

Conceptual model of sustainable human capital development in the context of digitalization of the environment

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Abstract. Human capital reproduction is formed under the influence of environmental, social, economic and regional factors. There is a need for scientific and methodological approaches to the comprehensive analysis of the state of the ecosystem of human capital reproduction in order to form an effective model of sustainable development. The system of criteria for sustainable development in the conditions of digitalization based on socio-economic and environmental factors was formed. Algorithmic support for the system of comprehensive assessment of the state of the ecosystem of human capital reproduction, taking into account the effects of global identification of negative externalities in the management of natural resources, has been developed.

1 Introduction

With the transition to the post-industrial model of the economy, the types of resources are changing, which are used as a means of achieving economic development from material to human, as the main component of the productive forces. Human capital is becoming the national wealth main source accumulation, the role and its importance in ensuring socio-economic development increases, since human capital participates in the reproduction process, is the main condition for economic growth and is an inexhaustible resource for innovative development [1, 2].

Human capital, like any other capital, has peculiarities: it can economically change its value and be amortized; is inseparable from a person; to ensure its reproduction, investments are needed in the development of the social sphere and infrastructure; multiplies as a result of gaining certain experience and improving skills [3, 4].

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Analysis of the indicators existing system for a comprehensive assessment of the human capital development sustainability [5, 6] revealed the following problematic issues in managerial decision-making support:

- lack of a single agreed set of indicators capable of reflecting both the human capital reproduction system state and the processes manifestation level in it that stabilize external negative impact;
- impossibility of tracking the changes nature in the links between human capital and the environment at different levels of the digitalization study;
- inconsistency of criteria for assessing the systems state in terms of socio-economic and environmental aspects of human capital sustainable development.

Taking into account the methodological support development direction for a comprehensive assessment of the human capital state, it is advisable to turn to the formation of scientifically based methods for a systematic study of the totality of economic, environmental and social components in their consistency in accordance with the human capital real development.

2 Materials and methods

In contrast to existing approaches to the analysis of socio-economic systems, which involve determining the local components state and presenting a generalized result [7, 8], it is proposed to implement the transition from the global to the micro level of human capital development.

The formation of a human capital sustainable development methodological assessment is considered from the standpoint of research universalization at the global, macro and micro levels, taking into account the manifestation of socio-economic and environmental aspects of systems in accordance with the self-organization processes synergetics [9, 10]. The human capital reproduction system state in a complex sense is assessed by the research sequential implementation:

- global level - assessment of the human capital reproduction systems general state through determining the digitalization potential;
- macro level - general characteristics of environmental friendliness of natural and technogenic systems in accordance with the systems analysis results;
- micro level - assessment of specific factors and violations processes of the ecosystems stationarity in accordance with the risk analysis of slowing down the human capital sustainable development.

The generalized ecological and economic assessment allows to focus on the study of the human capital development sustainability in order to establish the technogenic objects functionality compliance with the territorial complexes natural stationarity requirements, to determine the socio-economic objects destabilization factors to draw a conclusion about the human capital reproduction system effectiveness [11, 12].

At the macro and micro levels of the study, the changes elements and factors in the human capital reproduction are determined in order to identify the system stationarity violation processes and the processes of its stabilization. A systematic analysis of the destabilization states identification in the research object allows, first of all, to identify the disturbances factors that need to be neutralized, and the stabilization factors that should be activated in the digital economy [13, 14].

At the study global level, it is carried out to determine the resources availability correspondence in the ecological system S taking into account the consumption volumes, sustainability and the changes consequences in its natural state ΔU from the territories anthropogenic load in the form of an entropic shift ΔQ :

$$S = \Delta Q / \Delta U \quad (1)$$

The environmental friendliness coefficient of the human capital reproduction system HC_e is defined as the conditions ratio for preserving the natural environment from production to the amount of consumed natural resources R in the digitalization context:

$$HC_e = (1 - S) / R \quad (2)$$

The digitalization effect less losses from the impact on the human capital reproduction environment exceeds environmental externalities if the coefficient $HC_e > 1$. Systems for which the condition $HC_e < 1$ is not met are environmentally ineffective, since the net return from the natural resources use is not comparable with their value.

The human capital reproduction system sustainability at the macro level is determined based on the resources total amount characteristics that must be spent:

$$L_{ij} = \sum_{i=1}^N S_i K_i y_j / Q_j \quad (3)$$

where S_i is the intensity of the i the negative factor for the human capital reproduction ecosystem component; K_i is the concentration of the i the negative factor in the j the system in the amount y_j , that has productivity Q_j .

3 Results

The multi-criteria assessment determines the negative factors of impact on the human capital reproduction ecosystem in three components: environmental, economic, social.

The methodology for assessing the human capital development sustainability at the macro level provides for the identification of regions with a high level of danger based on an analysis of the environmental components state and the life quality violation problems priority in order to effectively eliminate risk factors affecting the human capital reproduction, as well as scientific and practical substantiation of measures to preserve and maintain functionality of ecosystem components [15, 16].

The ecological risk E at the macro level as the environmental objects stability disturbing probability depends on the existing state of the ecosystem and the anthropogenic pressure impact on territorial complexes. The environmental sustainability violation probability and the degradation processes development of the i the component of the human capital reproduction ecosystem in the negative factors presence is calculated by the equation:

$$E = 1 - \prod_{i=1}^N (1 - E_i) \quad (4)$$

where E_i is the probability of disrupting the human capital reproduction ecosystem sustainability.

The ecological risk ER of the considered state of the i the component of the human capital reproduction ecosystem is estimated according to the probabilistic characteristics of the discrepancy:

$$ER_i = -E_i \ln(E_i) \quad (5)$$

The application of the safety management principles presupposes a rational distribution of resource costs to reduce various types of risk with ensuring the achievement of such a level

of ecosystem quality, guaranteed in a given society by the development of economic, social standards and technical and technological capabilities [17, 18].

To take into account the random, stochastic, probabilistic nature of the systems transition, which at the macro level, with the manifestation of a negative reaction of the processes, can be hidden by the average values of the general indicators, an analysis of the human capital reproduction system ecological state at the micro level is carried out.

At the micro level, the analysis of technological and economic aspects of the organizations activities for the implementation of measures aimed at mitigating the human capital reproduction dysfunctions is carried out, taking into account the negative factors action implementation probability. For the established conditions of the minimum acceptable risk, a decision is made to regulate the situation in order to return the environmental subsystems stability.

A systems analysis of multifactorial risks for the i the components of the ecosystem is carried out in a generalized information form with their specification when solving problems for certain objects and conditions of their functioning. Each j the indicator of the component of the z_{ij} l the risk factor system is determined by the vector H_{ij} :

$$H_{ij} = \{z_{ij} | z_{ij} = \langle z_{jl} | l = 1, \dots, N_{ij} \rangle; z_{ij} \in Z; j \in N\} \quad (6)$$

The ecological risk factor l is characterized by an indicator of anthropogenic load. Anthropogenic load as a cause of disturbance in the ecosystems stability is established in accordance with the values of indicators a_{ij} :

$$A_i = \{a_{ij} | i \in N; j = 1, \dots, N_i\} \quad (7)$$

where A_i is the level of anthropogenic load on the j the ecosystem component, causing the i the type of the human capital development negative consequences risk; N is the number of risk factors of the i the type of anthropogenic load impact on the j the component of the ecosystem.

Environmental risks are characterized by stochasticity, uncertainty of processes in natural and technogenic objects, uncertainty of delayed reactions, as well as self-organization of negative effects.

Reducing the human capital sustainable development risks in the digitalization context is achieved through the competitiveness of digital technologies based on:

- compliance with the requirements of the sustainable development concept;
- economy by reducing compensation for damage when introducing digital technologies;
- certification according to the level of compliance with environmental quality standards.

An algorithm has been developed for a multicriteria analysis of the impact on the human capital reproduction with the establishment of destabilization dangerous factors at each stage of the study.

- Analysis of the human capital reproduction ecosystem.
- Determination of the human capital reproduction ecosystem structure.
- General assessment of the human capital reproduction ecosystem.
- If $L_{ij} > 1$, then there is a discrepancy between the ecosystem objects and the sustainable development requirements. Identify alternatives and proceed to step 1.
- Analysis of the research system components state.
- Risk analysis of the human capital reproduction ecosystem.

- If $0 < E \leq 1$ and $0 < ER_i \leq 1$, then determine the phenomenological analysis content. It is necessary to identify the processes of stabilization of the human capital reproduction quality control elements.
- Stabilization of the research system object state.
- Multi-criteria analysis of the human capital sustainable development risks in the digitalization context.
- If $0.5 < H_{ij} \leq 1$, then go to step 7.
- Elimination of destabilizing elements of the human capital reproduction ecosystem.

Management decisions to stabilize the human capital reproduction ecosystem are determined on the basis of economic and social criteria. Economic criteria in terms of content are responsible for the loss of the economic value of the human capital reproduction in the digitalization context. The economic effect characterizes, on the one hand, the benefits from digitalization, and on the other hand, economic losses. Such damage is determined by the needs of society in their comparison with the costs necessary to prevent the negative impact of digitalization. Economic criteria are calculated using the following equation:

$$U = (\sum_{i=1}^M (X_i^+ - X_i)^2)^{1/2} / (\sum_{i=1}^M (X_i^- - X_i)^2)^{1/2} + (\sum_{i=1}^M (X_i^+ - X_i)^2)^{1/2} \quad (8)$$

where X_i is the economic efficiency from the human capital reproduction in the digitalization context (e-commerce, blockchain, electronic payments); X_i^+ is the maximum value of the economic efficiency; X_i^- is the minimum value of the economic efficiency.

The social criterion for assessing the human capital reproduction ecosystem state determines the level of the population's health:

$$P = 1 - e^{Y_H/Y_E} \quad (9)$$

where Y_H is a complex indicator of the population incidence; Y_E is a complex indicator of the environmental pollution.

For the practical implementation of the methodology for a comprehensive ecological and economic assessment of the human capital reproduction ecosystem, it is necessary:

- normalize the complex assessment criteria to the same dimension and intervals of possible values;
- compare each of the indicators with its acceptable value;
- combine all indicators into a single comprehensive assessment based on various principles of optimality.

4 Discussion

Mathematical support for a comprehensive assessment of the human capital development sustainability contains the results of a sequential analysis of human capital reproduction indicators at different levels of research. The application of the proposed assessment system will make it possible to balance the ratio of environmental, economic and social criteria with each other and to achieve a certain level of anthropogenic load that does not violate the sustainable development of human capital in the digitalization context. To increase the social criterion, it is necessary to reduce the probability of unfavorable factors affecting the population incidence, which is achieved by eliminating the diseases causes and introducing preventive measures. To increase the economic criterion, it is necessary to increase the costs aimed at preventing negative pollution, environmental and social benefits from digitalization, which include taxes, payments to the local budget, investment obligations aimed at developing the social sphere and infrastructure.

Scientific and methodological approaches have been developed to a comprehensive analysis of the human capital reproduction ecosystem state in terms of the sustainable development content on the basis of the system of socio-economic and environmental assessment and risk analysis with the negative externalities identification.

5 Conclusion

The human capital reproduction ecosystem sustainability is the correspondence of homeostasis for its constituent subsystems to the safety requirements for the following indicators: economic - maximizing production efficiency in the digitalization context; ecological - support at the optimal level of biological productivity of ecosystems; social - maximizing public health.

The human capital sustainable development conceptual model in the digitalization context makes it possible to establish the compliance of quality regulation of the studied objects in socio-economic and environmental aspects with the requirements of safety management, taking into account the acceptable risk concept.

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