Environmental and socioeconomic interconnection models and algorithms for managing competitively sustainable regional development

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Abstract. The relevance of the work is stipulated by the need to develop a measurement toolkit of energy, environmental, social, and economic processes in the focus of interdisciplinary research. The aim of the research is to form an objective tool for measuring the state of regional systems, taking into account the interrelation of environmental, social, and economic processes. The methodological basis of the work is physical and economic indicators reflecting the interrelation of natural and economic processes. The main hypothesis put forward is that it is possible to build an integral index that objectively describes the model of competitively sustainable development of regions in the context of the interrelation of energy, environmental, social, economic processes. The results of the study have shown that the physical-economic (natural-physical) law operating in economic life, in the economy is the law of conservation of energy (power) flow, and the methodological basis for the construction of an integrated model of regional development should be the requirements arising from the law of conservation of energy (power) flow. The work is the result of theoretical, methodological, and applied research on systemic natural-scientific analysis of development management in socioeconomic systems considered in interaction with the environment. The results of the study contribute to the understanding of methodological possibilities of non-monetary measurement and on this basis the construction of a multilevel complex model in terms of natural-scientific indicators. The analysis of the results of application of the developed models allows to reveal conditions and limitations of energy, ecological, social, economic development of regions.

1 Introduction

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2 Theoretical approaches to building a model and algorithms for regional development management
Time formulated the concept of sustainable development, suggesting that development should meet the needs of the current generation without depriving future generations of the opportunity to meet their needs [1, p. 24]. At the 1992 Earth Summit, the principle of environmental protection to achieve sustainable development was fixed in the Rio Declaration on Environment and Development [2]. Since then, we can talk about the official international formalisation of the ecological-socio-economic concept of regional development management. Moreover, the level of consideration of regions can be different: from separate administrative-legal territories within the state to interstate formations.

Several aspects of consideration of this issue should be emphasised. Along with the change of approaches to the consideration of social progress, the scientific understanding of the measurement of life processes began to change. If in the period from 1920s to 1960s the approach to measurement through economic indicators (monetary units, GDP, GRP, etc.) prevailed, then already in the second half of the XX century social indicators of well-being began to be introduced. Environmental indicators began to be actively added to them in the 1990s. Today, science comes to realise the need to improve the measurement tools for managing regional development.

The emergence of an expanded model of ecological-socio-economic indicators, taking into account a set of heterogeneous metrics, strengthens the concept of sustainable development. However, the creation of a system for assessing the quality of life, consisting of hundreds of indicators of different dimensions, does not allow to generalise them according to all the rules of science, so that the principles of reliability and compliance are perfectly observed. The lack of compatibility of social, economic and environmental metrics has led to a tendency to search for a universal measure of development. For example, the UN Commission on Basic Indicators of Economic Activity and Social Progress with the participation of Nobel laureates in economics D. Stiglitz and A. Sen proposed the quality of life as an integral category for such a measurement, allowing to go beyond the monetarist approaches [3].

International Scientific School of Sustainable Development named after P.G. Kuznetsov. International Scientific School of Sustainable Development promotes the concept of objective, physical-economic criteria for measuring the quality of life and regional development [4]. Such a value is power as energy per unit of time (unit of measurement - kW).

There are examples of independent confirmation of the correctness of the obtained theoretical conclusions stating the dependence between economic efficiency and reduction of losses of full capacity of production systems, i.e. "the less waste today, the more income tomorrow", which is one of the analytically expressed consequences of the law of conservation of capacity in projection on the socio-economic environment.

The UN definition of sustainable development contains two concepts: opportunity and need, which are necessary for the preservation and development of systems of any nature and purpose. Opportunity is the ability of an object to perform work for a certain time or power (work capacity per unit of time), which the object has in the system of nature-society-human. Need is an increased possibility (capacity), which the object does not have at a given time, but which it needs to have for its preservation, growth and development in the system of nature-society-human. Every satisfied need is at the same time a new or increased possibility. And any new increased opportunity is perceived as a satisfied need [4, p. 249].

Ecological-socio-economic development is the result of purposeful change of the management object (system) in the supersystem "man-society-nature" (Fig. 1) [4, p 81, 291]. In this case, the management of ecological-socio-economic development is effective if three pairs of conditions in the supersystem "man-society-nature" are satisfied.
3 Methodological approaches to building a model and algorithms for regional development management
are the measures related and how to measure sustainable development of systems of different levels?

As an example, we can cite various systems of sustainable development indicators: environmental-economic accounting system, human development index (until 2013 Human Development Index (HDI)), real progress index and sustainable economic well-being index, true progress indicator, international happiness index, Physical Quality of Life Index (PQLI), Gross National Happiness (GNH), Economist Intelligence Unit quality of life index, Vanderford-Riley well-being plan, Vanderford-Riley Quality of Life Index (VQLI), and other indicators.

The development of ecological-socio-economic models attracts the attention of many researchers. For example, the work of I.N. Pustovit and V.A. Prilipko proposes a method of setting criterion indices to determine the level of socio-ecological situation in a given territory. This method involves the use of two approaches: 1) the creation of an information and methodological bank that combines a database of experimental environmental and social indicators and a database of standard indicators that are monitored. 2) Construction of integral indicators, which are measured in points.

Other researchers (V.I. Khavronichev and G.M. Tyulyu) consider an integral rating of socio-economic development as a resultant attribute for analysing the impact of environmental factors on socio-economic development, while the factor attribute is a composite environmental index.

Another solution to the problem is presented in the work of I.A. Zabelina in the form of a multiplicative model based on the extended welfare function of A. Sen. In the work by E.V. Ryumina, a variant of the environmental index is proposed based on the number of air and water samples exceeding the MPC as a percentage of the total number of samples studied.

In the works of foreign researchers, the problem is often considered in the context of building integral environmental indices. In the work of G. Balaganesh, Ravinder Malhotra, R. Sendhil, Smi Sirohi, Sanjit Maiti, K. Ponnusamy, Adesh Kumar Sharma the index calculation was based on the approach of the Intergovernmental Panel on Climate Change using impact, sensitivity and adaptive capacity. In another article authored by Md. Galal Uddin, Stephen Nash, Agnieszka I. Olbert gives an overview on water quality assessment indices and their development since their first mention. According to this paper, water quality assessment models typically involve four sequential steps: (1) selection of water quality parameters, (2) generation of sub-indices for each parameter (3) calculation of parameter weights and (4) aggregation of sub-indices to calculate an overall water quality index. Another example of work done in this direction is the work of Traci P. DuBose, Gina K. Himes Boor, Margaret Fields, Elizabeth L. Kalies, Ana Castillo, Matthew P. Moskwik, Jeffrey F. Marcus, Jeffrey R. Walters. In their works, the authors provide arguments in favour of using the remote sensing index method.

The analysis of domestic and foreign studies on the problem of measuring sustainable development has revealed a number of advantages and disadvantages.

Advantages:
- The factors determining the sustainable development of society, accelerating and slowing down the pace of development are clearly distinguished;
- The formal-logical connection of ecological social, economic components is shown.

Disadvantages:
- There are no indicators that make it possible to determine environmental, social and economic development in commensurable values;
- Sustainability of development is analysed on the basis of subjective expert assessments;
- There is no comprehensive consideration of the development of social and natural systems.
The analysis has shown that the methodology used by the expert community to construct sustainable development indicators is based on heterogeneous, disparate and incomparable measures, and the normalisation procedure is used to perform arithmetic operations. However, the normalised indicators are also heterogeneous, as they are based on heterogeneous values expressed in non-comparable indicators, which generates false estimates and, as a result, ineffective management. It is impossible to make the transition to sustainable development without having a clearly formulated goal in terms of measurable values. If there is no compatibility between the measures of the object and the subject of management, it is impossible to judge the sustainable development of the system as a whole.

To resolve the contradiction between society and the natural environment, it is necessary, first of all, to learn how to measure different-quality social and natural processes-flows. It is necessary not just to measure them, but to measure them in the same units. If we set the task of comparing public resource flows measured in monetary units and natural resource flows in natural measures, the comparison turns out to be impossible, and, therefore, the above-mentioned questions remain open.

The hypothesis of the study is that it is impossible to produce a single product, good, service without spending time and energy or energy flow, i.e. power, and any socio-economic system cannot exist without interacting with its natural environment and combines two conjugate processes: the active flow of impacts on the environment, which determines the capabilities of the system, and the use by society of the flow of resources resulting from this impact to meet the needs of the system. There is a relationship between the capabilities and needs of a socio-economic system:

- the opportunity measure is the capacity for a given time (energy flow or energy per unit of time);
- the demand measure is the increased capacity, which the system does not have at the given time, but which it is necessary to have for the transition to sustainable innovative development.

In most works, the choice of methods for building a comprehensive model of regional development is made on the basis of criteria "adequate to the specific situation", which include:

1. validity. The method should correspond to the type of the problem to be solved.
2. Cognitiveness. It is necessary to take into account the time expenditure of the decision-maker (LPR) necessary for the application of the method.
3. Efficiency. The method should provide an opportunity to perform the maximum number of operations on the computer and lead to the final result.
4. Verifiability. The method should allow the possibility of verifying the reliability of the information that the decision maker (DM) provides as input data.
5. Sensitivity. For operations performed by the DM, the method must be insensitive to changes in the number of criteria and alternatives, i.e. in the case of adding or deleting criteria and alternatives, the DM's involvement in the application of the method is required only with respect to these changes.

The listed requirements are necessary in solving current management tasks, but insufficient in designing and managing sustainable innovation development. As a result of systematisation and analysis of publications, methodological requirements to the construction of a comprehensive, ecological-socio-economic model of regional development were formulated:

1. The use of measurable quantities reduced to a single measure (unit of measurement) for systems open at the input and output by energy (power) flows;
2. Construction of the model in accordance with the law of power conservation and the principle (criterion) of sustainable development expressed in terms of natural-scientific indicators;
4 System-energy approach taking into account the interconnection of environmental, social, economic processes

All systems of the surrounding world can be divided into equilibrium and non-equilibrium (Fig. 2), the essence of which is associated with the exchange of energy flows with the external environment and can be defined as follows [4, p. 128]:

1. the total energy of the systems is constant or not constant (the system evolves);
2. the free energy (exergy) flux is zero or different from zero (the system has the ability to do external work);
3. free energy (exergy) dynamics (tends to minimise or increases);
4. the system is closed or open (there is an exchange of energy flows with the external environment).

Fig. 2. Classification of systems

Non-equilibrium systems are divided into two classes:
1. systems evolving towards the state of equilibrium;
2. systems evolving from the state of equilibrium.

The essence of the first class of non-equilibrium systems is determined by the law of increasing entropy. According to this law, the evolution of non-equilibrium systems is carried out in the direction in which the ability of the system to perform external work with the passage of time decreases. The main properties of non-equilibrium systems evolving to equilibrium follow from this law:

1. the flux of total energy is monotonically decreasing (total power is decreasing);
2. the flow of free (transformable) energy (exergy) decreases (the ability to do external work decreases) (useful power decreases);
3. the flux of coherent (irreversible) energy (anergy) increases (power losses increase).
Dissipative (energy dissipating) processes belong to this class of non-equilibrium systems.

The essence of the second class of nonequilibrium systems is determined by the principle of stable nonequilibrium, known in science under the name of the E.S. Bauer-V.I. Vernadsky law. According to this law, the evolution of this type of systems is carried out in the direction in which the ability of the system to perform external work does not decrease in time. The main properties of non-equilibrium systems evolving from the state of equilibrium follow from this law:

1. The flow of total energy does not decrease in time (total power does not decrease);
2. The flow of free (transformable) energy (exergy) does not decrease in time (useful power does not decrease);
4. The flow of coherent (irreversible) energy (anergy) does not increase (power losses do not increase).

The second type of non-equilibrium systems includes all systems with energy accumulation, a vivid representative of which is living matter as an open planetary system (as defined by V.I. Vernadsky).

On this basis, the principle of sustainable development can be formalised and presented as the law of transformation of energy flows in the system "society-environment".

The law of transformation of energy flows in the system "society-environment" (G. Kron (1935), P.G. Kuznetsov (1958)) is the statement that in a system open to energy flows (The systems open to energy flows of systems include systems that have the property of non-equilibrium of living systems, including ecological, social, economic, technical systems capable of consuming, transforming and producing energy flows (P.G. Kuznetsov, O.L. Kuznetsov, B.E. Bolshakov) [4, p. 247]) total power $N$ at the input to the system is equal to the sum of useful power $P$ and loss power $G$ at the system output (Fig. 3) [4, p. 242-244]:

\[
N(t) = P(t) + G(t) \quad (t)
\]

\[
P(t) = N(t) \cdot \eta(t) \cdot \varepsilon(t)
\]

where

- $N(t)$ is total power input to the system;
- $P(t)$ is useful power at the system output;
- $G(t)$ is loss power at the system output;
- $\eta(t)$ is generalised technology excellence ratio;
- $\varepsilon(t)$ is consumer availability (or absence) coefficient (planning quality);

$\varphi(t) = \eta(t) \times \varepsilon(t)$ defines efficiency of resource utilisation (full capacity) of the system.

**Fig. 3.** Formulation of the power conservation law

The total power can be represented as the sum of useful power and loss power ($N = P + G$). It follows that a decrease in the loss power can be achieved (with the total power constant) only by increasing the useful power while ensuring an increase in the efficiency of the system's resource utilisation.
\[ \begin{align*}
\dot{E} &= \frac{dE}{dt}, \\
\dot{B} &= \frac{dB}{dt}, \\
\dot{A} &= \frac{dA}{dt}; \\
\end{align*} \] (2)

\[ \begin{align*}
\dot{B} &= B + \dot{E}; \\
\dot{A} &= A - \dot{E}; \\
\end{align*} \] (3)

\[ \begin{align*}
\dot{P} \cdot T &= P \cdot t + P \cdot t^2 + P \cdot t^3 > 0 \\
\dot{\phi} \cdot T &= \phi \cdot t + \phi \cdot t^2 + \phi \cdot t^3 > 0 \\
\dot{G} \cdot T &= G \cdot t + G \cdot t^2 + G \cdot t^3 < 0 \\
\dot{N} \cdot T &= \text{const} \\
\end{align*} \] (4)

Here, \( t \) defines a zoom step; \( T \) is a fixed period, \( T \leq t \).

The criteria presented in the system of equations (5) are the criteria of competitively sustainable development of regional organisational systems.

Thus, the competitive sustainable development of regional organisational systems is characterised by a non-decreasing growth rate of the system's useful capacity (\( P \)) due to an accelerated increase in the efficiency of resource use (\( \phi \)) while maintaining the rate of consumption (\( N \)).

Then, the model of competitively sustainable development of regional organisational systems can be represented as a formalised process of interaction between society and the natural environment: society under the influence of a share of the produced flow of convertible energy (\( \alpha \cdot P \)) after some time (\( \tau_0 \)) receives at its disposal a consumable flow of resources (\( N \)), which after a time period with a certain efficiency (\( \phi \)) is used by society to fulfil needs (Figure 4).
Based on this model, the equations of the relationship between the socio-economic system and the natural environment are written down:

\[ P \tau + \tau = N \tau \cdot \phi \tau \]  

\[ N \tau + \tau + \tau \Pi = P \tau + \tau \cdot \zeta \tau \]  

\[ G \tau + \tau + \tau \Pi = N \tau + \tau + \tau \Pi - P \tau + \tau \]  \tag{5} 

\[ \eta N \tau = P \tau + \tau \]  

\[ N \tau + \tau \Pi = \xi \Pi \cdot P \tau \]  \tag{6} 

\[ N \tau + \tau + \tau \Pi = \eta \xi \Pi \cdot N \tau \]  \tag{7}
Table 1. Natural-scientific indicators of opportunities and needs of the regional socio-economic system

<table>
<thead>
<tr>
<th>Basic concepts</th>
<th>Indicator</th>
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<td>Capability</td>
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"Table 1. Natural-scientific indicators of opportunities and needs of the regional socio-economic system"
Fig. 5. Model of interactions with natural environment

Fig. 6. Population - economy - natural environment model
5 Conclusions

Science has been applying physical laws to analyse social and economic systems for more than a hundred years. However, it is necessary to recognise that the management of social and economic systems lacks systemic links with natural, economic and social processes expressed in a sustainably measurable form, which leads to incorrect assessments and generates crises. On the way of establishing links with natural, economic and social phenomena, on the recommendation of the UN, most of the world's states, including Russia, adopted the basic principle of sustainable development and a set of indicators of sustainable development, the analysis of which showed their insufficiency and disproportionality, on the one hand, and, on the other hand, the lack of interaction of objective laws (invariants) of nature and the principle of sustainable development of society.

The complex crisis situation in the world poses a challenge to the scientific community to develop theoretical and methodological provisions based on natural-physical indicators, which would be initially adequate to describe natural systems, and at the same time would be sufficiently applicable to assess socio-economic phenomena.

The physical-economic (natural-physical) law, operating in economic life in the economy, is the law of conservation of energy (power) flow. Thus, the methodological basis for the construction of a comprehensive, ecological-socio-economic model of regional development should be the requirements arising from the law of conservation of energy (power) flow. That is why the basis of the work is objective physical and economic indicators reflecting the interrelation of natural, social, and economic processes, which provides an opportunity for interdisciplinary assessment of the possibilities of regional development and the solution of actual applied problems.

The presented work is the result of theoretical, methodological, and applied research on systemic natural-scientific analysis of development management in socioeconomic systems considered in interaction with the environment.

It has been established that the actual socio-economic, scientific, technical and environmental factors determining the sustainability of the regional system development are analytically related and formalised in terms of measurable quantities reduced to a single measure (unit of measurement) for systems open at the input and output by energy (power) flows. The criteria and models of multilevel regional systems are developed, the structure of strategic information containing a system of natural-scientific knowledge used in the theory...
and practice of management, taking into account the interrelation of environmental, social and economic processes.

The results of formalisation of the principle of sustainable development as a projection of the law of power conservation in the socioeconomic environment are presented, which made it possible to identify a number of nontrivial properties and requirements of regional development management. On the basis of the formulated requirements, the highlighted theoretical and methodological basis is the basis for the basic formulaic relations uniting social and natural processes.

The formalised description of the multilevel model of the region in terms of natural-scientific indicators as a strict system of rules for describing the properties and regularities of the socio-economic system development is presented. The analysis of the results of application of the developed models allows to reveal conditions and limitations of ecologic-socio-economic development of regions. The presented direction forms alternative assessments of regional development expressed in non-monetary, natural-scientific indicators, and can also become a scientific basis for the formation of sovereign assessment centres in the interests of Eurasian economic integration.

6 Acknowledgements.

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