DOI: 10.61954/2616-7107/2024.8.2-2 *ISSN 2616-7107*

UDC 338.45.01
JEL: L50, O10, O14

MOMENTUM OF INDUSTRIAL GROWTH: METHODS OF CALCULATION AND WAYS OF USE

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Received: 27/02/2024
Accepted: 30/05/2024

DOI: 10.61954/2616-7107/2024.8.2-2

Introduction. This study analyses countries' industrial development using the momentum of industrial growth and the product of the added value created by industry by its growth rate. It is constructed by analogy with momentum in mechanics, just as the measure of production of movement of a body depends on its mass and velocity; therefore, the measure of industrial growth is determined by the volume of production (scale factor) and the rate of its change (speed factor).

Aim and tasks. This research aims to define the concept of the momentum of industrial growth and justify the possibility of its use for the identification of supranational industrial ecosystems, specifically for groups of countries whose industries are characterized by close development parameters. The subject of this research is the historical dynamics and geographical diversity of the industrial ecosystems of the states.

Results. The momentum of industrial growth depends on many factors, among which we can distinguish sets of institutional, economic, scientific-technological, labour, and environmental factors. Based on the analysis of the array of 21 indicators of these sets for a sample covering 67 countries, five indicators were selected that had the closest connection with a performance indicator, such as the specific momentum of industrial growth (per capita). This indicator allows the comparison of industrial systems of different sizes and considers not only the specific industrial output but also the rate of its growth.

Conclusions. The selected indicators were used to identify supranational industrial ecosystems, groups of countries whose national industries have similar development parameters. In total, using cluster analysis, five large groups of countries were singled out, which, in turn, can be divided into subgroups: industrial ecosystems with the closest characteristics. Ukraine is included in Group V “Developing countries with the lowest specific momentum of industrial growth”. Unlike the group of leaders, which included the most industrially developed states, Group V was characterised by a lower scientific-technical production level, more significant reproduction problems, and a level of human capital along with traditionally influential informal institutions. To specify the cluster factors of growth and consider them in the formation of the national industrial strategy, it is reasonable to devote particular research to the issues of their analysis in time and space.

Keywords: momentum of industrial growth, industrial ecosystem, Industry 4.0, innovations, production technologies.

1. Introduction.

World economics defines geography, institutions and culture as primary factors, and they, in turn, directly determine, in particular, the features of technology development (Acemoglu & Robinson, 2012; Harrison, 2012; Vyshnevskyi, 2022). Such factors determine the reproductive potential of industrial ecosystems and are the subject of research in institutional and evolutionary economic theories. The industrial development of states can be considered through the momentum of industrial growth (MIG). Similar to the measure of the movement of a body depending on its mass and velocity, industrial growth is determined by production volumes and rates of change, which characterise the features of the development of national industrial systems. The tools of evolutionary biology, in particular the concept of ecosystems, extended to the economy, allow the consideration of industrial development not only within national borders but also within the framework of the concept of global (supranational) industrial ecosystems that unite the industries of a number of states with similar or congruent national technologies, institutions, and culture.

In the context of ecology, the concept of industrial ecosystems, both global and national, is of great importance for understanding global and regional environmental issues and for developing policies in this area. From the viewpoint of technological development, industrial ecosystems are considered dynamic networks of interconnected enterprises of different countries, which function in a limited geographical space and are formed based on the corresponding production technologies and institutions that form the mechanisms of their functioning and determine their evolution. In recent years, this industrial development vision has gained particular importance in connection with geo-economic fragmentation.

The concept of “momentum” is used in securities circulation, which characterises the rate of acceleration of the price of a security, that is, the rate of price change (Rajeev, 2023). The use of momentum in industrial development is another direction of analysis that allows studying the deterministic behaviour of industrial ecosystems over time under the influence of internal and external factors to analyse their dynamics, inertia, and sensitivity to challenges and shocks.

The industry of each state is unique, and its development depends on the size of the industry itself and the external influencing factors that determine its dynamics, such as the level of development of the national economy as a whole, its resource potential, institutional specificity, places, and roles in international economic systems and processes (production, trade, investment).

At the same time, industrial complexes of different states also have common features that provide objective grounds for distinguishing their characteristic types. Such a generalisation is vital for the correct understanding of common problems and opportunities for developing national industrial ecosystems (NIE), the study of the experience of their functioning in regional and global contexts, and the correct use of the most successful practices. The outlined subject is an argument in favour of the fact that the research can be attributed to comparative economics (Hantrais, 1999; Rose & Mackenzie, 1991), which is gaining importance in the current international reality.

2. Literature review.

Of interest within the framework of this study are works close to the nature of comparative economics, which in a certain way characterises the industry of different states, particularly the level of innovation, technological structure, and the impact of digitalisation.

Kravchenko and Zanizdra (2018) studied the formation of typologies of supranational innovation ecosystems in 136 countries based on the concept of a four-link spiral. The identified types are given a qualitative interpretation: developed countries with strong institutions of the Confucian and Muslim types; developed countries with strong institutions of the inclusive type; developing countries with strong institutions of the Muslim and Buddhist-Hindu type; developed countries that are developing with strong informal institutions, in particular of the post-Soviet type; developing countries with extractive-type institutions.

A comparison with the images of typical innovation leaders in a cluster and global context makes it possible to establish differences in functioning and to determine the primary vectors for reducing the backlog for the innovation system of Ukraine.

Subsequently, a scientific and methodological approach to modelling the impact of digitalisation on the economy of countries in general and the industrial sector in particular was suggested and implemented (Vishnevsky et al., 2021). According to the results of the cluster analysis of indicators of the development of the digital economy and indicators of the development of technologies in the field of material production in 98 countries, three demarcated groups were identified, which were interpreted as the countries of Industry 4.0, Industry 3.0, and Industry 2.0. Using the analysis results, the dependence of GDP growth on the growth of the digital economy in different clusters of countries was established, which, in the authors' opinion, should be interpreted based on the individual characteristics of states.

Gryshova et al. (2020) aimed to define the national industry's structure that can be deemed progressive, as well as the relationship between the industry's progressivity, the nation's economic growth, and the people's standard of living, and how these factors are impacted by the country's industrial structure's transition to a progressive state. Data on inter-industry balances for 36 nations constituted the analytical database, which was used to group nations worldwide into clusters. The obtained results confirmed the hypothesis, which in this study is considered the foundation for forming an appropriate state policy regarding the beneficial impact of the industrial structure of countries approaching a progressive state on the population's quality of life and sustainable economic development.

However, it should be noted that the groups of countries formed based on the cluster analysis results did not gain a straightforward interpretation in the context of the institutions and technologies dominant in the countries. The studies above (Kravchenko & Zanizdra, 2018; Vishnevsky et al., 2021), despite significant differences in the results obtained due to the specifics of the problems to be solved, demonstrate a certain similarity in the initial premises, conceptual provisions, and analytical tools.

Vishnevsky et al. (2021) substantiate the general idea of economic systems that go beyond existing administrative boundaries and are formed based on the vision of the arrangement and self-reproduction of societies as complex production systems. This idea can be further developed based on such an indicator as the momentum of industrial growth.

3. Aim and tasks.

This study aims to define the concept of the momentum of industrial growth and justify its use for identifying supranational industrial ecosystems for groups of countries whose industries are characterised by close development parameters.

The subject of this research is the industrial ecosystems of countries considered in terms of their historical dynamics and geographical diversity.

4. Results.

4.1. Definition of the momentum of industrial growth (MIG) and its use for cross-country comparisons.

MIG (I_i) is the product of the value added created by industry (V_i) in the year i by its growth rate (T_i):

$$I_i = V_i T_i.$$

In turn, the specific (per capita) MIG (I_{si}) is the product of the average per capita “density” of industry (V_i / P_i) by its growth rate:

$$I_{si} = V_i T_i / P_i = (V_i / P_i) T_i.$$

The expediency of using the MIG based on the average per capita "density" of the industry is due to the presence of NIEs of different sizes but similar in essential characteristics.

The results of the calculation of the specific MIG are presented in Table 1 in order of its decreasing. As seen, out of 67 countries included in the sample, Ukraine is among the ten countries that close the list together with Albania, Moldova, the Philippines, El Salvador, Guatemala, Morocco, India, Honduras and Pakistan.

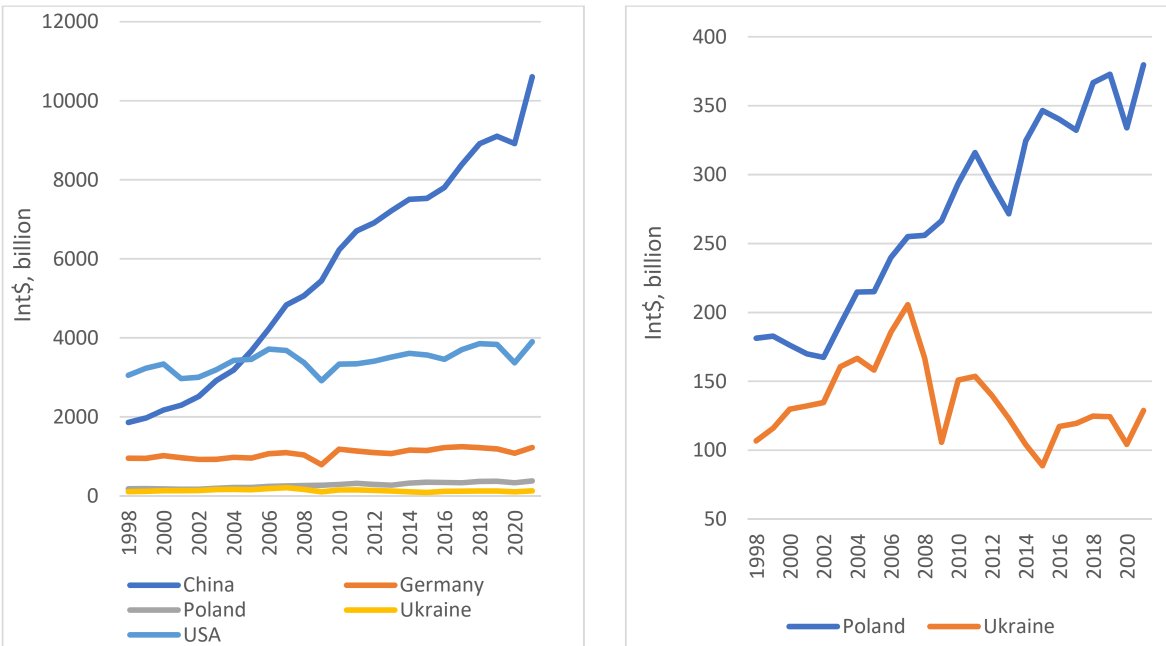
Table 1. Specific momentum of industrial growth, I_{si}, (by the value added in industry (including construction*), 2010-2019 in international dollars.

No.	Country	$I_{si} > 6000$	No.	Country	$I_{si} < 6000$
1.	Singapore	22442,7	39.	Thailand	5848,3
2.	Ireland	22342,9	40.	Argentina	5552,5
3.	Norway	20547,0	41.	China	5410,2
4.	Switzerland	16932,8	42.	Croatia	5283,8
5.	Germany	13864,3	43.	Latvia	5024,0
6.	Austria	13679,3	44.	Uruguay	4794,6
7.	Korea, Republic of	13280,1	45.	Algeria	4777,3
8.	Australia	12027,5	46.	Paraguay	4339,6
9.	Czech Republic	12002,9	47.	Indonesia	4239,2
10.	Sweden	11239,0	48.	Greece	4129,1
11.	Japan	11142,8	49.	Colombia	4105,6
12.	Finland	11086,0	50.	Ecuador	3998,3
13.	Canada	11019,4	51.	Costa Rica	3918,6
14.	the United States	11001,3	52.	Egypt, Arab Republic	3768,2
15.	Denmark	10846,0	53.	Sri Lanka	3712,1
16.	Netherlands	10037,4	54.	South Africa	3358,8
17.	Belgium	9841,7	55.	Brazil	3065,8
18.	Slovenia	9699,1	56.	Vietnam	2958,5
19.	Malaysia	9435,5	57.	Tunisia	2816,7
20.	Italy	8777,9	58.	**Ukraine**	**2714,2**
21.	Slovak Republic	8603,5	59.	Albania	2683,3
22.	New Zealand	8514,2	60.	Moldova	2302,3
23.	Poland	8424,6	61.	Philippines	2300,1
24.	Kazakhstan	8380,4	62.	Salvador	2113,9
25.	Lithuania	8071,2	63.	Guatemala	1964,7
26.	UK	8064,5	64.	Morocco	1932,7
27.	Spain	7814,2	65.	India	1525,4
28.	Russian Federation	7805,6	66.	Honduras	1362,7
29.	Romania	7805,3	67.	Pakistan	903,9
30.	France	7690,6			
31.	Estonia	7625,8			
32.	Panama	7516,1			
33.	Israel	7470,7			
34.	Chile	7019,9			
35.	Hungary	6991,2			
36.	Turkey	6987,0			
37.	Portugal	6122,9			
38.	Mexico	6065,6			

** Industry (including construction) comprises value added in mining, manufacturing, construction, electricity, water, and gas.*

Source: based on World Bank (2023a).

Table 1 shows Ukraine's critical lag in terms of the MIG not only from highly developed countries, where inclusive institutions have long traditions, but even similar socialist countries like Poland (23rd position), where the XX century was the result of economic and political transformations or, in a broader context of the shift in global geopolitics, which affected Central and Eastern Europe. China has remained the world leader in terms of absolute MIG for a long time due to large volumes of production and their high growth rates (Fig. 1a). However, this country has a relatively low MIG per capita, which indicates the existing potential for its further industrial development.



a. b.

Fig. 1. Absolute MIG of China compared to Germany, Poland, Ukraine and the USA (a) and Ukraine and Poland (b).

Source: based on World Bank (2023a).

In Fig. 1a, the absolute MIG for some countries is shown (China long ago overtook the USA and Germany). These countries are at a lower level, and even much lower herein, Poland demonstrates clear advantages over Ukraine.

Fig. 1b is only for Poland and Ukraine but on a different scale. The following task is to single out groups of supranational industrial ecosystems, outline their composition, and identify factors that determine the positive dynamics of some countries and not-so-positive or negative dynamics of others.

4.2. Use of MIG to identify NIE.

The following hypothesis is based on the assumption of different NIE types, which can be identified using the MIG and to which all industrial systems of the world can be referred to extent.

The development of each type of NIE is specific because of the influence of many factors, such as historical, sociocultural, economic, and ecological (anthropogenic). Based on the evolutionary nature of the development of industrial ecosystems and the expediency of their research in the ecological and technological context, it seems reasonable to identify existing NIEs by the following classification features: institutional, economic, scientific-technological, labour, and environmental.

To perform such an analysis, 21 indicators that characterise the effects of various influencing factors on the development of industrial ecosystems were used for a sample of 67 countries worldwide. The following countries were excluded from the list: countries with a population of up to 1 million people, those with an added value created by the processing industry of less than US$200 per capita, and the specific economies of the Persian Gulf based on the extraction of coal and hydrocarbons. The countries presented in the analysis differ in their levels of economic development and are located in different geographical regions.

The values of the indicators reflect their state in 2019 and 2020, and most of them are averages for several years (mainly from 2010 to 2019). A total of 1,407 indicator values were used in this study, and the indicators of the classification features are presented in Table 2.

Table 2. Components of characteristics of industrial ecosystems of the world.

Legend	Indicator	Source
Institutional component		
Rr_i	Property right, points	World Economic Forum (The Global Competitiveness Index)
T_i	Total tax and contribution rate, % of profit	The World Bank
EGS_i	Efficiency of government spending, points	World Economic Forum (The Global Competitiveness Index)
Economic component		
MVA_i	Manufacturing, value added per capita, US$	World Bank
I_i	Specific MIG per capita, Int$	Calculated using data from World Bank
GDP_i	GDP per capita, US$	World Bank
MHI_i	Medium and high-tech industry (including construction) per capita, US$	Calculated using data from World Bank
GCF_i	Gross capital formation per capita, US$	Calculated using data from World Bank
Scientific-technological component		
RDE_i	R&D expenditures per capita, US$	Calculated using data from World Bank
Pa_i	Patent applications per million people, items	World Bank
HTE_i	High-tech exports per capita, US$	Calculated using data from World Bank, UNIDO
MCT_i	Number of mobile subscribers per 100 people	World Economic Forum (Readiness for the Future of Production Report 2018)
DSE_i	Download Speed Experience, Mbit/s	Opensignal (The state of mobile network experience 2020: One year into the 5G era)
IU_i	Internet users, % of the population	World Economic Forum (Readiness for the Future of Production Report 2018)
Labor component		
ME_i	Manufacturing employment per 1000 people, person	Calculated using data from World Bank
KIE_i	Knowledge-intensive employees per 1000 people, person	World Economic Forum (Readiness for the Future of Production Report 2018)
DS_i	Digital skills of the population (by information from managers, points from 1(absent) to 7 (sufficient)	World Economic Forum (Readiness for the Future of Production Report 2018)
$SCIE_i$	Researchers in R&D per million people, person	World Bank
Environmental component		
CO_{2i}	Environmental efficiency of CO_2 emission in manufacturing per capita, US$ /1000 t	Calculated using data from World Bank
Rec_i	Recycling rate (a component of the Environmental Performance Index), %	Yale Centre for Environmental Law & Policy, Yale University; Centre for International Earth Science Information Network, Columbia University with support from the McCall MacBain Foundation
AS_i	Adjusted net savings, including particulate emission damage, % of gross national income	World Bank

The influence of *the institutional component* is taken into account based on three indicators: the total rate of taxes and contributions (by the World Bank), which characterizes the tax burden on a typical enterprise in different countries of the world, and the indicators of right and the efficiency of government spending, which characterize the state institutions and are used in the calculation of the Global Competitiveness Index. The values of the last two indicators are determined from 1 to 7, with a higher value for more effective functioning of the corresponding institution.

The economic component of NIE development is represented by indicators that characterize the economic conditions of industrial development, such as the added value created by manufacturing, GDP, medium- and high-tech industry (including construction) and gross capital formation (per capita and in US$).

*The scientific-technological componen*t includes effective indicators of scientific activity, such as the number of patent applications by resident's high-tech exports, and an indicator that reflects the conditions created in the country for innovative activity as R&D expenditures.

The technological factor is represented by an indicator based on the results of expert assessments and given in the report "Readiness for the Future of Production Assessment 2018". It demonstrates how successfully countries adopt novel digital technologies through the number of mobile subscribers per 100 people. Also, "Download Speed Experience (Mbps)" was added to the list of indicators since peak speeds are essential in production activities for uploading and downloading data and supporting real-time data transfer.

The labour component is represented by indicators that quantitatively characterize the country's labour capital involved in industrial production and provide an opportunity to evaluate it in a general form according to the competencies and skills associated with the requirements of Industry 4.0. Among them are leadership skills, technical skills, process understanding skills and media skills, which we evaluated using the "knowledge-intensive employees" indicator from the International Standard Classification of Professions (WIPO, 2015).

The indicator of the same name characterizes digital skills of the population; the indicator of the share of researchers in the total population allows for conclusions about the possession of the population with technological, analytical and research skills.

The study of NIE in *the environmental context* was carried out using indicators of the efficiency of CO_2 emissions in the creation of value in manufacturing, which is a component of the environmental performance index (Yale University, 2022), as well as adjusted net savings, which includes including particulate emission damage and is available in the database of the World Bank (2023a). The environmental efficiency of CO_2 emissions in value creation in manufacturing is calculated as the ratio of value added by manufacturing per capita to CO_2 emissions. The indicator was used by UNIDO (2016) in the "Industrial Development Report 2016", with the difference that in this study, it is calculated per capita to avoid the influence of the country size factor.

It is assumed that in industrialized countries that actively develops and uses modern advanced technologies and introduces circular business models into production processes and whose industry is characterized by higher growth rates of added value, the efficiency of CO_2 emissions is greater (Soldak, 2021). When selecting a set of indicators, the available data for as many countries as possible were used. Their representative sample was compiled under the conditions of having the complete set of selected quantitative and qualitative indicators.

The data were reduced to the range from "0" to "1" according to the formula:

$$x_{ijstand} = \frac{x_{ij} - x_{ijmin}}{x_{ijmax} - x_{ijmin}} \quad (1)$$

Where, $x_{ijstand}$ is the standardized value of the i-th indicator of the j-th country; x_{ij} is the original value of the i-th indicator of the j-th country; x_{ijmax} is the maximum value of the indicator among the sample countries; x_{ijmin} is the minimum value of the indicator among the sample countries.

Confirmation of the significance of the selected indicators for each country is based on their connection with the effective resultant indicator, that is, the specific momentum of industrial growth.

To reduce the dimensionality of the factor space within which clustering was performed, one indicator was selected from each classification feature based on a combination of the following criteria: high and statistically reliable density of the connection between the specific momentum of industrial growth and the corresponding indicator; absence or insignificant level of collinearity between the selected indicators; meaningful assessment of the significance of the indicator in determining the characteristics of the corresponding classification feature.

The formal criterion for selecting the representatives of relevant classification features is pairwise correlation coefficients that meet the statistical reliability criteria. For example, according to the institutional component, the maximum density of the connection of the specific MIG of industrial growth is observed with the "Property right" indicator (r = 0.69), which indicates a relatively close and statistically reliable connection between them. According to the second classification feature, the "Manufacturing, value added" indicator was chosen.

The expediency of such a choice is determined by taking into account two requirements: one is the presence of a close and statistically reliable connection with the resultant feature (r = 0.73), and the other is the absence or a lower level of collinearity between this indicator and the one already selected for the institutional component. A similar approach was used to select representative indicators for other components (classification features).

Cluster analysis of the research objects aimed at determining the number of NIE types and the distribution of countries within the resultant groups was carried out for the STATISTICA software package using a hierarchical algorithm and a non-hierarchical cluster analysis based on the *k*-means algorithm.

4.3. Results of NIE clustering.

Based on the clustering results by Ward's method (Fig. 2), four clusters were determined (Table 3).

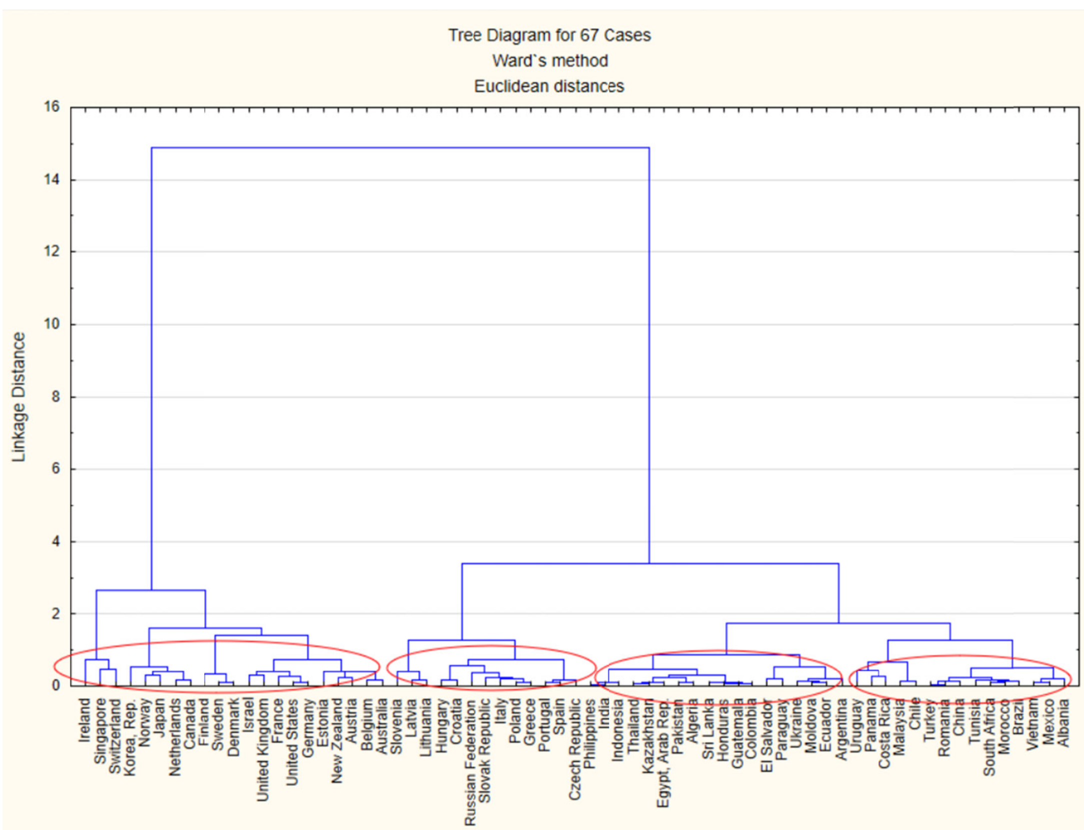


Fig. 2. Graphic representation of the sequence of combining countries into clusters according to Ward's method, 2010-2019.

Table 3. Clustering results upon building Ward's tree, 2010-2019.

No.	Cluster I 20 countries	Cluster II 14 countries	Cluster III 18 countries	Cluster IV 15 countries
1.	Australia	Greece	Algeria	Albania
2.	Austria	Estonia	Argentina	Brazil
3.	Belgium	Spain	Guatemala	Vietnam
4.	Denmark	Italy	Honduras	China
5.	Israel	Latvia	Ecuador	Costa Rica
6.	Ireland	Lithuania	Egypt, Arab Republic	Malaysia
7.	Canada	Poland	India	Morocco
8.	Republic of Korea	Portugal	Indonesia	Mexico
9.	Netherlands	Russian Federation	Kazakhstan	Panama
10.	Germany	Slovak Republic	Colombia	South Africa
11.	New Zealand	Slovenia	Moldova	Romania
12.	Norway	Hungary	Pakistan	Tunisia
13.	UK	Croatia	Paraguay	Turkey
14.	Singapore	Czech Republic	Salvador	Uruguay
15.	The United States		Thailand	Chile
16.	Finland		**Ukraine**	
17.	France		Philippines	
18.	Switzerland		Sri Lanka	
19.	Sweden			
20.	Japan			

Subsequently, to check the stability of the conducted statistical analysis, the *k*-means method was used, which consists of dividing the items into clusters to maximize the difference in the mean values across all variables inside the clusters. Six groups of countries were determined using the *k*-means method. As seen in Fig. 3, the countries included in Cluster II (a group of countries such as Australia, Austria, Belgium, Canada, Germany, France, United Kingdom, Israel, Japan, Korea, Netherlands, Norway, New Zealand, United States) and Cluster 6 (a group of countries such as Switzerland, Denmark, Finland, Ireland, Singapore, Sweden) are characterized by high values of indicators of property right, added value created in manufacturing, Internet speed and number of researchers.

The essential difference between these groups is that the countries of the sixth cluster are significantly more efficient in terms of emissions into the environment accompanying the processes of creating added value in the industry. However, for the analysis and based on the fact that the countries of both clusters (2 and 6) are world leaders in terms of the specific MIG, it is reasonable to combine them into one cluster – Group II (Table 4).

Comparison of the cluster analysis results by the methods of Ward and *k*-means, presented in Table 2 and Table 3, respectively, gives reason to conclude that the comparable groups coincide almost wholly (more than 70%). Therefore, the cluster solution can be considered stable and accepted for further analysis.

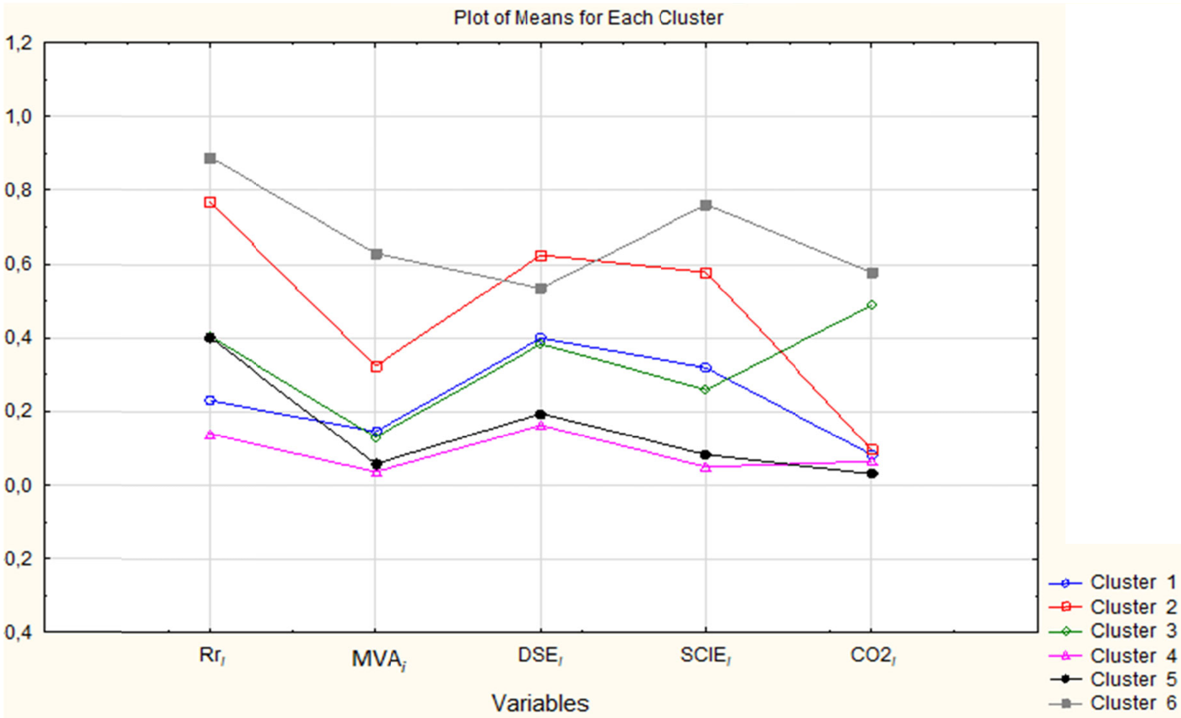


Fig. 3. Plot of the means of indicators (standardized) by the *k*-means method.

Note: Variables are described in Table 2.

Table 4. Results of *k*-means clustering, 2010-2019.

No.	Group I 10 countries	Group II (clusters 2 and 6) 20 countries	Group III 6 countries	Group IV 18 countries	Group V 13 countries
1.	Greece	Australia	Estonia	Albania	Brazil
2.	Spain	Austria	Costa Rica	Algeria	India
3.	Italy	Belgium	Latvia	Argentina	Indonesia
4.	Poland	Denmark	Lithuania	Vietnam	China
5.	Portugal	Israel	Slovenia	Guatemala	Malaysia
6.	Russian Federation	Ireland	Uruguay	Honduras	Morocco
7.	Slovak Republic	Canada		Ecuador	Panama
8.	Hungary	Korea, Republic		Egypt, Arab Republic	South Africa
9.	Croatia	Netherlands		Kazakhstan	Romania
10.	Czech Republic	Germany		Colombia	Tunisia
11.		New Zealand		Mexico	Turkey
12.		Norway		Moldova	Philippines
13.		UK		Pakistan	Chile
14.		Singapore		Paraguay	
15.		the United States		Salvador	
16.		Finland		Thailand	
17.		France		**Ukraine**	
18.		Switzerland		Sri Lanka	
19.		Sweden			
20.		Japan			

The results of the cluster analysis using both methods indicate that Ukraine, according to the chosen indicators (property right; added value created by manufacturing per capita; data download speed; researchers in R&D per million population; efficiency of CO_2 emissions in creating value in manufacturing), cannot be included in the same group as the countries of the European Union and European countries in general (except for Moldova when grouped by the hierarchical method and Albania and Moldova when clustered by the *k*-means method).

A more detailed analysis of the results is focused on five groups obtained by *k*-means clustering. The statistical characteristics of the sample indicators and the composition of the NIE groups are presented in Table 5. Here and further, the groups are arranged to decrease the specific MIG.

Table 5. Statistical characteristics of sample indicators and composition of NIE groups, 2010-2019.

Groups	Number of countries in the group	Specific MIG, Int$	Absolute MIG, billion Int$	Property right, points	Manufacturing, value added, USD per capita	Download Speed Experience, Mbit/s	Researchers in R&D per million people, person	Environmental efficiency of CO_2 emission in manufacturing per capita, US$ /1000 t
I	20	12654	482	6,0	7060	37	4632	108
II	10	7595	271	4,1	2589	26	2347	38
III	6	6522	16	4,6	2334	26	1915	219
IV	13	4878	985	4,6	1136	15	632	14
V	18	3753	170	3,8	777	13	390	29

For a better visual perception, the standardized indicators (max normalization) are graphically presented in Fig. 4. According to economic, scientific, technological and labour factors indicators, Groups I and II are prominent leaders, and Groups IV and V are apparent outsiders. Concerning the environmental factor, the countries of Group III stand out here.

And the participants of Group II lag behind the others in terms of institutional components, although to a lesser extent than the countries of Group V. Table 6 briefly describes groups of countries based on their geography and institutions. Next, let's focus on the brief characteristics of groups of countries.

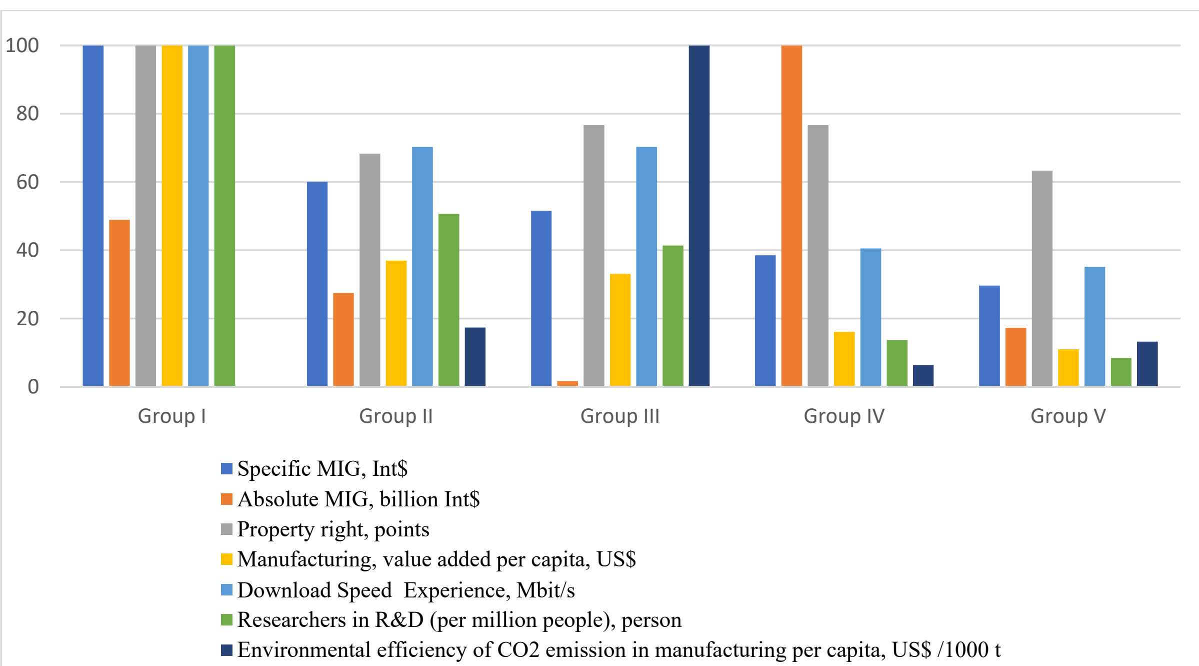


Fig. 4. Standardized values of sample indicators by groups, 2010-2019.

Table 6. Distribution of the composition of country groups by geography, economic development and specific MIG

	The most developed countries with the highest specific MIG	
Group I 20 countries	Western, Central and Northern Europe	Austria, Belgium, Denmark, Ireland, Germany, Netherlands, Norway, United Kingdom, Finland, France, Switzerland, Sweden
	North America	United States, Canada
	East Asia	Republic of Korea, Japan, Singapore
	Asia-Pacific region	Australia, New Zealand
	Middle East	Israel
	Developed countries with a high specific MIG	
Group II 10 countries	Central and Northern Europe	Slovak Republic, Czech Republic, Hungary
	Southern Europe	Greece, Spain, Italy, Portugal, Croatia
	Eastern Europe	Poland, Russian Federation
	Developing countries with a high specific MIG	
Group III 6 countries	Baltic countries	Estonia, Latvia, Lithuania
	Central Europe	Slovenia
	Latin America	Costa Rica, Uruguay
	Developing countries with a lower specific MIG	
Group 1V 13 countries	Latin America	Brazil, Panama, Chile
	North and South Africa	Morocco, Tunisia, South Africa
	East and South Asia	India, Indonesia, China, Malaysia, Philippines
	Southern Europe	Romania, Turkey
	Developing countries with the lowest specific MIG	
Group V 18 countries	North-Eastern Europe	Moldova, Albania, **Ukraine**
	Latin America	Argentina, Guatemala, Honduras, Ecuador, Colombia, Mexico, Paraguay, El Salvador
	South, Central and Western Asia	Vietnam, Thailand, Pakistan, Sri Lanka, Rep. Kazakhstan
	Africa	Algeria, Egypt

Group I. The most developed countries with the highest specific MIG.

Group I consists of the most industrially developed countries of the world. According to the widespread theory of Wallerstein (2004), all of them are part of the world-system core of states with the highest level of competitiveness, scientific and technological progress and economic dynamics. The cluster shows the maximum values for almost all indicators of the sample, inferior only to the indicator of the efficiency of emissions in the creation of value in the production sector in Group III.

More than two-thirds of the group countries are developed countries of Western, Central and Northern Europe, as well as North America, which share, as defined by Huntington (2004) and the values of Anglo-Protestant culture or are based on the Romano-Germanic heritage (Piliaiev, 2020). The priority of law marks these cultures, respect for human rights and freedoms, and the rights of minorities.

The other countries of this group are the Republic of Korea, Japan and Singapore, whose development took place under the influence of the religious and ethical views of Confucianism (Japan) and in the conditions of cooperation and integration achieved by the Protestant and Confucian worlds in such areas as industry, finance, trade, informatics (South Korea, Singapore) (Piliaiev, 2020).

Countries with a high level of cultural capital include Israel, where education and commitment to work are highly valued (Harrison, 2012).

Group I countries have more in common than just institutional characteristics. The macroeconomic indicators of countries are determined by the processing industry, which is based on high indicators in the field of modernization and improvement of production technologies and a significant share of high-tech products in the export structure (Harrison, 2012).

Group II. Developed countries with a high specific MIG.

Group II mainly includes some European countries that are members of the European Union (except for the Russian Federation) and are not leaders in the world industry. The exemption is for Italy, a country of the "Big 7", which is one of the most automated countries and is recognized worldwide for the quality of the production of machines, components and robots (Ministry of Foreign Affairs and International Cooperation, 2023). The relatively low index “Property right” (4 points against 6 points on average for the countries of Group II) limits the possibilities of this country being included in Group I “The most developed countries with the highest specific MIG”.

The industrial policies of most of the Group's countries shape the EU's industrial strategy. It aims to increase the economy's competitiveness. It is focused on ensuring the free movement of goods and services during any future crises, supporting the development of small and medium enterprises, and stimulating the green and digital transitions in the industry (European Commission, 2022a).

On average, the countries of Group II are characterized by relatively high indicators of economic, scientific-technical, and labour classification characteristics. As for the efficiency of emissions into the environment accompanying the processes of value creation in the production sector, it is deficient in the Russian Federation (1 US$ /1000 t) and Poland (7 US$ /1000 t) due to the high carbon intensity of production. The import of capital is of great importance in the industrial growth of the Group I countries. Poland and the Czech Republic accumulate large volumes of direct foreign investment (UNCTAD, 2021; Wach & Wojciechowski, 2016).

Group III. Developing countries with a high specific MIG.

As a result of the statistical division of the sample of countries, six of them were singled out in Group III: the Baltic States − Estonia, Latvia and Lithuania; Central Europe − Slovenia and Latin America − Costa Rica and Uruguay. According to the institutional, economic, scientific-technical, and labour components of their economies, they are similar to those of Group I, as shown in Fig. 3.

Their separation is connected with quite a high indicator of the efficiency of emissions in the creation of value by the production sector, which is caused, to some extent, by the low-carbon structure of the industry of these countries. For example, the developed industries of Costa Rica are the food, textile and clothing industries; Estonia specializes in the fields of electronics and telecommunications.

Group IV. Developing countries with a lower specific MIG.

This Group is mainly represented by developing Asian, African and Latin American countries with institutions of the extractive type. On average, their indicators of institutional, economic, scientific-technical and labour classification characteristics are quite low.

China stands out significantly, which, by our calculations, is the world leader in terms of the absolute MIG. The state supports high-tech industrial production to consolidate leadership within the «Made in China 2025» program, which reproduces German Industry 4.0. The country is rapidly developing its R&D base and has already become a world leader in the number of patents for artificial intelligence, virtual reality, and Internet of Things technologies (Armstrong, 2021). Notably, Group V occupies the last position among other groups by the environmental index. China and India have the lowest emissions efficiency when creating value in the manufacturing sector among 67 countries studied as 0,2 and 0,1 US$ /1000 t, respectively, and are responsible for most of the pollution in the world due to CO_2 emissions (European Commission, 2022b).

Group V. Developing countries with the lowest specific MIG

Ukraine belongs to this group, which is geographically less homogeneous than the first two groups. It consists mainly of South and Central American countries. The European continent is represented by post-Soviet countries (Ukraine and Moldova) and Albania. These countries are characterized by a level of cultural capital that does not contribute to economic development because of the business ethics of a non-protestant type and stable informal institutions. The statistical characteristics of the countries according to their MIGs and indicators used in the clustering are given in Table 7.

Table 7. Indicators of the countries of Group V (located in order of decreasing specific MIG).

Country	Specific MIG, Int$ per capita	Absolute MIG, Int$	Property right, points	Manufacturing, value added, USD per capita	Download Speed Experience, Mbit/s	Researchers in R&D per million people, person	Environmental efficiency of CO_2 emission in manufacturing per capita, US$ /1000 t
Kazakhstan	8380	145	4,1	1104	12	570	4,9
Mexico	6066	719	4,0	1627	20	313	3,4
Thailand	5848	408	4,1	1609	9	658	6,3
Argentina	5552	236	3,6	1930	17	996	10,7
Algeria	4777	185	3,8	993	4	494	7,4
Paraguay	4340	27	3,7	1021	11	108	163,2
Colombia	4106	192	3,9	751	13	73	9,9
Ecuador	3998	64	3,3	880	13	153	23,0
Egypt	3768	361	3,9	591	11	579	2,7
Sri Lanka	3712	78	4,1	617	10	111	33,7
Vietnam	2959	272	4,0	297	21	545	1,6
Ukraine	**2714**	**123**	**3,3**	**291**	**14**	**1210**	**1,3**
Albania	2683	8	3,7	228	26	156	45,2
Moldova	2302	6	3,3	315	12	749	39,0
Salvador	2114	13	3,5	596	6	64	88,63
Guatemala	1965	30	4,0	568	15	26	39,0
Honduras	1363	12	3,8	403	13	29	43,7
Pakistan	904	188	3,6	173	8	187	1,1

Regarding the specific MIG, Kazakhstan is significantly different from the other cluster members, and Mexico is in terms of the absolute MIG. The latter, together with Brazil (Group IV), Argentina, and Colombia, are the largest economies in Latin America.

The industrial character of Kazakhstan's economy is more strongly influenced by its geopolitical situation than by scientific and technological factors, at least in terms of the classification features chosen in the study.

Ukraine participates in globalization processes, the priority of which is European integration. Therefore, the national economy must develop "considering the possibilities, prospects, and consequences of its entry into the European Economic Area due to the extremely high degree of its openness" (Heyets, 2023). For our research, it is crucial and necessary to consider Ukraine from a global perspective. However, it is necessary to consider the characteristic features of the type of its national industrial ecosystem that set certain parameters of economic behaviour that contribute to or hinder further development.

During the years of independence, Ukraine's industry suffered a catastrophic decline. In 2021, the gross added value created in the industrial sector (including construction) amounted to 31% of the 1990 level (World Bank, 2023a). The technological structure of the industrial complex needs to meet the needs for stable growth in the Ukrainian economy. The 3rd and 4th technological structures dominate (Lyashenko & Soldak, 2021). The technological backwardness causes low industrial efficiency and weak competitiveness in the world market. High-tech exports per capita in Ukraine amount to 65.3 US dollars. This is an order of magnitude lower than in the other countries of the group, for example, in Poland (US$456.2) and several orders of magnitude lower than in the Czech Republic (US$2,734.9).

The national industry has suffered significantly from the losses due to the full-scale war. According to the State Statistics Service of Ukraine, in 2022, the industrial production of Ukraine decreased by 38%.

Ukraine has almost lost an industrial platform for an innovative economy to develop (Amosha et al., 2021). This is evidenced by the state of the technological structure of industrial production in Ukraine, which consists mainly of activities related to low (46.4%) and medium-low (43.8%) technologies in science capacity. Since gaining independence, Ukraine has preferred traditional raw materials export-oriented industries such as ferrous metallurgy and chemical industry (nitrogen fertilizer production), which employ over 250,000 workers (13% of all employed in industry) and export 25% of the total exports. However, these industries cannot be considered locomotives of economic growth in a strategic dimension.

The lag in developing the R&D sphere, caused by insufficient funding due to low business demand for scientific and technical developments, is unacceptable. Domestic research and development costs amounted to US$14.2 per capita, with the average value in the group being US$190 per capita according to the authors' calculations using the data of the World Bank (2023b; 2023c). In addition to the minimal funding, Ukraine ranks second to last in terms of the number of researchers compared to Argentina. Investigating the degree of readiness of the national industry for smart transformations, domestic scientists draw attention to the fact that "for the money spent on them (by the sum of current and capital expenditures), Ukrainian researchers produce much more products than their colleagues in the world on average\ and even more than colleagues in such industrial leaders as the USA, China, and Germany. This, however, does not mean that national science as a whole works quite satisfactorily" (Vishnevsky & Kniaziev, 2018).

It is known that the implementation of the concept of highly efficient, interconnected, and flexible production systems requires reliable communication systems capable of providing low latency and high data download and transfer speeds, as well as the possibility of simultaneously operating many devices (Kiesel et al., 2020; Kniaziev, 2021). For the sake of fairness, it should be noted that recently, thanks to the government's efforts, many successes have been achieved in Ukraine regarding access to high-speed mobile Internet.

However, our country still lags behind developed countries in terms of the technical characteristics of modern communication, particularly data download speed.

In the presented group of countries, Ukraine is unfavourably distinguished by the indicator of CO_2 emission efficiency. Between 1990 and 2020, Ukraine's greenhouse gas (GHG) emissions decreased by 315.94 million tons per year, or 65.1% (United Nations Climate Change, 2022). CO_2 emissions in 1990 amounted to 674.19 Mt and decreased by 69.6% as of 2020 to the level of 204.83 Mt. The catastrophic economic downturn that followed the collapse of the USSR in 1991 led to an initial significant reduction in energy consumption and, thus, a reduction in CO_2 emissions.

However, reducing emissions against deindustrialization did not improve the environmental efficiency of production. Among the branches of the processing industry, the largest polluter is the metallurgical industry, whose share of the total CO_2 emissions is 26%. The state support for Ukraine's mining and metallurgical industry in the late 90s and early 20s did not lead to the renewal of production capacities of metallurgical enterprises, which led to the continued use of outdated resource- and energy-consuming technologies. Cheap energy and poor environmental legislation eased the pressure on restructuring.

The tax on CO_2 emissions in Ukraine was introduced only in 2011 as a component of the environmental tax. However, the tax rate, although constantly increasing from UAH 0.26 (US$ 0.023) to UAH 0.41 (US$ 0.015) per ton of CO_2 emissions from 2011 to 2018, remained very low (Verkhovna Rada of Ukraine, 2018), which did not stimulate entrepreneurs to introduce energy-efficient measures and modernize equipment.

Only in 2018, the tax was increased to UAH 10.0 (US$ 0.37) per ton of CO_2 emissions, and in 2021, to UAH 30 (US$ 1.10) per ton of CO_2 emissions, but it remained a very low indicator compared to other European countries. As a result, the rate of wear and tear of fixed metallurgy assets remains one of the highest in Ukraine's industry. In 2020, it was 55.4%, while the average indicator for the industrial complex was 63.9%.

In 2023, the EU reached a key agreement on reforming the GHG emission trading system. For Ukraine, the trading quotas for the GHG emissions system are an entirely new tool for implementing state policy on climate change. It has no analogues in other spheres of public administration; therefore, it requires significant systemic transformations and the creation of an appropriate legislative framework, institutional structure, and the necessary organizational and technical prerequisites. Because of the war, this process has slowed down (Interfax Ukraine, 2023). The first reliable and verified data on the actual GHG emissions at the installation level can be available within 3 months after the abolition of martial law in Ukraine (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023).

Implementing the national system of trading quotas for GHG in Ukraine is a crucial element of implementing CBAM (Carbon Border Adjustment Mechanism), an additional duty or tax for goods from countries with a low carbon tax burden. As a country with less stringent emissions requirements than the EU, Ukraine may face a negative impact of CBAM implementation on the economy. As of 2021, the EU accounted for about 40% of Ukraine's total merchandise exports, including CBAM goods such as iron, steel, aluminium, cement, and fertilizers. According to the State Statistics Service of Ukraine, ferrous metals accounted for 20% of goods exported to the EU in 2021. Such trade patterns make Ukrainian exporters particularly vulnerable to the implementation of CBAM.

According to the calculations published in the work (Chepeliev, 2021), Ukraine's losses from introducing CBAM only on the metal market will amount to $720.8 million. The Kyiv School of Economics (KSE, 2021) predicts losses to the Ukrainian economy of EUR 396 million in 2030, of which EUR 248,396 million will be in the metallurgical industry. The results published in the study (Assous et al., 2021) indicate losses of EUR 920 million, of which more than 85%, or EUR 800 million, are losses in the steel industry.

Ukraine's institutional characteristics are the worst among the sampled countries. Ukraine shares the lowest "Property Right" indicator, with Moldova and Ecuador at 3.3 points against the average of 3.8 points.

The volume of the shadow economy, which by various sources is fixed at the level of 20–50% of GDP (International Centre for Prospective Studies, 2014), is a reflection of the active criminalization of economic processes, high corruption of state authorities, and low legal and tax cultures of legal entities and individuals. All these factors inhibit the development of internal factors of industrial growth and, in the future, will hinder the inflow of investments from abroad, which are indispensable for the industrial development of Ukraine.

4.4. Interpretation of the cluster analysis results.

The results of the analysis can be used to justify Ukraine's long-term industrial development strategy. However, as mentioned earlier, only considering the characteristic features of its NIE type sets certain parameters of the system that facilitate or hinder further development.

Ukraine is among the countries with a relatively low average level of specific MIG. Its index is significantly lower than the group average, while Kazakhstan is the leader in this indicator in Group V. To improve the Ukrainian situation, based on the results of the cluster analysis, it is appropriate to turn to the experience of this country, which has achieved much over recent decades. On the other hand, concerning the historical past, a natural question arises: Can this experience, in principle, serve as a strategic reference point for Ukraine, even if its choice of European integration is not considered? After all, industrial development should ensure a high quality of life for the population, and such possibilities are indicated, for example, in the work (Gryshova et al., 2020).

Without focusing on the components of such a category as the indicator of the population's well-being, we will use the GDP per capita. For the analysis, five representative countries of five groups were selected, with approximately the exact value of the specific MIG as Kazakhstan's (US$8,000). According to this criterion, there were singled out the United Kingdom (US$8,064) out of Group, Poland (US$8,424) – Group II, Lithuania (US$8,071) – Group III, Romania (US$7,805) – Group IV, and Mexico as a country of Group V with high absolute and specific MIGs.

The dynamics of GDP per capita are graphically presented in Fig. 5. The United Kingdom is almost four times higher than Kazakhstan. In general, it should be noted that over the past 20 years, the GDP per capita of European countries in Groups I, II, III, and IV with close specific MIGs increased faster than in Kazakhstan. The impact of a global crisis such as the COVID-19 pandemic slightly reduced GDP per capita in all countries in 2020, but the general trend did not change.

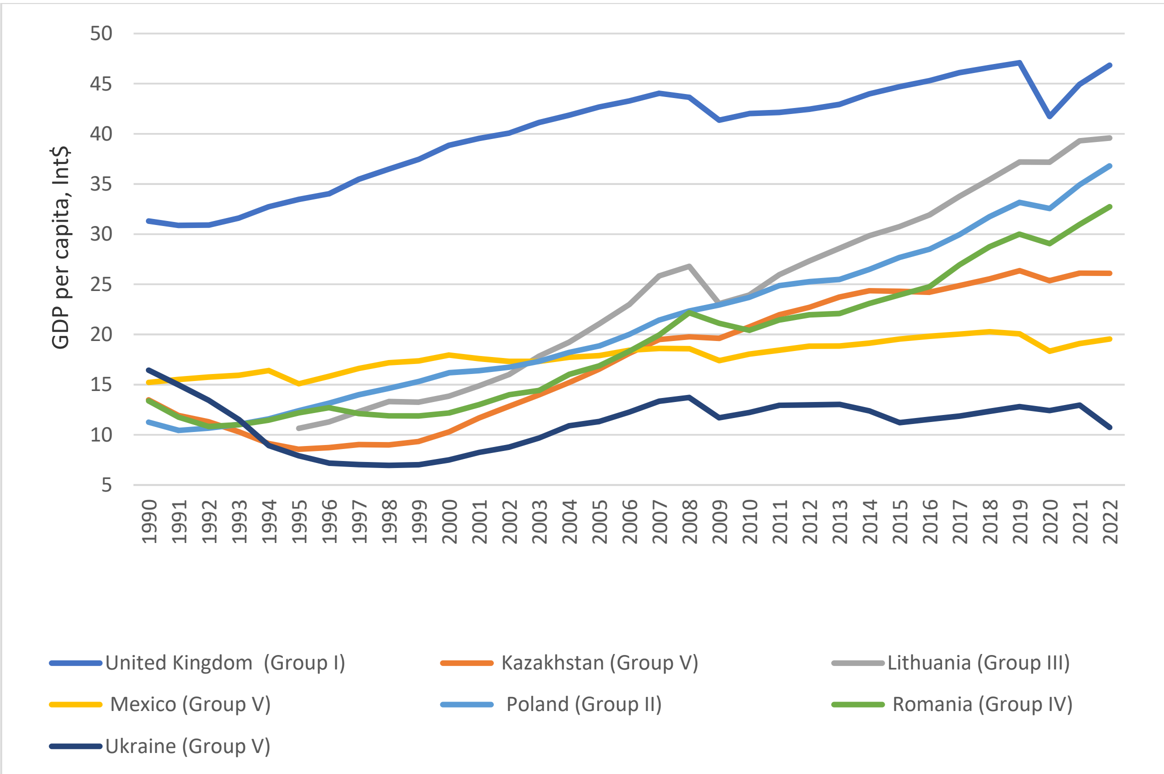


Fig. 5. GDP per capita of Ukraine, Mexico and countries representing five groups with a specific MIG close to Kazakhstan's (US$8,000).

Source: based on the World Bank (2023d).

As for another country of Group V, Mexico, its GDP per capita is significantly higher than Kazakhstan's, but high growth rates do not characterize it, and the value of this indicator is significantly lower than in Poland, the United Kingdom, Lithuania and Romania. Such a superficial analysis is vital for further research in determining target orientations for developing Ukraine's industrial ecosystem. Ukraine's transition to another group, "Developed countries with a high specific MIG", can be considered a reference point. In this context, comparing some indicators that affect the MIG is possible. As seen in Figs. 6, the gap in GDP created by the processing industry at the end of the 90s of the last century significantly increased 20 years later.

At the same time, R&D expenses in Ukraine underwent a catastrophic reduction, while in Poland, they have increased significantly, although they have not reached the level of developed industrial countries.

Thus, the potential of the developed scientific-methodical approach to the clustering of the world's countries lies in its usefulness for developing policy in the field of industry, taking into account specific empirical and comparative analysis**.** When grouping countries, industrial activity is at the very centre of attention and can reflect differences between systems. Consequently, there is an opportunity to identify specific problems that should be the objects of industrial policy.

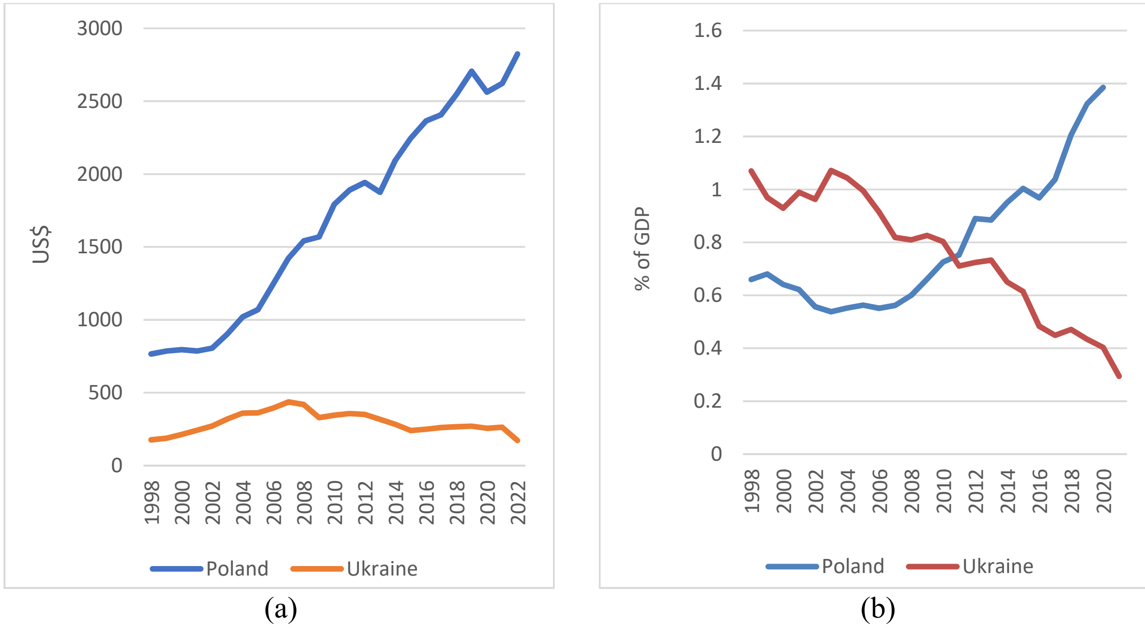


Fig. 6. GDP per capita created by manufacturing (a) and expenditures (b) on R&D in Poland and Ukraine.

Source: based on the World Bank (2023d).

5. Discussion.

The peculiarity of the proposed approach is that the MIG indicator considers large-scale (volume of production) and speed (rate of change) factors. Using these two factors separately to evaluate and compare a country is only sometimes correct since some countries, mainly those with small volumes of developing industry, can demonstrate high growth rates, remaining on the periphery of the world industry. According to the World Bank, Ethiopia had the highest growth rate for the period from 1998 to 2019 (12.7%). However, industrial physical measures are very small compared to giants such as Germany, the USA, the Republic of Korea, and Japan, whose growth rates in the same period were 1.3%, 1.4%, 2.5%, and 1.1%, respectively. In addition, using these indicators simultaneously and per capita (as a specific MIG) allows economies of different sizes to be compared.

At the same time, the proposed indicator has some shortcomings. The analysis results demonstrated that countries with similar values of the specific MIG differ significantly in the innovative and technological levels of industry and well-being in general. This shortcoming can be partially eliminated by identifying the common characteristics of dominant institutions and technologies in the countries and then grouping them according to these findings. However, from a scientific perspective, it is difficult to divide countries according to a single rigid criterion. Each has its peculiarities due to the influence of many factors, including historical, socio-cultural, economic, and environmental factors.

The analysis had statistical limitations. Although all indicators were taken from respectable sources, some were of expert origin. Simultaneously, the developed toolkit makes it possible to formulate and confirm the hypothesis of the existence of groups of countries with similar characteristics of supranational industrial ecosystems, which can be identified and to which all national industrial systems of the world belong to some extent.

This study should be continued to draw certain conclusions about the possible directions of national industrial policy. In particular, it is crucial to determine which vectors can be used to move Ukraine to the best group at the post-war recovery stage and what industrial growth factors should be given special attention. To highlight the main factors determining the development of groups of countries with higher MIG, it is advisable to analyse space-time (panel) data, which can be the subject of further research.

The analysis performed in this work is based on historical data up to 2019, without considering the impact on the economy of the consequences of the COVID-19 pandemic and active military operations in Ukraine. It proceeds from the premise that the phenomena that dramatically change the world economy will cease to operate and that the factors under consideration have a long-term nature so that the analysis will retain, at least partially, its meaning.

6. Conclusions.

Production volumes and rates of change characterise national industrial systems. By analogy with momentum in mechanics, where the measure of the movement of a body depends on its mass and velocity, the measure of industrial growth is determined by the production volumes (scale factor) and their rates of change (speed factor). Here, the industrial development of states has been analysed MIG as the product of the added value created by industry and its growth rate.

The advantage of the proposed indicator is that it simultaneously considers the scale and speed factors. Using them separately for cross-country comparison is only sometimes correct since some countries, mainly those with small volumes of developing industry, can demonstrate high growth rates, remaining on the periphery of the world industry. The simultaneous use of indicators of added value created by industry and rates of change per capita as a specific MIG allows the comparison of economies of different sizes.

The subject of this research is the industrial ecosystem of states, namely, national industrial ecosystems. These are considered in terms of their historical dynamics and geographical diversity. In ecology, the concept of industrial ecosystems, both global and national, is of great importance for understanding planetary and regional environmental issues and for developing policies in this area. From the viewpoint of technological development, industrial ecosystems are considered dynamic networks of interrelated enterprises in different countries that function in a limited geographical space and are formed based on appropriate production technologies and institutions, which form the mechanisms of their functioning and determine their evolution.

The outlined subject argues that the research can be attributed to comparative economics, which is gaining notable importance in the current international reality.

The performed calculations of the specific (per capita) momentum of industrial growth demonstrate the critical lag of Ukraine (58th position among 67 countries) not only from the highly developed economies of the world, where inclusive institutions have long traditions, but also from similar, at least in terms of the socialist past, Poland (23rd position), where, as in Ukraine, the crisis phenomena in the industry in the early 90s of the last century were a consequence of economic and political transformations, or in a broader context - a shift in global geopolitics, which affected Central and Eastern Europe.

In terms of absolute the momentum of industrial growth, China remains the leader due to its large production volumes and high growth rates over a long period of time.

Countries with similar values for the specific momentum of industrial growth of industrial growth differ significantly in terms of existing institutions, innovative and technological industry levels, and general well-being. Countries were grouped using the MIG indicator to identify common characteristics. Considering the evolutionary nature of the development of industrial ecosystems and the expediency of studying them in the ecological and technological context, identifying existing national industrial ecosystems should be carried out according to classification features such as institutional, economic, scientific, technological, labour, and environmental.

Based on the analysis of the array of 21 indicators of these groups for a sample covering 67 countries of the world for 10 years, five indicators were chosen that have the closest connection with the effective indicator, the specific momentum of industrial growth. The developed toolkit makes it possible to formulate and confirm the hypothesis of the existence of groups of countries with similar characteristics of supranational industrial ecosystems, which can be identified and to which all national industrial systems of the world belong to some extent.

In total, using cluster analysis, five large groups of countries were singled out, which, in turn, can be divided into subgroups: industrial ecosystems with the closest characteristics. As for Ukraine, it is included in the large Group V “Developing countries with the lowest specific MIG”, which is characterised by a scientific-technical level of production, more significant problems with the reproduction and level of human capital, traditionally influential informal institutions (in particular, a relatively large sector of the shadow economy).

Further scientific research will focus on determining the possible directions of Ukraine’s national industrial policy. In particular, it is necessary to determine, with the help of which vectors Ukraine can move to the best group at the stage of post-war recovery and to which factors of industrial growth special attention should be paid. To identify the main factors determining the development of groups of countries with higher MIG, it is advisable to analyse space-time (panel) data, which can be the subject of further research.

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