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CONTENTS

Ahmed H. Alsharif, Salmi Mohd Isa, Lina Pilelienė Global Academic Trends of Metabolic and Electrical Biomedical Tools in Marketing	1
Anmar Pretorius Integration of the Baltic Stock Markets with Global Markets during the Previous Decade	20
Julius Ramanauskas, Šarūnas Banevičius, Putinas Bielskis Evaluation of Smartness of the Tourism Destination Websites of the Klaipeda Region	31
Juraj Ondriaš, Mykola Palinchak, Kateryna Brenzovych The Economic Influence of France in West and Central Africa	40
Katana Gafarova Legal and Economic Principles of the Foreign Policy of Independent Azerbaijan in Relation to Neighboring Countries	53
Konul Akhundova International and National Legal Mechanisms of Judicial Liability in the Conditions of Economic Globalisation of Modern Society	64
Lachezar Borisov Impact of Energy Prices on Prices of Basic Tourism Services in the Euro Area	76
Paweł Dziekański, Łukasz Popławski, Fabio Fragomeni Intra-Regional Differentiation of Entrepreneurship of Municipalities of the Świętokrzyskie Voivodeship in Terms of Sustainable Development in 2010 and 2020	83
Romans Dyakons, Vsevolods Karajevs, Rostislavs Kopitovs Increasing Value-Based Company Potential: The Grounds of a Full-Scale Assessment	92
Olga Verdenhofa, Remigijus Kinderis, Galina Berjozkina AI as a Creative Partner: How Artificial Intelligence Impacts Student Creativity and Innovation: Case Study of Students from Latvia, Ukraine and Spain	111
Ruslan Boiko, Roman Martsenyuk, Arsen Protsykevych Assessment of the Region's Investment Environment and Policy Instruments for the Implementation of its Investment Potential in Wartime	120
Dmytro Bondar The System of Entities Using Information Technologies in the Field of Life Safety: Administrative, Legal and Economic Principles of Effective Functioning	131

Andrii Borovyk, Oleksandr Golovach, Oleksandr Shyra Victim of an Offence: Legal and Economic Analysis in an Interjurisdictional Context	137
Eldar Veremchuk, Hennadii Vasylchuk Tools of Intercultural Communication in International Business: A Postcolonial Approach	146
Inna Honcharuk, Dina Tokarchuk Review of the European Experience of AIC Development and the Role of Green Technologies in the Modernisation of This Process	155
Olena Guzenko, Svitlana Nikolaichuk, Dmytro Ivanenko Smart Specialisation as a Basic Component of Socio-Economic Development	166
Tetyana Calinescu, Olena Zelenko, Serhii Pidmohylnyi Regional Factors of Mechanisms Transformation for Strengthening the Economic Security of Entrepreneurial Activity in the Industrial Sector of Ukraine	173
Ivan Klopov, Julia Ohrenych The Model of Economic Recovery of Ukraine in the Post-War Period: The Strategy of the Economic Miracle	184
Natalia Koval, Oksana Kubai, Natalia Germaniuk Administrative Prerequisites for Financial Management and Marketing of Small Businesses at the Regional Level	192
Viktoriia Kovpak, Nataliia Lebid, Viktor Burenkov Entrepreneurship of Memory in Public Space and Social Communication: A Postcolonial Approach in Time of War	203
Denys Komarnytskyi, Liudmyla Sylenko, Roman Tytykalo Functions of the State and Local Self-Government Bodies in the Regulation of Funeral Services: Economic Aspects and Ensuring Social Standards	211
Maksym Korniienko, Hanna Foros, Serhii Baranov Economic Crime under Martial Law in Ukraine	222
Ihor Kupchuk, Tatiana Yemchyk, Yaroslav Gontaruk Prospects for the Development of Biodiesel Production in Ukraine with Consideration of Socio-Economic and Environmental Efficiency	228
Andrii Lapkin, Daryna Yevtieieva, Daria Kukovynets Economic Aspect of Criminal Law Counteraction to Justification of Armed Aggression against Ukraine: Risks for the State Budget in the Light of the Practice of the European Court of Human Rights	234

Georgii Logvynskiy	
Instrumental Capacity of International Business in Modern Conditions	248
Oleksii Makarenkov	
Digitisation of Legal Algorithms to Prevent Public Procurement Corruption	254
Olha Mashchenko, Anastasiia Khodus	
Tax Compliance Risk as an Element of the Tax Risk Management Concept in an Enterprise	266
Andriy Melnyk	
Marketing Evolution: From Traditional to Web 3.0	273
Yuliia Okhota, Denys Titov, Svitlana Dotsiuk	
Mechanisms for Ensuring the Economic Development of Rural Areas Through the Formation of Their Energy Dependence Based on the Intensification of Biofuel Production	282
Vitalii Palamarchuk, Roman Lohosha, Vadim Krychkovskiy	
Energy and Economic Efficiency of Bioethanol Production Depending on the Quality of Corn Grain	293
Serhii Petrukha, Nina Petrukha, Roman Miakota	
The Public Debt of Ukraine: A New Dimension of Dynamics and Architecture of the Model Framework of the Management System	305
Yuliya Pustovit, Olena Dragan, Alina Berher	
World Experience in Administrative and Legal Support of Food Security	315
Hanna Pantsyreva	
Economic Aspects of Organic Soy Production in Ukraine	324
Svitlana Radziyevska	
GDP of the G7 After the Financial Crisis	332
Mykyta Slyusar, Vitaliia Nikitenko, Valentyna Voronkova	
Digital Humanism in the Age of the Internet and Artificial Intelligence: Challenges, Opportunities, and Prospects for Development	344
Alyona Sorokina, Larysa Lebedeva, Tetiana Lositska	
Digital Determinants of National Economy Resilience	353
Volodymyr Filippov, Iryna Bashynska, Elvin Yangulov	
Exploring the Influences on Displaced Citizens' Decision to Repatriate: A Classification of Positive and Negative Factors	364
Ivan Shumeiko, Juraj Ondriaš, Olga Sokolenko	
Principles of Application of Financial Administrative Sanctions in the Legal Doctrine of Ukraine and the World	374

MECHANISMS FOR ENSURING THE ECONOMIC DEVELOPMENT OF RURAL AREAS THROUGH THE FORMATION OF THEIR ENERGY DEPENDENCE BASED ON THE INTENSIFICATION OF BIOFUEL PRODUCTION

Yuliia Okhota¹, Denys Titov², Svitlana Dotsiuk³

Abstract. The article is dedicated to the study of the mechanisms for ensuring economic development in rural areas of Ukraine by promoting energy independence and intensifying biofuel production. The subject of the research is the use of renewable energy sources, in particular biomass, as a tool for achieving energy autonomy and economic stability of rural communities. This is especially relevant in conditions of energy dependence on imported energy carriers. The study examines biomass as a resource with significant potential to meet local energy needs, create additional jobs and stimulate economic growth in rural areas. The paper discusses key aspects of the use of renewable energy sources, particularly biomass, in agriculture as an effective tool for local economic development, reducing dependence on traditional energy resources and increasing the country's energy security. The *purpose* of this article is to study the mechanisms of economic development of rural areas through energy independence and development of the biofuel sector. To achieve this goal, the article discusses the theoretical aspects of energy independence, analyzes current practices of biofuel production, and provides recommendations for their further implementation. Particular attention is paid to the role of bioenergy in reducing environmental risks and implementing sustainable solutions in rural hromadas (communities). The study analyses international experience in the development of the bioenergy sector and its adaptation to Ukrainian conditions, taking into account the natural and economic characteristics of rural areas. Key factors that facilitate the effective implementation of biofuel production projects are identified, including innovation, investment and government support. The *methodological basis* of the study includes the application of methods of comparative analysis, systematisation and statistical data processing. This comprehensive approach enabled an in-depth analysis of the opportunities and limitations of bioenergy in Ukraine, in particular by comparing biomass use practices in developed countries and identifying effective strategies for the Ukrainian context. The article also discusses the prospects for improving the regulatory framework to create favourable conditions for bioenergy development, the need for infrastructure improvements and the involvement of local communities in renewable energy projects. The economic and social benefits to rural communities of implementing bioenergy solutions are examined separately. The study puts forward a series of proposals for the advancement of Ukraine's bioenergy sector. These include the enhancement of financing mechanisms and the promotion of private initiatives. Furthermore, the paper explores the potential of agricultural waste as a foundation for biofuel production. It is hypothesised that this could enhance the economic efficiency of the agricultural sector and reduce reliance on imported energy resources. The primary findings demonstrate that the development of biomass-based bioenergy has the potential to contribute significantly to the enhancement of economic stability and social well-being within rural hromadas. In order to implement energy independence in an effective manner, there is a necessity to improve the legislative framework, encourage investment in biomass

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storage and transportation infrastructure, and foster collaboration between local governments and state institutions. The implementation of these measures will facilitate a gradual transition of rural regions to sustainable economic development by reducing dependency on external energy sources and supporting local biofuel production.

Keywords: rural areas, agriculture, economic development, biofuels, energy independence, state regulation, economic effects.

JEL Classification: P25, Q42, Q57

1. Introduction

The economic development of rural areas is a critically important factor for achieving balanced and sustainable national economic growth. Most rural areas have significant development potential due to the availability of natural resources, in particular land and biomass, and opportunities to implement innovative energy technologies. However, rural areas often face many challenges, such as high unemployment, depopulation, inadequate infrastructure and dependence on traditional energy sources.

The establishment of mechanisms to ensure the economic development of rural areas is a fundamental aspect of contemporary economic policy. These mechanisms encompass diverse approaches, including the development of the agro-industrial complex, economic diversification, the adoption of innovative technologies, and enhancements in energy efficiency. A pivotal role in this context is played by the promotion of energy independence in rural areas through the development of bioenergy, particularly the production of biofuel.

The article under scrutiny here sets out to examine the importance of mechanisms for the economic development of rural areas, focusing in particular on the building of energy independence and the intensification of biofuel production as key tools for sustainable growth. Drawing upon an analysis of contemporary practices and scientific methodologies, the study explores the potential of these processes in the context of socio-economic development in rural regions. Vinnytsia National Agrarian University is actively researching the issue of ensuring the economic development of rural areas on the basis of sustainable development, in particular the production of biofuel, within the framework of the tasks of scientific research work on the topic: "Development of mechanisms for increasing the competitiveness of enterprises of the AIC and ensuring energy independence of rural areas through the intensification of biofuel production" (state registration number 0124U000340).

2. Literature Review

Significant attention is devoted by Ukrainian researchers, such as Kaletnik H.M. et al. and Shpykuliak O.H. et al., to issues of ensuring economic development in rural areas of Ukraine, which face

serious challenges in securing a stable energy supply for hromadas (communities). In addressing this issue, the authors believe that "green" energy co-operatives deserve particular attention, as they foster energy democracy and are an essential component of social equity in the process of building a "green" economy and achieving sustainable development, including in rural areas. The establishment of energy co-operatives in rural areas is emphasised, with the uniting of representatives of local businesses, citizens, and municipalities being pivotal in this regard. This, in turn, has been shown to increase economic benefits for businesses and territorial communities (Kaletnik, 2022; Shpykuliak, 2024).

In their 2019 study, Yasnolob I.O. et al. emphasised the potential of biomass in facilitating energy independence in rural regions. This approach was found to generate additional financial resources, thereby enabling further development, while considering environmental, social, and economic criteria.

Honcharuk I.V. proposes a series of technologies for the production of biogas in a waste-free manner, based on the principles of a circular economy. These technologies take European experience into account, and ensure energy autonomy for agricultural enterprises. They also reduce the need for long-distance transport of biogas and waste, and have a local economic impact on rural areas (Honcharuk, 2023).

In the scientific work of Tokarchuk D.M. and Pronko L.M., a methodology for developing rural waste management programs is presented, where community-based waste management strategies are an integral part of implementing the National Waste Management Strategy in Ukraine. This methodology takes into account the particularities of rural waste generation and the challenges of effective waste management, with the objective of achieving economic and environmental benefits, with a particular emphasis on energy aspects (i.e., the transformation of waste, including agricultural, into energy sources) (Tokarchuk, Pronko, 2023).

Mudombi S., Ochieng C. et al. emphasise in their studies that the production of biofuel feedstocks has been identified as a potential pathway to stimulate rural development. Households engaged in biofuel feedstock production have been found to generally have higher incomes compared to those not involved in this activity (Mudombi, 2021).

In terms of transformation prospects for rural Africa, Miftah F. Kadir sees the need for the production of liquid biofuels, which should be integrated into agriculture for both smallholder farmers and large-scale investors, in order to create and industrialise jobs in the agricultural sector (Miftah, 2023).

Based on his research, Butlewski K. proposed the concept of a biomass and organic waste processing plant using locally available organic materials in rural areas. Specifically, a four-module biomass processing unit is proposed, designed to integrate various biomass conversion methods aimed at reducing the costs of producing bioenergy vectors (e.g., biofuel, heat, electricity) and valuable products (Butlewski, 2022).

Notwithstanding the substantial corpus of publications by both domestic and foreign scientists on the aforementioned problem, it is the contention of the present study that further research is required.

3. Organisational and Economic Mechanism for the Development of Rural Hromadas (Territorial Communities)

Rural areas have been shown to play a crucial role in supporting economic and social development, especially in agriculture-based economies. Nevertheless, inadequate infrastructure, constrained innovation prospects, and reliance on external energy supplies represent substantial impediments to sustainable development in these regions. A potential solution to these issues is the promotion of energy independence through the development of bioenergy, with a particular emphasis on intensified biofuel production.

The organisational and economic mechanisms for the development of rural hromadas are based on the concept of sustainable and balanced development, integrating social, economic, and environmental components along with effective public governance. The key outcomes of rural hromada development include increased rural economic efficiency, higher employment rates, improved quality of life for rural residents, population stabilisation, social protection, infrastructural development, and rational utilisation and renewal of natural resources.

State support for rural hromadas and regional development is an important component of this mechanism, as an appropriate level of support helps to strengthen the financial and economic potential of these territories and has a positive impact on the development of hromadas, especially newly formed ones. In recent years, the largest share of state support has been directed to energy independence, road infrastructure development and regional growth.

The components of the organisational and economic mechanism for the development of rural hromadas should be considered as interconnected and mutually reinforcing, which give a greater effect when applied

in the hromada's activities. The creation of an effective organisational and economic mechanism with the above components allows establishing rules based on sustainable and balanced economic development of rural areas. The use of this mechanism can contribute to positive trends in energy efficiency, human capital development, research, socio-economic and regional progress.

The institutions comprising this mechanism are responsible for establishing a distinct economic order within society, necessitating the regulation of socio-economic relations, institutionalisation, and the establishment of an institutional environment that fosters connections between pivotal economic agents and regulatory market policies (Suprun, 2011).

The effectiveness of the organisational and economic mechanism is determined not only by state measures to improve it, but also by the actions of local self-government bodies and the administrative staff of the amalgamated hromadas. They are responsible for using various tools and levers to address local issues.

Within this mechanism, certain state regulatory tools are identified and illustrated in Figure 1.

These regulatory instruments allow local governments to exercise their powers, including partnerships with private businesses, setting local taxes and fees, organising municipal loans and special funds for specific projects with the voluntary participation of the hromada, optimising the costs of energy saving measures, improving energy efficiency, creating new jobs, and establishing local development institutions.

Consequently, the utilisation of these instruments within the development of rural hromadas will enhance the efficiency of their activities, provide novel opportunities for the utilisation of resources at the disposal of the hromadas, and augment the economic potential of the territory. This, in turn, will contribute to the enhancement of the quality of life for the rural population.

In addition, a professional approach to the elaboration of hromada development strategies should take into account the specific features of the territories in terms of introducing new types of non-agricultural activities as an alternative to agriculture, in particular, to create economically and energy independently developed rural areas.

The replacement of traditional energy sources with alternative and renewable ones is currently supported worldwide. Therefore, the concept of creating energy-independent rural areas in Ukraine is quite relevant and appropriate, which will ensure their sustainable development. In addition, the creation of such an energy-independent village will help solve many pressing social issues and ensure the rapid development of new businesses, as well as create a huge market for advanced domestic scientific and technological developments in various fields, including alternative

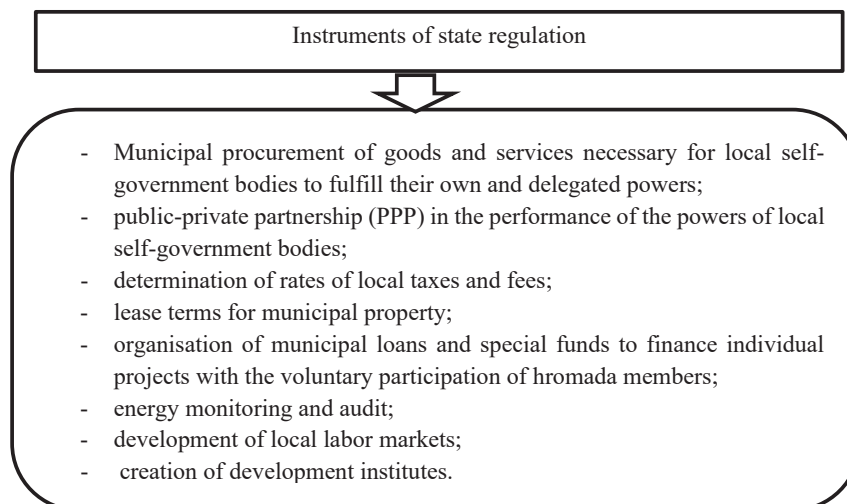


Figure 1. Instruments of state regulation of rural hromadas' development

Source: summarised by the authors on the basis of (Zhalilo, 2019)

energy, waste recycling and smart homes using information technology, for which there is currently no real demand in Ukraine (Yasnolob, 2019).

Moreover, in comparison with other countries, Ukraine still faces the challenge of insufficient utilisation of the bioenergy potential of agricultural waste, a problem that is particularly relevant in the present day given the increasing deficit of domestic energy resources due to the damage to energy generation facilities as a result of military actions by Russia. Rural territories are particularly affected by this, as the restoration of energy facilities after shelling does not progress as quickly as in urban areas (Tokarchuk, Pronko, 2023).

The purpose of amalgamation of hromadas at the level of settlements, villages and cities is to achieve the ability to function more effectively in the financial, social and economic environment, as the underdevelopment of the regions and low resource endowment of individual hromadas does not allow them to develop independently on a par with others. The formation of a joint budget for amalgamated hromadas enables an increase in the financial potential of the territories, promoting their effective development.

Regardless of the type of hromada, the main priorities of its socio-economic development should be the development of entrepreneurship, support for local producers; attraction of investments; social protection, increase of citizens' income and employment; implementation of energy saving measures, encouragement of the population to save energy resources; ensuring environmentally oriented use of natural resources, the main of which is land; strengthening of responsibility for offences related to environmental damage (Khvesyuk, Ilina, 2019).

The development of rural territories is a fundamental component in ensuring national economic stability, particularly in countries with a well-developed agricultural sector. Agriculture, being both a supplier of food products and a key element in shaping national export positions, employment, and ensuring food security, is of particular importance. Conversely, rural territories frequently exhibit a lower level of development than urban centres for a number of reasons, including a paucity of infrastructure, constrained investment, and an inequitable distribution of state resources.

In order to address these challenges, governments and international organisations are actively working on creating and implementing effective mechanisms for the development of rural territories. Among the main strategies, the following can be highlighted:

1. Agro-industrial development. This is a traditional way of developing rural areas through the intensification of agricultural production, modernisation of equipment and application of the latest agricultural technologies.
2. Economic diversification. Rural areas have significant potential not only in the agricultural sector, but also in other economic sectors such as tourism, handicrafts and bioenergy. Expanding economic activities beyond traditional agriculture can significantly improve the well-being of local hromadas.
3. Infrastructure development. Improving transport and energy infrastructure is crucial for market access, investment and productivity.
4. Human capital development. Education, vocational training and the creation of conditions for attracting young people to rural areas are important factors for long-term growth.

5. Energy independence and sustainable development. One of the modern and promising approaches to the economic development of rural areas is to create energy independence through the development of renewable energy sources, in particular biofuels, which not only reduces dependence on traditional energy sources but also creates new economic opportunities.

4. Energy Independence of Rural Areas

Energy independence, especially in the context of rural development, is not only a key to economic sustainability, but also an important factor in ensuring national energy security. Rural regions often feel the greatest impact of energy price fluctuations and limited access to energy resources, which creates risks for economic growth. Building energy independence in rural areas involves the introduction of renewable energy technologies, such as biomass, solar and wind energy, to meet the energy needs of local hromadas and businesses.

The production of biofuels in rural areas of Ukraine, particularly from biomass as a renewable resource, has immense potential. This assertion is supported by Ukraine's existing land resources, 70% of which is agricultural land (Kaletnik, 2020). In this context, land is of pivotal importance as it serves as the primary means of agricultural production, from which biomass for biofuel production is derived. The state of Ukraine's land fund in terms of agricultural land in 2021-2024 is shown in Table 1.

As demonstrated in Table 1, an analysis of land area availability in Ukraine reveals a decline of 31.74% in 2022 compared to the pre-war period (2021), including a 32.12% decrease in agricultural land.

However, the dynamics of the percentage decrease in the land stock in 2023-2024 compared to 2022 began to decrease, in particular, in 2023 the percentage decrease was 22.48% (including agricultural land – 23.16%), and in 2024 – 20.29% (including agricultural land – 20.79%), which indicates a positive trend. However, the full availability of land with the area of the pre-war period, unfortunately, has not yet been achieved for obvious reasons.

Land, as a primary source of biomass, is indisputably linked to bioenergy, and both play a pivotal role in the endeavour to achieve energy independence in rural regions. Agricultural waste can be efficiently repurposed for the production of biofuels, thereby reducing reliance on external energy sources and lowering energy expenditures (see Table 2).

The economic development of rural areas in the context of establishing energy independence is contingent upon the implementation of biofuel projects. The production of biofuels from local resources has the potential not only to meet energy needs, but also to stimulate economic activity and generate employment opportunities. In addition to the direct impact on the energy sector, such projects have a multifaceted economic impact, affecting related sectors and the overall living standards of the local population. Table 3 below summarises the key economic benefits of biofuel projects and the main obstacles that can hinder their implementation.

As the table shows, biofuel projects can have a significant positive impact on rural economies by creating new jobs, reducing dependence on imported energy resources and improving the environment. However, to realise their full potential, a number of

Table 1
Dynamics of the land fund of Ukraine in terms of agricultural land in 2021-2024

Total area before invasion in 2021, thousand hectares	Including	Agricultural land	Arable land and fallow land	Hayfields and pastures	Forests and wooded lands
Available land after the invasion in 2022-2024, thousand hectares					
2021 (pre-war period)					
57057,69	including	39509,68	31551,55	6202,972	10120,78
2022					
41194,97	including	28042,84	22409,87	4260,77	7903,03
<i>Change in % compared to the pre-war period*</i>					
31,74	including	32,12	31,93	43,45	26,05
2023					
46787,98	including	31742,15	25184,61	5128,69	9225,63
<i>Change in % compared to the pre-war period*</i>					
22,48	including	23,16	23,51	31,93	13,67
2024					
48109,77	including	32723,51	26004,85	5286,40	9367,70
<i>Change in % compared to the pre-war period*</i>					
20,29	including	20,79	21,02	29,84	12,34

Source: (Nykolyuk, 2023)

Table 2

Key benefits of energy independence for rural areas

Benefits	Description
Reduction in energy costs	Local production of energy from renewable sources reduces transportation and import costs, which stimulates economic activity and increases the competitiveness of local businesses.
Resilience to energy market fluctuations	Energy independence reduces the vulnerability of rural areas to global energy crises and fluctuations in fossil fuel prices.
Reduction of greenhouse gas emissions	The use of biofuels and other renewable energy sources reduces greenhouse gas emissions, helping to mitigate climate change and improve the environment in the regions.
Job creation	The development of the bioenergy sector contributes to the creation of jobs in the production and management of energy projects.
Economic diversification	Bioenergy projects allow rural areas to diversify their economies, reducing their dependence on agriculture and providing income stability.
Increase in local economic potential	Energy independence promotes the development of local businesses that benefit from affordable energy, creating new opportunities for small and medium-sized enterprises.
Energy stability in crisis situations	Access to local energy sources, such as biofuels, reduces vulnerability to global crises. In the event of disruptions in the supply of traditional energy sources, rural areas can maintain stable operations.

Source: compiled by the authors on the basis of (Tokarchuk, 2020; Honcharuk, 2023b) and own research

Table 3

Economic effects of implementing biofuel projects

Type of economic effect	Description	Expected outcomes for rural areas	Main barriers to implementation
Direct economic effect	Increased number of jobs in the biofuel sector, higher household incomes, and increased investment in rural infrastructure.	Reducing unemployment, increasing local budgets, and attracting investors.	Lack of qualified personnel in the biofuel sector, low government support.
Indirect economic effect	Positive impact on related industries: agriculture, transport, logistics and infrastructure for biomass collection and processing.	Increase revenues in related industries, develop transport and processing capacities, and modernise infrastructure.	Lack of investment in infrastructure, poor coordination between businesses.
Induced economic effect	Increased demand for goods and services due to rising household incomes and the development of local entrepreneurship.	Increased purchasing power of the population, growth of local businesses and increased tax revenues to local budgets.	Distrust of new technologies, lack of information support and awareness raising.
Environmental economic effect	Reduction of energy costs, reduction of CO ₂ emissions and use of agricultural waste for energy production.	Decreased environmental impact, improved local ecological conditions, and reduced dependence on imported energy.	High initial investment in new technologies, dependence on commodity markets.

Source: compiled by the authors on the basis of (Chikov, 2023; Okhota, 2024; Honcharuk, 2024a) and own research

challenges need to be addressed, including lack of investment, insufficient government support and a shortage of skilled labour. Overcoming these obstacles will not only ensure energy independence for rural areas, but also contribute to their sustainable economic development.

5. Energy Independence and Environmental Conditions for the Sustainable Functioning of Enterprises

Enterprises operating within rural areas play a pivotal role in the economic development of these regions. The implementation of alternative energy sources, with a particular focus on biofuels, is a pivotal factor in enhancing the competitiveness, stability, and resilience of such enterprises. The utilisation

of renewable energy sources enables enterprises to reduce their reliance on external energy resources, notably fossil fuels, which are often subject to considerable price volatility and unstable supply.

This, in turn, ensures energy independence for enterprises, a particularly salient consideration in rural areas where energy supply infrastructure may be less developed. The utilisation of biofuels contributes to a reduction in energy resource costs, as enterprises can employ local raw material resources, such as agricultural waste, to generate energy. This enhances the efficiency of production processes and promotes the disposal of waste, which has a positive impact on the environment.

In addition, the introduction of alternative energy sources helps to attract investment to rural areas, which is an important factor in the development of

local economies. Investors are increasingly favouring projects that focus on renewable energy and sustainable development, creating new opportunities for businesses in rural areas. This helps to create new jobs, expand production capacity and modernise equipment. Such companies can also receive support from the government through various mechanisms, including subsidies, tax incentives and grants for the implementation of energy-efficient technologies. This encourages companies to use biofuels and other renewable energy sources more actively, thereby improving their profitability and long-term sustainability.

It is evident that the energy independence of enterprises through the utilisation of biofuels and alternative energy sources exerts a profoundly positive influence on the economic development of rural areas. This phenomenon is characterised by an enhancement in the operational efficiency of enterprises, alongside the development of local infrastructure, the attraction of investments, and the creation of new employment opportunities. Consequently, this strengthens the regional economy and elevates the standard of living for the population.

Moreover, the utilisation of renewable energy sources, such as biofuels, contributes to the enhancement of the ecological sustainability of rural regions. The reduction of greenhouse gas emissions due to decreased consumption of fossil fuels has a beneficial effect on the environment and allows regions to adapt to climate change. Initiatives of this nature have been demonstrated to support the natural balance, whilst concomitantly engendering a favourable image of the region amongst potential investors and partners who prioritise ecological standards. In the long term, this can become an important factor for the development of a "green" economy and increasing the export potential of rural areas focused on producing environmentally friendly products.

In order to facilitate the sustainable development of the regional economy, energy independence, and particularly its ecological component, it is necessary to implement technologies in enterprises with the aim of greening both the end product and the production process itself. The successful implementation of such a process is contingent upon the presence of specific conditions within enterprises. To elucidate the specific conditions under discussion, it is recommended to examine the framework of sustainable enterprise functioning with regard to the ecological aspect, as illustrated in Figure 2 (Nahara, 2022).

The model of ecological sustainability for enterprises involves the achievement of three objectives: the assurance of social justice, the optimisation of economic efficiency through the augmentation of energy efficiency, and the establishment of an ecological imperative, resulting in a systematic-synergetic effect

on the development of environmentally responsible entrepreneurship.

The ecological conditions for the sustainable functioning of an enterprise influence a number of factors, including social-ecological-economic efficiency, the mobilisation of "green" investments in environmentally sustainable infrastructure, the development of renewable energy sources, the provision of energy independence, and the modernisation of business processes (Nahara, 2022).

In light of the significance of cultivating organic production in the present phase of entrepreneurship, it is evident that to attain the anticipated outcomes, encompassing ecological and energy autonomy, a systematic approach is imperative in formulating and implementing a comprehensive set of measures that will stimulate, promote, and regulate the advancement of ecological agriculture in Ukraine. In addition, the greening of production activities in agricultural enterprises is a component of the basic strategies for increasing their competitiveness, and primarily involves meeting consumer demand for environmentally friendly products, reducing the negative impact of agricultural production on the environment, conserving natural resources and achieving energy independence through the implementation of ecological innovations (Butko, 2022; Mazur, 2023).

6. Indicators of Energy Efficiency and Energy Independence of Rural Areas through Intensification of Biofuel Production and Use

Biofuels are a key element of bioenergy development and a tool for achieving energy independence in rural areas. Intensification of biofuel production includes a number of steps aimed at improving efficiency and increasing the volume of this type of energy. The main intensification mechanisms include:

- Technology modernisation. The use of the latest technologies for biomass processing and biofuel production significantly improves process efficiency and reduces production costs.
- Expansion of the raw material base. Agricultural waste, such as straw, husks and other plant residues, can be used to produce biofuels. In addition, forest waste and biomass from the food industry are promising sources of feedstock.
- Investments in research and innovation. Research in the field of biofuels contributes to the development of new methods of biomass processing, increasing the efficiency of resource use and reducing environmental impact.
- Development of state support. Subsidies, tax breaks and soft loans for biofuel producers help boost the

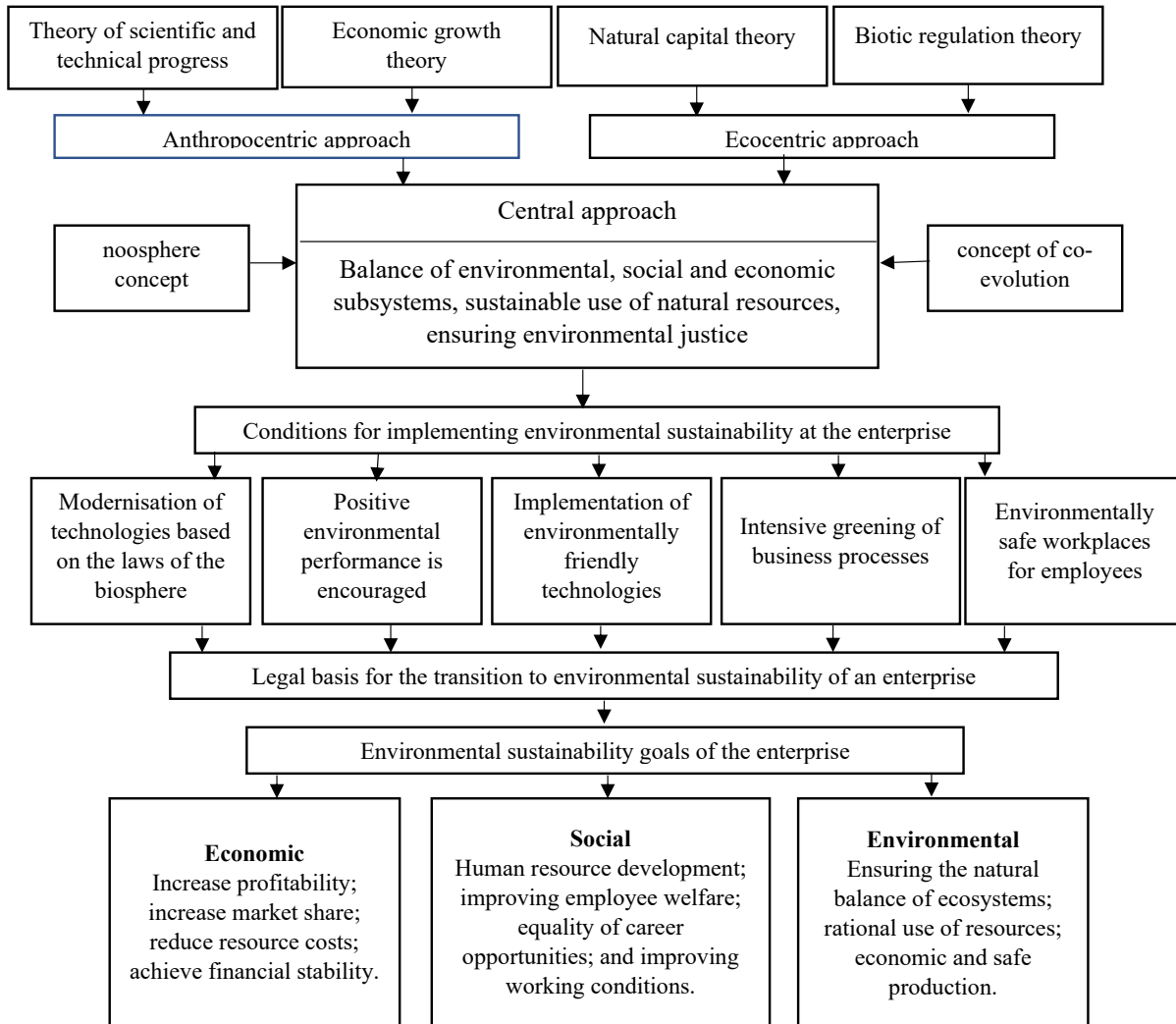


Figure 2. Environmental conditions for the sustainable operation of the enterprise

Source: compiled on the basis of (Nahara, 2022)

sector and create favourable conditions for the development of bioenergy projects in rural areas.

– Attracting private investment. The private sector can play a significant role in the development of the biofuels industry by financing innovative projects and establishing new biofuel production facilities (Dotsiuk, 2024).

Furthermore, a potential avenue for augmenting biofuel production and ensuring the economic development of rural areas is the utilisation of waste-free technologies for biogas production, as proposed by Honcharuk (Figure 3).

The production of biogas is an integral component of the circular economy, wherein waste generated during agricultural activities is repurposed as a raw material for biogas production. The resulting biogas is utilised as an energy source or is purified into biomethane. Furthermore, during agricultural processes, agrarian enterprises utilise the produced biogas and digestate. Therefore, such zero-waste biogas

production technologies ensure energy autonomy for agricultural enterprises whilst also reducing the transportation of biogas and waste over long distances, thus having a local impact on the economy of rural areas (Honcharuk, 2023a; Honcharuk, 2024b).

In order to assess the energy efficiency and energy independence of rural areas, it is essential to utilise specific indicators (see Table 4) that reflect various aspects of this process. The following key indicators are proposed as the benchmarks by which the energy efficiency and independence of rural regions should be measured.

These indicators can function as benchmarks for rural areas aspiring to achieve energy efficiency and independence. It is imperative that these indicators undergo regular assessment and adjustment in accordance with the attainment of results and the evolution of the technological, economic, and social milieu. The indicators of energy efficiency and independence thus form the basis for management

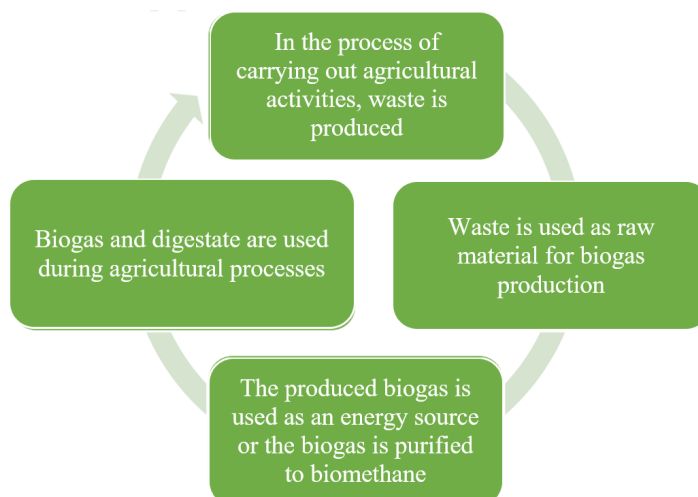


Figure 3. Circular use of biogas

Source: (Honcharuk, 2023a; Honcharuk, 2024b)

decisions that are oriented towards increasing the share of alternative energy sources. This, in turn, contributes to a reduction in environmental impact and the support of the local economy. The development of a methodological approach to defining energy efficiency and energy independence indicators will create a standardised framework for monitoring the energy progress of rural areas and enhance their resilience to energy crises.

7. Conclusions

The research showed that the creation of energy independence in rural areas through the intensification of biofuel production is a promising development direction that can ensure stable economic growth, increase employment levels and improve the well-being of the population. One of the main conclusions is the need for systematic support at the state level,

Table 4
Indicators of Energy Efficiency and Energy Independence for Rural Areas

Indicator	Objective	Target	Measurement
Share of renewable energy sources (RES)	Achieving a high share of RES in the overall energy balance	50-70% of total energy consumption	Measured as a percentage, reflects the amount of energy from RES (biofuel, solar, wind, etc.) relative to total consumption.
Energy efficiency of buildings	Increasing energy efficiency of buildings	Reduction in consumption by 20-30%	Measured in kWh/m ² /year, reflects energy used for heating, lighting, etc.
Biofuel production volume	Increasing biofuel production volumes	10-20% of total energy consumption	Measured in litres or tonnes per year, it reflects the production of bioethanol, biodiesel and biogas.
Energy consumption per capita	Optimisation of energy consumption	Reduction by 10-15%	Measured in kWh/person/year, reflects the total energy used per resident in rural areas.
Level of autonomous energy supply	Increasing autonomy of energy supply	Autonomy level at 70-80%	Measured as a percentage, reflects the share of energy generated by local RES relative to total energy consumption.
Greenhouse gas emissions	Reducing greenhouse gas emissions	Reduction by 20-30%	Measured in tons of CO ₂ -equivalent per year, reflects emissions from energy consumption.
Use of agricultural waste	Increasing the use of waste for energy production	Recycling of at least 50% of waste	Measured as a percentage, reflects the share of agricultural waste used relative to total waste volume.
Investment in RES infrastructure	Increasing investments in RES infrastructure	At least 10-15% of total capital investments	Measured in percentages or monetary value (e.g., million UAH/year), reflects financial contributions.
Energy efficiency in agricultural production	Improving energy efficiency in agriculture	Reduction by 15-20%	Measured in kWh/ton or L/kg, reflects energy used per unit of agricultural output.
Education and awareness levels	Raising education and awareness regarding energy efficiency	Increase in educational programs by 30-40%	Measured by number of activities (courses, seminars), or percentage of the population aware of energy efficiency benefits.

Source: generated by the authors

in particular through the creation of favourable conditions for investors, the development of a clear legal framework and the stimulation of scientific research and the implementation of innovations in the bioenergy sector.

Moreover, it was determined that the advancement of bioenergy capacities could serve as a pivotal component of Ukraine's ecological strategy, thereby reducing reliance on conventional energy sources and contributing to a reduction in greenhouse gas emissions. In order to achieve these objectives, it is recommended that a comprehensive programme be implemented, encompassing both economic stimulation measures and educational initiatives. The latter are to be designed to raise awareness among the rural population of the benefits of using biofuels.

The role of international experience in building energy independence in rural areas was also examined, with a particular focus on co-operation with the European Union and the implementation of sustainable development standards. The utilisation of contemporary technologies in conjunction with the active involvement of non-governmental organisations (NGOs) has the potential to substantially expedite this process and ensure the resilience of the agricultural sector in the face of contemporary challenges. The implementation of the proposed mechanisms

has the potential to not only make rural areas energy self-sufficient but also competitive in the global energy market.

In order to enhance and develop the bioenergy sector further, it is necessary to establish incentives to attract private capital to biofuel production, to expand co-operation between government agencies and private enterprises, and to integrate modern agricultural waste processing technologies. A pivotal step in this process is the development of infrastructure for the storage and transportation of biofuels, with the objective of reducing production costs and enhancing utilisation efficiency. In addition, there is a need to strengthen support for small and medium-sized enterprises with the objective of enabling them to assume a leadership role in the bioenergy sector. This should be achieved through the creation of preferential credit programmes and grants for innovative projects.

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