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ДИПЛОМНА РОБОТА

на тему: «Моделювання рівня соціально-економічного розвитку регіонів (Modelling of the level of socio-economic development of regions)»

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РЕФЕРАТ

Звіт про дипломну роботу: 61 сторінка, 3 розділи, 31 рисунків, 3 таблиці, 40 джерел.

Об’єкт дослідження – процеси управління соціально-економічним розвитком регіонів.

Предметом дослідження є методи економіко-математичного моделювання рівня соціально-економічного розвитку регіонів.

Мета дослідження - побудова моделей методами кластерного аналізу та головних компонент для аналізу соціально-економічного розвитку українських та словацьких регіонів, які дозволяють порівняти рівномірність розвитку регіональної економіки України та іншої країни, котра стала незалежною у той самий час як і Україна та згодом долучилась до ЄС, а також аналіз механізмів державного регулювання регіонального розвитку.

Проаналізовані наявні визначення поняття «регіональний розвиток», «місцеве самоврядування» та «17 Цілей сталого розвитку»; визначені фактори, що мали найбільший вплив на стан соціально-економічного розвитку українських регіонів; розроблені моделі кластерного аналізу соціально-економічного розвитку регіонів України та Словаччини; побудовані системи головних компонент, визначені найбільш та найменш розвинуті українські регіони за допомогою проведення ранжування на основі отриманих значень головних компонент; розглянуті методи державного регулювання регіонального розвитку.

КЛЮЧОВІ СЛОВА: РЕГІОН, РЕГІОНАЛЬНА ПОЛІТИКА, СОЦІАЛЬНО-ЕКОНОМІЧНИЙ РОЗВИТОК, КЛАСТЕРНИЙ АНАЛІЗ, МЕТОД ГОЛОВНИХ КОМПОНЕНТ

ABSTRACT

The thesis report: 61 pages, 3 chapters, 31 figures, 3 tables, 40 sources.

The object of research is the processes of managing the socio-economic development of regions.

The subject of the study is the methods of economic and mathematical modelling of the level of socio-economic development of regions.

The purpose of the study is to build models using the methods of cluster analysis and principal components to analyse the socio-economic development of Ukrainian and Slovak regions, which allow comparing the uniformity of development of the regional economy of Ukraine and another country that became independent at the same time as Ukraine and subsequently joined the EU, as well as to analyse the mechanisms of state regulation of regional development.

The article analyses the existing definitions of the concepts of "regional development", "local self-government" and "17 Sustainable Development Goals"; identifies the factors that had the greatest impact on the socio-economic development of Ukrainian regions; develops models for cluster analysis of socio-economic development of regions of Ukraine and Slovakia; builds systems of principal components; identifies the most and least developed Ukrainian regions by means of ranking on the basis of the obtained values of the principal components; considers methods of state regulation of regional development.

KEYWORDS: REGION, REGIONAL POLICY, SOCIO-ECONOMIC DEVELOPMENT, CLUSTER ANALYSIS, PRINCIPAL COMPONENTS METHOD

CONTENTS

INTRODUCTION

Analyzing the socio-economic situation in the regions and their impact on the country's economy is an important component of the country's development. Regions may differ in terms of economic development, employment, living standards and infrastructure, etc.

Developed regions can become a driver of economic growth for the country as a whole. They can be leaders in innovation, research and development of high-tech industries, which stimulates the development of other regions.

The development of regional infrastructure (transport networks, energy systems, communication networks) can also have a positive impact on the economy by providing convenient and fast access to markets and reducing transport and energy costs. In addition, the development of regional innovation and technology centers can contribute to the creation of new jobs and high-tech production. This can stimulate the development of other sectors of the economy, increasing GDP and creating new opportunities for economic growth.

In addition to the positive impact of regional development on the national economy, it is also important to pay attention to the issue of regional asymmetry. If some regions are in a deep economic crisis, this can lead to an increase in unemployment, a decrease in demand for domestically produced goods and services, which in turn can reduce domestic consumption and economic growth.

If some regions remain underdeveloped, but with significant potential, this can lead to a decrease in the economic growth of the country as a whole. Therefore, to achieve a more balanced development of the state, it is important to develop and implement an effective regional development policy.

Ukraine is a country with a large number of diverse regions with different levels of economic and social development. Today, most regions of Ukraine are experiencing major economic and social challenges due to political, economic and social factors. Therefore, the level of development of the regions should be analyzed and compared

with the level of development of European countries, such as Slovakia, in order to draw conclusions about the even distribution of development in Ukrainian regions.

The purpose of the study is to build models using cluster analysis and principal components to analyze the socio-economic development of Ukrainian and Slovak regions, which allow comparing the uniformity of development of the regional economy of Ukraine and another country that became independent at the same time as Ukraine and subsequently joined the EU, as well as to analyze the mechanisms of state regulation of regional development. In order to achieve this goal, the following tasks were set and solved:

to analyze the existing definitions of the concepts of "regional development", "local self-government" and "17 Sustainable Development Goals";

to identify the factors of socio-economic development of the regions of Ukraine and Slovakia;

to conduct a cluster analysis of the regions of Ukraine and Slovakia by the level of socio-economic development;

to apply the principal components method to analyze the development of Ukrainian regions and to rank the regions based on the results obtained;

to compare the uniformity of regional development in Ukraine and Slovakia and to formulate conclusions on smoothing the asymmetry of regional development.

The object of research is the processes of managing the socio-economic development of regions.

The subject of the study is the methods of economic and mathematical modelling of the level of socio-economic development of regions.

The information base of the study is the data of the State Statistics Service of Ukraine on the indicators of socio-economic development of Ukrainian regions, as well as the data of the Statistical Office of the Slovak Republic on the indicators of development of Slovak regions.

CHAPTER 1. THEORETICAL FOUNDATIONS OF MANAGEMENT OF SOCIO-ECONOMIC DEVELOPMENT OF REGIONS

1.1. The concept of socio-economic development of regions (SERD). The main factors of the SERD

The concept of regional development is primarily associated with the concept of "region". The term "region" comes from the Latin "regio" (country, area). A team of scientists defines a region as "...a territorial entity with clearly defined administrative boundaries, within which social and economic processes of ensuring the vital activity of the population, determined by the region's place in the system of territorial and social division of labour, are reproduced".

It is worth analysing the concept of "regional development". According to Article 1 of the Law of Ukraine "On the Principles of State Regional Policy", regional development is "...a process of social, economic, environmental, humanitarian and other positive changes in the regions" [1].

The concept of "regional development" has different interpretations by scholars. Here is the most accurate definition by A. Melnychuk: "Regional development is a set of positive, scientifically based structural and functional-territorial changes in socio-economic and environmental activities of people over a certain period of time" [2].

The essential characteristic of the factors of influence on the socio-economic development of regions in terms of the priority of their impact is that first of all, those factors are considered whose influence in a particular period is the greatest. Today, a number of factors can be identified that have a growing impact on regional development.

- Natural resource and climatic factors. Describe the presence of non-mobile resources in the region, such as forests, rivers, minerals, land with regard to agricultural use and soil cover, faunal resources, etc. They emphasise the peculiarities of the natural environment (in particular, average annual temperatures, average annual precipitation, duration of the heating season), recreational conditions of the population, the

environmental situation in the region and affect the standards and lifestyle of the population [3]. They have an impact on the development of recreation, tourism, and the health resort industry in the region;

- Transport and geographical factors. They characterise the geographical location of the region, its proximity to central transport interchanges and major highways. They are used to transport goods. Under the influence of this factor, specific economically favourable conditions are created for the development of various types of human activity, which arise on the basis of increased functional connectivity, contact, mobility, mutual permeability and complementarity of various elements of regional social systems;

- Demographic factors. The demographic situation in the region determines the labour potential. The state of the population refers not only to the number of people, but also to its qualitative characteristics: the distribution of the population by age, gender, education level, etc. The demographic crisis is one of the main reasons that hinders the socio-economic development of Ukraine's regions. There is a narrowing of the demographic base for reproduction of labour potential due to low birth rates, high mortality rates, labour emigration of the working-age population, reduced life expectancy, deterioration of the age structure, and a decrease in the number of economically active population, which leads to an annual decline in the level of labour potential and a reduction in human resources in the regions [4, 5];

- Environmental factors. Characterise the level of anthropogenic environmental pollution. The use of environmentally safe technologies, an effective mechanism for preserving fresh and mineral water sources, measures to provide the population with environmentally friendly drinking water, protection of rivers, streams and reservoirs from clogging and pollution by industrial and domestic wastewater. Creation of new landfills, as well as opening of industrial and household waste recycling facilities in the region. The extent to which the problem of household waste collection and disposal has been resolved. The implementation of these measures has a positive impact on socio-economic development;

- Infrastructure factors. Infrastructure (industrial, social, scientific and technical, environmental, and intellectual) is what holds back or stimulates the development of a region. A well-developed regional infrastructure means enhanced security and stronger ties between residents and the economy. Infrastructure development depends on the specifics of industries and regions and is carried out in line with changes in the production sector. The structure of production in today's environment is characterised by a growing focus on regional rather than sectoral management. The infrastructure of a modern city and the quality of the urban environment are determined by the activities of a range of municipal services that support the city's population and production. Infrastructure plays a key role in economic development, as its existence is linked to the state of productive forces and the territorial division of labour, as well as the efficiency of the material production sector [6]. On the one hand, the infrastructure arrangement of the regional economy depends on the pace of modernisation, and on the other hand, it is the supplier of socio-economic development of the regions;

- Production and industrial factors. The development of the region's industry involves the rational and more complete use of natural resource potential, taking into account environmental safety requirements, intra-regional demographic features, employment levels, labour and human resources, the establishment of inter-regional links within the single space of Ukraine, and the development of international industrial integration;

- Financial and economic factors. One of the most important financial and economic factors in the development of any region of Ukraine is the availability of natural resources, a developed industrial sector, infrastructure, external and internal economic relations, market conditions, qualified labour resources, budget revenues, attractive investment conditions, the degree of dependence on external sources of resources and energy, which are related to the level of socio-economic development of the country and each specific region, the level and structure of employment in public production; and

- Military and political factors. The military conflict caused the greatest damage to the mining, chemical, mining and metallurgical, and machine building industries. As

the crisis worsened, the problems of the regional industrial complex that had been accumulating for years became apparent: excessive dependence on external conditions in the markets for key export goods, high energy and material intensity of production, which led to a sharp rise in production costs, lack of funds for the modernisation of fixed assets, and reduced sales in the domestic market due to a decrease in demand for intermediate consumption and investment products;

- Factors of state influence and regional policy. Possibility of using the existing mechanism of regulation of economic development of the region, factors of the state's regional policy [8]. This concept is understood as both state regulation of territorial social development and regulation of regional development carried out by the centre. The basic object of regional policy in Ukraine is currently the oblast region. In particular, the problems of depressed regions cannot be solved on their own, and require constant attention and financial assistance from the state;

- Factors of public, cultural and social activities. Priority tasks in the field of social infrastructure include ensuring the outpacing development of communication and trade infrastructure, housing and communal reform to ensure an adequate level of public services. These factors include the availability of housing, pre-schools, secondary schools, medical facilities, cultural, retail, consumer services, sports facilities, etc., i.e. facilities that provide the population with conditions for normal life and social protection. The main result of the socio-economic development of the region should be a full-fledged healthy person, improvement of his or her life, implementation of measures to ensure social protection of the population, development of healthcare, education and science, culture and art, physical culture and sports, creation of favourable conditions for harmonisation of interethnic and interfaith relations in all spheres of life;

- Technical and technological factors. The ability to quickly implement scientific and technological advances. The growth rate of industrial production will require an increase in energy consumption. The introduction of energy-saving technologies is the main reserve for sustainable energy supply and reduction of the share of energy per unit of output;

- Competitive factors. The instability of socio-economic development has led to the need to find new markets for goods in foreign markets, develop new types of products and re-profile production. There is a change in the sectoral specialisation of the regional economy, in particular in the areas of export-oriented production [9];

- Market factors. Depending on the specific features and availability of infrastructure for business development in the region, as well as certain conditions of preferential taxation, specific conditions for the reproduction of goods and services and labour can be determined. These indicators determine the movement of prices, production, employment, and living standards. The main characteristic of market conditions is the degree of balance between supply and demand. This assessment allows us to diagnose the type of regional market conditions;

- Factors of investment attractiveness. The main goal of activating investment activity in the region is to increase the level of living standards of the population and increase the volume of sources of own investment resources by increasing production volumes and improving the economic condition of business entities [10, 11];

- Factors of food security. In the context of the formation of regional food markets, food security is of particular importance. The level of food security in each region is determined by its specific characteristics: natural and climatic conditions of the region, socio-economic situation, state of agricultural production and food market, food sufficiency, etc. The food security of a region depends on the ability of the regional system to generate and distribute food resources, to provide all categories of the population with food in sufficient quantity, quality and range throughout its territory, and on the ability of different population groups to purchase the required amount of food of high quality. The task of regional authorities is to ensure equal conditions for the functioning of the food market, in particular, to create real, not declarative, opportunities for all producers, including small ones, to combat the monopolisation of the food market by resellers, and to create conditions for the production of environmentally friendly food with the "bio" label;

- Information factors. They characterise the possibility of free access of every resident of the region to all information that is needed in the course of their activities,

leisure and everyday life, openness of local governments to dialogue with the public, formation of levels of information needs and information culture of the population, ensuring information security of the region and each of its residents. Transformation of the region's information resources into a strategic resource for sustainable and progressive development aimed at achieving the main goal of the region's development - a steady improvement in the quality of life of all segments of the population;

- Institutional factors. They have a significant impact on the level of socio-economic development of regions. They characterise the degree of completeness of structural transformations and institutional market reforms in the region. The institutional environment of an economic system is a set of socio-cultural, political and legal institutions and the interrelationships between them that affect the nature of people's economic activity and the formation of sustainable structures of their interaction within the economic system of the region [12].

Each of these factors forms the conditions for the existence and vital activity of regions in a new quality, which requires appropriate regulation of regional development by the state. A comprehensive approach to the development of territories could make regulation and the state regional policy in general more effective. According to experts, regional policy needs to move from a policy of solving point problems to a policy of integrated development of territories and integrated planning of territories. This would help to achieve the goals of ensuring stable and efficient development of regions.

1.2. Peculiarities of regional policy formation

According to Article 1 of the Law of Ukraine "On the Principles of the State Regional Policy", the purpose of the state regional policy is to create conditions for the dynamic, balanced development of Ukraine and its regions, ensure their social and economic unity, improve living standards, create safe conditions, and comply with social standards guaranteed by the state for every citizen regardless of their place of residence [1]. The state regional policy is implemented on the basis of the following

principles: legality, cooperation, parity, openness, subsidiarity, cohesion, equal rights and opportunities for women and men, inclusiveness, and integrated development [13].

The formation of market relations in a country often leads to an increase in the differentiation of people's financial situation. The process of improving the living standards of the region's population is its socio-economic development, which includes such aspects as: production and income growth; changes in the institutional, social and administrative structures of the region; changes in public consciousness; and renewal of traditions and customs. This is an increase in the quantity and quality of public and private goods (goods, works, services) provided to the population, including those obtained through mutually beneficial exchange with other regions.

Sustainable socio-economic development of a region implies choosing a means that, if implemented now, will help achieve the goals in the future. This multidimensional process is considered from the perspective of a set of different social and economic goals, rational and reasonable use of the region's potential, which will preserve resources for future generations.

In Ukraine, the system of regional governance has always combined two levers of governance - state regional administration and local self-government. The Constitution of Ukraine provides for two systems of local government: local state administrations and local self-government.

According to Article 140, ".... local self-government is exercised by the territorial community in accordance with the procedure established by law, both directly and through local self-government bodies: village, settlement, city councils and their executive bodies...." [14]. Based on these definitions, there are several fundamental differences between regional state administration and local self-government. The functions and powers of local administrations and the local self-government sector are based on the principles of sectoral competence.

In order to avoid duplication of work between local governments and state regional administration, the task was to reform the territorial and administrative system towards decentralization, i.e. transferring powers, resources, finances and responsibilities from state bodies to communities as close as possible. The main

objectives of the reform were to: optimize the country's administrative system; redistribute powers between levels of government and strengthen the role of the regions; distribute productive forces more efficiently; boost the development of depressed regions and create special economic zones to stimulate economic activity in the regions; implement financial decentralization and stimulate the inflow of investments that could accelerate growth and promote the development of depressed regions.

The first phase of the decentralization reform in Ukraine was carried out in 2014-2019 and achieved the following results:

1. Establishment of a new entity of administrative and territorial structure - an amalgamated territorial community (ATC). The main features of ATCs were: voluntary creation; radius of the total territory from the main village of 20-25 km; availability of a secondary school; common interests of local importance and social interaction of community members in the process of ensuring these interests; psychological self-identification of each community member; common communal property, payment of communal taxes.

2. Approval of the main conceptual document - the Concept of Reforming Local Self-Government and Territorial Organization of Power [15], and the Action Plan for its implementation, which launched the reform. In order to implement the provisions of the Concept and the objectives of the Action Plan, appropriate amendments to the Constitution of Ukraine were required, as well as the development of a package of new laws. However, in 2014, the government launched the reform within the framework of the current Constitution.

3. Adoption of the Laws on Amendments to the Budget and Tax Codes of Ukraine, which resulted in financial decentralization and increased local budgets by about 4 times ("...from 68.6 billion in 2014 to 275 billion UAH in 2019..." [16]).

4. Adoption of the Law on Voluntary Amalgamation of Territorial Communities. This made it possible to start creating a strong basic level of local self-government. Between 2015 and 2019, 982 amalgamated territorial communities (ATCs) were created in Ukraine. The law also introduced the institution of leaders in ATCs, who represent the interests of rural residents in the community council. In 2018, the amalgamated

communities received almost 1.5 million hectares of agricultural land outside settlements into communal ownership. [16]

5. The Law "On Cooperation of Territorial Communities" created a mechanism for solving common problems of communities: waste recycling, development of common infrastructure, etc.

6. After the adoption of the Law "On the Principles of State Regional Policy", it can be stated that support for regional development and community infrastructure development has increased more than 40 times (from UAH 0.5 billion in 2014 to UAH 20.75 billion in 2019). Due to this support, more than 12 thousand projects were implemented in regions and communities in 2015-2019 [16].

The second stage of decentralization is currently underway, and has already yielded the following results:

1. In June 2020, the government approved a new basic-level administrative and territorial structure. In accordance with the CMU Orders, 1469 territorial communities covering the entire territory of the country have been established in Ukraine. On 17 July 2020, the Resolution "On the Formation and Liquidation of Regions" [17] was adopted, which approved 136 regions in Ukraine. The old 490 regions were liquidated.

2. The Budget Code removed the rayon level from local funding. Today, the community is the primary unit in the administrative and territorial structure of our country. Currently, 1469 communities have been established. The issue of organizing the management of districts in cities falls within the competence of the councils of the respective communities. By 1 July 2021, the legal successor of the rayon council of the rayon is obliged to transfer to the communal ownership of territorial communities' certain objects of joint ownership of territorial communities of the rayon located on the territory of these territorial communities, in accordance with the division of costs between budgets established by the Budget Code of Ukraine [18].

1.3. Analysis of the problem of uneven socio-economic development of Ukrainian regions

Each country has leading regions with higher economic and social potential, which ensure the development and competitiveness of the entire economy. Leading regions, as a rule, have high economic development indicators, such as gross regional product, industrial and agricultural production, investment in fixed assets, etc. and are distinguished by a highly organized urban living environment [19].

And Ukraine, of course, is no exception. Moreover, the current difficult business environment and political situation only exacerbate the problems of regional disparities in the country.

Disparities in regional development significantly slow down the growth of the national economy and have a destructive impact on public confidence in government authorities, as the regulatory framework does not fully meet the requirements of today, and the reforms expected by society and business representatives are not being implemented at a pace that could yield the expected economic and social effect.

The existing problems of socio-economic development of Ukraine's regions pose a number of issues for the public authorities to address in order to ensure harmonious economic growth in all regions. First of all, this concern: improving the quality of life of the population; reducing mortality; increasing the level of environmental safety; developing priority industries; and increasing the competitiveness of regional economic systems.

The actualization of state regional policy issues in Ukraine has become a natural response to the significant socio-economic transformations that have taken place in the regions in recent years, to a number of significant contradictions in the relations between central and regional executive authorities and local governments at all levels of government to address the problems of regional and local development [20].

Another important problem in the socio-economic development of Ukraine's regions is the lack of interest of business structures in investing in social regional projects that would significantly affect the living standards of the population and the

competitiveness of the territory. In addition, foreign investors are also very slow to invest even in projects related to industrial production, hospitality, construction, etc. This situation did not develop in the country yesterday, and it has a serious legal, financial and economic basis.

One of the biggest obstacles to investing in the economy of Ukraine and its regions is corruption, investor insecurity and administrative barriers to the development and implementation of business projects. This means that investors often do not get what they expect.

On the other hand, it should be noted that Ukraine has always attracted investors due to its strategic geographical location, climate, resources and human potential. Most investors initially believe that it is possible to gain a long-term foothold in the promising Ukrainian market for goods and services and to earn a stable profit.

It also should be noted that decentralization has created opportunities for economic development of certain territories, in particular through attracting investment. However, it should be borne in mind that bona fide investors who act transparently and with purely entrepreneurial motives are guided by ratings regularly compiled by influential international organizations when choosing a country to invest in. Therefore, if we turn to reputable international rankings, we can see that over the past ten years, Ukraine has remained in a rather low position in terms of global competitiveness [21].

Given the political and economic situation in Ukraine, it is safe to say that the redistribution of economic resources between regions, which dominates regional policy today, does not produce the expected results and has a small and temporary economic effect.

CHAPTER 2. METHODS OF MODELLING THE LEVEL OF SOCIO-ECONOMIC DEVELOPMENT OF REGION

2.1. Conceptual framework of the study

The paper proposes a conceptual scheme for assessing the level of socio-economic development of regions. We present main stages of the conceptual scheme.

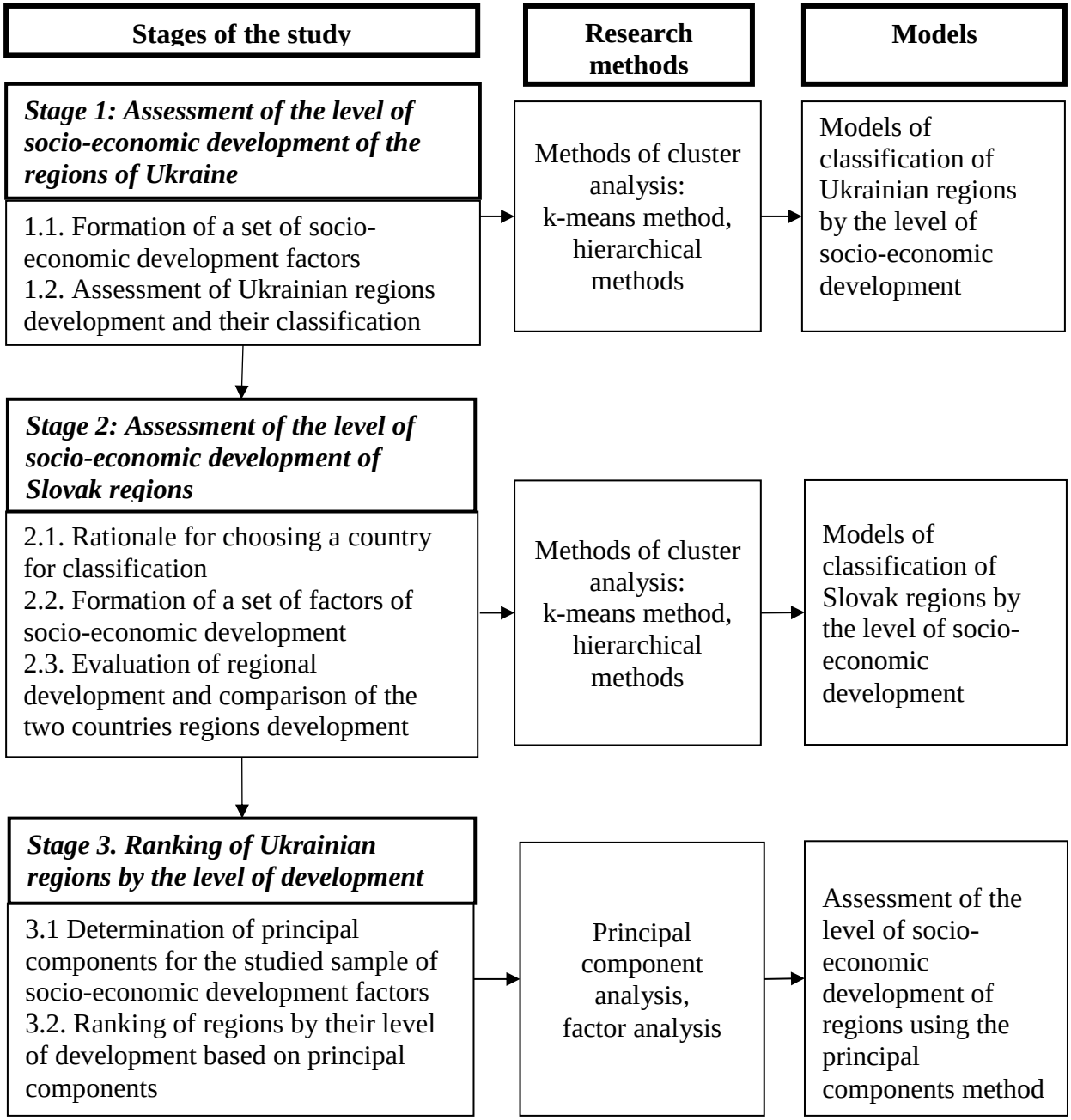

Figure 2.1. Conceptual diagram of the study

Source: developed by the author

The content of the first stage of the conceptual scheme is to assess the socio-economic development of the regions of Ukraine. At this stage, a system of indicators of socio-economic development of regions is formed, considering the specifics of state verified databases, grouping regions by the level of socio-economic development based on hierarchical agglomerative and iterative methods of cluster analysis, and assessing interregional socio-economic differentiation. The study of the characteristics of cluster structures will allow to determine the signs of stratification of regions in the Ukrainian economy, the share of core regions and regions with low levels of development, the degree of gap between cluster regions in terms of economic and social indicators, and to assess the level of threat of disintegration of the economic space.

The purpose of the second stage of the study is a comparative analysis of the uneven regional development of Ukraine and the EU countries on the example of Slovakia. At this stage, a system of diagnostic indicators of socio-economic development is built, considering the specifics of state databases. In particular, the system of indicators such as GRP per capita, per capita income, unemployment rate, etc. is universal. However, the statistical databases of Slovakia are more complete and include such an indicator as the level of social exclusion, which reflects the multidimensional level of poverty, i.e. takes into account the level of income, access to education, healthcare, etc. This indicator allows us to assess the level of social differentiation of regional systems. Next, the article groups the regions of Slovakia by the level of socio-economic development using hierarchical agglomerative and iterative methods of cluster analysis, and assesses the structural characteristics of the organization of the economic space of Slovakia and Ukraine.

At the third stage of the study, the regions of Ukraine are ranked in the formed clusters on the basis of such a method of factor analysis as the principal component method. The application of the principal component's method allows to identify the dominant factors of socio-economic development of Ukrainian regions, to carry out a linear ordering of multidimensional objects into clusters with different levels of socio-economic development.

Implementation of the proposed conceptual scheme will allow assessing the degree of interregional differentiation and developing recommendations for reducing the asymmetry of regional development. Next, the essence of the economic and mathematical modelling methods used in solving the tasks of each stage is considered.

2.2. Peculiarities of applying cluster analysis methods to assess the level of socio-economic development of territories

Multidimensional classification methods allow to group objects taking into account all the essential structural and typological features and the nature of the distribution of objects in a given system of features. Such classification is based on the desire to gather in one group similar objects in some sense, and so that objects from different groups are as dissimilar as possible [22].

Cluster analysis is a set of methods that allow to classify multidimensional observations, each of which is described by a set of initial variables X1, X2, ..., Xn. The purpose of cluster analysis is to form groups of similar objects, which are commonly called clusters. In contrast to combinational groupings, cluster analysis leads to a division into groups taking into account all the features simultaneously, i.e. they are taken into account all at once when assigning an observation to a particular group. At the same time, as a rule, there are no clear boundaries of each group, and it is not known in advance how many groups it is advisable to distinguish in the population under study.

Cluster analysis methods - divide the set of objects under study into homogeneous classes according to certain features that are considered simultaneously. The peculiarities of these methods include the fact that the number of clusters of clusters is unknown in advance, there are no dependent variables and outcome measures [23].

The following terminology is used in cluster analysis:

Cluster - class, taxon, cluster, group, bunch.

TA - taxonomy, automatic classification, stratification, unsupervised classification, self-learning recognition.

An object is an event, a subject, a taxonomic unit.

A feature is a variable, characteristic, property.

The input data matrix is a matrix of dimension m * n

Similarity means likeness, closeness, coherence, associativity.

Similarity coefficients are a measure of similarity (correlation coefficient, distance measures, associativity coefficient, probabilistic similarity coefficient).

A similarity matrix or proximity matrix is a matrix of dimension m*m or n*n.

As a result of applying cluster analysis methods, the objects under study are divided into certain clusters that have the following properties: density; dispersion; size; shape; separability.

For the convenience of writing formalized cluster analysis algorithms, we introduce the following notation:

X1, X2, ..., Xn - a set of objects of observation;

Xi = (Xi1 ,Xi2, … Xim) – the i-th multidimensional observation in the m-dimensional feature space (i = 1, 2, ..., n);

dij – the distance between the i-th and j-th objects;

zij – the normalized values of the original variables;

D – a matrix of distances between objects.

An important stage of cluster analysis is the calculation of the degree of similarity between objects, since in the course of clustering, each cluster should include objects with similar characteristics. In each specific task, this choice is made in a different way, considering the main purpose of the study, the physical and statistical nature of the information used, etc.

Cluster analysis can use measures of similarity: correlation coefficients, distance measures, associativity coefficients, probabilistic similarity coefficients. Each of these indicators has its own advantages and disadvantages, which should be considered beforehand.

As a result of analyzing the set of input data, homogeneous groups are created in such a way that objects within these groups are similar to each other according to some criterion, and objects from different groups differ from each other.

The similarity or difference between objects is established depending on the metric distance between them. If each object is described by k features, then it can be represented as a point in a k-dimensional space, and the similarity with other objects will be defined as the corresponding distance.

Here are the distance measures between objects used in the cluster analysis [24]:

the Euclidean distance: $d_{ij} = \sqrt{\sum_{k=1}^{m}(x_{ik} - x_{jk})^2}$; (2.1)

the weighted Euclidean distance: $d_{ij} = \sqrt{\sum_{k=1}^{m} w_k(x_{ik} - x_{jk})^2}$; (2.2)

the city-block distance: $d_{ij} = \sum_{k=1}^{m} |x_{ik} - x_{jk}|$; (2.3)

the Minkowski distance: $d_{ij} = (\sum_{k=1}^{m} |x_{ik} - x_{jk}|^p)^{1/p}$; (2. 4)

the distance of Mahalanobis: $dij = (X_i - X_j)'S^{-1} * (X_i - X_j)$; (2. 5)

where

d_{ij} – the distance between the i-th and j-th objects;

x_{i1}, x_{j1} – the values of the l-th variable in the i-th and j-th objects, respectively;

X_i, X_j – vectors of variable values in the i-th and j-th objects;

S^{-1} – the total covariance matrix;

w_k – the total covariance matrix.

If the clustering algorithm is based on a measure of similarity between variables, then similarity can be used as a measure of similarity:

- linear correlation coefficients;
- rank correlation coefficients;
- contingent ratios, etc.

Combining similar objects into groups can be done in different ways. There are certain groups of cluster analysis methods [24]:

- hierarchical methods;
- Iterative methods;
- Factor methods and clustering methods;
- methods that use graph theory.

The most common are hierarchical methods, among which there are agglomerative and divisive methods.

The main idea of the agglomerative method is that in the first step, each object is considered a separate cluster. The two closest objects are merged, and a new cluster is formed. The procedure continues until all objects are combined into one cluster. If the similarity matrix initially has dimension n * n, then the clustering process is completed in n-1 steps, and all objects will be combined into one cluster. The sequence of merging is easily interpreted geometrically and can be represented as a tree graph (dendrogram).

The main idea of the divisive method is that all objects initially belong to the same cluster. Groups of similar objects are separated from this cluster. Thus, at each step, the number of clusters increases, and the measure of distance between classes decreases.

Hierarchical cluster analysis methods are used for small data sets. The advantage of hierarchical clustering methods is their visibility. Hierarchical algorithms are associated with the construction of dendrograms (from the Greek dendron - "tree"), which are the result of hierarchical cluster analysis. The dendrogram describes the proximity of individual points and clusters to each other, and represents the sequence of cluster merging (splitting) in graphical form.

A dendrogram is a tree diagram containing n levels, each of which corresponds to one of the steps in the process of sequential cluster enlargement. It is also called a tree diagram, a cluster tree, or a hierarchical structure tree. A dendrogram is a nested grouping of objects that changes at different levels of the hierarchy.

A visualization of the cluster structure is shown in Fig. 2.2:

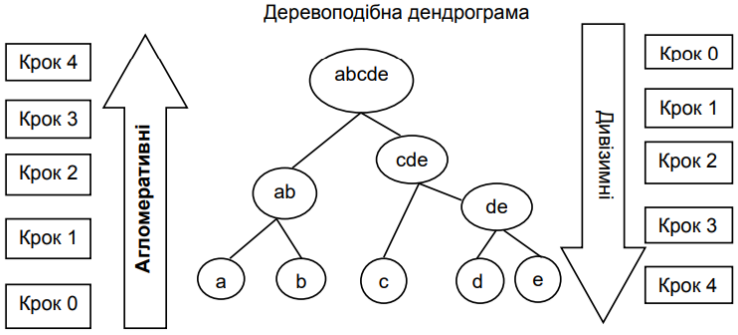

Figure 2.2 Visualization of the cluster structure using hierarchical methods

The set of methods of hierarchical cluster analysis differs not only in the measures of similarity (difference) used, but also in the classification algorithms. Among them, the most common are the single linkage method, the full linkage method, the average linkage method, and the Ward method [24].

Single linkage method. The algorithm for creating clusters is as follows: based on the similarity (difference) matrix, the two most similar or close objects are identified, and they will form the first cluster. The next step is to select the object to be included in this cluster. This object will be the one that has the greatest similarity to at least one of the objects already included in the cluster. If the data coincide on the basis of the same similarity (difference) measures, several clusters will be formed at once.

The advantages of this method include the insensitivity of the algorithm to transformations of the original variables and its simplicity. The disadvantages are the need to constantly store the similarity matrix and the impossibility of determining, based on the results of clustering, how many clusters can be formed in the studied set of objects.

The method of full connection. A new object is included in the cluster only if the distance between the objects is not less than a certain specified level.

The average connection method. To decide whether to include a new object in an existing cluster, the average value of the similarity measure is calculated and then compared to a specified threshold level. When it comes to merging two clusters, the distance between their centres is calculated and compared to the specified threshold value.

Ward's method. Optimization of the minimum variance within clusters: objective function (sum of squared deviations (SSD) → min; clusters of approximately equal size are formed, with a hyper spherical shape).

Ward's method algorithm:

1) normalization of initial data;

2) calculation of the distance matrix or similarity measure matrix;

3) a pair of the nearest clusters is found and merged. The new cluster is assigned the smaller of the numbers of the merging clusters. For the newly formed cluster, the SSD is calculated using the formula:

$$V_k = \sum_{i=1}^{n_k} \sum_{j=1}^{p} (x_{ij} - \overline{x_{jk}})^2; \qquad (2.6)$$

where

k – the cluster number;

i – object number;

j – number of the feature;

p – the number of features that characterise each object;

nk – the number of objects in the k-th cluster.

4) subsequently, at each step of the algorithm, those objects or clusters that give the smallest increase in the value of Vk are combined.

Procedures 2, 3, and 4 are repeated until all objects are combined into one cluster or until the specified "threshold" is reached.

The similarity measure for combining two clusters is determined by four methods [24, 25]:

Nearest Neighbor method - the degree of similarity is estimated by the degree of similarity between the most similar (closest) objects in these clusters.

The "distant neighbor" method - the degree of similarity is estimated by the degree of similarity between the most distant (dissimilar) objects in the clusters.

The average connection method - the degree of similarity is estimated as the average value of the degrees of similarity between cluster objects.

The median linkage method - the distance between any cluster and the new cluster resulting from the merger of clusters p and q is defined as the distance from the center of cluster S to the middle of the segment connecting the centers of clusters p and q.

The use of different clustering algorithms in hierarchical agglomerative methods leads to different cluster structures and greatly affects the quality of clustering. Therefore, the algorithm should be chosen taking into account the available information

about the existing structure of the set of observed objects or taking into account the requirements for optimizing mathematical criteria.

K-means method. Along with hierarchical classification methods, there is a large group of so-called iterative methods of cluster analysis. Their essence lies in the fact that the classification process begins with setting some initial conditions (the number of clusters formed, the threshold for completing the classification process, etc.

Iterative methods, to a greater extent than hierarchical methods, require intuition from the user when choosing the type of classification procedures and setting the initial conditions for the breakdown, because most of these methods are very sensitive to changes in the parameters. Therefore, it is advisable to first perform a classification using one of the hierarchical methods or based on expert opinions, and then select the initial partitioning and statistical criterion for the iterative algorithm.

As in hierarchical cluster analysis, iterative methods face the problem of determining the number of clusters. In general, the number of clusters may be unknown. Not all iterative methods require an initial setting of the number of clusters. However, several algorithms can be used to finally decide on the structure of the population under study, changing either the number of clusters formed or the set proximity threshold for grouping objects into clusters. Then it becomes possible to choose the best breakdown according to the entered quality criterion.

Unlike hierarchical procedures, the k-means method does not require the calculation and storage of a matrix of distances or similarities between objects. The algorithm of this method uses only the initial values of the variables. To begin the classification procedure, k randomly selected objects must be set to serve as standards, i.e., cluster centers. It is believed that reference type algorithms are convenient and fast. In this case, an important role is played by the choice of initial conditions that affect the duration of the classification process and its results.

The computational procedures of most iterative classification methods are reduced to the following steps:

Step 1. Selecting the number of clusters into which the population should be divided, setting the initial breakdown of objects and determining the centers of gravity of the clusters.

Step 2. According to the selected similarity measures, determine the new composition of each cluster.

Step 3. After all the objects have been fully reviewed and assigned to clusters, the centers of gravity of the clusters are recalculated.

Step 4. Procedures 2 and 3 are repeated until the next iteration yields the same cluster composition as the previous one.

This clustering method differs significantly from such agglomerative methods as tree clustering and two-way clustering. Let's say you already have hypotheses about the number of clusters (based on observations or variables). You can instruct the system to form exactly three clusters so that they are as different as possible. This is exactly the type of problem that the K-means algorithm solves. In general, the K-means method builds exactly K different clusters located at the largest possible distances from each other.

From a computational point of view, you can think of this method as a variance analysis in reverse. The program starts with K randomly selected clusters and then changes the assignment of objects to them to minimize the variability within clusters and maximize the variability between clusters. In K-means clustering, the program moves objects (i.e., observations) from one group (cluster) to another in order to obtain the most significant result in the analysis of variance.

The final stage of the clustering procedure is to assess the quality of the resulting classification. Using different methods of cluster analysis for the same population leads to different classifications of objects (different number of clusters, different degree of proximity of objects).

The characteristics of the cluster structure are significantly influenced by the following factors:

- a set of clustering features;

- type of clustering algorithm (cluster analysis method);

- selecting the degree of similarity between objects.

The problem of choosing the most qualitative classification of objects arises, which is solved by means of quality criteria for object classification. The measure of classification quality is commonly called functionality, or quality criterion. The best classification of objects according to the chosen functional is considered to be the one that achieves the extreme (maximum or minimum) value of the quality functional. To assess the quality of the partitioning by the degree of distance of the clusters from each other, the average interclass distances are used [24, 26].

2.3. Principal Component Analysis in the Analysis of Regional Socio-Economic Development

The principal component method is one of the most common data processing methods that aims to reduce the dimensionality of the data under study with minimal loss of useful information. This method consists in finding an additional system of lines or planes of the variable space that will reflect the maximum variance of the original values - such a line or plane is called a principal component. The main advantage of the principal component method is that it is the only mathematically sound method of factor analysis [27].

The algorithm of the principal component method is iterative and is explained as follows.

At the first stage, a matrix of initial data is formed X with dimension $p \times p$ where the rows of the matrix are the analyzed samples $(i = 1, \dots, p)$ and the columns are the initial variables x_{ij} $(j = 1, \dots, p)$ that characterise these samples.

Next, the original data should be centered using the formula $\tilde{x}_{ij} = x_{ij} - \bar{x}_j$ where $\tilde{x}_{ij}$ — is the centered value of the i-th row of the j-th column, and $\bar{x}_j$ — is the average value of the j-th column.

The next step is to find the first principal component from the linear combination $pc_i = \sum_{i=1}^{p} \alpha_k \tilde{x}_{ij}$ where $\sum_{i=1}^{p} {\alpha_k}^2$— are the factor mapping coefficients that satisfy the

orthogonality condition. This linear combination should have the largest variance among all other normally centred linear combinations. That is, the condition $|pc_i|^2 = \sum_{i=1}^{p} \alpha_k \tilde{x}_{ij} \rightarrow max$.

The ratio of the variances of the principal components and the input data serves as a measure of the informativeness of the factors.

The principal components (PCs) are linear combinations of the input variables $x_1, x_2 \ldots x_N$ that share a normal distribution with a vector of means $\vec{m} = m_1, m_2 \ldots m_N$ and the covariance matrix S. The PCA can be written as a linear combination of the input data [28].

$$Y_1 = \sum_{j=1}^{N} \alpha_{1j} \times x_j ; Y_2 = \sum_{j=1}^{N} \alpha_{2j} \times x_j, \ldots, Y_N = \sum_{j=1}^{N} \alpha_{Nj} \times x_j, \ldots, ; \quad (2.7)$$

$$cov(Y_1, Y_j) = 0, \text{ when } i, j = \overline{1, N}, i \neq j, \quad (2.8)$$

that is, these variables are uncorrelated. They are ordered in descending order of variance $D(Y_i), i = \overline{1, N}$.

The vectors $\vec{a} = a_{i1}, a_{i2} \ldots a_{iN}$ that define the principal components are eigenvectors corresponding to the eigenvalues L_i equal to the variance $D(Y_i)$. The total variance does not change as a result of the transition from variables $x_1, x_2 \ldots x_N$ to the principal components $Y_1, Y_2 \ldots Y_N$, so

$$D = \sum_{i=1}^{N} \delta_{1i} = \sum_{i=1}^{N} D(Y_i), \quad (2.9)$$

Each principal component of the variables explains $\left(100 \times \frac{D(Y_i)}{D}\right)$ % of the total variance. Then a subset of the first $p < N$ variables Y_i explains most of the total variance, and thus a concise description of the structure of the dependence of the input variables is obtained [28]. Therefore, the classes to be separated in [29] are canonically represented by the first two PCs Y_1 and Y_2 (explaining the largest variance of all variables), and illustrated by a graph (Fig. 2.3), since the initial input data space $x_1, x_2 \ldots x_N$ is of relatively high order.

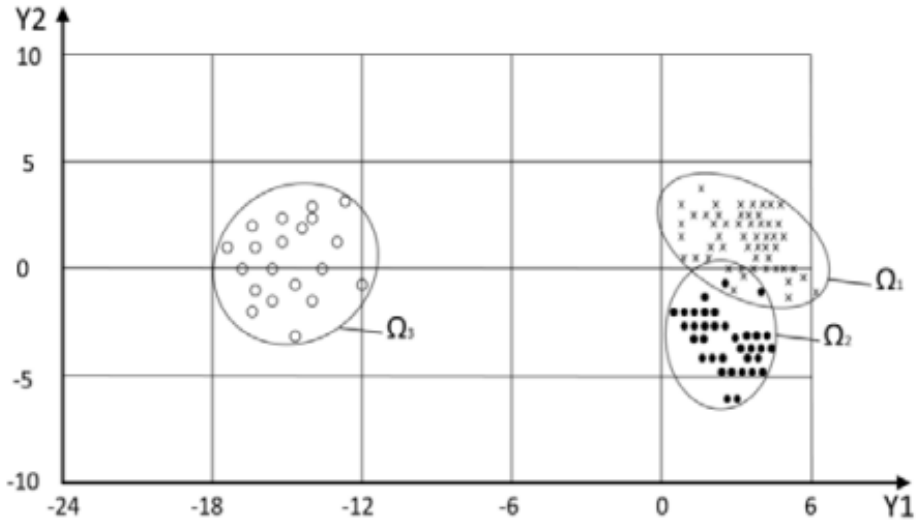

Figure 2.3. Division of input data into classes of defect-free and defective classes

From Fig. 2.3 shows that the use of PCM clearly allows for the separation of data classes. But the values obtained from objects in different clusters overlap.

Let us describe the algorithm of the principal components method as finding the decomposition of the input matrix X, i.e. calculating the product of matrices T and P

$$X = T \times P^t + E = \sum_{a=1}^{A} t_a \times p_a^t + E, \quad (2.10)$$

where

P - load matrix;

E - is the matrix of residuals.

The largest values of the load vectors reflect the most important features of the input data, while the remaining values are residuals, which mainly contain noise. The residual data are discarded, reducing the dimensionality of the input data space, without losing the main informative parameters.

There are four main types of tasks that can be solved by the principal components method: constructing integral indicators of different levels, assessing the relationship between integral indicators and a set of primary features, ranking and/or classifying units of the studied population, and structural analysis of information.

Today, the principal component method is used in many areas of science and technology [30-31] and can be used quite effectively in the system of monitoring the socio-economic development of regions.

CHAPTER 3. IMPLEMENTATION OF MODELS FOR ASSESSING THE LEVEL OF SOCIO-ECONOMIC REGIONS DEVELOPMENT

3.1. Analysis of the indicators of sustainable development of European countries and Ukraine, justification of the research framework

Ensuring regional sustainable development in the context of economic processes in Ukraine requires the implementation of a strategy of social, economic and environmental transformations. The transition to sustainable development in Ukraine already determines the importance of regional participation in these processes.

The seventeen Sustainable Development Goals (SDGs), adopted by all 193 UN member states, are the most prominent example to date that defines quantifiable sustainable development goals to be achieved by 2030. They broadened the definition of sustainable development to include economic, social, and environmental factors and are firmly rooted in the concept of sustainable development, i.e. "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The SDGs are linked to the Paris Climate Agreement (which is included in SDG 13). They apply to both developing and developed countries [32].

The European Union (EU), its institutions and member states have played a key role in the adoption of the 2030 Agenda, the SDGs and the Paris Agreement. In particular, the EU and its member states have been crucial in promoting an integrated, universal agenda that continues the Millennium Development Goals' (MDGs) focus on extreme poverty in all its forms and adds important issues of environmental sustainability, social inclusion, economic development and governance [33].

In fact, all the problems of the social, economic and environmental levels originate at the regional level, and only then become more widespread. The regional policy of sustainable development is one of the main activities of the state, which considers certain goals, principles and strategic objectives [34, 35].

Therefore, it is proposed to consider the achievement of the Sustainable Development Goals by European countries and Ukraine. In this way, we will get a

general picture of the development of the countries under study. In order to monitor the countries' compliance with the development plan set out in the 2030 Agenda, a progress assessment is generated for each country. To calculate this score, information on more than 400 indicators is collected and analyzed, including: Education level, Inflation, Proportion of people with an income below 50 per cent of the median income, Mortality, Gross Domestic Product, Forest area, CO2 emissions and Exports of goods and services [37].

Figure 3.1 visualizes the progress that EU countries have made towards (or away from) the SDGs over the past 5 years according to the Hametner and Kostetckaia progress indicator [36]:

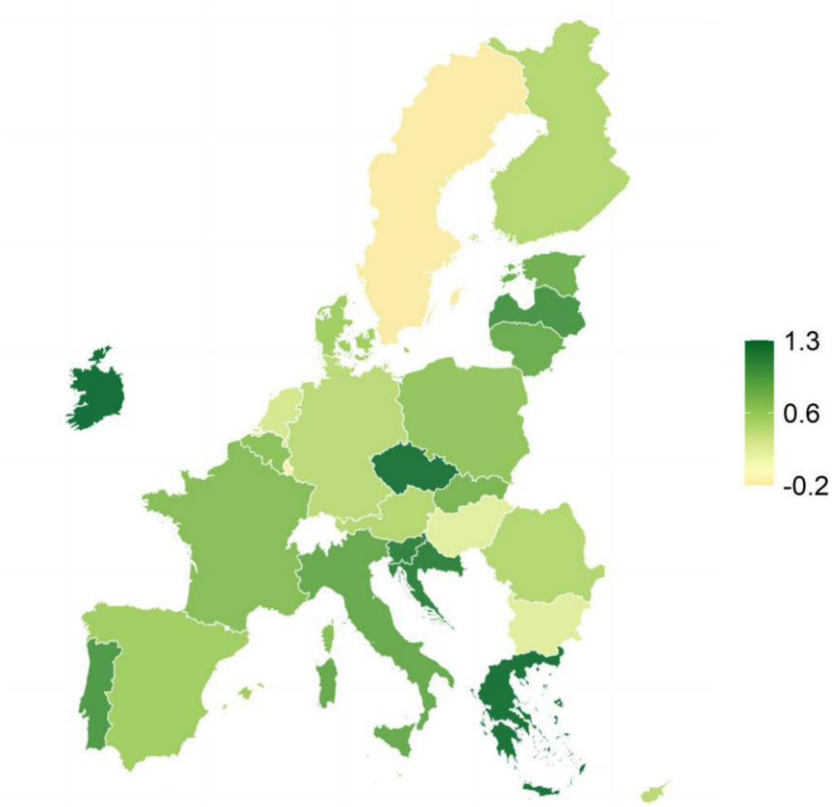

Figure 3.1: Visualization of the progress made by EU member states over the last 5 years according to the progress measurement

Source: [36]

Having analyzed Figure 3.1, we can conclude that the list of countries with the best results includes Ireland, Greece, the Czech Republic, Croatia, Slovenia, Latvia, Portugal, Italy, Lithuania and Slovakia.

For further research, it is proposed to compare the dynamics of economic indicators of the SDGs for Ukraine's neighboring countries, namely Poland, Slovakia, Moldova, Hungary and Romania, and Ukraine. The indicators under study include:

- New business density (new registrations per 1000 people aged 15-64);
- Inflation, consumer prices (annual %);
- GDP per capita (USD).

Let us present the resulting graph of the dynamics of the new business density indicator in the period between 2010 and 2020 for the countries under study (Fig. 3.2):

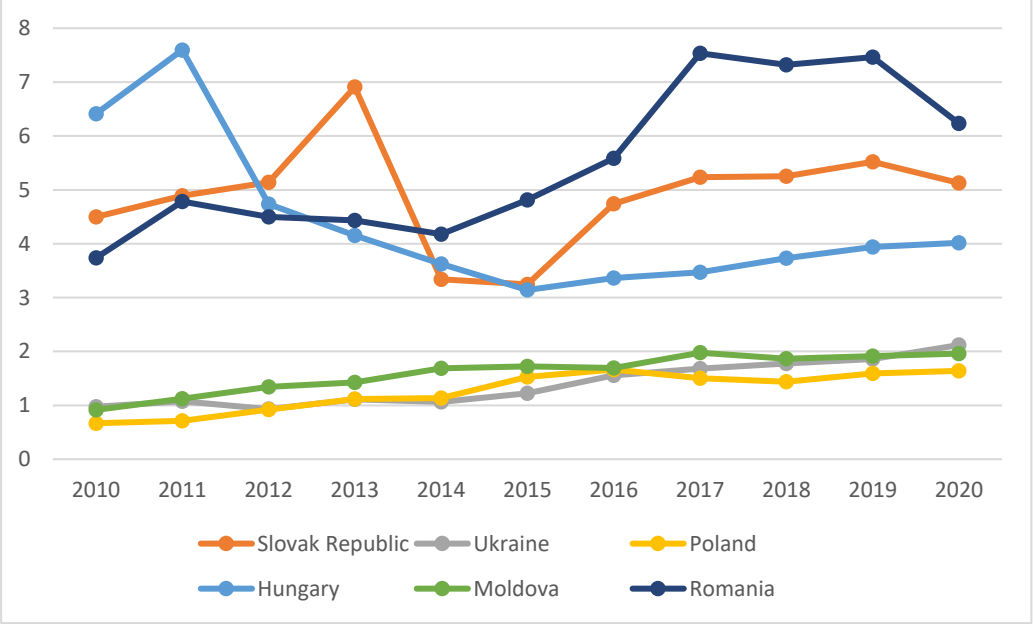

Figure 3.2. New business density (new registrations per 1,000 people aged 15-64)

Source: developed by the author based on [37]

Let us visualize the dynamics of the inflation rate between 2010 and 2020 for the countries under study:

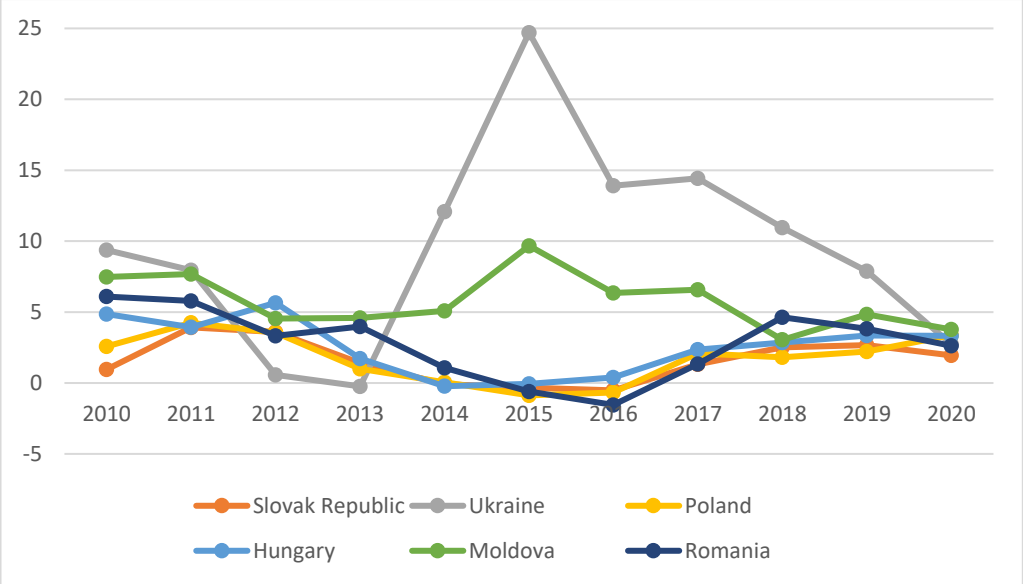

Figure 3.3. Inflation, consumer prices (annual %)

Source: developed by the author based on [37]

Let's plot the dynamics of GDP per capita between 2010 and 2020 for the countries under study:

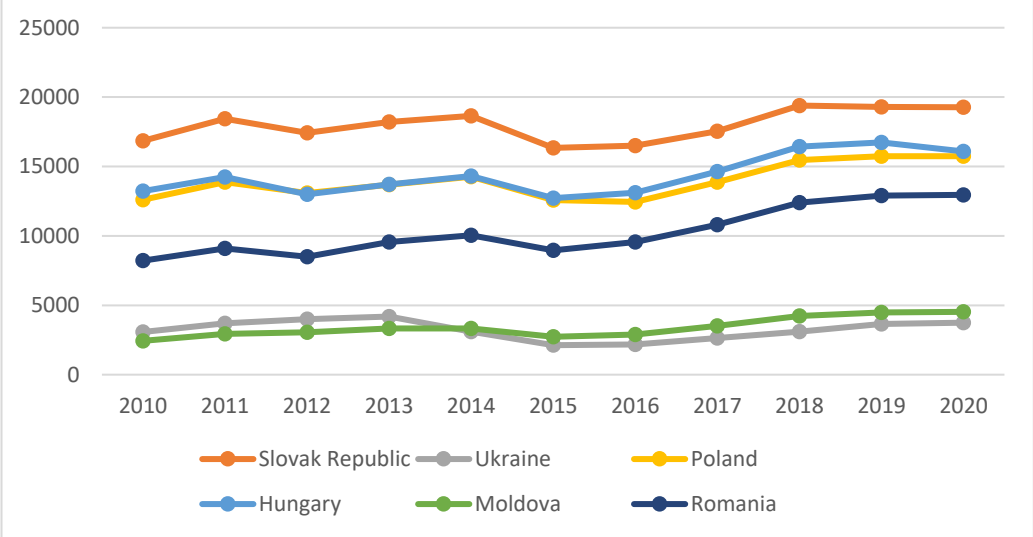

Figure 3.4. GDP per capita (current US$)

Source: developed by the author based on [37]

From the graphs, we can conclude that among the countries studied, Slovakia had the best development dynamics in the period 2010-2020 for all three indicators. Therefore, it is proposed to conduct a cluster analysis to assess the level of socio-economic development of the regions of Ukraine and Slovakia in order to compare the results and draw conclusions.

3.2. Application of cluster analysis methods to assess the level of socio-economic development of Ukraine and Slovakia regions

The following indicators were selected to analyze the level of socio-economic development of the regions of Ukraine (the initial data are given in Appendix A [38]):

1. Number of active enterprises;
2. Capital investments;
3. Permanent population;
4. The volume of foreign trade in goods;
5. Consumer price indices.

Let us conduct a cluster analysis of the regions of Ukraine using this data for 2022. It is necessary to divide our sample into clusters, and we will use the Ward method. Before conducting further research, the data was standardized.

The classification dendrogram was constructed using the Ward method as a pooling rule and the conventional Euclidean metric as a distance calculation measure.

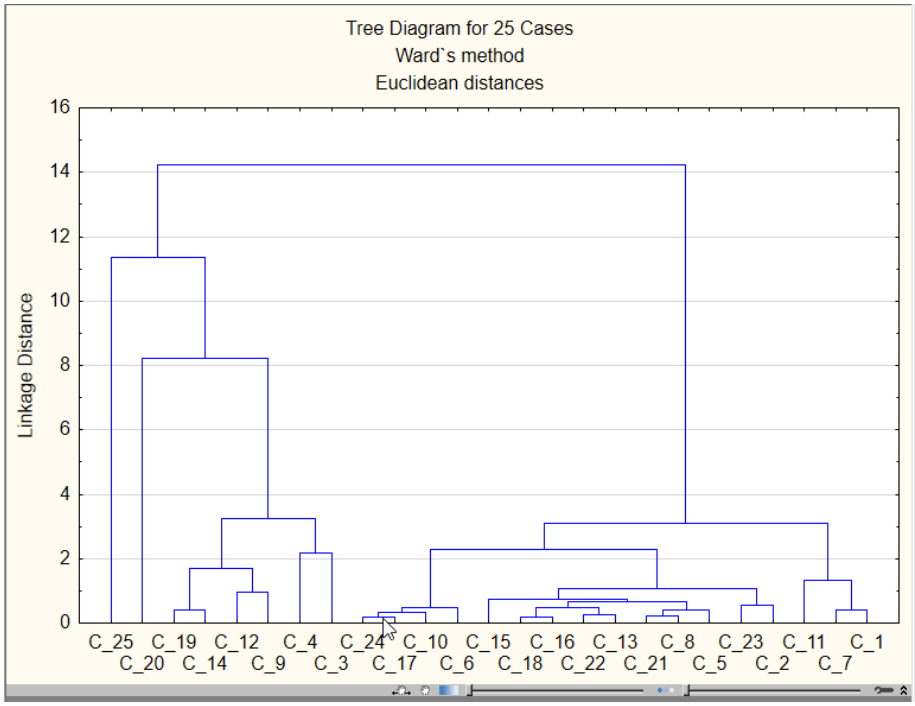

Figure 3.5. Grouping of Ukrainian regions by the Ward method

We can see 2 large clusters of homogeneous states in the observed population or 5 smaller and more homogeneous clusters. Based on the analysis of the Ward

dendrogram, we will divide the sample into 3 clusters. Let's analyse the clusters using the K-means method (Figures 3.6-3.7).

Cluster Number	Euclidean Distances between Clusters (Spreadsheet1) Distances below diagonal Squared distances above diagonal		
	No. 1	No. 2	No. 3
No. 1	0.000000	10.59068	14.30046
No. 2	3.254332	0.00000	0.93674
No. 3	3.781595	0.96786	0.00000

Figure 3.6. Euclidean distances between cluster centers

Variable	Cluster Means (Spreadsheet1)		
	Cluster No. 1	Cluster No. 2	Cluster No. 3
Number of active enterprises	4.23203	0.559618	-0.421652
Capital investments	4.53163	0.168008	-0.307760
Resident population	1.53554	1.302728	-0.519551
Volumes of foreign trade in Goods	-4.46937	0.020691	0.241401
Consumer price indices	0.17517	-0.283893	0.069745

Figure 3.7. Average values of indicators in clusters

Below is a graph of the average values of the clusters in Figure 3.8.

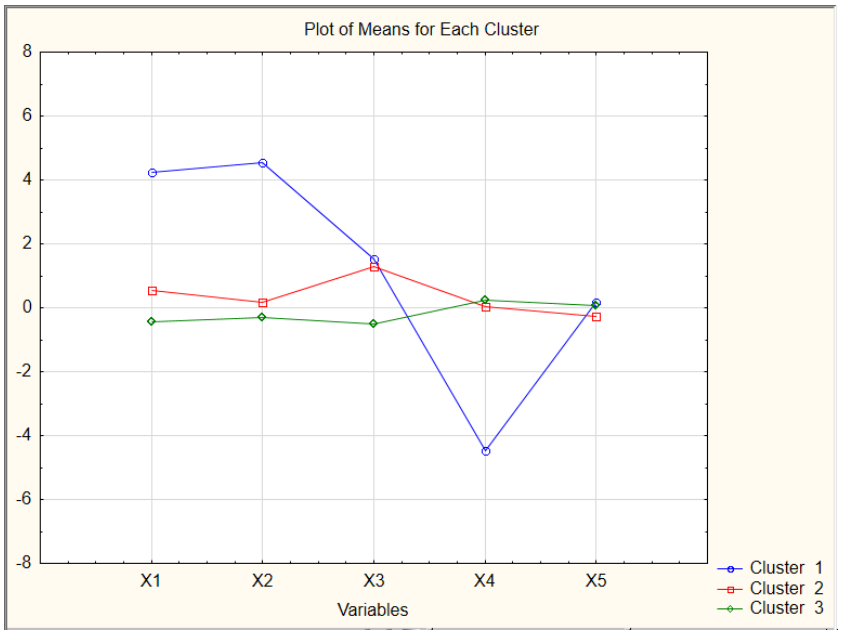

Figure 3.8. Graph of average values of indicators for clusters

The clusters differ most in terms of indicators: Number of active enterprises, Capital investment, and Volume of foreign trade in goods.

The difference is less significant in terms of indicators: Resident population, Consumer Price Indexes.

Let's present the results of the analysis of variance for assessing the quality of

indicators. The table shows the values of intergroup and intragroup variances of the attributes (Fig. 3.9).

Variable	Analysis of Variance (Spreadsheet1) Between SS	df	Within SS	df	F	signif. p
Number of active enterprises	22.98934	2	1.01066	22	250.2159	0.000000
Capital investments	22.40992	2	1.59008	22	155.0291	0.000000
Resident population	17.39929	2	6.60071	22	28.9957	0.000001
Volumes of foreign trade in Goods	21.02675	2	2.97325	22	77.7919	0.000000
Consumer price indices	0.59884	2	23.47258	22	0.2806	0.757967

Figure 3.9. Table of variance analysis

Since the F-parameters are the largest for the indicators "Number of active enterprises" and "Capital investment", they best characterize the cluster membership of an observation.

Let us present descriptive statistics for the selected clusters (Fig. 3.10):

Variable	Descriptive Statistics for Cluster 1 (Spreadsheet1) Cluster contains 1 cases Mean	Standard Deviation	Variance
Number of active enterprises	4.23203	0.00	0.00
Capital investments	4.53163	0.00	0.00
Resident population	1.53554	0.00	0.00
Volumes of foreign trade in Goods	-4.46937	0.00	0.00
Consumer price indices	0.17517	0.00	0.00

Variable	Descriptive Statistics for Cluster 2 (Spreadsheet1) Cluster contains 6 cases Mean	Standard Deviation	Variance
Number of active enterprises	0.559618	0.323585	0.104707
Capital investments	0.168008	0.488644	0.238773
Resident population	1.302728	0.933874	0.872121
Volumes of foreign trade in Goods	0.020691	0.642427	0.412713
Consumer price indices	-0.283893	0.203524	0.041422

Variable	Descriptive Statistics for Cluster 3 (Spreadsheet1) Cluster contains 18 cases Mean	Standard Deviation	Variance
Number of active enterprises	-0.421652	0.169276	0.028654
Capital investments	-0.307760	0.152666	0.023307
Resident population	-0.519551	0.363002	0.131771
Volumes of foreign trade in Goods	0.241401	0.231324	0.053511
Consumer price indices	0.069745	1.169854	1.368557

Fig. 3.10. Descriptive statistics of clusters

Cluster 1 has the highest indicators X1, X2, X3, X5. That is, all but the volume of foreign trade in goods. This cluster includes only the city of Kyiv.

Cluster 2 has average values of X1, X2, X3, X4. However, it is characterised by the lowest average value of X5. This cluster includes regions with average socio-economic development.

Cluster 3 has the lowest indicators X1, X2, X3. However, it has the highest average cluster indicator of foreign trade in goods. This cluster includes regions that do not specialize in manufacturing or have been heavily affected by the hostilities. Therefore, they are included in the cluster of the least socio-economically developed regions.

Fig. 3.11 shows the element regions of each of the clusters:

Members of Cluster Number 1 (Spreadsheet1) and Distances from Respective Cluster Center
Cluster contains 1 cases

Case No.	Distance
C_25	0.00

Members of Cluster Number 2 (Spreadsheet1) and Distances from Respective Cluster Center
Cluster contains 6 cases

Case No.	Distance
C_3	0.631694
C_4	0.801092
C_9	0.577802
C_12	0.422418
C_14	0.267814
C_19	0.211977

Members of Cluster Number 3 (Spreadsheet1) and Distances from Respective Cluster Center
Cluster contains 18 cases

Case No.	Distance
C_1	0.433133
C_2	0.250263
C_5	0.257399
C_6	0.090033
C_7	0.538255
C_8	0.135321
C_10	0.195105
C_11	0.578023
C_13	0.205313
C_15	0.214732
C_16	0.231412
C_17	0.198609
C_18	0.241093
C_20	2.000052
C_21	0.160044
C_22	0.231294
C_23	0.280028
C_24	0.240404

Figure 3.11: Cluster members and their distances to the cluster center

Thus, we can analyze the obtained clusters and conclude that the majority of regions (18 regions) are in the cluster with the lowest socio-economic development. The cluster with the highest level of development, i.e. the first cluster, includes only the city of Kyiv. The middle cluster includes 6 regions.

The results of the cluster analysis are shown in Figure 3.12.

Cluster 1	*Cluster 2*	*Cluster 3*
Kyiv city	Dnipropetrovsk	Vinnytsya
	Donetsk	Volyn
	Kyiv	Zhytomyr
	Lviv	Zakarpattya
	Odesa	Zaporizhzhya
	Kharkiv	Ivano-Frankivsk
		Kirovohrad
		Luhansk
		Mykolayiv
		Poltava
		Rivne
		Sumy
		Ternopyl
		Kherson
		Khmelnytskiy
		Cherkasy
		Chernivtsi
		Chernihiv

Figure 3.12. Results of cluster analysis of Ukrainian regions

The following indicators were chosen to analyze the level of socio-economic development of the Slovak regions (the initial data are presented in Appendix B [39]):

1. Social isolation;
2. Average net nominal monthly earnings;
3. Regional gross domestic product;
4. The level of registered unemployment.

Let's conduct a cluster analysis of the regions of Slovakia using this data for 2020. It is necessary to divide our sample into clusters, and we will use the Ward method. Before conducting further research, the data were standardized.

The classification dendrogram was constructed using the Ward method as a pooling rule and the usual Euclidean metric as a distance calculation measure (Figure 3.13).

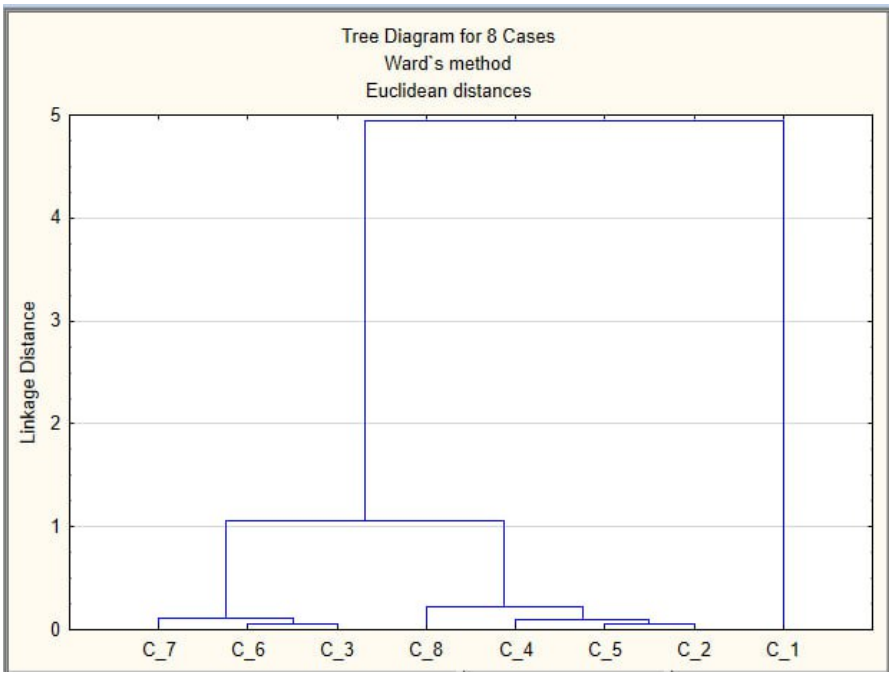

Figure 3.13. Ward's method

We can see 2 large clusters of homogeneous states in the observed population or 3 smaller and more homogeneous clusters. Based on the analysis of the Ward dendrogram, we will divide the sample into 3 clusters. Let us conduct a cluster analysis using the K-means method (Figures 3.14-3.15).

Cluster Number	Euclidean Distances between Clusters (Spreadsheet9) Distances below diagonal Squared distances above diagonal		
	No. 1	No. 2	No. 3
No. 1	0.000000	1.922200	2.495402
No. 2	1.386434	0.000000	0.037346
No. 3	1.579684	0.193250	0.000000

Figure 3.14. Euclidean distances between cluster centers

Variable	Cluster Means (Spreadsheet9)		
	Cluster No. 1	Cluster No. 2	Cluster No. 3
Poverty	-0.546080	-0.544763	-0.543857
Net Income	-0.326300	-0.382290	-0.389630
Regionak GDP	4.039130	1.266827	0.880398
Unemployment	-0.546290	-0.545900	-0.545563

Figure 3.15. Average values of variables in clusters

Next, a graph of the average variables values in the clusters is presented in Fig.3.16:

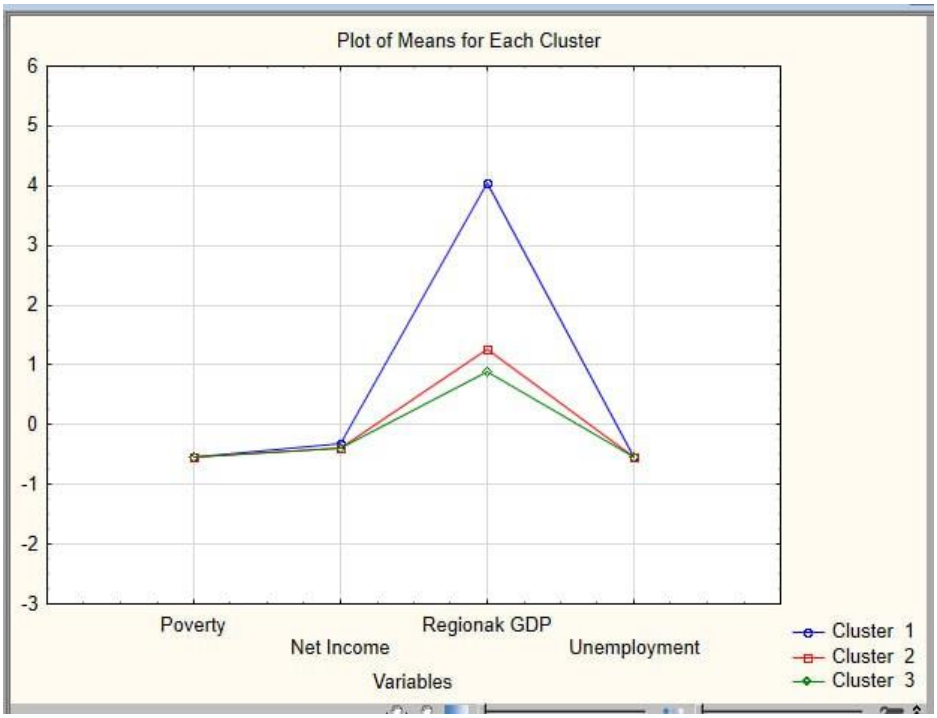

Figure 3.16. Graph of average values of indicators for clusters

The clusters differ most in terms of Regional Gross Domestic Product. The difference is less significant for all other indicators.

Let's present the results of the analysis of variance for assessing the quality of indicators. The table shows the values of intergroup and intragroup variances of the attributes (Fig. 3.17).

	Analysis of Variance (Spreadsheet9)					
Variable	**Between SS**	df	Within SS	df	F	signif. p
Poverty	0.000004	2	0.000005	5	2.0107	0.228693
Net Income	0.003152	2	0.000231	5	34.1425	0.001216
Regionak GDP	7.808419	2	0.038005	5	513.6395	0.000002
Unemployment	0.000000	2	0.000001	5	0.9640	0.442491

Figure 3.17. Table of analysis of variance

Since the F-parameters are the largest for Regional GDP and Average Net Nominal Monthly Earnings, they best characterize the cluster membership of an observation.

Let's present descriptive statistics for the selected clusters (Fig. 3.18):

Descriptive Statistics for Cluster 1 (Spreadsheet9)
Cluster contains 1 cases

Variable	Mean	Standard Deviation	Variance
Poverty	-0.546080	0.00	0.00
Net Income	-0.326300	0.00	0.00
Regionak GDP	4.039130	0.00	0.00
Unemployment	-0.546290	0.00	0.00

Descriptive Statistics for Cluster 2 (Spreadsheet9)
Cluster contains 4 cases

Variable	Mean	Standard Deviation	Variance
Poverty	-0.544763	0.000787	0.000001
Net Income	-0.382290	0.004381	0.000019
Regionak GDP	1.266827	0.100294	0.010059
Unemployment	-0.545900	0.000432	0.000000

Descriptive Statistics for Cluster 3 (Spreadsheet9)
Cluster contains 3 cases

Variable	Mean	Standard Deviation	Variance
Poverty	-0.543857	0.001236	0.000002
Net Income	-0.389630	0.009307	0.000087
Regionak GDP	0.880398	0.062565	0.003914
Unemployment	-0.545563	0.000544	0.000000

Figure 3.18. Descriptive statistics of clusters

Cluster 1 has the highest values of X2, X3, and the lowest values of X1, X4. This cluster includes only the Bratislava region.

Cluster 2 has average indicators X1, X2, X3, X4. This cluster includes medium-sized regions in terms of socio-economic development.

Cluster 3 has the worst values of indicators X1, X2, X3, X4. This cluster includes regions that are classified as the least developed regions.

Fig. 3.19 shows the element regions of each of the clusters:

Members of Cluster Number 1 (Spreadsheet9)
and Distances from Respective Cluster Center
Cluster contains 1 cases

Case No.	Distance
C_1	0.00

Case No.	Members of Cluster Number 2 (Spreadsheet9) and Distances from Respective Cluster Center Cluster contains 4 cases Distance
C_2	0.008922
C_4	0.052850
C_5	0.020952
C_8	0.065172

Case No.	Members of Cluster Number 3 (Spreadsheet9) and Distances from Respective Cluster Center Cluster contains 3 cases Distance
C_3	0.004510
C_6	0.031133
C_7	0.031809

Figure 3.19. Cluster members and their distances to the cluster center

Thus, we can analyze the obtained clusters and conclude that clusters 2 and 3 have average values of indicators that do not differ significantly, and the number of regions in these clusters is approximately the same. In the cluster with a high level of development (the first cluster), there is only 1 region that differs from the others only in the average value of the Regional GDP parameter. Thus, we can see that the regions of Slovakia are characterized by uniform development. The result of the cluster analysis is shown in Figure 3.20.

Cluster 1	***Cluster 2***	***Cluster 3***
Region of Bratislava	Region of Trnava	Region of Trenčín
	Region of Nitra	Region of Banská Bystrica
	Region of Žilina	Region of Prešov
	Region of Košice	

Figure 3.20. Results of cluster analysis of Slovak regions

In general, the share of regions with a high level of socio-economic development in Ukraine is 28%, while in Slovakia it is 63%. The dendrogram of classifications also shows a much lower level of interregional differentiation of Slovak regions compared to Ukrainian regions. It should be noted that the gap in economic activity is quite large for the regions of Slovakia. For example, the GDP of the capital region is more than 2.5 times higher than that of the next leading region. The gap in the levels of economic development of Slovak regions is 3.3 times. At the same time, there is little differentiation

in social development indicators. In Ukraine, there is a significant gap in both economic and social indicators.

Thus, the analysis allows us to conclude that the share of "core" regions in the Ukrainian economy is low and, as a result, there is significant social differentiation, which indicates the need to adapt the strategy of socio-economic development of regions at the state level, considering the development of cluster structures that allow for the formation of a coherent economic space.

3.3. Application of the Principal Component Method to analyse the level of socio-economic development of regions

To analyze the level of socio-economic development of Ukraine's regions using the principal components method, the same indicators were studied as those selected for the classification of regions by cluster analysis (the initial data are given in Appendix A [38]):

1. Number of active enterprises;
2. Capital investments;
3. Permanent population;
4. Volumes of foreign trade in goods;
5. Consumer price indices.

Let us analyze the initial data for 2022 using the principal components method. We need to determine the principal components for the model. To do this, we will derive the standard results of principal component analysis. Before conducting further research, the data were standardized. Figure 3.21 shows the results of the principal component information assessment.

Principal Components Analysis Eigenvalues (Spreadsheet7)
Number of components is 4
Principal Components Analysis sum of variance 5.0030

Component	Eigenvalues	% Total variance	Cumulative eigenvalue	Cumulative %
1	3.076203	61.48747	3.076203	61.48747
2	1.109075	22.16831	4.185279	83.65578
3	0.670297	13.39796	4.855575	97.05374
4	0.128551	2.56949	4.984126	99.62323

Figure 3.21. Standard results of principal component analysis

In the previous analysis, a model was built with the maximum number of principal components, i.e. 4. Having analyzed the eigenvalues of each component, we see that the variances of the first and second components are greater than 1. Therefore, according to the Kaiser criterion, the first two components should be retained. The table also shows that the first component explains 61.5% of the total variance, and the second component explains 22.2%, i.e. the system of the first two components explains 83.7% of the variance of the original set of features.

We also apply the rocky scree criterion to visually confirm the choice of the number of principal components for the sample of values under study. Let's display the graph of eigenvalues in Fig. 3.22.

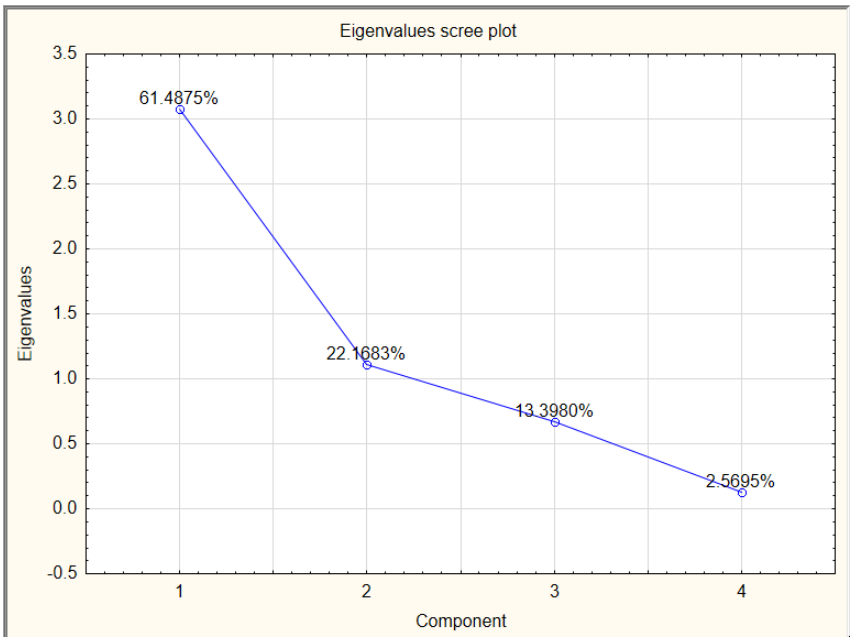

Figure 3.22. Graph of eigenvalues

Since the decline in the graph from left to right slows down as much as possible after the second point, only the "factor scree" is located to the right of the second point. Therefore, according to this criterion, it is also necessary to leave 2 principal components for further calculations.

Now we need to analyze the main factors for the selected data. Let's do this using the results of the correlation matrix for the variables (Figure 3.23):

Variable	Correlations (Spreadsheet7) Casewise deletion of MD N=25 **Number of active enterprises**	Capital investments	Resident population	Volumes of foreign trade in Goods	Consumer price indices
Number of active enterprises	1.00	0.96	0.62	-0.83	-0.08
Capital investments	0.96	1.00	0.43	-0.88	-0.05
Resident population	0.62	0.43	1.00	-0.30	-0.19
Volumes of foreign trade in Goods	-0.83	-0.88	-0.30	1.00	-0.07
Consumer price indices	-0.08	-0.05	-0.19	-0.07	1.00

Fig. 3.23. Correlation matrix

We can see that the most correlated indicators are the number of active enterprises, capital investment, resident population and foreign trade. In contrast, the CPI is not correlated with the other indicators. Therefore, we can explain that there are two relatively independent factors that are reflected in the correlation matrix: one relates to the activities of enterprises, and the other to the financial sector, i.e. inflation.

Now we should conduct a principal components analysis and consider a two-factor solution. To do this, we look at the correlations between the variables and the two factors, i.e. the new variables (Figure 3.24).

Variable	Factor Loadings (Quartimax normalized) (Spreadsheet7) Extraction: Principal components (Marked loadings are >.700000) **Factor 1**	Factor 2
Number of active enterprises	0.978834	-0.105808
Capital investments	0.966274	0.006938
Resident population	0.577884	-0.493946
Volumes of foreign trade in Goods	-0.910496	-0.188371
Consumer price indices	0.007343	0.915047
Expl.Var	3.054809	1.128020
Prp.Totl	0.610962	0.225604

Figure 3.24. Factor loadings

We can conclude that the first factor is more correlated with the first four variables that have the highest correlation with each other. But the second factor is most correlated with the CPI, which has no significant impact on all the others. This can be explained by the fact that the factors are selected sequentially and contain less and less total variance.

Now we should consider the importance of each socio-economic factor on the overall result, i.e. regional development. To do this, we obtain a power table, which is shown in Figure 3.25.

Variable	Variable importance (Spreadsheet1) Number of components is 2		
	Variable number	Power	Importance
Number of active enterprises	1	0.969307	1
Capital investments	2	0.933356	2
Volumes of foreign trade in Goods	4	0.863058	3
Consumer price indices	5	0.844837	4
Resident population	3	0.572206	5

Figure 3.25. Importance of regional development factors

Thus, we can conclude that the least important variable for development is the "Resident population", and the two most important are "Number of active enterprises" and "Capital investment" for the sample under study.

It is also worth considering the uniformity of regional development by plotting the Hotelling distribution (Figure 3.26).

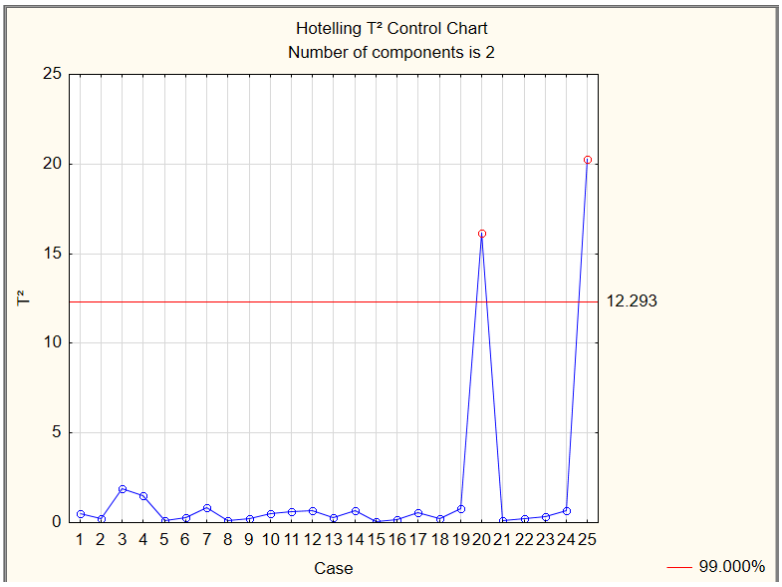

Figure 3.26. Hotelling distribution graph

The resulting distribution graph shows that Kyiv city and Kherson region are the most distinctive among all regions. Kyiv is in the first cluster with the highest socio-economic development. And Kherson region, which is part of the cluster with the lowest development indicators in 2022, has the highest CPI in 2022, which is 142.3.

Further, on the basis of the values of individual principal components obtained by calculating the values of individual principal components after rotation according to the quartimax normalized criterion [40], a table of principal component values was obtained for each of the studied regions (Table 3.1).

Table 3.1

Principal component values for the regions under study

Region	Factor 1	Factor 2
Vinnytsya	-0.318184	-0.63434
Volyn	-0.264752	0.42319
Dnipropetrovsk	0.547918	-1.28225
Donetsk	0.325082	-1.22354
Zhytomyr	-0.341156	-0.09183
Zakarpattya	-0.391512	0.35831
Zaporizhzhya	-0.369346	-0.82329
Ivano-Frankivsk	-0.327959	-0.0126
Kyiv	0.457823	-0.1614
Kirovohrad	-0.506535	0.48009
Luhansk	-0.363241	-0.71409
Lviv	0.756667	-0.31299
Mykolayiv	-0.505877	-0.05879
Odesa	0.185095	-0.79828
Poltava	-0.235946	0.03047
Rivne	-0.393551	-0.11666
Sumy	-0.461476	0.59959
Ternopyl	-0.467841	-0.07042
Kharkiv	0.251073	-0.84382
Kherson	-0.249853	3.99021
Khmelnytskiy	-0.332526	-0.03853
Cherkasy	-0.429814	-0.18103
Chernivtsi	-0.540686	0.14935
Chernihiv	-0.480114	0.67078
Kyiv city	4.456711	0.66189

Fig. 3.27 shows the regions distribution by the main component of development:

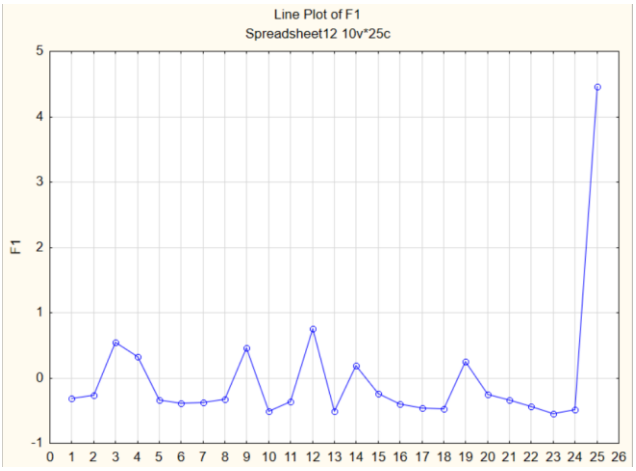

Figure 3.27. Regions distribution by the main component of economic development

Graph shown on figure 3.27 confirms the significant asymmetry of economic development, namely between the capital region (Kyiv) and other regions of Ukraine. Among the regions with a high level of development, the best values of the main component of economic development are characteristic of Dnipropetrovsk and Lviv oblasts. Among the regions with a low level of development, Chernivtsi and Kirovograd regions are the most problematic.

The distribution of regions by the main component of social development is shown in Fig. 3.28.

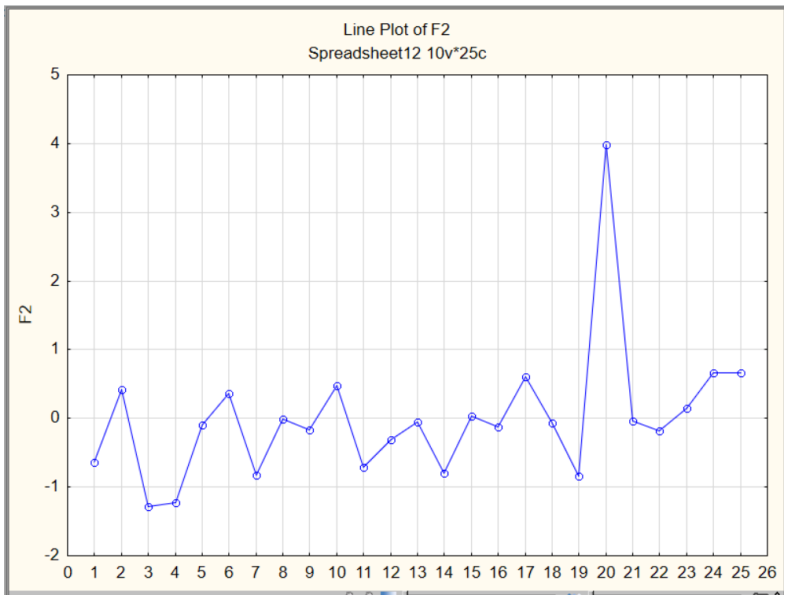

Figure 3.28. Distribution of regions by the main component of the level of social development

As can be seen from Fig. 3.28, the most unfavorable social situation is observed in Kherson region, and the leader in terms of the second principal component is Dnipropetrovsk oblast.

Thus, the constructed principal component system allows us to identify the leading regions, problematic regions in the formed clusters of regions, and assess the degree of interregional socio-economic asymmetry.

CONCLUSIONS

The socio-economic development of Ukraine's regions is an important component of the country's overall development. Today, Ukrainian regions have different levels of development, which affects the socio-economic situation in the country.

Therefore, the aim of the study was to develop models that investigate the socio-economic development of Ukrainian regions and allow them to be ranked by these indicators to determine the degree of uniformity of development of Ukrainian regions. Another objective was to conduct a comparative analysis of the regional development of Ukraine and Slovakia, which has experienced steady socio-economic growth in recent years.

To study the indicators of regional development, three models of classification of indicators of regional development in Ukraine and Slovakia were built.

The cluster analysis of regions by socio-economic development resulted in 3 clusters. As of 2022, only the city of Kyiv has a high level of economic development and a more developed infrastructure. In contrast, Odesa, Kharkiv, Kyiv, Lviv, Donetsk, and Dnipro regions have an average level of development. All other 18 regions have a low level of development.

One of the problems with the socio-economic development of Ukraine's regions is the uneven development of cities and villages. Urban areas are usually more developed than rural areas, which often lack sufficient infrastructure and employment. Also, of course, all of Ukraine's eastern and central regions have suffered damage due to martial law and shelling of industrial enterprises. An example of a region that in 2020 belonged to the cluster of regions with an average level of development, but now has a low level of socio-economic development is Poltava region.

Slovakia was used to compare how evenly the regions are developing in the European Union member states. After the analysis, it can be concluded that all socio-economic indicators of Slovak regions are not as differentiated as for Ukrainian regions.

Thus, the most developed cluster is the Bratislava region, which is explained by the fact that the capital of the country is located in this region. The second cluster includes the Trnava, Nitra, Žilina and Košice regions. The third cluster includes the Trenčín, Bansko Bystrica and Prešov regions.

However, it is worth noting that although the second and third clusters are characterized by lower values of socio-economic development, they still have similar values. This suggests that Slovakia, which became independent at the same time as Ukraine and joined the EU in 2004, was able to raise the level of development in all regions. Similarly, Ukraine has the opportunity to improve the living standards of its population by pursuing sound social and economic policies.

Finally, the principal components method was applied to analyze the socio-economic development of the regions. In the course of the analysis, 2 principal components were identified: one related to the activities of enterprises, and the other to the financial sector, i.e. inflation. It was also found that the most important variables for economic development are "Number of active enterprises" and "Capital investments".

The ranking of the regions by their socio-economic development in 2022 confirmed the results of the cluster analysis. Thus, the most developed regions are the city of Kyiv, which is part of the first cluster, followed by Lviv, Dnipro, Kyiv, Donetsk, Kharkiv, and Odesa regions, which are part of the second cluster. Other regions with negative principal components were assigned to the third cluster.

Thus, the study found that the socio-economic development of Ukraine's regions is uneven. Therefore, the implementation of regional policy is an important component of the state apparatus. The paper provides an example of successful implementation of regional development in Slovak regions, which had the same development pattern as Ukrainian regions before 2004.

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APPENDIX A

Table A.1

Input data for classification of Ukrainian regions by socio-economic level of development

Region	Number of active enterprises	Capital investments	Resident population	Volumes of foreign trade in Goods	CPI
Vinnytsya	21753	14122.1	1500653	977660.7	124.3
Volyn	15413	9535	1018042	-968527.7	127
Dnipropetrovsk	50939	40477.9	3089842	2299222	125.3
Donetsk	28807	5564.9	4043520	145108.9365	126.9
Zhytomyr	16728	6113.2	1178333	-487930.5495	125.4
Zakarpattya	16159	6818	1240888	324983.8288	127.7
Zaporizhzhya	26128	9312.5	1635533	1613231.6	124.1
Ivano-Frankivsk	18774	6851.5	1347839	86553.6	126.3
Kyiv	35294	31168.6	1789763	-1525375.4	126.8
Kirovohrad	15296	7096.7	895860	623699.8	127.6
Luhansk	11918	270.8	2097056	-3605.23065	124.9
Lviv	43473	26161.4	2457743	-2362693.4	126.4
Mykolayiv	18982	5008.6	1089777	909356	125.9
Odesa	39401	13546.7	2338689	267636.7	125.2
Poltava	21511	17537.6	1342726	665568.7	126.6
Rivne	14691	12042.5	1139842	193283.3	125.4
Sumy	12865	5498	1032172	141138.2	128.2
Ternopyl	14596	8501.8	1017702	261535.4	125.4
Kharkiv	38133	9586	2580614	-373197.8931	125.3
Kherson	14508	700.4	998938	20162.2	142.3
Khmelnytskiy	18139	9753.2	1224311	72678.5	125.9
Cherkasy	18652	9227.6	1155571	686926	125.4
Chernivtsi	10659	3358.7	886863	-199731.6	125.9
Chernihiv	12606	8305.9	949123	417052.8	128.4
Kyiv city	124330	143100.4	2909395	-11539856.4	127.4

APPENDIX B

Table B.1

Input data for the classification of Slovak regions by socio-economic level of development

Region	Social isolation	Average net nominal revenue per month (EUR)	Regional Gross Domestic Product (bln EUR)	Rate of registered unemployment (%)
Region of Bratislava	5,90	1261,00	26189,74	4,71
Region of Trnava	10,80	970,00	10456,21	5,18
Region of Trenčín	10,70	950,00	8148,27	5,39
Region of Nitra	9,30	909,00	9755,80	5,50
Region of Žilina	14,30	944,00	10119,25	6,53
Region of Banská Bystrica	24,30	904,00	7796,32	9,83
Region of Prešov	20,80	844,00	8510,85	11,39
Region of Košice	19,40	942,00	11102,82	10,55