level in July 2023. From the second half of 2023, prices began to increase again, reaching a new maximum in early 2025. Price volatility emphasizes the need to diversify energy sources and intensify the transition to more sustainable and renewable energy solutions, in particular based on the use of biomass as a strategic direction of energy security.

1.2. Dynamics of global prices on the coal market

Coal, as a traditional energy source, plays a significant role in the global energy balance, especially in the context of providing electricity and heat in economic activity. Despite the gradual transition to low-carbon technologies and international obligations to reduce greenhouse gas emissions, demand for coal remains, in particular in countries with energy-intensive economies.

The price situation on the global coal market is determined by leading exchanges that provide futures quotes based on market expectations and contractual agreements. World coal prices are set in USD per ton on such platforms as the aforementioned New York Mercantile Exchange NYMEX and the Intercontinental Exchange (ICE), as well as at the Newcastle Coal Terminal in Australia. Prices take into account both over-the-counter transactions and contracts for difference (CFDs). The results of coal trading on international commodity exchanges are shown in *Figure 2*.

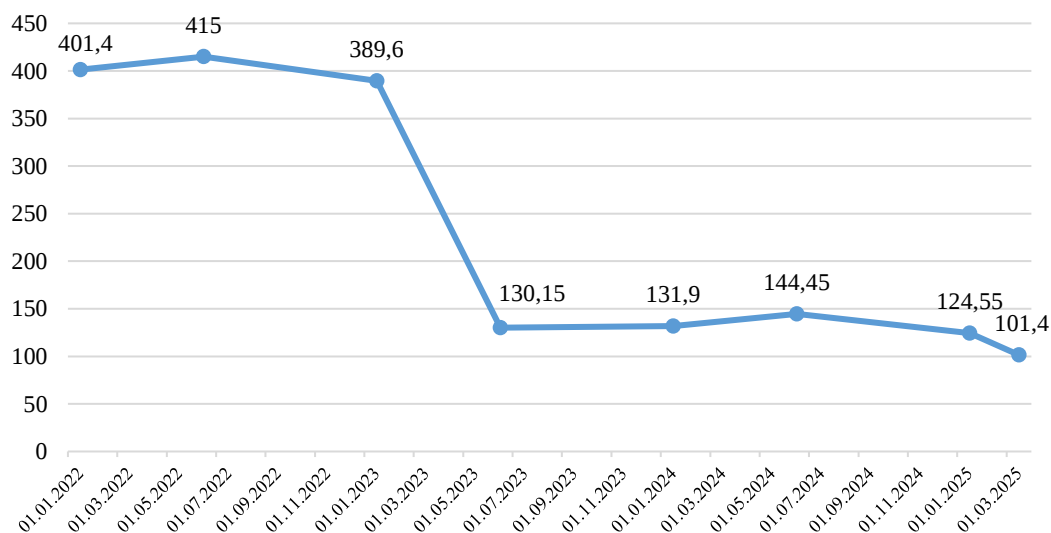


Figure 2. Dynamics of world coal prices, USD per ton

Source: compiled by the authors based on (Ministry of Finance, n. d.).

To ensure the comparison of the research results, the same time period of observation was used as in the case of the analysis of the natural gas market. Therefore, the dynamics of world coal prices demonstrate similar trends and phases of fluctuations. The highest price values were observed in March–June 2022, which coincides with the period of geopolitical tension and energy instability. Subsequently, a gradual decrease was noted, with a temporary sharp decline in May–June 2023 and reaching a minimum level in March 2025. Such price fluctuations indicate a high sensitivity of the coal market to global economic and political factors, which necessitates the diversification of energy sources.

1.3. Dynamics of world prices on the oil market

The world oil market demonstrates exceptional sensitivity to global economic, political and environmental changes. In particular, as a key source of energy, oil determines the pace of development of national economies, affects the structure of the balance of payments of exporting countries and forms a significant part of the cost component for importing countries. Its pricing is based not only on the ratio of demand and supply, but also on the qualitative characteristics of the resource, the geography of deposits, supply logistics, as well as on geopolitical stability in the regions of production.

The establishment of world market prices for oil, in particular for its individual types, which differ in the content of heavy hydrocarbons, sulfur, alkanes and other impurities, as well as the location of the deposit, is carried out according to three main reference grades: American WTI (West Texas Intermediate) – mainly for the American market; European Brent (Brent Crude) – as a reference for Europe and OPEC countries; russian Urals is the benchmark grade for russian oil. Monitoring of world prices recorded on the above international commodity exchanges is presented in *Figure 3*.

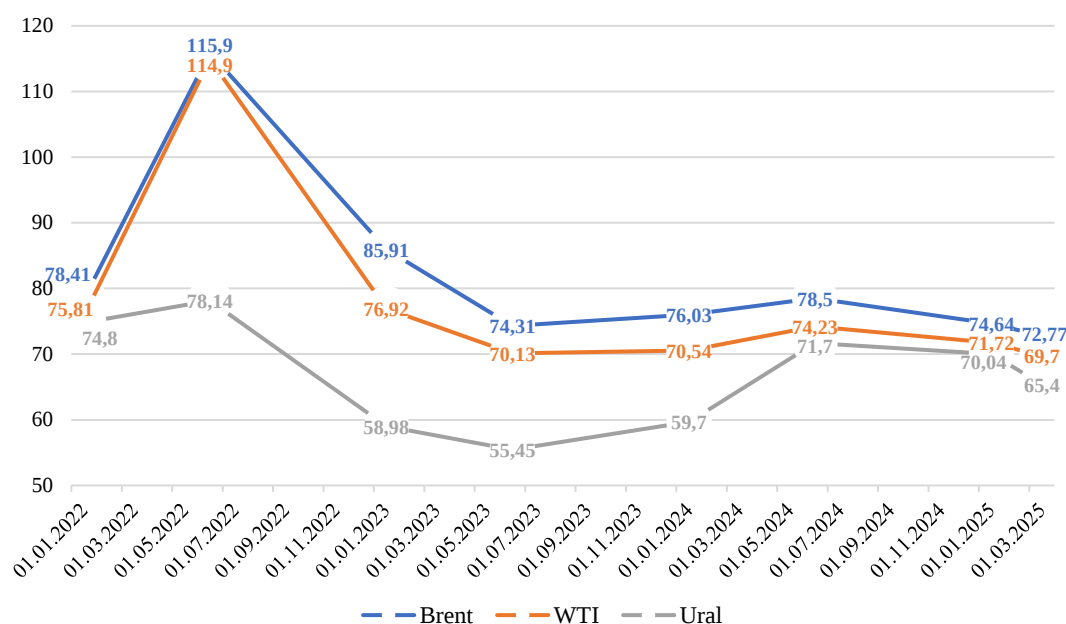


Figure 3. Dynamics of world oil prices, USD per barrel

Source: compiled by the authors based on (Ministry of Finance, 2025).

Monitoring of world oil prices reveals trends that are largely correlated with trends in the natural gas market. The highest level was recorded in May–June 2022, which is directly related to the beginning of Russia's full-scale invasion of Ukraine and the introduction of sanctions against the aggressor country. However, the re-election of the US president and changes in the foreign policy of this state led to the fact that after Trump's

inauguration in February–March 2025, prices for Russian Urals oil did not show significant volatility, as in 2022–2023.

Therefore, price trends in the world market for natural gas, coal and oil are interconnected and have similar vectors of change. The current stabilization of world prices for major thermal energy resources is seen as a positive factor that contributes to reducing uncertainty in energy markets, providing more predictable conditions for the formation of national energy strategies and investment decisions in the bioenergy sector.

1.4. Dynamics of world prices on the timber market

Price monitoring and assessment of the timber market situation is a rather complex task given the diversity of the product range, its grades, quality characteristics and final destination. In industry classification, experts distinguish two main types of wood: industrial and energy. Industry differentiation makes it possible to carry out an accurate analysis of demand, supply and pricing, since each of the segments has its own specific market price dynamics and influence factors.

According to experts from the Association of Woodworking Enterprises of Ukraine, "the global lumber market has been demonstrating a steady downward trend over the past two years. There is a decrease in demand for coniferous lumber in key regions, which is due to a number of interrelated factors, in particular, a decrease in housing construction, a decrease in the scale of repair work and a general decrease in the level of consumption of goods" (Association of Woodworking Enterprises of Ukraine, 2025). Based on information and analytical data provided by experts, the main global trends in the wood market have been systematized (*Table 1*).

Table 1

Characteristics of the global timber market by major regions

Market Characteristics	Northern and Central Europe	North America	China and the Middle East and North Africa Region
Condition	Wood prices in Scandinavian countries reach highest level in a decade	Colombia is facing a timber shortage, high production costs and other issues that are reducing production. In 2024, production was less than half of what it was a decade ago	China's lumber imports fell 7% year-on-year in the first ten months of 2024. In the Middle East and North Africa, imports fell 4% in the first nine months of 2024.
Price	Rising raw material prices are putting pressure on sawmills as the increase in raw material costs outpaces lumber prices, reducing their profitability	Roundwood prices in the US South have fallen to their lowest level in 30 years, a trend that could potentially spur new investment in the region's sawmills	Uneven demand and pricing across regions

End of Table 1

Market Characteristics	Northern and Central Europe	North America	China and the Middle East and North Africa Region
Forecast	In Northern Europe, controlling production costs becomes critical due to rising raw material prices	Low roundwood prices in the US South could make the region attractive to investors in 2025 and beyond	Trends will affect businesses differently in different regions. The decline of the sawmill sector in British Columbia is an example of how changing demand, regulation and global competition can transform the industry

Source: compiled by the authors based on (Association of Woodworking Enterprises of Ukraine, 2025, January 8).

Therefore, the analysis of the current situation on the world timber market reveals significant regional differences in the market situation, price dynamics and forecast indicators, which necessitates a differentiated approach to strategic planning. In particular, in Northern and Central Europe, a steady trend of increasing timber prices to record levels over the past decade is recorded, which negatively affects the profitability of sawmills due to the outstripping growth in the cost of raw materials. This fact emphasizes the critical importance of optimizing production costs to ensure competitiveness.

Meanwhile, in North America, despite a shortage of wood and high production costs that have led to a significant decline in production volumes (less than 50% of the level of a decade ago), the decline in roundwood prices in the southern USA states to a 30-year low creates the potential to attract new investments in the sawmill industry starting in 2025. In the regions of China, the Middle East and North Africa, a decrease in sawn wood imports is observed (by 7% and 4%, respectively, in 2024), which is accompanied by uneven demand and pricing due to regional specific market conditions and increased sensitivity to global economic changes.

Thus, for international companies operating in the timber market, regional differences in roundwood prices highlight the strategic value of geographical diversification as a mechanism to reduce the impact of market volatility. In addition, the growth of European sawn wood exports to the US can be seen as a new opportunity to expand supply in foreign markets. In general, the industry demonstrates sensitivity to changes in demand, regulatory frameworks and global competition, which requires constant adaptation and flexibility of business models.

Analyzing the prices of the region closest to us – Western Europe – it was found that the average European prices for wood, mainly industrial, fluctuate between 75–115 euros per cubic meter (*Table 2*).

Table 2

Prices for spruce and pine saw logs in selected European countries in 2024,
euros per cubic meter (excluding VAT)

Country	Minimum	Maximum
Austria	75	115
Latvia	85	100
Germany	103	115
Finland	79.96	90

Source: compiled based on data (Association of Woodworking Enterprises of Ukraine, 2025, March 28).

The results of monitoring the global timber market indicate a steady trend towards an increase in prices for industrial timber, even in conditions of declining demand. In particular, according to 2024 data, despite a decrease in overall demand, the average price for timber increased by 7%. Price dynamics in this segment are largely due to the development of the construction industry, the growth in demand for repair and construction services, as well as the level of solvency of the population.

At the same time, prices for low-quality energy wood are forecast to stabilize or even decrease due to an excess of existing stocks. This objective factor complicates the sale of wood chips and other waste from the forestry industry. As of today, real stocks of firewood exceed their consumption. Demand for them has decreased due to the high level of prices for the population and state regulation of natural gas tariffs. Sales volumes of wood chips remain low, and the price situation in this market segment is stable without signs of significant growth.

Thus, the global timber market situation demonstrates differentiated price dynamics depending on the quality and purpose of the resources. At the same time, it remains an important factor influencing the adoption of economically sound decisions at the local level, in particular regarding the diversification of energy sources, forest resource management and stimulation of biomass use.

2. The impact of global trends on local decisions

Local decisions are shaped by external macroeconomic trends, including fluctuations in global energy prices and increasing environmental requirements. The above-mentioned factors necessitate adaptation of local strategic decisions in the energy, forestry and agricultural sectors. The search for sustainable and affordable energy sources is becoming increasingly relevant, with biomass playing a significant role as an energy resource, especially in the context of the need to rethink energy consumption models and national energy security priorities.

2.1. The potential of biomass as an energy resource in Ukraine

Biomass is one of the most promising renewable energy sources for Ukraine, given the existing agricultural potential, the volume of forestry waste and the high level of dependence on imported fossil fuels. For the production of thermal and electrical energy in Ukraine, it is planned to attract biomass of forest, wood, agricultural, agricultural and other relevant origin. Three main groups of resources are most often used as solid fuel at thermal power plants (TPP) and combined heat and power plants (CHPP): peat biomass; plant biomass (including energy crops and agricultural residues); wood (Figure 4).

Peat group	Plant group	Wood group
• pellets • peat chunks • milled peat • peat briquettes	• sunflower husks • buckwheat husks • rice husks • corn husks, • straw, chaff • miscanthus • switchgrass • sedge	• firewood • wood chips • wood shavings • sawdust • pellets • granules • energy willow

Figure 4. Main types of solid fuel from renewable energy sources used to produce heat and electricity

Source: constructed by the authors.

This diversification of the raw material base for energy purposes provides flexibility, allowing for consideration of regional characteristics, seasonality, logistical costs, and the level of infrastructure development. At the same time, the effective use of biomass as an energy source requires a detailed analysis of the available volumes and the features of its spatial distribution.

2.2. Resource potential of biomass for energy purposes in the Polissia region: the example of Zhytomyr region

The Polissia region of Ukraine, in particular the Zhytomyr region, has significant potential for the development of bioenergy due to the presence of a wide biomass resource base, which is due to natural and climatic conditions and the structure of land use, especially in the forest and agricultural sectors. One of the determining factors of the biomass energy potential in the region is the significant forest cover of the territory. The area of Zhytomyr region is about 29.8 thousand km² and has a forest cover level of 35.2%, which provides it with the fourth place among all regions of Ukraine in this indicator. The total area of the forest fund of the region is 1094.4 thousand hectares. Such a level of forest cover creates a stable raw material base for

obtaining wood biomass, in particular firewood, wood chips, wood chips, sawdust, wood granules, pellets, etc. In addition, the region has significant areas of peatlands, which can serve as an additional source of peat biomass.

Along with forest resources, agricultural waste is a significant source of biomass in the region. According to the State Statistics Service of Ukraine, in 2023, Zhytomyr region produced 2.418 million tons of grain and leguminous crops, 934 thousand tons of sugar beets, 361 thousand tons of sunflower seeds, 1.902 million tons of potatoes and 400 thousand tons of open ground vegetables (Statistical Yearbook of Ukraine for 2023, 2024). Accordingly, the by-products of these productions, in particular straw, husks, stalks, husks and other agricultural waste, form a significant potential for the production of solid biofuels in the form of briquettes, pellets or for direct combustion in appropriate boiler rooms.

An important element of realizing the biomass potential in the Zhytomyr region is the presence of three generation facilities that are already operating on the basis of bioenergy technologies. For example, LLC "Poliska TPP" (Ovruch city), which operates a thermal power plant on solid biofuel, the main types of wood residues from the woodworking industry and energy willow. Two more power plants operate on biogas: LLC "LNK", which combines seven biogas plants, and LLC "Dionys Biogas Energy". The activities of these enterprises indicate the practical feasibility and economic viability of using biomass for energy needs within the Polissia region. This gives grounds to assert that favorable conditions have been formed in the Zhytomyr region for the large-scale use of biomass for energy purposes. The combination of wood, peat, and agricultural biomass sources creates a powerful resource base for the implementation of regional strategies for the development of renewable energy, which will become an important component of energy security, decarbonization of the economy, and sustainable development of territories.

3. Technical and economic comparison of heat energy sources

To make strategically sound decisions on the effective use of the available resource potential for energy purposes, a technical and economic assessment of alternative sources of thermal energy is important. Therefore, the study carried out a comparative analysis of technical and technological parameters and economic efficiency of thermal energy production from various types of solid biofuels and natural gas in the conditions of Ukraine.

As of the beginning of 2025, in accordance with current legislation in Ukraine, differentiated prices for natural gas have been established depending on the categories of consumers, which significantly affects their energy consumption and competitiveness (Law of Ukraine "On Natural Gas Markets", 2015). The lowest price is for households and is UAH 7.96 per m³. At the same time, the cost of gas for budgetary institutions is 2.1 times higher, which creates an additional financial burden on social infrastructure

facilities. For industrial enterprises, the price of gas exceeds the tariff for the population by 2.5 times, which significantly reduces the competitiveness of domestic products, taking into account the constant growth of the energy component in the cost structure (*Table 3*).

Table 3

Technical characteristics and assessment of thermal energy production from solid fuels (2025)

Technical data	Average cost with transport and VAT	Units of measurement	Heat capacity	Units of measurement	Cost of energy unit, UAH
Natural gas for the population	7960	UAH/ thousand m ³	33.5	MJ/m ³	238
Natural gas for the budget sector	16554				494
Natural gas for industry	20250				604
Natural gas imported by Ukrtransgaz	31000				925
Electricity for the population	4.36	UAH/kWh	—		1211
Electricity for the population consumed through a heat pump with COP ¹ =2.7					449
Electricity for households consumed through a heat pump with COP =3.5					346
Electricity for non-household consumers	10				2778
Electricity for non-household consumers consumed through a heat pump with COP =2.7					1029
Wood chips	2500	UAH/t	10.5	MJ/kg	238
Wood pellets	9000		17		529
Husk pellets	7000		17.5		400
Bale of straw or corn stalks	2000		14.6		137

Source: compiled by the authors based on (Oliinyk, 2024).

The price level of natural gas under import contracts, supplied through the operations of JSC Ukrtransgaz, is particularly indicative. Its cost is UAH 31 per m³, which is 3.89 times higher than the tariff for household consumers, 1.87 times higher than the tariff for budget institutions, and approximately 1.5 times higher than the tariff for industry (Ministry of Energy of Ukraine, 2024). Such price disparities need to be taken into account when developing an energy policy aimed at expanding the use of alternative, economically

¹ COP (a coefficient of performance) is an indicator of the energy efficiency of equipment that works on heat, for example, heat pumps or air conditioners. It shows the ratio of the thermal power produced by the device to the electricity consumed.

viable heat sources, in particular biomass. Electricity as a source for generating heat energy in Ukraine is regulated differently for two main groups of consumers: household and non-household. According to the Ministry of Energy of Ukraine, as of the beginning of 2025, the tariff for household consumers with value added tax is UAH 4.32 per kWh, including in cases of using electricity for heat pumps with a coefficient of performance (COP) of 2.7 or 3.5. However, for non-household consumers, i.e. business entities, the cost reaches UAH 10 per kWh, which is 2.3 times higher than the tariff for the population (National Commission for State Regulation in the Spheres of Energy and Utilities, n. d.). Such price differentiation significantly affects the competitiveness of products of national producers, as the energy component continues to grow, increasing the total cost of goods and services.

To justify the choice of the optimal source of thermal energy in the conditions of Ukraine, a comparative characteristic of four main types of solid biofuels presented on the Ukrainian market was carried out:

- wood chips, wood chips, which are used (for example) in LLC "Clear Energy-Zhytomyr", but belong to the low-price category (approximate price – UAH 2500 per t);
- wood pellets, pellets – the most expensive solid fuel (9000 UAH per t);
- sunflower husk pellets – belong to the higher-than-average price category (UAH 7000 per t);
- baled straw or corn stalks, the cheapest solid fuel (2000 UAH per t).

After converting the specified types of biofuels into the corresponding calorific equivalents, it is advisable to analyze the cost of thermal energy produced from them.

According to calculations by Yevhen Oliinyk, an expert at the Public Union "Bioenergy Association of Ukraine", the cost of thermal energy from various types of solid biofuels (in UAH/MJ) is: wood pellets – UAH 529/MJ (the most expensive option), sunflower husk pellets – UAH 400/MJ, wood chips – UAH 238/MJ, baled straw and corn stalks – UAH 137/MJ (the cheapest option). This indicates that wood chips, which are actively used in Clear Energy projects for energy production, combine a relatively high calorific value with an affordable market price, making it one of the most effective and economically feasible renewable energy sources for heat generation (Clear Energy, n. d.).

Separate studies conducted by specialists in the heat and power sector, including expert Yevhen Oliinyk, also took into account the economic efficiency and return on investment in the implementation of bioenergy technologies. The most expensive type of biofuel in terms of purchase price remains wood pellets from waste from the logging and woodworking industries – UAH 6.500/t, while the cost of biofuel from wood chips, wood chips (non-marketable crushed wood) and baled straw is practically the same – UAH 1.700/t and UAH 1.667/t, respectively (*Table 4*).

Table 4

Investment efficiency in the production of thermal energy
from various types of solid fuel

Technical data	Units of measurement	Wood chips	Baled straw	Pellets
Thermal capacity of biofuel boilers	kW	1000		
Calorific value of biofuel	MJ/kg	8.4	14.2	17.2
Production of thermal energy from biofuel	thousand Gcal	3.45		
Consumption of fuel raw materials	thousand tons	2.0	1.18	0.98
<i>Prices and tariffs</i>				
Electricity without VAT	UAH/kWh	6.5		
Chemically treated water without VAT	UAH/m ³	15		
Maintenance, repairs, materials	UAH/Gcal	32		
Biofuel with delivery, excluding VAT	UAH/t	1700	1667	6500
Thermal energy tariff (population), excluding VAT	UAH/Gcal	1500		2500
Investment activity expenses	UAH million	5.4	8.1	2.7
Operating activity expenses	UAH million	5.1	3.4	8.7
<i>Investment efficiency</i>				
Internal rate of return	%	13	28	54
Net present value	UAH million	3.0	12.9	9.5
Payback period	Years	6.4	4.2	2.8

Source: compiled by the authors based on (Oliinyk, 2024).

Due to the systematic damage to Ukraine's energy infrastructure as a result of Russia's armed aggression, there is an objective need to diversify energy sources and strengthen the role of local initiatives. In this context, it is advisable to consolidate the efforts of the Zhytomyr City Council, the Zhytomyrteplokomunenergo municipal enterprise, as well as to attract the experience, material and technical base, and high professionalism of specialists from Clear Energy-Zhytomyr LLC and its parent company Clear Energy to implement a new promising project for the production of electricity from renewable sources, which will increase the energy sustainability of the region, reduce dependence on imported energy carriers, and contribute to the development of a low-carbon economy in the region (Zhytomyr City Council, p. 1).

Tariffs for thermal energy for the population, including VAT, vary depending on the type of biofuel used. In particular, for cheaper sources such as wood chips and baled straw, the cost is about UAH 1.500/Gcal, while for heat produced from wood pellets, it reaches UAH 2.500/Gcal. According to the above calculations, the highest costs were for the implementation of

investment projects involving the use of wood pellets as an energy source (UAH 8.7 million). The capital costs for projects using baled straw are somewhat lower (UAH 8.1 million), and the lowest costs are typical for projects based on wood chips (UAH 5.4 million).

At the same time, the operating costs for the installation and operation of equipment demonstrate an inverse relationship: for wood chips they are the largest – 5.1 million UAH, for baled straw – UAH 3.4 million, and the project using wood pellets requires the least costs – UAH 2.7 million. The highest level of profitability from the point of view of economic efficiency is demonstrated by the project based on wood pellets – 54%, with a payback period of 2.8 years and an average income of UAH 9.5 million. The most attractive in terms of overall financial results is the investment project based on baled straw, since the net present value is UAH 12.9 million, the payback period is 4.2 years, and the level of profitability is 28%. Accordingly, the above indicators indicate the high potential of the project for generating profit and a quick return on invested funds. Taking into account the above financial indicators, the project based on baled straw deserves attention as a promising long-term investment. Its implementation can be ensured through combined financing, which includes state support, attracting international grants and using own funds of enterprises in the thermal energy sector. This approach will allow diversifying sources of financing and reducing the risks associated with the implementation of the project.

The generalized results of the technical and economic comparison of thermal energy sources confirm that the use of biomass is an economically feasible alternative to traditional energy carriers in the conditions of Ukraine. Among the studied types of biofuels, the highest profitability is demonstrated by projects based on wood pellets; however, they require the highest investment costs. At the same time, the highest net present value is the project on the use of baled straw, which indicates its high investment attractiveness in the medium term. Wood chips, as a resource with moderate cost and stable operational characteristics, provide an optimal balance between efficiency, availability and cost level. Overall, the results of the analysis confirm the need to form differentiated approaches to the implementation of bioenergy solutions at the local level, taking into account the resource base, economic parameters, and technical capabilities.

Conclusions

In the context of global price fluctuations in energy markets and the need to strengthen energy security, Ukraine is faced with the urgent task of diversifying energy sources. The analysis confirms that bioenergy solutions can become an effective tool for increasing the energy autonomy of regions, in particular Polissia, by combining forest, agricultural and peat resources. Zhytomyr region has an appropriate resource base and implemented examples of effective use of biomass in energy.

The feasibility study of various types of fuel allowed us to identify economically profitable areas for potential investments. In particular, baled

straw and wood chips turned out to be the most balanced in terms of cost, efficiency and availability. Provided that the state, municipalities and international donors support, biomass-based thermal energy production projects have a high potential for implementation. Thus, the development of bioenergy is an important component of the national energy transformation and a key direction in the country's sustainable development strategy.

The results of the research confirm the hypothesis that global fluctuations in prices for traditional energy carriers create the prerequisites for increasing the economic feasibility of implementing local bioenergy projects, especially in the presence of a stable resource base and a moderate level of investment support. The conducted feasibility study of various biofuel options (wood chips, baled straw, pellets) confirmed their competitiveness compared to natural gas and electricity, which indicates the significant potential of such solutions in the conditions of the modern energy market. Thus, the hypothesis of the study has been empirically confirmed.

The methodological platform for further research is the development of models for integrating bioenergy solutions into regional energy strategies, which will allow increasing the energy sustainability of territories, minimizing dependence on imported energy carriers and ensuring the achievement of the goals of decarbonization of the Ukrainian economy.

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The authors received no direct funding for this study.

Kilnitska, O., Yareмова, M., & Sokolova, A. (2025). Bioresources in the transformation of Ukraine's energy system. *Scientia fructuosa*, 5(163), 93–110. [http://doi.org/10.31617/1.2025\(163\)06](http://doi.org/10.31617/1.2025(163)06)

Received by the editorial office 22.07.2025.

Accepted for printing 12.08.2025.

Published online 21.10.2025.