PROBLEMY EKOROZWOJU/ PROBLEMS OF SUSTAINABLE DEVELOPMENT

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Sustainable and Resilient International Agricultural Trade: Global Uncertainty and Regional Reactions

Zrównoważony i resilentny międzynarodowy handel produktami rolnymi: globalna niepewność i reakcje regionalne

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Abstract

The research presents a complex analysis of modern tendencies in agricultural sector development focusing on the interaction between sustainable and resilient development concepts and international trade. The linear regression analysis established a statistically significant dependence between production volume, input costs, and export volumes. The influence of several factors on the agricultural sector's efficiency has been confirmed, making the results significant for forming development strategies and management solutions in agriculture. As a complying carrying out the clustering analysis, a group of countries whose approaches to agricultural sector development most fully comply with sustainability principles and whose efficiency of trade activity of agricultural products tends to rise constantly, has been distinguished. It has been highlighted that the European Union is an example of one of the most efficient combinations of economic and trade relationships and sustainable development. Major determinants of economic development in the industry have been distinguished within the context of agricultural production and trade transformation. Fundamental pillars of its transformation, in particular, the concept of bioeconomy and innovative technology implementation, have been defined. It has been highlighted that the effectiveness of bioeconomic policy substantially depends on regional peculiarities and the readiness of a country to adjust these strategies to its economic context. Using the integration of statistical methods and theoretical models, strategies of sustainable and resilient development in the agricultural sector under global economic and ecological challenges have been formed considering future generations' need to use the planet's resources efficiently.

Key words: agriculture, international trade, sustainability and resilient, regional reactions

Streszczenie
Badania przedstawiają kompleksową analizę współczesnych tendencji w rozwoju sektora rolnego, skupiając się na interakcji między koncepcjami zrównoważonego i resilentnego rozwoju a handlem międzynarodowym. Analiza regresji liniowej ustaliła statystycznie istotną zależność między wolumenem produkcji, kosztami nakładów i wolumenem eksportu. Wpływ kilku czynników na efektywność sektora rolnego został potwierdzony, co czyni wyniki istotnymi dla kształtowania strategii rozwoju i rozwiązań zarządczych w rolnictwie. Jako zgodne przeprowadzenie analizy klastrowania, wyróżniono grupę krajów, których podejście do rozwoju sektora rolnego jest w pełni zgodne z zasadami zrównoważonego rozwoju i których efektywność działalności handlowej produktami rolnymi ma tendencję do stałego wzrostu. Podkreślono, że Unia Europejska jest przykładem jednej z najefektywniejszych kombinacji relacji gospodarczych i handlowych oraz zrównoważonego rozwoju. Główne determinanty rozwoju gospodarczego w branży zostały wyróżnione w kontekście produkcji rolnej i transformacji handlu. Zdefiniowano podstawowe filary jej transformacji, w szczególności koncepcję biogospodarki i wdrażania innowacyjnych technologii. Podkreślono, że skuteczność polityki bioekonomicznej w znacznym stopniu zależy od specyfiki regionalnej i gotowości kraju do dostosowania tych strategii do swojego kontekstu ekonomicznego. Wykorzystując integrację metod statystycznych i modeli teoretycznych, strategie zrównoważonego i resilentnego rozwoju w sektorze rolnym w obliczu globalnych wyzwań ekonomicznych i ekologicznych zostały opracowane z uwzględnieniem potrzeby przyszłych pokoleń, aby efektywnie wykorzystywać zasoby planety.

Słowa kluczowe: rolnictwo, handel międzynarodowy, zrównoważony rozwój i resilencja, reakcje regionalne

Introduction

The growing population and rising standards of living in many countries are leading to a higher demand for agricultural products. Ensuring a stable and efficient agri-food system is crucial for achieving food security. At the same time, agricultural production faces significant challenges related to its impact on ecosystems, particularly concerning water pollution, biodiversity loss, and climate change.

Considering these trends, the United Nations has developed the Sustainable Development Goals (SDGs), which address social, economic, and environmental aspects. Agricultural production is closely connected to many of them, particularly Goal 2 (Zero Hunger), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action). Understanding the relationship between international trade in agricultural products and sustainable development can help develop effective strategies to optimize resource use and enhance sustainability in the global food supply under conditions of uncertainty. This study aims to identify optimal practices for addressing these challenges, ensuring a balance between agricultural growth and environmental conservation while fostering sustainable global economic development.

Literature review

Growing performance, increasing range of products, minimization of losses during collecting and storing, balanced stability, impact on workforce and employment, and innovation in the food processing sector – all these aspects of technology and innovation in agriculture have a substantial influence on sustainable and resilient development and international trade of agricultural products. Studying these issues is a key task for developing efficient policies and strategies to boost the balanced use of natural resources in agriculture and stimulate trade activity. Given the urgency, a considerable number of scientific papers are dedicated to the issue.

In particular, J. Sachs investigated the influence of globalization and the world economy on global sustainable development and the fight against poverty (Sachs, 2005; Sachs, 2006); J. Stiglitz considers the problems of international trade, inequality, and social and economic development (Stiglitz, 2002; Stiglitz, 2012). H. Daly promotes concepts of ecological economy and sustainable development where growth cannot be infinite (Daly, 1996; Daly, 2008). P. Ekins focuses on the connection between economic growth and preservation of the environment (Ekins, 2000; Ekins, 2017). A significant contribution to economic science has been made by scientists who investigated regional reactions of the European Union on the complementarity of international trade and sustainable and resilient development and considered the issue of interconnection of trade, economic development, and sustainability in the European context.

The EU trade policy, regional initiatives, and the influence of trade on sustainable development are important issues of their studies. A. Poletti researches the EU trade policy, its effect on global trade and possibilities to influence sustainable development (Poletti, 2012), M. Garcia considers the EU's role in international trade negotiations and its impact on sustainable development and regional integration (García, 2012).

Among the scientists who investigated regional reactions of the EU in the agrarian sector to the complementarity of international trade and sustainable development, A. Matthews may be distinguished as the one who studies the evolution and influence of the Common Agricultural Policy of the EU on agriculture and agricultural products trade focusing on sustainable development (Matthews, 2012a; Matthews, 2012b), S. Davidova with colleagues

analyzes the transformation of agriculture in countries of Central and Eastern Europe and its effect on sustainable development of the region (Kostov & Davidova, 2021; Chaplin et al., 2004). The above-mentioned scientists have made several significant conclusions connected with the influence of the agricultural policy of the EU on sustainable development and international trade of agricultural products. The scientists highlight the significance of providing competitiveness of the EU agricultural sector on the global market while providing sustainable development and saving nature. Furthermore, scientists point out risks connected to intensive agriculture which may cause a decrease in biodiversity and pollution of the environment.
The attention in the articles (Osaulenko et al., 2020; Tananaiko et al., 2023; Mykhailova et al., 2023) is paid to researching the issues of determining tendencies of mutual influence of international trade and sustainability in the agricultural sector. Scientists consider the development and implementation of innovations in agriculture to be an opportunity to save resources and its sustainability enhancement. Innovations may boost both performance improvement and save the environment. It has been highlighted that it is important to conclude international trade agreements that encourage free trade of agricultural products and consider sustainability and the environment (Bazaluk et al., 2020).
The influence of new agricultural technology on competitiveness and sustainability in the development of countries and stimulating their trade activity at their expense requires further investigation. Understanding these aspects is vital for developing effective policies and strategies to save natural resources, and social and economic growth of the agricultural sector in light of intensifying international trade activity.

Materials and methods

The research was carried out to study the complementarity of international trade and sustainable and resilient development in the regional context, particularly, their structures, features, and interaction among components. The study presents a research methodology that includes general and specific methods.
In particular, an analysis of scientific resources has been carried out to review prior research and methods related to the research object. Statistical analysis of the collected data has been carried out to identify the main tendencies and features of the research object. Furthermore, the use of k-means clustering and linear regression must be distinguished.
The linear regression method has been exploited to analyze and model the dependence between a dependent variable and one or several independent variables. Within the context of forecasting economic indices, this method was used to define and determine the quantity connection between time (years) and some economic indices for world regions. The linear regression method consisted of the following stages: defining the dependent variable and independent variables; building a model (a regression model that defines a linear connection between independent variables and the dependent variable and includes coefficients that characterize its pace of change has been developed); model adjustment (using statistical methods to find optimum model coefficients values that will best fit real data); efficiency estimation (using metrics such as r^2 determination coefficient to estimate how well the model reflects initial data); and outcome interpretation. The use of the linear regression method in the forecasting context let us define and quantify the impact of independent variables on the dependent variable. Also, it enabled us to forecast future values of the dependent variable based on the developed model and considering tendencies.
The clustering method has been used to group countries based on similar characteristics. K-means clustering has been used to define cluster centers and place objects in particular clusters accordingly. The estimation of clustering efficiency has been carried out using an intracluster sum of squares of distances. The interpretation of received clusters has been carried out to define internal relationships and each country group's peculiarities. The clustering and analysis results have drawn conclusions that reflect each cluster's major features and interconnections within them. The presented research methodology has been proven effective in studying the complementarity of international trade and sustainable and resilient development, particularly due to the use of the k-means clustering method which let systemizing and classifying the objects considering their common features.

Results

Over recent years, agriculture as an industry has been encountering serious challenges that considerably influence its profitability. Skyrocketing input costs for fertilizers, chemicals, etc., as well as manpower, threaten agricultural production's economic viability. In our prior research, we have carried out market analysis of agrifood supply chain disruptions due to the war in Ukraine and sanctions against Russia. The war has already led to food deficit in the EU and Near East countries, considerable food and energy sources price growth, and a decrease in accessibility of goods exported by Ukraine (Mykhailova et al., 2023; Waldl et al, 2024). This challenge is aggravated by climate conditions deterioration which leads to growing economic conditions instability and the emergence of new pests and weeds (FAO, 2023a). Within the context, several countries recognize the need to implement sustainable and resilient agricultural practices, and it is reflected in ambitious goals set, for instance, by the European Green Deal or Canada's initiatives to reduce the use of fertilizers (European Green Deal, 2021). Meanwhile, the use of automatization in agriculture is outlined as an effective tool for achieving goals, especially in the reduction of the use of fertilizers. The results of a survey carried out among farmers by McKinsey in 2022 demonstrate the readiness of agricultural producers to innovations and the use of modern technology which may boost an increase in productivity and ensure the sector stability (Bland et al., 2023). Customers appear to be interested in stable food systems. It creates additional pressure on farmers to reconsider their approaches to production. Products that are produced considering various sustainability aspects are in strong demand which demonstrates growing customers' awareness of these issues (FAO, 2023b). Generally, the complementarity of international trade and sustainable and resilient development of the agricultural sector is becoming an important strategic direction to ensure the industry's competitiveness and its sustainable development within the conditions of the global economic environment.

Considering the above-mentioned challenges, it is reasonable to thoroughly study countries according to their agricultural sector's efficiency, readiness to shift to sustainable technologies, and activity on international markets of agricultural products. Let us analyze the aspects and forecast trends in the mentioned issues within the regional context. To do this, let us use the method of linear regression which is realized with curved trends that describe expected changes in particular economic values. Each model is characterized by coefficients that reflect the pace and direction of changes within the studied indices during the study period. The curved trend equations reflect the parameters of regression analysis for each region and index. The adequacy of the model is estimated with the help of the R^2 determination coefficient indicating a degree of the model corresponding to real data (Table 1, Table 2).

Table 1. Forecasting economic activity of the agricultural sector considering sustainability in the world region context, source: the forecast is made based on data (FAOSTAT, 2024)

Region	Index	Year						Trend line	R²
		2022	2023*	2024*	2025*	2026*	2026 / 2022, %		
Africa	Gross production costs (constant prices in 2014-2016, international dollars mln). Agriculture.	405228	419990	430339	440687	451036	111	y = 1E+07x + 3E+08	0.9908
Asia		2192800	2223889	2262259	2300630	2339000	107	y = 4E+07x + 2E + 09	0.9931
Caribbean region		12564	12037	11880	11723	11566	92	y = -100205x2 + 4E+08x - 4E+11	0.8614
Europe		556279	569966	572117	574268	576420	104	y = 1E+07ln(x) + 5E+08	0.7074
North America		415681	424803	426135	427468	428801	103	y = -58877x4 + 2E+06x3 - 1E+07x2 + 5E+07x + 4E+08	0.6851
Oceania		69222	65252	65573	65894	66214	96	y = 4839.8x6 - 168450x5 + 2E+06x4 - 1E+07x3 + 4E+07x2 - 6E+07x + 9E+07	0.6965
South America		426881	437828	444427	451027	457626	107	y = 7E+06x + 4E+08	0.9496
World		4169291	4246550	4307127	4367704	4428282	106	y = 6E+07x + 4E+09	0.9944
Africa	Value added (agriculture, forestry, and fishery), prices in 2015, USD mln	449092	464927	476693	490197	503701	112	y = 13504x + 341650	0.9962
Asia		2522829	2602648	2671933	2752145	2832357	113	y = 80212x + 2E+06	0.9977
Europe		12099	12270	12134	12066	11998	101	y = 2553.5x + 181746	0.7323
North America		322323	325775	327891	327811	327731	99	y = 1712.5x + 323603	0.7786
Oceania		214251	220884	220843	221403	221963	98	y = 559.87x + 215244	0.1469
South America		52398	53797	53113	54387	55661	106	y = 1274.1x + 40372	0.6721
World		194680	201597	202843	204772	206701	103	y = 1929.2x + 183551	0.8115
Africa	Agricultural land square used for organic agriculture. Agricultural land share, %	0.23	0.24	0.25	0.26	0.28	120	y = 0.0117x + 0.135	0.9594
Asia		0.55	0.52	0.55	0.57	0.60	109	y = 0.0274x + 0.2718	0.861
Europe		3.89	4.15	4.34	4.53	4.72	121	y = 0.1911x + 2.4264	0.9977
North America		0.77	0.81	0.83	0.85	0.87	113	y = 0.0192x + 0.64	0.9108
Oceania		9.55	10.70	11.10	11.50	11.89	125	y = 0.396x + 7.1407	0.8001
South America		1.54	1.88	1.97	2.07	2.16	140	y = 0.0935x + 1.0382	0.8804
World		1.63	1.78	1.85	1.92	2.00	123	y = 0.0744x + 1.1064	0.9335

* Forecast data. For Value added (agriculture, forestry, and fishery), prices in 2015, USD mln forecast data is since 2024

High determination coefficient (R^2) values that vary between 0.80 and 0.99 for different regions and indices prove the high accuracy of the model. Also, using various mathematical formulas and logarithmic functions in the forecasting methods enhances their scientific validity and the possibility of considering complicated economic dependencies. However, it is vital to take into consideration that forecasts are based on suppositions and their accuracy may be limited in case of unfavorable changes in social and economic environment or unpredictable events.

Analyzing the data in the context of different world parts over recent years and making forecasts (Table 1, Table 2), it has been determined that there is a stable increase in the agricultural production sector. In 2026, the total production cost of the global agricultural production sector will rise by 6% with a simultaneous increase in organic production demonstrating the industry stability. At the same time, it must be stated that each region has its unique features and challenges which require individual approaches to reach optimum analysis results.

Table 2. Forecasting export-import activity within the agricultural sector considering sustainability in the context of world regions, source: the forecast is made based on data (FAOSTAT, 2024)

Region	Indices	Year						Trend line	R^2
		2022	2023*	2024*	2025*	2026*	2026 / 2022, %		
Africa	Export value index (2014-2016 = 100)	130	131	135	140	144	111	y = 4.2976x + 92.286	0.8953
Asia		141	137	143	149	155	110	y = 5.7143x + 86.036	0.8696
Caribbean region		138	140	146	152	158	114	y = 5.3571x + 88.429	0.9081
Europe		140	134	139	145	151	108	y = 5.7024x + 82.214	0.8426
North America		144	135	140	146	152	105	y = 5.7143x + 83.286	0.7609
Oceania		165	149	157	165	172	105	y = 7.8571x + 78.143	0.813
South America		143	139	146	152	158	110	y = 6.0476x + 85.036	0.9075
World		136	131	136	141	146	107	y = 5.1905x + 83.893	0.8404
Africa	Import value index (2014-2016 = 100)	157	153	161	169	177	113	y = 7.9881x + 81.179	0.9022
Asia		136	133	139	144	149	110	y = 5.2143x + 86.536	0.9204
Caribbean region		155	147	153	160	167	108	y = 6.7024x + 86.214	0.8734
Europe		136	135	140	145	149	110	y = 4.8095x + 91.607	0.9483
North America		147	140	147	154	161	109	y = 7.0595x + 76.107	0.8654
Oceania		146	142	148	155	161	111	y = 6.4524x + 83.964	0.9043
South America		130	131	135	140	144	111	y = 4.2976x + 92.286	0.8953
World		141	137	143	149	155	110	y = 5.7143x + 86.036	0.8696

* Forecast data

In the African region, gross production costs and added value in agriculture are stable. It is forecasted that the indices will increase by 11% and 12% respectively. Additionally, the interest in organic agriculture is growing, which may indicate rising attention to sustainable and resilient development. At the same time, some African countries experience difficulties in implementing innovations due to social-cultural and economic limitations as well as due to lack of infrastructure. However, there are initiatives for developing sustainable and resilient agriculture in these regions.

Currently, Asia is a world leader in producing agricultural products and it is forecasted that there is a tendency for further growth. The values of gross production costs and added value in the sector demonstrate stable development. A slight decrease in gross production costs and added value in the Caribbean region may be linked to climate and economic challenges. However, being focused on increasing the role of eco-friendly technologies, it has a chance to attract new consumers and improve its competitiveness within the global market.

Europe is distinguished by maintaining stable growth in agriculture and a large interest in organic production (the forecasted growth is 21% before 2026). Progressive industry development policy lets the region keep its leadership. At the same time, the EU provides farmers with a wide range of support that facilitates stable production and the development of technical equipment of producers. In the EU, there are high standards set to ensure the high quality of products which boost consumers' trust and provides its competitive position in international markets. The European Union is one of the world's largest trade super countries, which makes it an important player in international agricultural products trade. It has the world's biggest number of international trade agreements – more than any other country or region. The EU has concluded agreements with countries that account for 36% of the global GDP. The majority of EU international trade agreements contain a regulation on protecting human, workers', environment, and climate rights (Valerdi, 2009). According to Eurostat data, imports and export of goods between the EU and the countries with which international trade agreements are concluded surpassed €2 trillion in 2022 (European Commission, 2023). Over the recent years, the EU has concluded new international agreements with several countries, e.g. Canada, Japan, Vietnam, and Singapore, and is negotiating agreements with other countries, e.g. Mercosur and New Zealand. At the same time, economic instability and growing geopolitical risks in the region resulting from the military aggression of the RF against Ukraine have led to the strengthening of security measures and ensuring stability in international trade relations in agriculture. This includes reviewing contracts and providing alternative sources of supplying agricultural products to prevent possible risks of supply interruptions.

Progressive technologies and a high level of investment play a key role in reaching positive results in the North American region. The United States and Canada are widely known for their high productivity in agriculture and active participation in the global market which is proved by the results of the forecast. Special attention is paid to sustainable and resilient development and ecological issues. Crop insurance programs in the USA and Canada help farmers decrease production loss risks by stimulating trade stability and development. A high level of mechanization and modern technologies in agriculture increase productivity and competitiveness in international markets and let them upgrade their strategies in sustainable and resilient agriculture. The use of technologies in production and seeking a decrease in impacting the environment define their policy.

Oceania is experiencing a decrease in gross production costs, but it is extending its opportunities in the organic agriculture sector. The countries of Oceania, e.g. Australia and New Zealand, are great agricultural product exporters, particularly in the meat and dairy sectors. They are also actively working on providing sustainable and resilient development. Implementing efficient mechanisms in water resources management contributes to their protection and sustainable production.

Rising production volumes and focus on organic production demonstrate positive tendencies in the agricultural sector development of the South American region. Brazil and Argentina are key players in the region's production and international trade of agricultural products. However, their achievements are accompanied by ecological challenges. Being key players in agriculture in South America, Brazil and Argentina concentrate on improving their strategies to maintain sustainable and resilient development. A high level of exports of agricultural products (which, according to the forecast, is expected to increase) to different world areas, particularly Asia and Europe, innovation exchange and ensure stable development of the agricultural sector.

The outlined tendencies in each region are aimed at sustainability and increasing trade activity in international markets, and they develop considering specific needs and available opportunities. International trade of agricultural products is becoming not only an exchange of goods, but also a transfer of technologies and innovations which ensures growing sustainability and competitiveness of agricultural activity in different regions. Focus on sustainable and resilient development creates conditions for forming common standards and it boosts the exchange of eco-friendly technologies, increasing quality and safety in international trade. Furthermore, the European Union operates one of the largest market systems in the world and has a considerable impact on the international trade of agricultural products.

To group countries according to several parameters that characterize their complementarity of economic efficiency and agro-sector sustainability, let us use the clustering method. Clustering belongs to the category of learning without a teacher. To make a model, let us use one of the most widely spread clustering forms – the so-called k-means method. The main idea is to divide data into a previously specified number of clusters (k) so that objects within a cluster are more similar to each other than to objects from different clusters. The algorithm seeks to minimize sums of squares of distances between objects and centroids inside a cluster. K-means is effective for spherical clusters and can be sensitive to initial conditions, therefore sometimes it requires several starts with different initial centroids. Let us analyze the R environment. To do that, certain data must be prepared. In particular, lines should reflect separate observations, and columns should contain variables. Any missing data must be deleted or filled in. Data must be standardized (scaled) to give variables comparative characteristics. Standardization presupposes converting variables so that their average value equals zero and standard deviation equals one.

Despite the fact that European Union countries run common policy within the block and have several common features and values (e.g. encouraging the mutual exchange of goods, services, investments, etc.; have common standards and regulations in various spheres, particularly, technical standards, food safety, and ecological norms; develop common humanitarian and social policies aimed at protecting human rights, equality, and social justice), it has been proved reasonable to consider each European Union country as a separate subject for several reasons: diversity (EU countries differ within many parameters, e.g. economic development, cultural and language peculiarities, ecological conditions, geographical location, etc.); heterogeneity of economy (EU countries have different levels of economic development and thus studying each one separately will let us define peculiarities of each economy including specialization spheres and production peculiarities); unique challenges (each country may encounter its unique challenges, e.g. problems in agriculture development, ecological issues, demographic difficulties, etc.); the political and social-cultural differences (EU countries have different political systems and social-cultural contexts, and studying each country separately lets us consider these differences while analyzing); potential differences in sectors (different countries may differ in economy and specialization structure in particular sectors. It must be taken into account while developing economic development strategies). Such an approach lets us receive a more detailed and individualized understanding of each country.

The algorithm of clustering within the mentioned approach includes the following stages: choosing corresponding features (selecting variables that are considered to be significant for identification and understanding differences among the studied groups); data scaling (standardizing each variable to mean 0 and standard deviation to mean 1 is a general approach); searching bias; selecting clustering algorithm; studying the number of clusters; obtaining final cluster solution; result visualization; cluster interpretation; and result validation. FAO data from 2021 in the context of all global countries was used to form clusters according to the following indices: Gross Domestic Product Value (US per capita, 2015 prices, USD), Gross Domestic Product Value (US, million USD),Value Added (Agriculture, Forestry, and Fishing), Gross Production Index Number (2014-2016 = 100), Import Value (Base Period Quantity, 1000 USD), Export Value (Base Quantity, 1000 USD), Import Value Index (2014-2016 = 100), Export Value Index (2014-2016 = 100), Agriculture Area Actually Irrigated (Share in Agricultural Land, %), Agriculture Area Under Organic Agriculture (Share in Agricultural Land, %), Land Area Equipped for Irrigation (Share in Cropland, %), Total Expenditure (General Government, Value US$, 2015 prices, million USD), Credit to Agriculture (Value US$, 2015 prices, million USD).

Building a correlation matrix is a significant step for analyzing data on the adequacy of its use in modeling. It also provides information on the degree of interconnection among different variables in the data set. Let us use the correlation function in the programming language R (UC Business Analytics 2018). Building a heat map or a correlation chart helps visualize the correlation degree among variables. Lighter shades may indicate a strong correlation while darker shades indicate the absence or weak correlation. To avoid multicollinearity, let us build a correlation matrix (Figure 1).

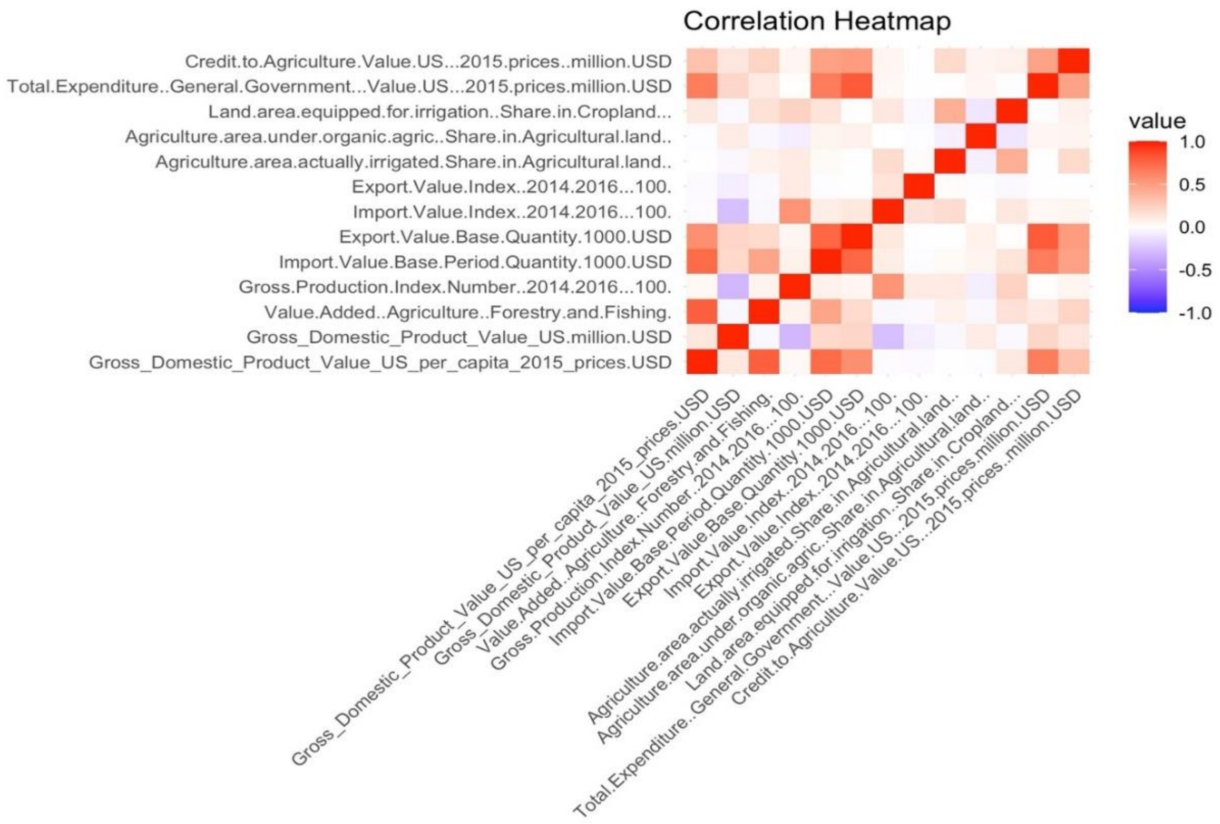

Figure 1. The chart of clustering model input data correlation, source: own research

Based on the generalized data, it is apparent that some variables must be either scaled or normalized. We can normalize data using average value and standard deviation or use scale function to normalize the data. The normalization outcomes are visualized in the data distribution charts within each variable (Figure 2).

After the data had been prepared for clustering using k-means to estimate the stability of cluster solution, R packets, i.e. fpc, clv, and clValid (MacQueen, 1967; Datanovia, 2020) were used. Therefore, the fviz_nbclust() function was used to build a chart of cluster quantity distribution to the total sum of their squares (Yunus, 2918). As a result, the chart has an elbow where the sum of squares starts bending or decreases evenly. As a rule, it is an optimal number of clusters.

Figure 3 demonstrates that there is a particular elbow or a bend at k=7. Therefore, we can do clustering using k-means with a data set using an optimal k value that equals 7 (Table 3, Figure 4).

Obtained results may serve as a basis for further investigation of interconnections between the cluster nature and defining major factors that impact country development in different groups.

Cluster 1. This cluster comprises a diverse range of nations across various global regions, characterized by significant variability in economic performance indicators. GDP levels and production indices range from low to medium, reflecting varying stages of economic development. Many of these nations exhibit a pronounced reliance on agriculture as a primary source of income and food security. Agricultural practices vary, with some countries adhering to traditional methods while others are transitioning to modernized approaches. Malnutrition remains a pressing challenge in numerous states within this cluster, underscoring the urgent need for enhanced food security policies and targeted international assistance.

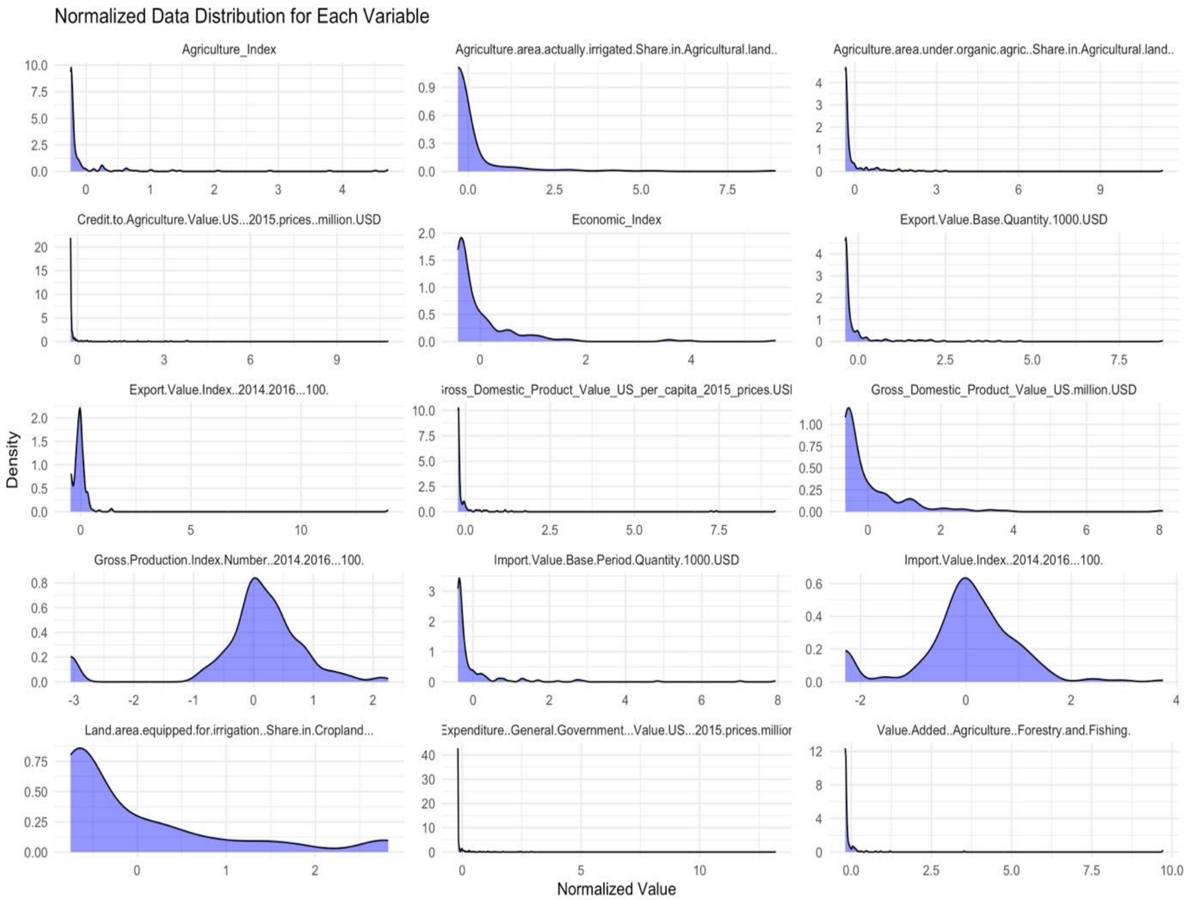

Figure 2. Histograms of data distribution that was used to build a cluster model, source: own research

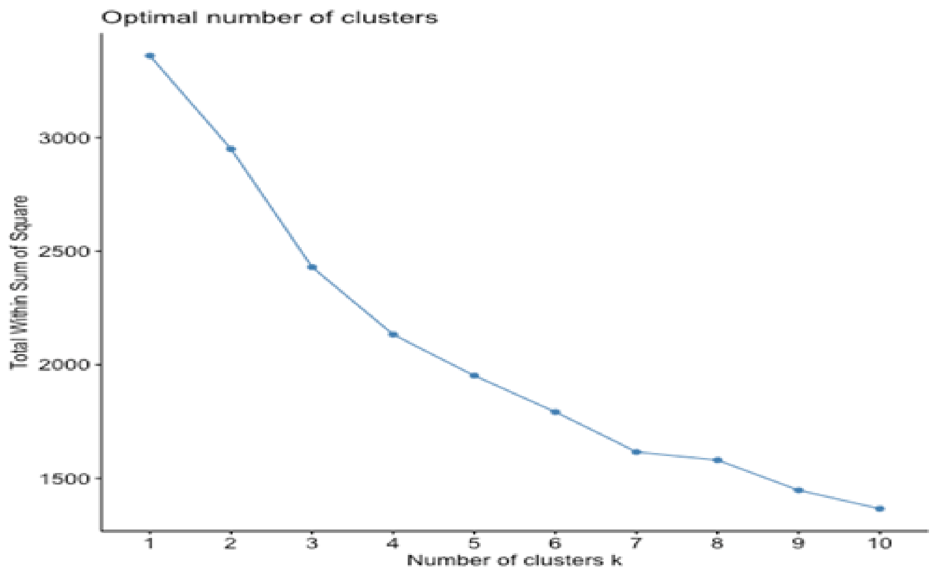

Figure 3. The chart of the number of clusters distribution to the general sum of their squares, source: own research

Cluster 2. Countries in this cluster are distinguished by a high degree of industrialization and moderate GDP per capita. The production sector is well-developed, while agriculture predominantly serves domestic needs. Japan and South Korea are global leaders in advanced manufacturing and technological innovation, whereas the Russian Federation leverages its vast natural resource base as a cornerstone of its economic strategy. Food security across this cluster is generally stable, supported by robust policy frameworks.

Table 3. The result of country clustering, source: own research

Index	Value
Cluster 1	Afghanistan, Albania, Angola, Anguilla, Antigua and Barbuda, Armenia, Aruba, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belize, Benin, Bermuda, Bhutan, Bolivia (Plurinational State of), Bosnia and Herzegovina, Botswana, British Virgin Islands, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Cayman Islands, Central African Republic, Chad, China (Macao SAR), Comoros, Congo, Cook Islands, Costa Rica, Côte d'Ivoire, Cuba, Curaçao, Cyprus, Democratic People's Republic of Korea, Democratic Republic of the Congo, Djibouti, Dominica, Dominican Republic, Ecuador, El Salvador, Equatorial Guinea, Eritrea, Estonia, Eswatini, Ethiopia, Fiji, Finland, French Polynesia, Gabon, Gambia, Georgia, Ghana, Greenland, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Iceland, Iraq, Israel, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Latvia, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Lithuania, Luxembourg, Madagascar, Malawi, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Micronesia (Federated States of), Monaco, Mongolia, Montenegro, Montserrat, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, New Caledonia, Nicaragua, Niger, Nigeria, North Macedonia, Oman, Palau, Palestine, Panama, Papua New Guinea, Paraguay, Peru, Puerto Rico, Republic of Moldova, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Senegal, Serbia, Seychelles, Sierra Leone, Sint Maarten (Dutch part), Slovakia, Slovenia, Solomon Islands, Somalia, South Sudan, Sri Lanka, Sudan, Suriname, Syrian Arab Republic, Tajikistan, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Turks and Caicos Islands, Tuvalu, Uganda, United Republic of Tanzania, Uzbekistan, Vanuatu, Venezuela, Yemen, Zambia, Zimbabwe
Cluster 2	Japan, Republic of Korea, Russian Federation
Cluster 3	United States of America
Cluster 4	Argentina, Australia, Belgium, Brazil, Canada, Germany, Indonesia, Italy, Malaysia, Mexico, Poland, Spain, Thailand
Cluster 5	Algeria, Chile, Hong Kong SAR, Colombia, Czechia, Denmark, Egypt, Greece, Hungary, Iran, Ireland, New Zealand, Pakistan, Philippines, Portugal, Romania, Saudi Arabia, Singapore, South Africa, Sweden, Switzerland, Türkiye, Ukraine, United Arab Emirates, Viet Nam
Cluster 6	India, People's Republic of China
Cluster 7	France, Germany, Netherlands, United Kingdom of Great Britain and Northern Ireland

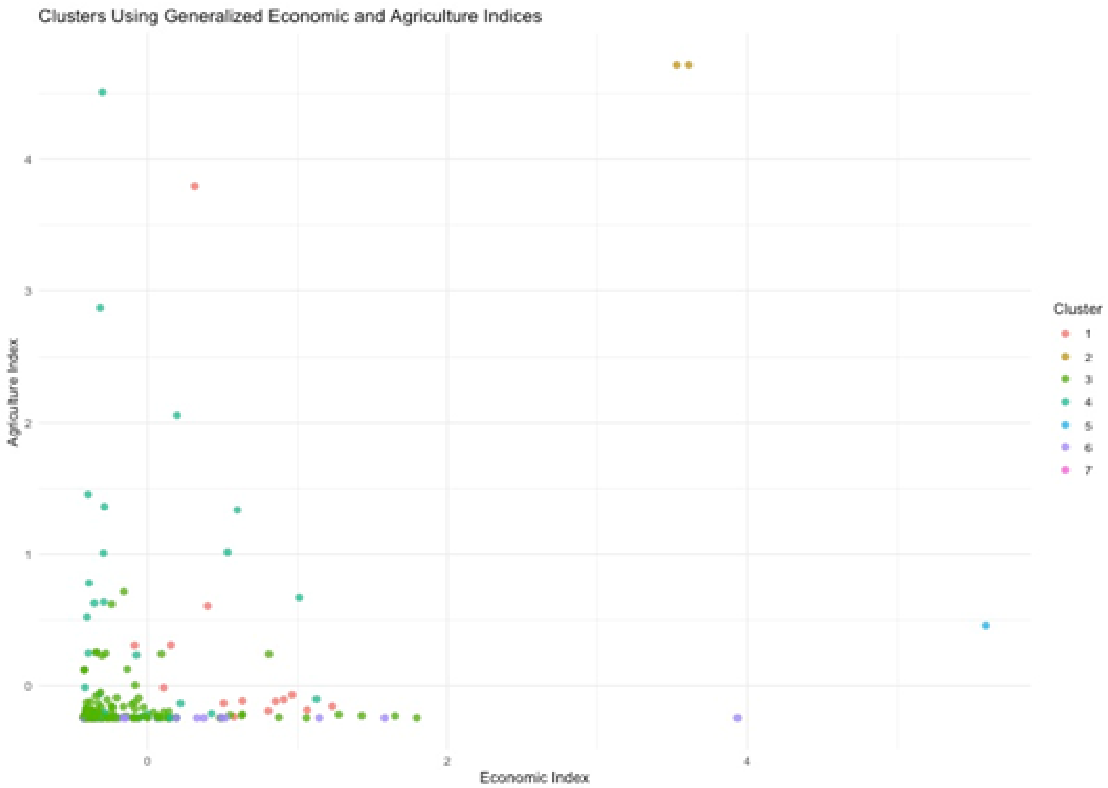

Figure 4. Distribution of world countries by clusters according to input data, source: own research

Cluster 3. The United States forms a standalone cluster, reflecting its unparalleled economic performance. As the world's largest economy, the U.S. demonstrates exceptionally high GDP and labor productivity levels. Its industrial sector is characterized by innovation and efficiency, while the agricultural system, heavily reliant on advanced technologies, ensures domestic food security and supports a substantial export market. The U.S. serves as a benchmark for economic resilience and technological leadership.

Cluster 4. This cluster encompasses advanced economies such as EU members (Germany, Belgium, Italy, Spain, Poland) and major non-European powers like Australia, Brazil, Canada, and Argentina. These nations exhibit high GDP per capita, robust industrial infrastructures, and well-established agrarian systems. Their agricultural sectors are marked by high productivity and innovation, supported by substantial investments in technological advancement. These economies play a pivotal role in global trade, particularly in the export of agricultural commodities, and are driven by strategies prioritizing sustainable growth and competitiveness.

Cluster 5. This cluster includes nations such as Chile, Greece, Turkey, and Ukraine, characterized by substantial heterogeneity in economic performance. GDP per capita varies between moderate and high levels. Agriculture remains a key sector, though the degree of technological modernization is uneven across the cluster. Traditional farming practices coexist with modern approaches, reflecting the transitional nature of these economies. Many countries in this cluster are actively pursuing structural reforms aimed at fostering economic growth and enhancing food security.

Cluster 6. China and India represent two of the largest economies in terms of population and production. These nations focus on ensuring food security for their vast populations, increasingly employing advanced technologies and innovative practices in agriculture. China is a global leader in industrial output and technological innovation, while India retains a strong agricultural orientation, supported by its expansive labor force and evolving policy frameworks.

Cluster 7. This cluster represents the pinnacle of global economic development, with nations demonstrating exceptionally high GDP per capita, advanced technological infrastructure, and efficient agricultural systems. These countries exhibit unparalleled levels of food security and sustainability, driven by heavily automated agricultural practices. As significant exporters of agricultural products, they exert considerable influence on international food markets. Predominantly EU member states, these countries account for a substantial share of the region's agrarian gross output, underscoring their strategic importance in the global economy.

Cluster 4 and Cluster 7 can be integrated into a single group of highly developed economies due to their comparable economic attributes, including high GDP per capita, advanced industrial frameworks, and sophisticated agricultural systems. While the scale of their economies may differ, their strategic orientations – focusing on stability, productivity, and technological advancement – are remarkably aligned. This consolidation simplifies the analytical framework while highlighting their shared global significance.

Among the countries that belong to this cluster, some countries are EU members. At the same time, they form over 60% of the gross production value of the region's agrarian sector (Table 4).

At the same time, according to the results of the forecast and clustering models, it may be stated that one of the most effective combinations in forming economic relationships, particularly, trade relations and sustainable and resilient development, is the example of the European Union. The EU's experience and achievements in sustainable and resilient development, considering its multifactor approach to agrarian policy, may become a significant pointer for other countries. Furthermore, unique peculiarities of the European Union include its great area, various climate conditions, and cultural differences among member countries. Considering the above mentioned, sustainable and resilient development and bioeconomy strategies developed for the EU can take this variety into account which makes them adjusted and effective in different geographic conditions (European Investment Bank, 2018).

The EU possesses great experience and resources to support innovations in agriculture as well as the unified trading system which contributes to efficient coordination among member states. In the context of the global strategy for agrarian development, the EU may act as a catalyst in the exchange of innovations and experience among world regions as well as in the implementation of a unified standard and ecological norms systems in agriculture (Agriculture, 2020). To effectively integrate bioeconomic principles in the agrarian sector following the example of EU member countries, partnerships with other regions must be actively developed, and tight relationships with countries demonstrating a high level of readiness for innovations and biotechnologies implementation should be built.

Considering the EU experience, there are perspective strategic directions in developing agrarian sector based on complementarity of international trade and the concept of sustainability, e.g. integration of bioeconomic principles in trade agreements (presupposes taking aspects of sustainable and resilient development into account and saving natural resources in trade relationships among countries; requires developing and signing agreements that include standards of sustainability and effective use of biological resources; facilitates development and exchange of technologies for sustainable and resilient agriculture through trade relations); creating platforms for experience exchange (presupposes setting initiatives to build common collaboration projects and programs for countries to exchange technical and scientific experience; conferences, seminars, and working groups for professionals in agriculture and bioeconomy to interact); developing common standards (facilitation in creating a unified system of standards in quality and safety for agricultural products); financial support and innovation stimulation (providing financial support for projects and programs aimed at implementation of innovations in agriculture); forming global partnerships, cooperation.

Table 4. Distribution of share of gross production value, added value, and total costs in agriculture of European Union countries in 2022, source: the forecast is made based on data (FAOSTAT, 2024)

Country	Index					
	Gross production value (constant prices in 2014-2016, I$ thousands), agriculture, $1,000 *	%	Value added (agriculture, forestry, and fishery), prices in 2015, USD mln *	%	General government total expenditure, USD value, 2015 prices, millions of USD *	%
Austria	423922.376	3	4890.76246	2		0
Belgium	519718.647	3	2557.15085	1		0
Bulgaria	62562.8814	0	2952.75771	1	26756.39	2
Croatia	64490.58	0	1725.65659	1		0
Cyprus	28596.2556	0	410.227819	0		0
The Czech Republic	214894.339	1	4163.21269	2	85829.83	6
Denmark	356222.058	2	2620.99361	1	130251.15	9
Estonia	28165.3609	0	388.653445	0		0
Finland	260758.35	2	5873.87706	3	74719.07	5
France	2655833.93	17	36819.947	17		0
Germany	3628159.27	24	23403.0788	11	659472.76	44
Germany	216951.153	1	8097.03391	4		0
Greece	158396.003	1	3761.23661	2		0
Hungary	526570.425	3	3916.31625	2		0
Italy	1973612	13	34217.407	16		0
Latvia	32216.2299	0	1141.50184	1		0
Lithuania	52319.7965	0	860.573747	0	19826.41	1
Luxembourg	72415.6574	0	127.845475	0	25579.3	2
Malta	16685.2483	0	172.425327	0		0
The Netherlands	903615.823	6	13957.8491	6	296208.89	20
Poland	632326.062	4	11284.506	5		0
Portugal	232543.397	2	4170.84328	2		0
Romania	237729.137	2	8349.6947	4		0
Slovakia	103827.553	1	2022.3432	1		0
Slovenia	54385.9213	0	904.550031	0		0
Spain	1343037.19	9	29436.8266	14		0
Sweden	584297.516	4	7219.28264	3	177417.28	12
The European Union	15384253.2	100	215446.554	100	1496061.08	100
The total share of EU countries from Cluster 7 and Cluster 4		76		70		64

*The figures are presented in constant prices in 2014-2016 / 2015 prices to eliminate the effects of inflation and price fluctuations, allowing for more accurate comparisons across different periods.

Therefore, the primary pillars in the transformation of agriculture and trade activity (particularly, international trade) are the concept of bioeconomy and the implementation of innovative and complementary technologies. However, the efficiency of bioeconomic policy implementation dramatically depends on regional peculiarities and the readiness of countries to adjust these approaches to their needs and conditions. One of the key aspects of bioeconomy within agriculture is the global diversity of regional strategies and approaches. Some regions have already proved to be leaders in the direction of demonstrating a high level of readiness for innovations and the use of biotechnologies while others fall behind. There are regions where strong agricultural production in the bioeconomy has already become a basis for economic development. For instance, European Union countries actively invest in research and development of biotechnologies, providing favorable conditions for developing a sustainable and resilient agricultural sector. European countries successfully implement principles of bioeconomy, boosting the creation of renewable energy and reduction of greenhouse gas emissions in agriculture. This aligns with the UN Sustainable Development Goals, specifically SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). However, there are regions where the implementation of these approaches is less active. Lack of infrastructure and limited accessibility to modern technologies can slow down bioeconomy and agrarian sector development on the whole in these regions. This highlights the importance of SDG 9 (Industry, Innovation, and Infrastructure), which advocates for strengthening infrastructure and technological advancement. At the same time, international trade is a significant factor in innovation transfer since it may assist in providing equal distribution of resources, improving the quality of life of the population, and reducing inequality among regions of the world and countries, directly supporting SDG 10 (Reduced Inequality).

Conclusions

Key tendencies that are currently typical for the agricultural sector are growing expenditures for source materials, market instability, negative changes in climate conditions, etc. These phenomena create a complicated challenge vector for agricultural systems requiring a systematic consideration of their responses to ecological, economic, and social aspects. In the context of such challenges, an understanding of the interconnection between international trade and sustainable and resilient development is critical. International trade connections become catalysts for innovation exchange and facilitate the effective implementation of sustainable agriculture practices. There are various regional responses to this connection that are formed under the economic, political, and social conditions of different regions. This underscores the importance of the UN Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 17 (Partnerships for the Goals).
Based on the linear regression analysis, it has been established that there is a statistically significant dependence between the volume of production, expenditures for source materials, and export volumes. The influence of several factors on agricultural sector efficiency has been confirmed, which makes the results useful for forming development strategies and making management decisions in agriculture. As a result of carrying out the cluster analysis, a group of countries (Argentina, Australia, Belgium, Brazil, Canada, Germany, Indonesia, Italy, Malaysia, Mexico, Poland, Spain, Thailand, France, Germany, Netherlands, United Kingdom of Great Britain and Northern Ireland), whose approaches in developing the agricultural sector most fully meet the principles of sustainability, and whose efficiency of trade activity tends to constantly rise, has been distinguished. Therefore, it has been established that one of the most effective combinations of forming economic relationships, particularly, trade relations, and sustainable and resilient development, is the example of the European Union. In the context of the transformation of agricultural production and trade activity, major tendencies acting as determinants of its economic development have been distinguished. The key factors of these changes are the bioeconomy concept and the implementation of innovative technologies that complement each other.
It has been established that the efficiency of bioeconomic policy greatly depends on regional peculiarities and the readiness of countries to adjust these strategies to their economic context. A variety of regional strategies and approaches in agriculture are highlighted as a significant aspect of bioeconomy development. At the same time, geopolitical and economic risks, such as wars and political instability, must be considered since they can seriously affect international trade relations and agricultural sector development. Our following scientific works will be dedicated to seeking effective coordination of international trade and ensuring sustainable and resilient development, which is of great importance for providing the economic and social welfare of humankind and achieving the UN SDGs.

References

1. BAZALUK O., YATSENKO O.; ZAKHARCHUK O., OVACHARENKO A., KHRYSTENKO O., NITSENKO V., 2020, Dynamic Development of the Global Organic Food Market and Opportunities for Ukraine, *Sustainability* 12(17), 6963, https://doi.org/10.3390/su12176963.
2. BLAND R., GANSEAN V., HONG E., KALANIK J.,2023, *Trends driving automation on the farm*, McKinsey & Company, https://www.mckinsey.com/industries/agriculture/our-insights/trends-driving-automation-on-the-farm.
3. CHAPLIN H., DAVIDOVA S., GORTON, M., 2004, Agricultural adjustment and the diversification of farm households and corporate farms in Central Europe, *Journal of rural studies* 20(1), 61-77, https://doi.org/10.1016/S0743-0167(03)00043-3.
4. DALY H.E., 1996, *Beyond Growth. The Economics of Sustainable Development,* Boston, https://books.google.com.ua/books?id=AgVoBAAAQBAJ&printsec=frontcover&hl=uk&source=gbs_atb#v=onepage&q&f=false.
5. DALY H.E., 2008, *Ecological Economics and Sustainable Development*. Northampton, Edward Elgar Publishing, https://www.e-elgar.com/shop/gbp/ecological-economics-and-sustainable-development-selected-essays-of-herman-daly-9781847209887.html.
6. DATANOVIA 2020, *K-Means Clustering in R: Algorithm and Practical Examples,* https://www.datanovia.com/en/lessons/k-means-clustering-in-r-algorith-and-practical-examples/.
7. EIB, 2020, *Agriculture, bioeconomy and rural development: overview,* https://www.eib.org/attachments/thematic/agriculture_bioeconomy_and_rural_development_overview_2021_en.pdf.
8. EKINS P., 2000, Economic growth and environmental sustainability: the prospects for green growth, Routledge, https://books.google.com.ua/books/about/Economic_Growth_and_Environmental_Sustai.html?id=uoS4AAAAIAAJ&redir_esc=y.
9. EKINS P., 2007, The living economy: a New Economics in the Making, Routledge, https://api.pageplace.de/preview/DT0400.9781134955688_A24765189/preview-9781134955688_A24765189.pdf.
10. EUROPEAN COMMISSION, 2021, *European Green Deal*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
11. European Commission, 2033, *Value of EU trade deals surpasses €2 trillion - 2023 Implementation & Enforcement Report,* https://ec.europa.eu/commission/presscorner/detail/en/ip_23_5742.

12. European Investment Bank. Agriculture and bioeconomy – Unlocking production potential in a sustainable and resource-efficient way, https://data.europa.eu/doi/10.2867/611457.
13. FAO, 2023, *Bioeconomy for sustainable food and agriculture: a global opportunity*, United Nations, https://openknowledge.fao.org/items/17c04076-d998-4fe4-ba88-85c773dbd293.
14. FAO, 2023, *Beyond the Price Tag: How Consumers are Changing the Game in 2022 and What Your Brands Need to Do to Keep Up in 2023,* https://www.linkedin.com/pulse/beyond-price-tag-how-consumers-changing-game-2022-what-your/
15. FAO, 2023, *Faostat*, https://www.fao.org/faostat/en/#data/.
16. GARCIA M., 2012, The European Union and Latin America: 'Transformative power Europe' versus the realities of economic interests, *Cambridge Review of International Affairs* 28(4), 621–640, https://doi.org/10.1080/09557571.2011.647762.
17. KOSTOV P, DAVIDOVA S., 2021, Common Policy but Different Outcomes: Structural Change in Family Farms of Central and East European Countries after Their Accession to the EU, *Agriculture* 11(11), 1074, https://ideas.repec.org/a/gam/jagris/v11y2021i11p1074-d669246.html.
18. MACQUEEN J., 1967, Some Methods for Classification and Analysis of Multivariate Observations, *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability* 1, 281–97, http://projecteuclid.org:443/euclid.bsmsp/1200512992.
19. MATTHEWS A., 2012, The Impact of WTO Agricultural Trade Rules on Food Security and Development: An Examination of Proposed Additional Flexibilities for Developing Countries, *Research Handbook on the WTO Agriculture Agreement*, eds. McMahon J.A., Melaku G.D., Edward Elgar Publishing,https://ideas.repec.org/h/elg/eechap/13302_4.html.
20. MATTHEWS A., 2012, *Trade Agreements, WTO Rules, And Food Security: New Rules of Trade?* San Diego, California 143183, International Agricultural Trade Research Consortium, https://ideas.repec.org/p/ags/iat12m/143183.html.
21. MYKHALOVA, M., YATSENKO O., ZAVADSKA, Y.; AFANASIEVA O., HAAS R., 2023, The War in Ukraine and Its Impact on Global Agricultural Trade, *Journal of Land Management, Food and Environment* 74(2), 91–105. https://intapi.sciendo.com/pdf/10.2478/boku-2023-0008.
22. OSAULENKO O.; YATSENKO O.; REZNIKOVA N.; RUSAK D.; NItSENKO V., 2020, The productive capacity of countries through the prism of sustainable development goals: challenges to international economic security and to competitiveness, *Financial and credit activity: problems of theory and practice* 2(33), 492-499, https://doi.org/10.18371/fcaptp.v2i33.207214.
23. POLETTI A., 2012, *The European Union and Multilateral Trade Governance: The Politics of the Doha Round,* Routledge, London, https://www.routledge.com/The-European-Union-and-Multilateral-Trade-Governance-The-Politics-of-the-Doha-Round/Poletti/p/book/9781138802377.
24. SACHS J.D., 2005, Challenges of Sustainable Development Under Globalization, *International Journal of Development Issues* 4(2), 1-20, https://doi.org/10.1108/eb045851.
25. SACHS J.D., 2006, *The end of poverty: Economic possibilities for our time,* The Penguin Press, New York, http://www.economia.unam.mx/cedrus/pdf/jeffrey_sachs_the_end_of_poverty_economic_possibilities_for_our_time__2006.pdf .
26. STIGLITZ J.E., 2002, *Globalization and Its Discontents*, Norton, New York.
27. STIGLITZ J.E., 2012, *The price of inequality: How today's divided society endangers our future,* https://business.columbia.edu/sites/default/files-efs/imce-uploads/Joseph_Stiglitz/Price%20of%20Inequality%20for%20Sustainable%20Humanity.pdf.
28. TANANAIKO T., YATSENKO O., OSYPOVA O., NITSENKO V., BALAEZENTIS T., STREIMIKIENE D., 2023, Economic Rationale for Manifestations of Asymmetry in the Global Trading System, *Sustainability* 15, 5316, https://doi.org/10.3390/su15065316.
29. UC, 2018, *UC Business Analytics R Programming Guide*, https://uc-r.github.io/.
30. VALERI E., 2009, The European Union Free Trade Agreements: *Implications for Developing Countries,* https://www.realinstitutoelcano.org/en/work-document/the-european-union-free-trade-agreements-implications-for-developing-countries-wp/.
31. WALDL D., 2024, Mykhailova, M.; Haas R. Entry points of the Russo-Ukrainian war into the EU's food supply chain and potential impacts, *International Journal on Food System Dynamics* 15(5), 453-466, https://doi.org/10.18461/ijfsd.v15i5.M1.
32. YUNUS A., 2019, *K Means Clustering Using R,* https://rpubs.com/abdul_yunus/Kmeans_Clustering.