

**STRATEGIC EUROPEAN INTEGRATION SCENARIOS OF UKRAINIAN AND POLISH
RESEARCH, EDUCATION AND INNOVATION SPACES**

Yurii Kharazishvili, Aleksy Kwilinski, Henryk Dzwigol, and Viacheslav Liashenko

Abstract. A comprehensive study was conducted in the direction of research and institutional support and comparison with the nearest neighbour - Poland, to determine the current state and justify strategic scenarios for Ukraine's integration into the research, educational and innovation spaces of the EU as a source of proactive sustainable innovative development. Analysis of the use of foresight technology to determine the possible future, create the desired image of the future and determine strategies to achieve it using methods developed in various research areas revealed that its application makes sense in determining long-term factors, trends and directions of national economies. That is, in foresighting, in contrast to forecasting, the emphasis is made on qualitative rather than quantitative results, which does not provide the expected targeted policy of the state, because it does not give clear, concrete results of actions - quantitative strategic benchmarks, monitoring which would control the process of these areas' development. The disadvantages of foresighting methods that limit its application are identified. Scientific substantiation of strategic scenarios of European integration of Ukrainian and Polish research, education and innovation spaces is based on the concept of sustainable development, which is grounded on applied systems theory, management theory and economic cybernetics and comprises the stages of identifying and strategizing. Identification is carried out taking into account the definition of the safe existence boundaries and simultaneous norming and integrated convolution of indicators and thresholds of education and innovation. Comparison on one scale of integrated indices of education and innovation makes it possible to carry out the goal-setting stage, identify possible strategic development scenarios and build the desired development trajectories, i.e., to implement the principle of strategizing "the future is determined by the trajectory into future." Thus, knowledge of the desired values of integrated indices in each year makes it possible, through their decomposition by the method of adaptive regulation from the management theory, to justify the values of indicators that provide the desired growth trajectory and achieve certain goals of research, educational and innovative spaces of Ukraine and Poland.

Keywords: education, innovation, boundaries of safe existence, integrated index, development trajectories, strategic scenarios

JEL Classification: C00, E00, O00

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1. Introduction

The fact of signing the Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their Member States, on the other hand, amending the Constitution of Ukraine to determine the strategic course of Ukraine to become a full member of the European Union, prove that Ukraine has demonstrated its intentions and readiness to access into the European space and the system of formal EU institutions, to adopt their rules, norms and practices, and to become an integral part of the European community. This choice provides Ukraine with significant advantages, one of which is the opportunity to establish a real partnership with EU member states in building common research, education and innovation spaces as a basis for ensuring economic development on innovative grounds.

Discussions on the ways, directions and tools of Ukraine's integration into the European community are ongoing, and in recent years, due to objective reasons, have intensified significantly. Traditionally, researchers of European integration issues focus on political and legal, socio-political, security, economic, financial and investment, foreign trade, social and labour, migration and social and communication aspects. Much less attention is paid to the research, educational and innovative components of Ukraine's European integration and their quantitative measurement. The potential for intensifying the processes of Ukraine's integration of the EU's research, educational and innovation spaces is underestimated, and its implementation should be considered as one of the key areas of the strategy to ensure its European vector.

Therefore, conducting a comprehensive study in the direction of research and institutional support and comparison with the nearest neighbour - Poland, to determine the current state and justify strategic scenarios of Ukraine's integration into research, educational and innovation spaces of the EU as a source of sustainable innovation is relevant and timely.

Thus, the purpose of the article is to identify, to carry out a comparative analysis and scientific substantiation of strategic scenarios of Ukrainian and Polish research, education and innovation spaces of European integration of Ukraine and Poland according to the modern methodology of identification and strategizing in the security dimension in the medium-term perspective.

2. Literature Review

Integration processes in research, education and innovation spheres are the subject of research by many scholars and experts. A significant number of analytical materials and research papers is devoted to the common EU policy on education, research and technology, cooperation under the program "Horizon 2020", the development of interstate and cross-border cooperation (Trippel, 2013; Radosevic & Stancova, 2017; Makkonen & Rohde, 2016; Marek et al., 2017; Chessa et al., 2013, Kharazishvili et al., 2021a; 2021b).

The attention of Ukrainian scientists to the issues of Ukraine's integration into the European - research, educational, innovation - spaces was uneven in time and volume. The first wave of research was devoted to the integration of higher education in Ukraine into the European educational space in terms of joining the Bologna Process and solving problems of ensuring European standards of education quality and academic mobility. The following publications reveal the current state, problems and ways of modernizing higher education in the context of the Bologna process, areas of improvement of legal support for Ukraine's integration into the European educational space, development of university science, participation of Ukrainian higher education institutions in European educational and research programs, and other issues of developing international academic cooperation (Vashchuk, 2011; Khan & Slyusarenko, 2016; Lugovyi & Talanova, 2017; Opanasyuk, 2017; Kraevska, 2014).

At the present stage, the scientific search for promising ways of innovative and research and technical development of Ukraine and Poland and the improvement of the research space in the context of European integration processes has intensified. Relevant research is carried out by scholars of leading research institutions of the National Academy of Sciences of Ukraine, as well as individual representatives of university science and experts: (Geets et al., 2015; Haustov, 2018; Egorov, 2016; Matyushenko et al., 2017; Borshchevsky et al., 2017; Babi, 2015; Lyashenko & Pidorycheva, 2019).

The abovementioned works consider the role and resources of international research and technical programs in stimulating the development of research, technical and innovative activities in Ukraine, the need to develop a system of indicators of innovation for Ukraine according to EU methods, priorities for research system, problems of forming a roadmap for Ukraine to access the European research space and expected results, prospects for creating a new research and innovation infrastructure, relevant legal framework, the role of clusters as a tool for integration and providing the competitive advantage in the European innovation space, research, education and investment and innovation potential for cross-border cooperation with relevant recommendations and proposals.

At the same time, it should be noted that Ukraine lacks a systematic approach to scientific elaboration and formation of the Strategy of Ukraine's integration into the research, education and innovation spaces of the EU. Meanwhile, no paper considers proposals for its own list of indicators and its own calculation of the current level of research, education and innovation spaces of European integration. Despite the attractive title of the article (Egorov, 2016) on the system of complex indicators for assessing research, technical and innovation activities in the context of European integration processes, the system of indicators itself is not provided, despite the sound reasoning behind the need to develop its own system of indicators for a particular country.

In addition, it is necessary to note the research related to sustainability in economic development, as well as the development of artificial intelligence in the information economy (Aleksander et al., 2020; Arefieva et al., 2021; Boiko et al., 2019; Bogachov et al., 2020; Borychowski et al., 2020; Chygryn et al., 2020; Cyfert et al., 2020; 2021; Czakon et al., 2020;

Czyżewski et al., 2020a; 2020b; Dalevska et al., 2019; Dementyev & Kwilinski, 2020; Dementyev et al., 2021; Dyduch, 2019a; 2019b; Dzwigol, 2016; 2019a; 2019b; 2020a; 2020b; 2021a; 2021b; Dzwigol & Wolniak, 2018; Dzwigol & Dźwigoł-Barosz, 2018; 2020; Dzwigol et al., 2019a; 2019b; 2019c; 2020a; 2020b; Furmaniak et al., 2018; 2019a; 2019b; Gorynia et al., 2019; Gorynia, 2019; Kaźmierczyk & Chinalska, 2018; Kharazishvili et al., 2020; 2021a; 2021b; Khrapkina et al., 2021; Klimas et al., 2020; Koibichuk et al., 2021; Kondratenko et al., 2020; Kuzior et al., 2019; 2021; Kwilinski, 2018a; 2018b; 2019; Kwilinski et al., 2019a; 2019b; 2019c; 2019d; 2019e; 2019f; 2020a; 2020b; 2020c; 2020d; 2020e; 2021; Kwilinski & Kuzior, 2020; Kyrilov et al., 2020; Lakhno et al., 2018; Lyulyov & Pimonenko, 2017a; Lyulyov & Shvindina, 2017b); Lyulyov et al., 2018; 2020a; 2020b; 2021; Mlaabdal et al., 2020; Miskiewicz, 2018; 2019; 2020a; 2020b; Melnychenko, 2020; 2021; 2019; Miśkiewicz & Wolniak, 2020; Pająk et al., 2016; 2017; Pimonenko & Lyulyov, 2019; Polcyn & Czyżewski, 2016; Prokopenko & Miskiewicz, 2020; Saługa et al., 2020; Savchenko et al., 2019; Shkodina et al., 2020; Tkachenko et al., 2019a; 2019b; 2019c; 2019d; 2019e; Trąpczyński et al., 2019; Vatamanyuk-Zelinska & Melnychenko, 2020; Zastempowski et al., 2020). The strengthening role of these aspects makes a certain trend when considering the issues of innovation space in the context of integration processes.

The main tool for measuring the innovative development of the European Union is the European Innovation Scoreboard (EIS), for which the measurement system has been significantly revised since 2017. The new EIS measurement system is represented by four groups of indicators, including 10 innovative measurements and 27 various indicators. (European Innovation Scoreboards, 2017):

- "framework conditions" cover the main factors of innovation activity that are external to the firm, and three innovative aspects: human resources, attractive research systems, as well as the innovation environment;
- "investment" includes public and private investment in research and innovation and covers two aspects: funding and support, as well as firms' investment;
- "innovation activity" covers innovation efforts at the firm level, grouped by three innovation dimensions: innovators, connections and intellectual assets.
- "impact" covers the sway of companies' innovation on two innovative aspects - employment and trade effects.

The use of a special methodology allows calculating Summary Innovation Index (SII) (EIS 2020 Methodology Report) for each country: after calculating each of the 27 indicators, the data undergo a ration setting process in order to translate the variation of normalized indicators in the range from 0 to 1. Standardization is carried out by the method of "scope of variation", for which the minimum and maximum values of indicators are calculated. After normalization of the data, the arithmetic mean value of the indicators is found, which forms a summary innovation index - SII, and then its relative value to the EU SII as a percentage.

There are a number of remarks on this methodology. Regarding normalization by the method of "scope of variation": if the minimum values are approaching or equal to "0", the normalized values very well reproduce the dynamics of the normalized indicators. However, with a

significant deviation of the minimum value of the indicator from "0", the dynamics of the normalized indicator increasingly deviates from the display of the output indicator dynamics, simulating not its dynamics, but the dynamics of its range transformation, which is not the same. Therefore, the change in the dynamics of the normalized indicators leads to a change in the factor load and, as a consequence, to a change in the weight coefficients and, thus, a distortion of the integrated index dynamics.

It is difficult to imagine that all indicators have the same effect on the integral index (1/27); this is a very significant simplification that does not correspond to reality. Therefore, a formalized definition of weight values is required. Expert estimates are full of subjectivity and do not exclude fundamental errors. Moreover, weight values cannot be constant - they are dynamic. "...Significant changes in the political and foreign economic situation lead after some time to radical changes in empirical estimates of econometric relationships, which, in turn, leads to changes in weight coefficients" (Kharazishvili, 2019). Otherwise, such an estimate of the SII index will reflect the average temperature in the hospital. In addition, the lack of a formalized definition of the limits of safe existence for each indicator - a vector of threshold values, leads to an artificial distribution of gradations of the integrated index (innovative leaders, strong innovators, moderate innovators, modest innovators) instead of scientifically grounded division of the integrated index range on optimal, pre-crisis, crisis and critical areas for which there exist scientifically grounded approaches. The impossibility of comparing the results of calculations for each year indicates the imperfection of the evaluation methodology.

Regarding the composition of EIS indicators, out of 27 indicators, 22 are resource components that characterize the capacities of individual resources for innovation in the country. That is, the external signs of innovation activity are considered, which, unfortunately, do not give an idea of how these external signs affected (if at all) the final result of economic growth or socio-economic development. Innovative potential, if it is not realized in the final product (in this case - in the resulting indicators of socio-economic development) can remain only a potential for a long time. Speaking in the language of mathematics, the availability of innovative potential or external signs of innovative activity to determine the level of innovative development is a necessary but insufficient condition.

The resulting EIS indicators, of which there are only 5, are divided into two groups: the impact on employment and the impact on sales. Unfortunately, 2 employment indicators can also be classified as resource, because an increase in employment is a condition (not always necessary) to increase the result, not the result itself. Thus, we can consider the following as resulting innovation indicators: medium and high-tech exports of production, exports of knowledge-intensive services, sales of products new for the market and innovative products new for companies.

According to the authors of this article, this resulting list of indicators lacks the most important - the indicator of scientific and technological progress (STP), recognized worldwide as the most important factor in qualitative changes in the economic system, which depends on many factors: technical and technological and organizational managerial innovation, efficiency of

using resources, models to organize production of goods and services, existing tariffs for energy and resources, the level of labour force qualification, the share of wages in output, research and development costs, costs of innovation, education costs, legal environment and others.

Therefore, it is very important to determine how all resource indicators - external signs of innovation, affected the rate of STP, i.e., what part of the country's GDP growth is due to the growth of the country's realised innovative potential, along with other factors.

Moreover, there is no considering the methodology of bringing the lagging countries closer to the optimal levels of educational and innovative spaces of the EU, that is, the methodology of strategizing, at all.

3. Methodology

Research in determining the level of research, educational and innovative spaces of European integration consists of several stages of the "concept of sustainable development" (Kharazishvili, 2019):

Determining the structure and system of indicators. This stage involves detailing the components and their indicators, forming the dynamics of indicators, identifying their affiliation to stimulants (S - increase of which is desirable), or de-stimulators (D - decrease of which is desirable).

Defining the boundaries of safe existence is the most important step in determining the level of security. A systematic study of the problem of sustainable development from the standpoint of security should include defining the boundaries of safe living conditions of the system, without the knowledge of which it is impossible to protect the vital interests of security subjects. That is why for each indicator it is necessary to determine *the vector of threshold values*: lower critical (x_{kp}^u); lower threshold (x_{nop}^u); lower optimal (x_{onn}^u); upper optimal (x_{onn}^e); upper threshold (x_{nop}^e); upper critical (x_{kp}^e) (Figure 1).

The most accessible among a number of methods for determining thresholds is the method of "t-criterion" (Paniotto, 2004), which means constructing a probability density function for a given sample and calculating statistical characteristics: mathematical expectation, standard deviation and asymmetry coefficient. From all variety of types of probability density function for all indicators it is possible to allocate types with the characteristic law of distribution: a) normal, b) lognormal and c) exponential for which formulas to calculate a vector of threshold values are defined (Table 1) (Kharazishvili, 2019; 2021a; 2021b) with clarifications of the distribution: tail to the right, tail to the left (Sukhodolya et al., 2020).

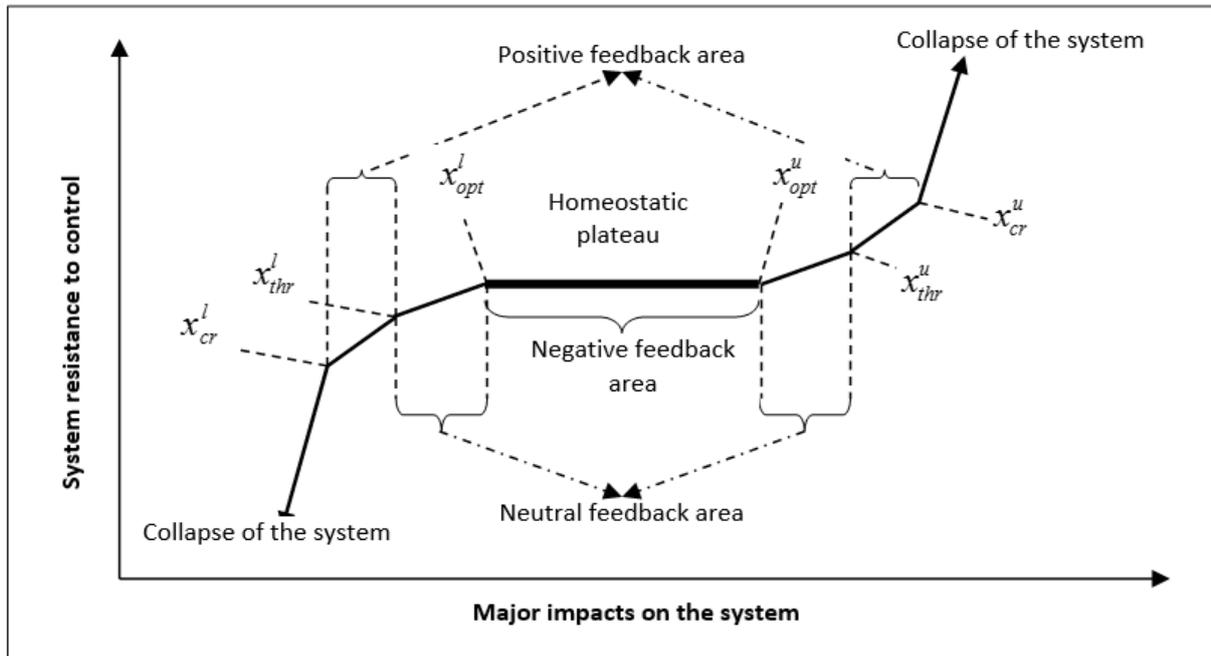


Figure 1. "Homeostatic Plateau" of the Dynamic System

Source: Kharazishvili (2019).

Table 1. Formalised Threshold Vector Values *

Type of Indicator Probability Density Function	Lower Threshold	Lower Optimal Value	Upper Optimal Value	Upper Threshold
Normal	$\mu - t \times \sigma$	$\mu - \sigma$	$\mu + \sigma$	$\mu + t \times \sigma$
Lognormal (tail to the right)	$\mu - t \times \sigma / k_{as}$	$\mu - \sigma / k_{as}$	$\mu + \sigma$	$\mu + t \times \sigma$
Lognormal (tail to the left)	$\mu - t \times \sigma$	$\mu - \sigma$	$\mu + \sigma / k_{as}$	$\mu + t \times \sigma / k_{as}$
Exponential (tail to the right)	$\mu - \sigma / k_{as}$	μ	$\mu + \sigma$	$\mu + t \times \sigma$
Exponential (tail to the left)	$\mu - t \times \sigma$	$\mu - \sigma$	μ	$\mu + \sigma / k_{as}$

Note: * For critical values, instead of t we use _3_ or more for short samples.

Source: own elaboration.

Identification of the level of research, education and innovation spaces of European integration consists in a step-by-step integrated convolution of indicators and their threshold values according to the modern universal methodology of integrated assessment (Kharazishvili, 2019; Kharazishvili et al., 2020; Kharazishvili et al., 2019):

the form of the integral index is *multiplicative* (1):

$$I_t = \prod_{i=1}^n z_{i,t}^{a_i}; \quad \sum a_i = 1; \quad a_i \geq 0, \tag{1}$$

where I is an integral index;
 z is a normalized indicator;
 a is a weighting factor.

The method of normalization is *combined* (2):

$$S : z_i = \frac{x_i}{k_{norm,t}}, \quad D : z_i = \frac{k_{norm,t} - x_i}{k_{norm,t}}, \quad k_{norm,t} \geq x_{max,t}, \quad (2)$$

where x_i is an indicator value;
 S is a stimulator; D is a de-stimulator;
 $k_{norm,t}$ is a norming coefficient: for stimulators it is equal to the maximum value from the sample of indicators and threshold values; for de-stimulators it exceeds the maximum values from the sample of indicators and threshold values by 5-10%.

Weighting factors are dynamic: based on the application of the method of "Main components" (3) and the method of "Sliding matrix":

$$C_i \times D_i = \begin{pmatrix} d_1c_{11} + d_2c_{12} + \dots + d_jc_{1j} \\ d_1c_{21} + d_2c_{22} + \dots + d_jc_{2j} \\ \dots \\ d_1c_{j1} + d_2c_{j2} + \dots + d_jc_{jj} \end{pmatrix} = \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_j \end{pmatrix}, \quad a_i = \frac{w_i}{\sum w_i}, \quad (3)$$

where C is a matrix of absolute values of factor loads;
 D is a vector-matrix of dispersions;
 a are weighting coefficients.

Determining the list and significance of the threats impact is carried out according to two criteria:

- by the remoteness from the point of sustainable development - the average value of the homeostatic plateau or the criterion of sustainable development (the list and importance of threats are determined); It is the simultaneous norming and integral convolution of indicators and their threshold values that makes it possible to compare on one scale the deviations of integrated indices from the relevant criteria of sustainable development.

- by the severity of the impact through calculating the coefficients of elasticity (4) (the degree of threats' impact is determined). The elasticity coefficients of each component and indicators explain the degree of influence of individual components and indicators on the level of the integrated index (by how many percent the output value will change when changing 1% of the input value) and are the necessary information to develop priority influence measures:

$$E = \frac{\Delta y}{\Delta x} \cdot \frac{x}{y} \quad (4)$$

The rate of STP is determined by the “Solow residue” method for the Cobb – Douglas production function (5) (Kharazishvili, 2018; 2021a; 2021b) by logarithmizing and obtaining logarithmic derivatives and determining the contribution of STP. In the following formulas, to simplify them, the symbol of time t is omitted, but is implied (6).

$$V_t^S(P_t) = e^{\gamma t} L_t^{\alpha_t} K_{z,t}^{1-\alpha_t} = e^{\gamma t} [\xi_t N_t(P_t) \frac{W_t}{P_t} k_{sn}]^{\alpha_t} (\mathcal{G}_t K_t)^{1-\alpha_t} \quad (5)$$

where V_t^S is the actual issue of aggregate supply;

$e^{\gamma t}$ is the scientific and technological progress (STP);

γ is the STP rate;

L is labour costs;

$\xi_t = N_{ef,t} / N_{zag,t}$ is the share of the effective number of taxpayers in total employment;

$N_{ef,t}$ is the effective number of taxpayers (employees plus another category of workers, reduced to the equivalent of employees for all taxes and wages);

$N_{zag,t}$ is general employment;

$N_t(P_t)$ is the function of optimal demand for labour, determined from the condition of equality of the labour marginal product value to the nominal wage rate;

W_t is the average annual nominal wages of employees;

$k_{sn,t}$ is the coefficient of social loads;

\mathcal{G}_t is the capital utilization ratio;

K_t is capital expenditures;

α_t is the coefficient of elasticity at labour costs;

$1 - \alpha_t$ is the coefficient of elasticity at cost of capital;

P_t is GDP deflator; t is the period of time.

$$\begin{aligned} \text{Tempo_NTP} = & \frac{\dot{V}}{V} - \dot{a}(\ln \xi + \ln 0,001N + \ln W12 - \ln P + \ln k_{sn}) - \\ & - a \left(\frac{\dot{\xi}}{\xi} + \frac{\dot{N}}{N} + \frac{\dot{W}}{W} - \frac{\dot{P}}{P} \right) + \dot{a}(\ln \mathcal{G} + \ln K) - (1-a) \left(\frac{\dot{\mathcal{G}}}{\mathcal{G}} + \frac{\dot{K}}{K} \right), \end{aligned} \quad (6)$$

where $\frac{\dot{V}}{V}, \frac{\dot{\xi}}{\xi}, \frac{\dot{N}}{N}, \frac{\dot{W}}{W}, \frac{\dot{\mathcal{G}}}{\mathcal{G}}, \frac{\dot{K}}{K}, \frac{\dot{P}}{P}$ are rates of the corresponding variables;

\dot{a} is a derivative of the coefficient of elasticity (N is set in million people, W in UAH per month).

The transition from output to GDP (GRP) is carried out through the coefficient of manufacturability (μ), which in each period is determined by the ratio of GDP (GRP) to output

according to macroeconomic identity (7) "output is equal to the sum of intermediate consumption and GDP":

$$GDP(P) = \sigma V^S(P) \quad (7)$$

Scientific substantiation of strategic scenarios of the European integration of research, education and innovation spaces of Ukraine and Poland. Most of the economically developed countries of the world, given the instability of economies' operation, have recognized the need not only to predict the future, but also its active formation by means of such a tool as Foresight. The main purpose of Foresighting is to determine the possible future, create the desired image of the future and determine strategies for achieving it. Forecasting, technology prospects estimates, research of the future and other forms of Foresight (SWOT analysis, expert estimates, trends' extrapolation, brainstorming) are an attempt to identify long-term trends and, based on them, to coordinate decision-making.

Unfortunately, expert estimates are full of subjectivity and do not exclude fundamental errors; forecasting trends using the principle of classical forecasting "*the past determines the future*" in the face of rapid change is inappropriate. For example, attempts to predict the integral indices' dynamics using polynomials or regression equations indicate incapability and generally discredit economic and mathematical modelling.

With this in mind, a strategic planning approach is proposed, which uses the principle "*the future is determined by the trajectory into the future*" (Kharazishvili, 2019), which consists of the following stages:

- identifying the current state through integrated assessment;
- goal setting for the desired perspective;
- constructing the desired trajectories according to development scenarios;
- sequential decomposing integral indices into components and indicators using adaptive control methods from the management theory (*Figure 2*);
- de-norming indicators: the implementation of the inverse norming procedure, i.e., the transition from dimensionless values to macro indicators in natural units of measurement according to norming formulas.

Strategic planning is to result in obtaining, in the dynamics per each year, the necessary values of indicators and relevant macro indicators, compliance with which will provide the desired trajectory of sustainable development.

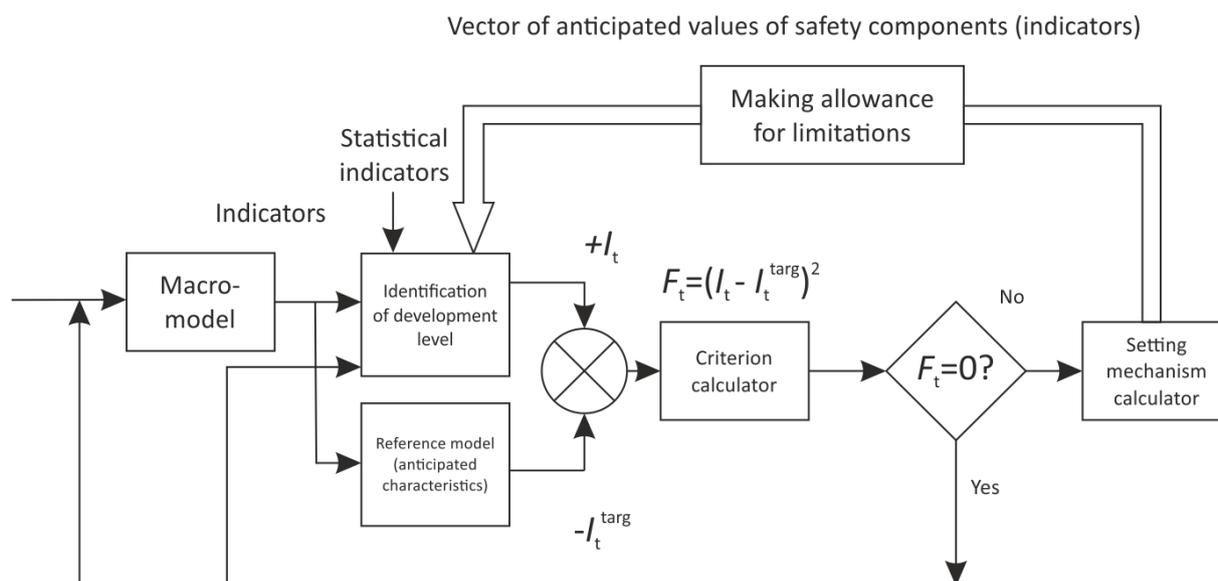


Figure 2. Generalized Scheme of Adaptive Control System with a Reference Model

Source: Kharazishvili (2019).

4. Results

The stage involves the development of the structure (*Figure 3*) and detailing of the components and their indicators, the formation of the indicators dynamics and their affiliation to stimulators (S) or de-stimulators (D) (*Table 2*).

Table 2. Components and indicators of subsystems of research, education and innovative spaces of European integration

Education (resource provision)	Science and innovation (resources and outcomes)
1. The level of higher education coverage, per 10 thousand population; (S)	1. The pace of scientific and technological progress (S)
2. The level of secondary education coverage, per 10 thousand population; (S)	2. The level of scientific research funding, % of GDP (S)
3. The level of state funding of education, % of output; (S)	3. The level of funding for innovation, % of GDP, (S)
4. The level of state funding of higher education, % of output; (S)	4. The level of innovation activity of enterprises, % of the total number (S)
5. Average costs per 1 pupil (student), thousand dollars US for PPP; (S)	5. The level of sales of innovative products, % of total sales (S)
6. The level of capital investment in education, % of total expenditure on education; (S)	6. The level of scientific research costs per person, USD US for PPP (S)
7. The level of labour remuneration in education of output; (S)	7. The level of invention activity (patents and utility models), per 1 million population (S)

Source: own elaboration.

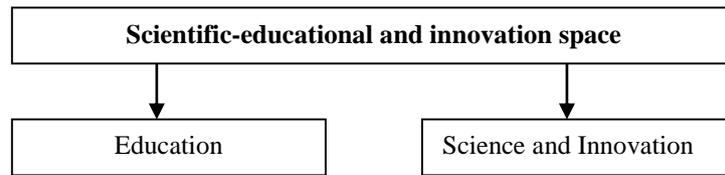


Figure 3. The structure of research, education and innovation spaces of European integration
 Source: own elaboration.

The dynamics of indicators of research, education and innovation spaces in Ukraine and Poland was determined according to the official data of the State Statistics Service of Ukraine and Poland. To calculate the vector of threshold values (Table 3), a sample of values of similar indicators from EU countries was used for international comparison of statistical services of Ukraine and Poland, as well as Eurostat data. The given list of indicators is not a dogma, it depends on the depth and objectives of the study, it should be consistent for all comparable countries and, finally, reflects the vision of the authors.

The identification of the level of research, education and innovation spaces consists in applying the proposed methodology of integrated evaluation and simultaneous integrated convolution both for indicators (I) and for their threshold values (P), which is reflected in the multifactor hierarchical model (4).

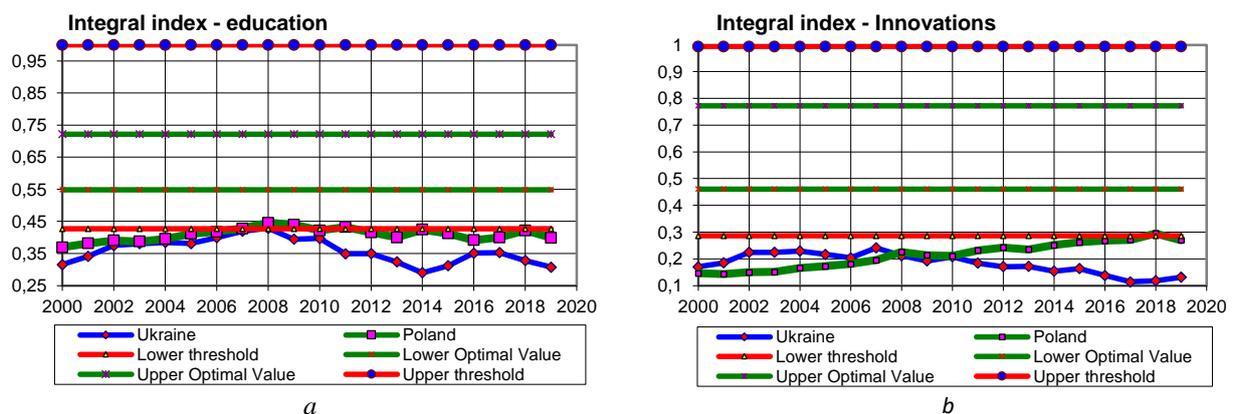
$$\left\{ \begin{array}{l} I_{educ_inov,t} = I_{educ,t}^{a_{1,t}} \cdot I_{inov,t}^{a_{2,t}}; \quad P_i = \prod_{j=1}^4 P_{ij}^{b_{ij}}; \quad P_{ij} = [P_{пор.,ij}^{нижн\epsilon}; P_{опт.,ij}^{нижн\epsilon}; P_{опт.,ij}^{верхн\epsilon}; P_{пор.,ij}^{верхн\epsilon}]; \\ I_{educ,t} = \prod_{i=1}^7 z_{educ,t}^{a_i}; \\ I_{inov,t} = \prod_{i=1}^7 z_{inov,t}^{a_i}; \end{array} \right. \quad (8)$$

Modelling the integrated indices dynamics of the components of the level of research, education and innovation spaces of Ukraine and Poland in comparison with the integrated threshold values, i.e., in the security dimension, gives the following picture of the current state (Figure 4) and in general (Figure 5).

Table 3. Vectors of Threshold Values of Indicators of Research, Education and Innovation Spaces of European Integration

Components and Indicators	Lower threshold	Lower Optimal Value	Upper Optimal Value	Upper threshold	Ukraine 2019	Poland 2019
Education						
- The level of higher education coverage, per 10 thousand population;	220	300	450	600	344	313,7
- The level of secondary education coverage, per 10 thousand population;	1050	1345	1650	2300	910	798
- The level of state funding of education, % of output;	2.5	2.8	3.9	6.0	2.24	1.87
- The level of public funding for higher education, % of output;	0.65	0.71	1.0	1.55	0.462	0.358
- Average costs per 1 pupil (student), thousand dollars US for PPP;	6.8	9.7	12.5	18.0	2.65	5.33
- The level of capital investment in education, % of total expenditures on education;	6.5	8.9	11	15	2.387	9.729
- The level of labour remuneration in education of output;	0.2	0.26	0.32	0.382	0.1754	0.233
Science and innovation						
- The pace of scientific and technological progress	0.2	0.5	2.0	5.0	-2.355	-0.356
- The level of scientific research funding, % of GDP	1.0	2.0	4.0	5.0	0.505	1.324
- The level of funding for innovation, % of GDP,	0.5	1.5	2.5	3.5	0.354	0.941
- The level of innovation activity of enterprises, % of the total number	25	45	60	80	15	21.7
- The level of sales of innovative products, % of total sales	10	15	30	40	1.0	9.3
- The level of scientific research costs per person, USD for PPP)	345	430	900	1100	36.9	207.7
- The level of invention activity (patents and utility models), per 1 million population	110	137	205	245	224.3	92.49

Source: calculated by the authors.

**Figure 4.** Dynamics of integrated indices of research, education (a) and innovation spaces (b) of Ukraine and Poland.

Source: own elaboration.

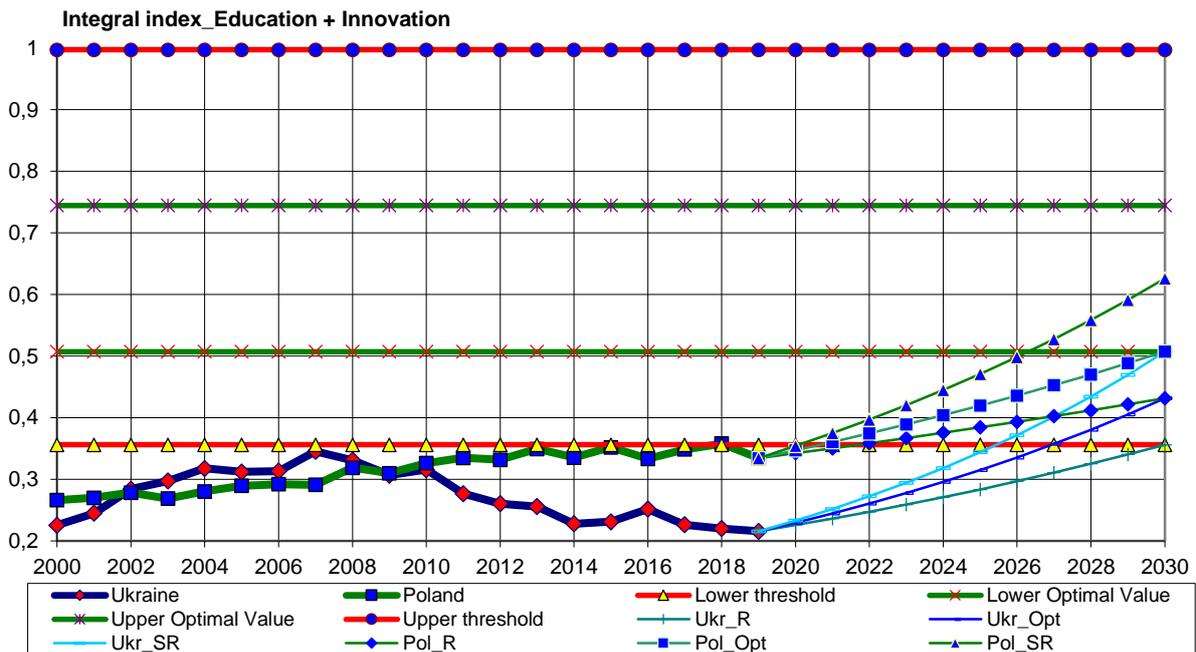


Figure 5. Dynamics of integrated indices of educational and innovation space of Ukraine and Poland with strategic goals and development scenarios until 2030

Source: own elaboration.

Thus, according to the results of calculations, Ukraine is in the crisis (orange) zone - below the lower threshold, Poland is on the border of the crisis-pre-crisis (orange-red) zone. It is the comparison of the dynamics of integrated indices with integrated thresholds on one scale that makes it possible to identify the current situation and carry out strategic planning for the medium-term perspective - three strategic scenarios for Poland (realistic, optimistic, sustainable development) and three for Ukraine: (realistic, optimistic, entry to the sustainable development zone). The scientific substantiation of the vector of threshold values and their integral convolution makes it possible to determine the gradations of the countries' distribution by level of innovative development: critical (red) level (below the lower critical threshold), crisis (orange) level (between the lower critical and lower threshold), pre-crisis (yellow) level (between lower optimal and lower threshold) optimal (green) level (between lower optimal and upper optimal), instead of subjective setting of artificial ranges distribution.

Determining the deviations of integrated indices from the average value of the "homeostatic plateau" - the criterion of sustainable development - demonstrates the imbalances of sustainable development and determines the list and importance of threats (Figure 6). The most important task of the policy is to eliminate imbalances, i.e., to reduce to zero the deviation of each indicator, for example, by the end of 2030. Out of 14 indicators of research, education and innovation space, 12 indicators pose a critical threat to Ukraine and 9 indicators to Poland.

Therefore, changing dynamics of these indicators from negative to positive to ensure their location in the optimal zone is a priority of the government of each country, which will be an objective indicator of the reforms' effectiveness in any area of security.

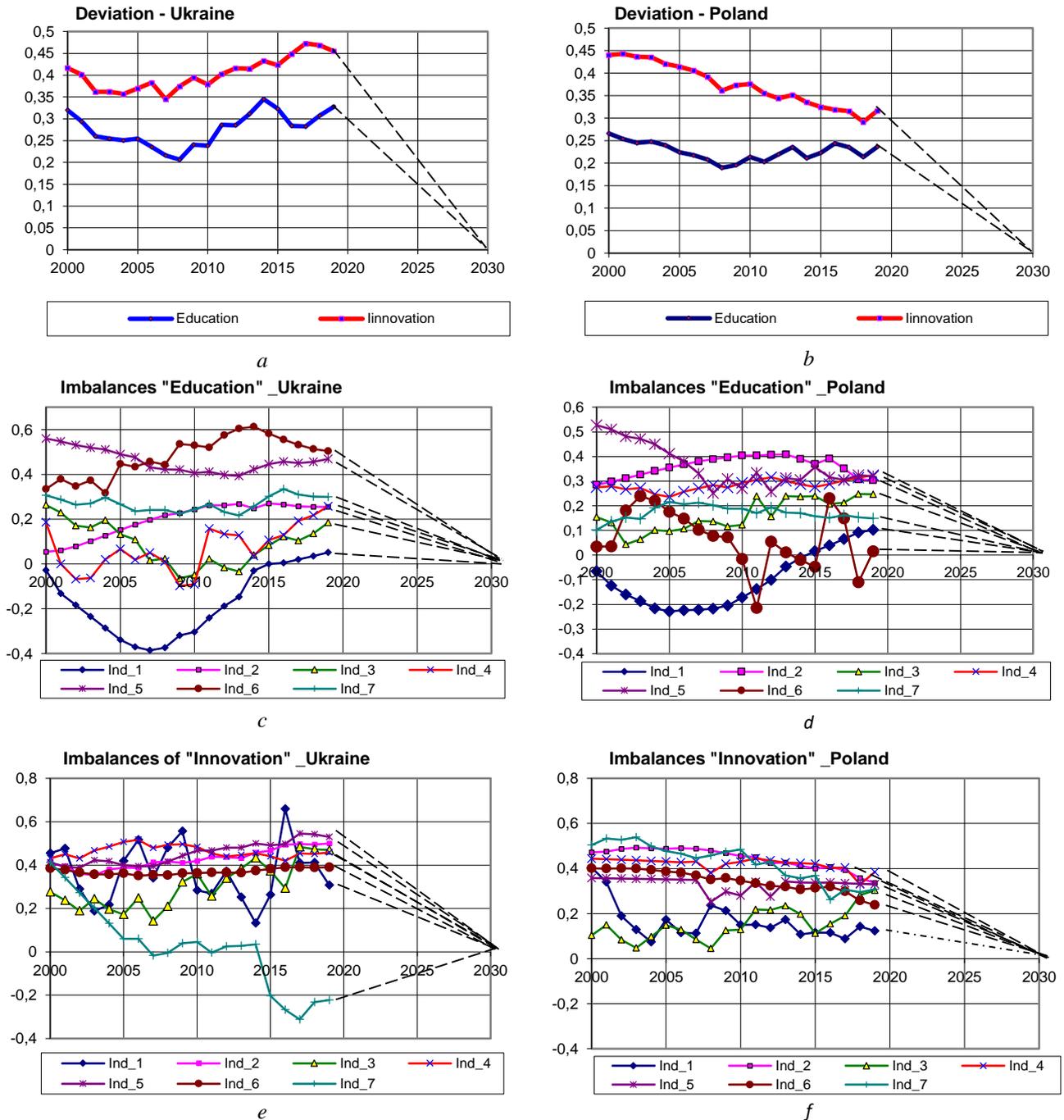


Figure 6. Dynamics of imbalances of research, education and innovative spaces of European integration

Source: own elaboration.

That is why the importance of the influence of individual components and indicators through calculating elasticity coefficients (4) (Table 4-5) is important for implementing regulatory actions aimed at reducing development imbalances.

Table 4. Critical threats and the importance of their impact on the level of research, education and innovation security of Ukraine

Components and indicators of research, education and innovation security - threats by remoteness from the criterion of sustainable development (importance of the threat)	Components and indicators of research, education and innovation security - threats in terms of the significance of the impact	Coefficient of elasticity
UKRAINE		
By components		
1. Innovation	1. Education	0.5812
2. Education	2. Innovation	0.4164
According to education indicators		
1. The level of capital investment in education, % of total expenditure on education;	1. The level of state funding of education, % of output;	0.1004
2. Average costs per 1 pupil (student), thousand US dollars /PPP;	2. Average costs per 1 pupil (student), thousand US dollars /PPP;	0.0998
3. The level of labour remuneration in education of output;	3. The level of higher education coverage, per 10 thousand population;	0.0982
4. The level of state funding of higher education, % of output;	4. The level of labour remuneration in education of output;	0.0981
5. The level of secondary education coverage, per 10 thousand population;	5. The level of capital investment in education, % of total expenditure on education;	0.0825
6. The level of state funding of education, % of output;	6. The level of state funding of higher education, % of output;	0.0617
7. The level of higher education coverage, per 10 thousand population;	7. The level of secondary education coverage, per 10 thousand population;	0.0391
According to indicators of innovation		
1. The level of innovative products' sales, % of total sales	1. The level of innovative products' sales, % of total sales	0.0671
2. The level of scientific research funding, % of GDP	2. The level of scientific research expenditures per person, USD for PPP);	0.0662
3. The level of financing the innovation activity, % of GDP,	3. The level of inventive activity (patents and utility models), per 1 million of population ;	0.0659
4. The level of enterprises' innovation activity, % of the total number;	4. The level of scientific research funding, % of GDP	0.0647
5. The level of scientific research expenditures per person, USD for PPP);	5. The rate of scientific and technological progress, %;	0.0592
6. The pace of scientific and technological progress, %;	6. The level of financing the innovation activity, % of GDP,	0.0545
7. The level of inventive activity (patents and utility models), per 1 million of population;	7. The level of innovation activity of enterprises, % of the total number;	0.0379

Source: calculated by the authors.

Table 5. Critical threats and the importance of their impact on the level of research, education and innovation security of Poland

Components and indicators of research, education and innovation security - threats by remoteness from the criterion of sustainable development (importance of the threat)	Components and indicators of research, education and innovation security - threats in terms of the significance of the impact	Coefficient of elasticity
POLAND		
By components		
1. Innovation	1. Education	0.5448
2. Education	2. Innovation	0.4527
According to education indicators		
1. The level of state funding of higher education, % of output;	1. The level of secondary education coverage, per 10 thousand population;	0.0961
2. Average costs per 1 pupil (student), thousand US dollars /PPP;	2. The level of higher education coverage, per 10 thousand population;	0.0942
3. The level of secondary education coverage, per 10 thousand population;	3. The level of labour remuneration in education of output;	0.0934
4. The level of state funding of education, % of output;	4. Average costs per 1 pupil (student), thousand US dollars /PPP;	0.0934
5. The level of labour remuneration in education of output;	5. The level of state funding of education, % of output;	0.0867
6. The level of higher education coverage, per 10 thousand population;	6. The level of capital investment in education, % of total expenditure on education;	0.0400
7. The level of capital investment in education, % of total expenditure on education	7. The level of state funding of higher education, % of output;	0.0396
According to indicators of innovation		
1. The level of enterprises' innovation activity, % of the total number;	1. The level of scientific research funding, % of GDP	0.0823
2. The level of scientific research funding, % of GDP	2. The level of scientific research expenditures per person, USD for PPP);	0.0807
3. The level of innovative products' sales, % of total sales;	3. The level of financing the innovation activity, % of GDP,	0.0766
4. The level of inventive activity (patents and utility models), per 1 million of population;	4. The level of innovation activity of enterprises, % of the total number;	0.0741
5. The level of financing the innovation activity, % of GDP,	5. The level of inventive activity (patents and utility models), per 1 million of population;	0.0668
6. The level of scientific research expenditures per person, USD for PPP);	6. The level of innovative products' sales, % of total sales	0.0481
7. The pace of scientific and technological progress, %;	7. The rate of scientific and technological progress, %;	0.0232

Source: calculated by the authors.

The results of the calculations show the fact that each country has its own "bottlenecks" in research, educational and innovative development. In terms of the components of "education" and "innovation", the component "innovation" most lags behind the level of the developed EU countries in Poland and in Ukraine, while "education" prevails in terms of the

importance of the impact. And this is quite logical, as the innovative capacity of scientists depends on the quality of education. If, according to the integrated education index, Poland balances at the level of the lower threshold value (*Figure 4, a*), Ukraine has a negative dynamic in the critical zone - below the lower threshold value. According to the integrated index of innovation after 2007, Poland has a positive dynamics of approaching from the critical to the crisis zone, and Ukraine has a negative one in the critical zone.

As for education indicators, the three most important critical threats to educational security in Ukraine are "the level of capital investment in education, % of total education expenditures," "the average cost per student, in thousand US dollars for PPP" and "the level of remuneration in education of output." The expected consequence of contempt for the financing of education in Ukraine is the critical level of almost all indicators of innovation. Another consequence of the current situation is the rejuvenation of the contingent of people with a doctorate degree with a simultaneous significant reduction in their scientific level.

The situation in Poland is somewhat better: the indicators "level of state funding of higher education,% of output", "the average costs per 1 pupil (student), thousand US dollars per PPP" and "the level of secondary education coverage per 10 thousand population" need improving, which determines the critical level of the following three indicators of innovation: "the level of innovative activity of enterprises,% of total", "the level of scientific research funding,% of GDP", "the level of innovative products' sales, % of the total sales".

Comparing the dynamics of integrated indices with integrated thresholds on the same scale allows setting strategic goals and building a trajectory of their achievement in a given perspective, i.e., implementing the principle "the future is determined by the trajectory into the future" (*Figure 5*). The most likely scenarios can be identified as follows:

for Poland:

1. *Realistic*: reaching the average level between the lower threshold and the lower optimal values.
2. *Optimistic*: reaching the level of the lower optimal value (entering the optimal zone of the EU).
3. *Scenario of balanced sustainable development*: reaching the level of average optimal value (homeostatic plateau) - the criterion of sustainable development.

for Ukraine:

1. *Realistic*: reaching the level of the lower threshold.
2. *Optimistic*: reaching the average level between the lower threshold and the lower optimal values;
3. *Sustainable development*: reaching the level of the lower optimal value (entering the optimal zone of the EU countries).

Strategic planning to achieve the target level of research, education and innovation security is carried out taking into account the trajectory of transferring the system from the current level

to the target one (Figure 5). Knowing strategic goals and desired values of the integrated index per each year determines the solution of the problem of decomposition of integrated indices, i.e., the synthesis of their necessary values using adaptive control methods from the management theory (Leondes, 1965; Aoki, 1965). To do this task, there is used the standard procedure of strategizing "Strategy" in the C++ programming language, developed by the author of the proposed method (Kharazishvili, 2019), which implements an adaptive method of regulation with a short feedback cycle (without a macro model). The long feedback mode is used for more serious research.

The reference to the standard procedure "STRATEGY" is carried out as follows:

$$F_{\min} = \text{strategy}(P, f, n_1, n_2, x, f_{zad}, p_{\max}, p_{\min}, eps, func) \quad (8)$$

where F_{\min} is the resulting error of the solution;

P is the vector of normalized indicators of the integrated index, from which the strategizing begins - the original vector of the desired values of the indicators corresponding to the specified value of the integrated index);

f is the initial value of the integral index;

n_1 is the initial number of the indicator;

n_2 is the end number of the indicator;

f_{zad} is the set value of the integral index;

p_{\max} is the vector of normalized maximum values of adjusted indicators;

p_{\min} is the vector of normalized minimum values of adjusted indicators;

eps is a set error of the solution;

$func$ is the function pointer that is called for computing the optimization criterion.

The initial vector of normalized indicators, the initial vector of normalized required values of indicators, as well as the initial vector of required values of indicators in natural (physical) measurement units through the use of the inverse normalization procedure are used for further calculations of macro indicators per each year of the future trajectory. The calculations give the following dynamics of the strategic values of the components and their indicators according to certain development scenarios (Table 6).

It is obvious that the calculated strategic values of indicators (these are relative values), which are determined by the ratio of macro indicators, can be obtained by many of their values, so it is necessary to link to the strategic values of some important macro indicator against which all other macro indicators can be calculated. Such a macro indicator can be "GDP per capita" at the current exchange rate "(Kharazishvili Y., Lyashenko V., 2019, p. 296).

Table 6. Evaluation of components' and indicators' strategic values of research, education and innovation spaces of the European integration at the end of 2030

<i>Indicators</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
UKRAINE			
research, education and innovation spaces	0.3561	0.4316	0.5071
Education	0.3616	0.4504	0.5464
- the level of higher education coverage, per 10 thousand population;	357.52	387.93	428.38
- the level of secondary education coverage, per 10 thousand population;	940.2	1008.1	1099.2
- the level of state funding of education, % of output;	2.447	2.891	3.444
- the level of state funding of higher education, % of output;	0.5035	0.5922	0.7031
- average costs per 1 pupil (student), thousand dollars US for PPP;	4.0346	6.356	8.793
- the level of capital investment in education, % of total expenditures on education;	3.3046	4.926	6.673
- the level of remuneration in education of output;	0.1861	0.2095	0.2397
Innovation	0.2116	0.3209	0.4268
- the pace of scientific and technological progress, %;	-2.214	-1.734	-0.991
- the level of scientific research funding, % of GDP	0.7047	1.192	1.756
- the level of financing the innovation activity, % of GDP,	0.4688	0.7621	1.1081
- the level of enterprises' innovation activity, % of the total number;	16.19	19.93	25.16
- the level of innovative products' sales, % of total sales	4.522	9.654	14.7
- the level of scientific research expenditures per person, USD for PPP)	117.63	248.24	378.8
- The level of inventive activity (patents and utility models), per 1 million of population	225.63	230.2	237.7
POLAND			
research, education and innovation spaces	0.4316	0.5071	0.6257
Education	0.4497	0.5446	0.6353
- the level of higher education coverage, per 10 thousand population;	336.37	383.17	375.0
- the level of secondary education coverage, per 10 thousand population;	927.54	1177.7	1497.5
- the level of state funding of education, % of output;	2.21	2.855	3.35
- the level of state funding of higher education, % of output;	0.4123	0.5179	0.86
- average costs per 1 pupil (student), thousand dollars US for PPP;	6.469	8.597	11.1
- the level of capital investment in education, % of total expenditures on education;	9.926	10.355	9.95
- the level of remuneration in education of output;	0.2453	0.2713	0.29
Innovation	0.3304	0.4371	0.6167
- the pace of scientific and technological progress, %;	-0.2435	0.0044	1.25
- the level of scientific research funding, % of GDP	1.64	2.223	3.0
- the level of financing the innovation activity, % of GDP,	1.145	1.527	2.0
- The level of enterprises' innovation activity, % of the total number;	26.19	34.63	52.5
- the level of innovative products' sales, % of total sales	11.01	14.27	22.5
- the level of scientific research expenditures per person, USD for PPP)	29.2	451.16	665.0
- the level of inventive activity (patents and utility models), per 1 million of population	10245	122.54	171.0

Source: calculated by the authors.

Construction of the probability density function of this indicator (exponential type of distribution) and calculation of statistical characteristics (*Figure 7, a*) for 64 EU and world countries makes it possible to calculate a scientifically sound vector of threshold values and build strategic scenarios for the growth of 'GDP per capita.'

For Poland:

1) *realistic* - achieving an average level between the lower threshold and lower optimal values, which corresponds to an average annual GDP growth of 2.2%;

2) *optimistic* - reaching the level of the lower optimal value, which corresponds to the average annual GDP growth of 4.3%;

3) *sustainable development* - achieving the average optimal value ("homeostatic plateau"), the criterion of sustainable development, which corresponds to an average annual GDP growth of 7.6%.

For Ukraine, similar scenarios are restricted to the most likely achievable growth rates:

1) *inertial* - which corresponds to an average annual GDP growth of 3.0%;

2) *realistic* - which corresponds to an average annual GDP growth of 5.0%;

3) *optimistic* - which corresponds to an average annual GDP growth of 7.0% (*Figure 7, b*).

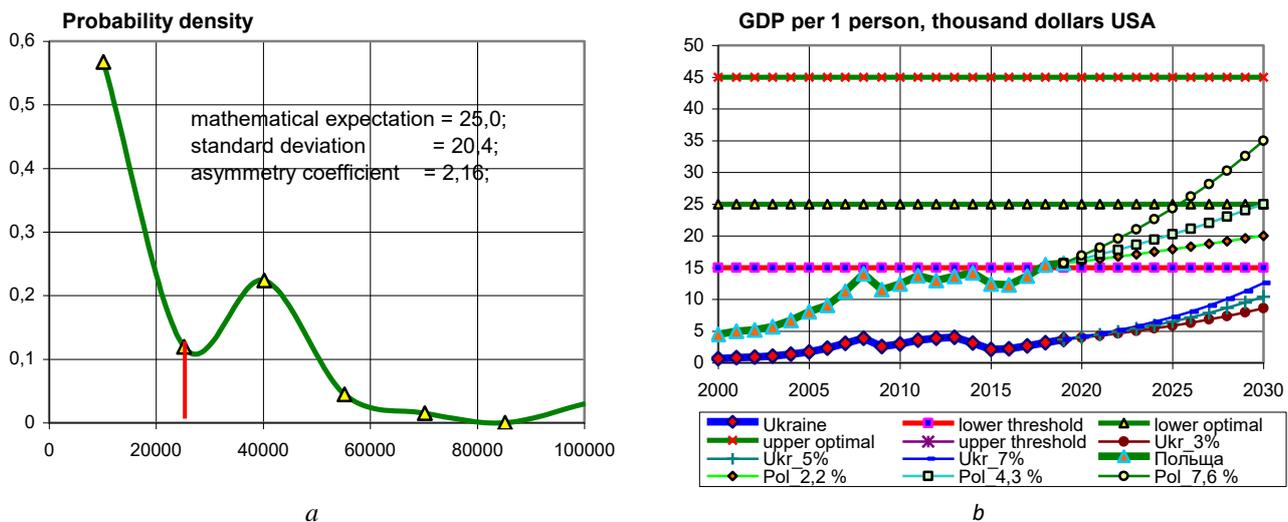


Figure 7. Determining threshold values (a) and strategic scenarios for the growth of the indicator "GDP per capita" for Ukraine and Poland

Source: own elaboration.

Thus, performing forecast calculations of the population size and the coefficient of manufacturability (ratio of GDP to output), we can obtain an assessment of strategic benchmarks of key macroeconomic indicators of research, education and innovation spaces of European integration in each year, the values of which at the end of 2030 * are given in *Table 7*.

Table 7. Estimating strategic benchmarks of key macro indicators of research, education and innovation spaces of European integration at the end of 2030

Indicator	2019	Scenario 1	Scenario 2	Scenario 3
UKRAINE				
1. Output, UAH billion	8969.9	21350.1	25051.5	29018.8
2. Coefficient of manufacturability	0.4431	0.455	0.47	0.49
3. Nominal GDP, UAH billion	3974.56	9714.3	11774.2	14219.2
4. Average annual GDP growth rate, %	3.2	3.0	5.0	7.0
5. GDP per 1 person, thousand dollars USA	3.67	8.58	10.39	12.55
6. Average annual population size, million people	41.85	41.68	41.68	41.68
7. The volume of education financing, UAH billion	200.76	522.47	724.3	999.57
8. Volume of higher education financing, UAH billion	41.428	107.49	148.35	204.03
9. Capital investments in education, UAH billion	4.792	17.26	35.68	66.71
10. Nominal salary, UAH	10378	34045	44978	59626
11. Number of students, million people	1.4397	1.4291	1.5506	1.7123
12. Number of pupils, million people	3.8094	3.7581	4.0294	4.3939
13. Expenditures on scientific research, UAH billion	19.9	68.457	140.396	249.71
14. Expenditures on innovations, UAH billion	14.22	45.547	89.727	157.57
15. Number of inventions, units	9536	9019	9202	9501
POLAND				
1. Output, PLN billion	4575.47	7690.4	9612.9	13458.1
2. Coefficient of manufacturability	0.5	0.5	0.5	0.5
3. Nominal GDP, PLN billion	2287.7	3845.2	4806.5	6729.1
4. Average annual GDP growth rate, %	4.5	2.2	4.3	7.6
5. GDP per 1 person, thousand dollars USA	15.69	20.0	25.0	35.0
6. Average annual population size, million people	38.419	38.268	38.268	38.268
7. The volume of education financing, PLN billion	86.34	170.0	274.4	450.85
8. Volume of higher education financing, PLN billion	16.5	31.71	49.79	115.74
9. Capital investments in education, PLN billion	8.4	16.87	28.42	44.86
10. Nominal salary, PLN	4944	8238	11387	17040
11. Number of students, million people	1.2057	1.2934	1.4734	1.4419
12. Number of pupils, million people	3.0658	3,5666	4.5286	5.7582
13. Expenditures on scientific research, UAH billion	30.28	63,06	106.87	201.87
14. Expenditures on innovations, PLN billion	21.52	44,03	73.38	134.78
15. Number of inventions, units	3555	3939	4712	6575

Source: calculated by the authors.

The calculated strategic guidelines of indicators and key macro indicators of research, education and innovation spaces of European integration in each year are a strategic plan for this area development and are the best criterion for estimating how effectively the

government and authorities of each country act by monitoring relevant indicators and macro indicators.

5. Conclusions

There were analysed the approaches to scientific elaboration and formation of the Strategy of integration of Ukraine and Poland into the research, education and innovation spaces of the EU, and the absence of a systematic approach was determined. No paper considers proposals for its own list of indicators and its own calculation of the current level of research, education and innovation spaces of European integration of Ukraine and Poland. There were formulated the remarks to the main tool for measuring the innovative development of the EU countries - the European Innovation Scoreboard (EIS), which concern both the list of evaluation indicators and the methodology.

There is proposed a systematic assessment of the level of research, education and innovation spaces of European integration of Ukraine and Poland, which consists of two subsystems: "education" and "innovation", for which a coordinated list of indicators for Poland and Ukraine has been developed. A total of 14 indicators are presented, 7 in each subsystem, including as the most important resulting indicator of qualitative changes in the economy, including innovation - the pace of scientific and technological progress.

For all indicators there were scientifically substantiated the limits of safe existence - vectors of threshold values at different levels through the construction of probability density functions, calculation of statistical characteristics, determination of affiliation to the type of distribution (normal, lognormal, exponential) and formalized calculation by "t-criterion" method. Such presentation makes it possible to identify the level of security of research, education and innovation spaces of European integration as a status of the system's security and its ability to adapt to new challenges.

To quantify the level of security of research, education and innovation spaces of European integration, a modern universal identification methodology was used, which provided a multiplicative form of the integrated index, a combined method of rationing and dynamic weights. Based on the proposed methodology, a multifactor hierarchical mathematical model for identifying the level of research, education and innovation spaces of European integration of Ukraine and Poland was developed and modeling was performed, which determined the current state of Ukraine as critical and tat of Poland as crisis.

Simultaneous hierarchical convolution of indicators and their thresholds makes it possible to compare integrated indices with integrated thresholds and scientifically substantiate the gradations of integrated indices as a critical, crisis and optimal states, as well as to identify strategic scenarios for medium-term development.

The calculation of deviations of integrated indices and their indicators from the criterion of sustainable development – the average value of "homeostatic plateau" – allows, by means of

defining imbalances, substantiating a list and importance of threats by the maximum deviation, and the calculation of elasticity coefficients – the importance of their impact on the level of education and innovation development in the security dimension. Such information provides substantiated directions of structural transformation of research, education and innovation spaces of European integration of Ukraine and Poland. Out of 14 indicators of research, education and innovation spaces, 12 indicators pose a critical threat to Ukraine and 9 indicators – to Poland.

One-scale comparison of integrated indices of education and innovation makes it possible to carry out the goal-setting stage, identify possible strategic development scenarios and build the desired development trajectories, i.e., to implement the principle of strategizing "the future is determined by the future trajectory." Thus, knowledge of the desired values of integrated indices in each year makes it possible, through their decomposition by the method of adaptive control from the theory of management, to justify the values of indicators that provide the desired growth trajectory and achieve definite goals of research, education and innovation spaces.

Constructing the probability density function for the indicator "GDP per 1 person / thousand USD" at the current exchange rate and determining its vector of threshold values made it possible to justify the strategic values of indicators and key macro indicators until 2030 according to development scenarios: for Poland - 20, 25 and 35 thousand US dollars with the corresponding average annual rate of real GDP growth - 2.2; 4.3 and 7.6%; for Ukraine - 8.6; 10.4 and 12.5 thousand US dollars with the corresponding average annual growth rates of real GDP - 3, 5 and 7%.

Thus, scientifically sound future values of indicators and macro indicators are the goal of strategic planning and the best criterion to estimate the effectiveness of authorities' and government's actions by monitoring current integrated indices and relevant indicators and macro indicators.

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