Development of a simulation model for the development of socio-ecological-economic systems in the process of making innovative decisions

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Abstract. The article presents market indicators that have the most significant impact on the development of socio-ecological-economic systems in the process of making innovative decisions. When developing recommendations for the use of models, a detailed analysis of the modeling results and its practical significance for assessing the performance of socio-ecological-economic systems is provided. A structural and logical model of the system is proposed that ensures the consistency of goals, plans, tools, budgets, indicators and results of implementing strategic changes in the process of its long-term development. The study and assessment of socio-ecological and economic indicators is proposed to be carried out using methods of simulation modeling and statistical data analysis. The article presents developed multifactor statistical models that determine the type and strength of relationships between indicators of socio-economic development of systems, as well as a simulation model that allows assessing the dynamics of these indicators. The proposed model apparatus for managing the competitive development of a system ensures that the indicators that shape its development are taken into account and allows, based on modeling of various economic situations, to analyze the state of the system and optimize the behavior of its subjects. A new approach to simulation modeling of infrastructure facilities is proposed. The tools developed within the framework of the approach for preparing and conducting large-scale experiments in a heterogeneous computing environment are based on a microservice architecture.

1 Introduction

The relevance of the study is confirmed by the lack of a perfect method to maximize the efficiency of the analysis, which requires a significant expansion of existing practice on issues of socio-ecological and economic development and determines the search for ways to

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make the most optimal decisions in conditions of uncertainty and instability of the macroeconomic environment.

Currently, simulation modeling methods and tools are widely used in studying the properties and processes of functioning of infrastructure facilities. Such objects form the basis for the life of a variety of technical, economic, cultural, social and other systems. Therefore, the results of modeling infrastructure facilities often make it possible to significantly improve the operating efficiency of such systems and ensure the adoption of optimal decisions on their creation and development. However, an analysis of the modern development of tools for the development and application of simulation models of infrastructure facilities shows the presence of a number of problems [1]. These include the complexity of developing the models themselves, organizing multivariate calculations using distributed computing, ensuring efficient use of the resources of a heterogeneous computing environment, supporting flexible and convenient end-user access to simulation models for the purpose of organizing and conducting large-scale experiments.

Simulation modeling is implemented through a set of mathematical tools, special computer programs and techniques that allow using a computer to carry out targeted modeling in the "simulation" mode of the structure and functions of a complex process, as well as optimization of some of its parameters. A set of software tools and modeling techniques determines the specifics of the modeling system and the possibility of its use for modeling processes in socio-ecological-economic systems [2, 3].

It is important that when running interacting computational processes in a computer, which are, in terms of their time parameters - accurate to the scale of time and space - analogues of the processes under study, an adequate picture of the behavior of the system under study is obtained.

It should be taken into account that when studying socio-ecological-economic systems, it is advisable to analyze the behavior of these systems through the behavior of their subjects on the basis of a multi-agent approach, taking into account the role of individual active agents and their influence on the processes occurring in the system [4].

In general, the theoretical justification for the development of such a problem-oriented decision support system should include the implementation of several sequentially interrelated stages that determine the main design features. As part of the conceptual stage, it is necessary to clearly define the basic principles and requirements for the development of decision support tools in relation to the task of developing innovative development strategies. The key principle of the study is a systematic approach, which consists in the need to analyze all the main elements and interrelations of the system that form the basis for innovative development, as well as a description of their most significant properties and determining factors of innovative development.

2 Methods and materials

To build a simulation system, algorithms were developed that made it possible to carry out several series of experimental calculations. Sustainable development for the long term assumes that the amount of renewable resources should at least not decrease over time and ensure a regime of simple reproduction; the maximum possible slowdown in the rate of depletion of reserves must be achieved; waste generation should be minimized - based on the introduction of waste-free and resource-saving technologies [5].

An analysis of the calculations carried out showed that, based on the information provided by experts during the experiment on a computer, it is possible to select an option for the development of socio-ecological-economic systems that will allow the system to be at the current level of technological development, that is, it makes it possible to conduct research in the following areas.

- determine the best ways to make decisions in individual blocks from the point of view of obtaining optimal results for the system as a whole;
- select the most effective technologies or their combinations at various stages of the management process;
- explore the properties and quantitative parameters of direct and feedback connections between blocks and change them if necessary [6, 7].

The study of various models of development of socio-ecological-economic systems in the process of making innovative decisions using methods of economic and mathematical modeling allows us to fix functional connections between the technological structure of the economy, investment policy, environmental conditions and the scientific research sector of the economy.

Having determined the nature of these connections, it is possible to approach the management of parameters that influence the process of modernization of socio-ecological-economic systems.

The algorithm for generating input parameters of the simulation model (scores of indicators used in the calculation process) is similar to that used previously in [8, 9]. Experts set interval estimates (localization ranges) of future indicator values, then the program averages their minimum and maximum values and uses these values as input parameters of the model; this uses the resulting beta distribution (or normal distribution). Note that the generation algorithm used allows us to correctly take into account the opinions of all experts (in "aggregated" form) and is simple enough to carry out calculations. During the calculations of individual indicators, their groups and the integral level of EBR, the method of linear convolution (linear combination of local criteria) was used; the importance coefficients of indicators and their groups were assessed based on averaging expert analysis data.

Modeling the development of socio-ecological-economic systems using the system dynamics method in conjunction with statistical analysis methods makes it possible to establish dependencies between indicators and predict changes in the behavior of the system in the future [10, 11. 12]. Using the developed methodology for the development of socio-ecological-economic systems in the process of making innovative decisions with a simulation model to obtain predictive values when calculating an integrated assessment, which will allow making an informed decision on the development of socio-ecological-economic indicators and taking into account differences in infrastructural shifts, as well as dynamics indicators.

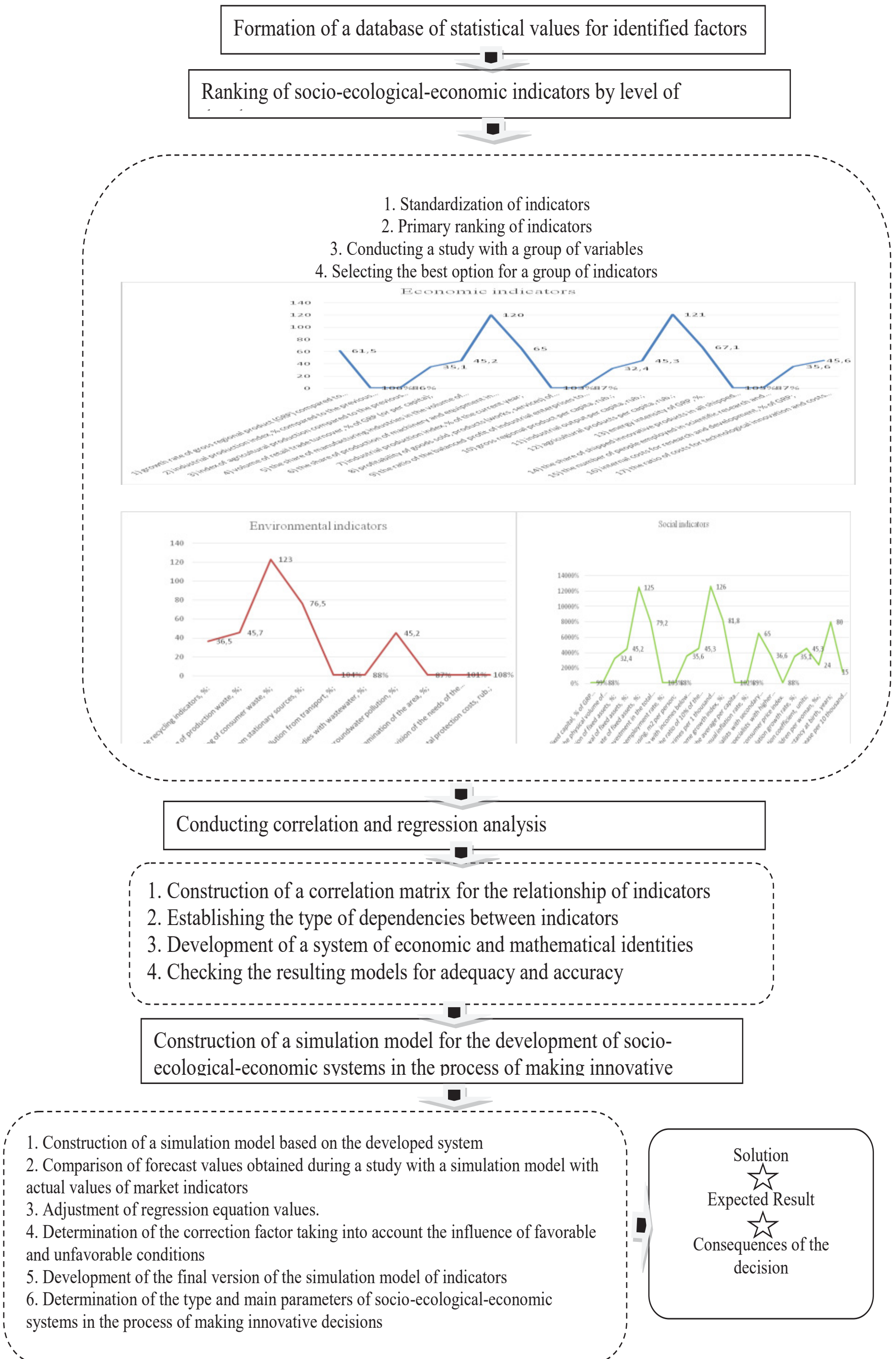

Fig. 1. Main stages of modeling the development of socio-ecological-economic systems

3 Results and discussion

In the course of calculations using several thousand simulations, data for environmental, economic, and social indicators were obtained and statistically processed. The results of calculations of the integral distribution functions 1 – F for the analyzed indicators are presented in Figure 2 (a 10-point scale is used). Let us recall that the integral distribution functions 1 – F allow us to estimate the probabilities that the values of groups of indicators determined by the method of linear combination of local criteria will be no less than any value of interest [13].

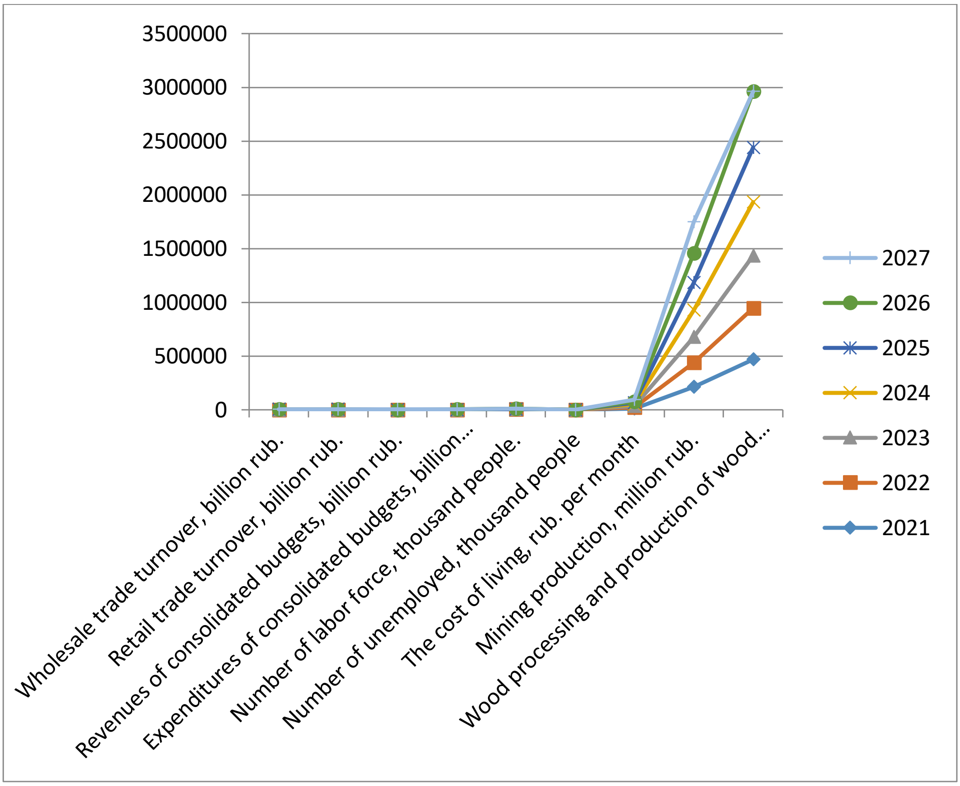

Fig. 2. Probability distributions 1 – F for individual groups of indicators

The results characterize the EDB in aggregated form. Obviously, it is often more important to examine individual indicators, taking into account their threshold values. The model and simulation calculation program make it possible to obtain information about the distribution of individual indicators. The figure shows that the spread of data on individual indicators is quite large, which characterizes significant differences in expert opinions and is typical for forecast analysis [14, 15,16].

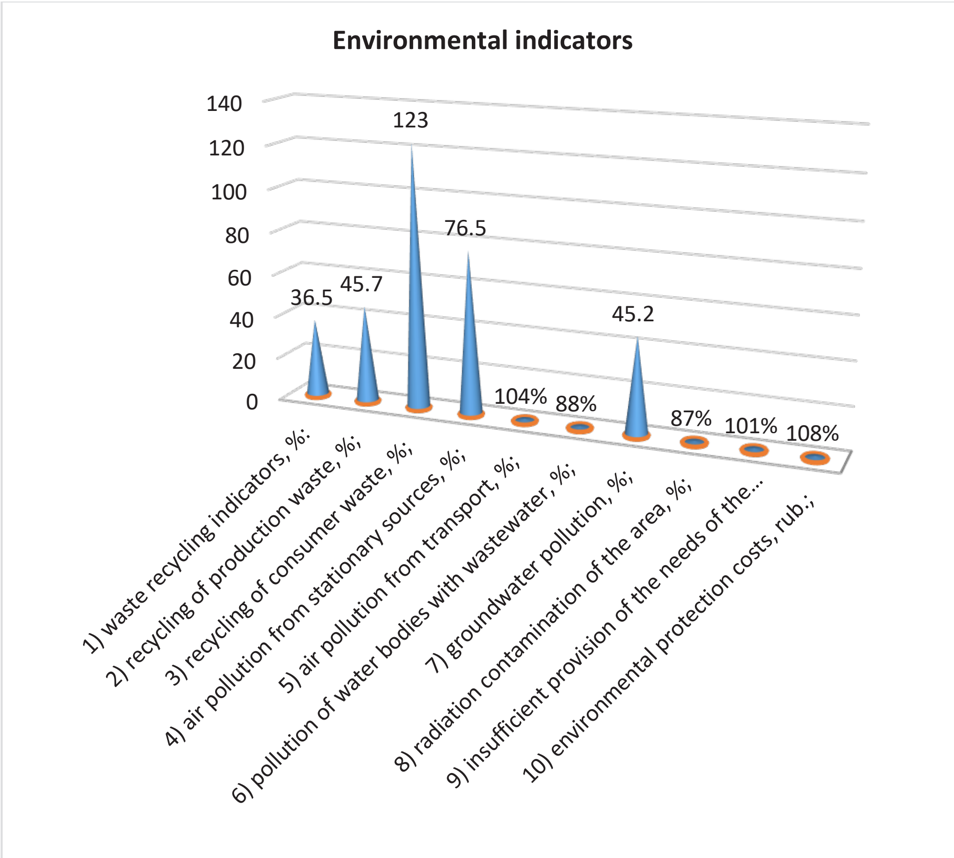

Fig. 3. Results of simulation calculations for individual groups of indicators

The spread of parameter values is a "necessary evil" and a kind of "calling card" of both simulation and regression models. Indeed, accurate forecasts are practically impossible to implement even in the short term, which does not allow obtaining deterministic indicator values. Note that with a greater "degree of agreement" among the members of the expert group, the width of the intervals will decrease.

Experimental calculations based on the above models of various mechanisms of innovative development make it possible to [17, 18]:

- assess at a quantitative level the effectiveness of managing scientific and technological development of the economy and the participation of the private sector in this process;
- determine the parameters of the interdependence between effective demand for innovation and the corresponding growth in production and scientific research.

4 Conclusion

To study socio-ecological-economic systems, the simulation method was used. The choice of method was due to the fact that it was necessary to solve multivariate problems, and the solutions largely depended on expert assessments and the ability to view various options in the machine experiment mode. The validity of the choice of simulation modeling method and the analysis of the constructed models is a very complex and multifaceted process. When developing and building models, much attention was paid to this issue. Let us note a number of elements included in the justification of simulation models. Thus, the developed model complexes consist of a large number of simple models, for which mathematical elaborations and interpretations are well known. The sensitivity of the models to changes in various parameters is easily visible from the algorithms used; some of them were selected as a result of numerous machine experiments. Thus, the developed simulation model allows us to analyze the identified and formalized numerous relationships between environmental, social and economic aspects of the system's development and determine the conditions for the growth of the number of competitive entities. Research into relationships using this model provides the development of scientific recommendations for managing socio-ecological-economic systems in the process of making innovative decisions [19, 20].

The prospects for further scientific research by the authors lie in modeling the processes of optimal distribution of resources of the socio-ecological-economic system, as well as in developing methodological tools for analyzing the strategic management system of an enterprise in the digital economy.

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