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THE PROBLEM OF SUSTAINABILITY OF THE DEVELOPMENT OF AN INTEGRATED MAN-MADE SYSTEM IN AN INNOVATIVE ECONOMY AND "INDUSTRY 4.0"

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An integrated sustainable development model as a set of models for the development of integrated information systems for environmental-and-economic and socio-humanistic management of different socio-organizational systems, especially for technogenic economic units, has been shown. The sustainable development issue has been studied in terms of 7 main (capital) assets that support functioning of socio-environmental-economic systems. Sustainable development concept, global measurement system for the sustainable development and sustainable development level have been defined. The presented methodology for the formation of humanitarian component of technogenic regional production (TRV) uses available statistical data, is described by the humanitarian index and included in the quality index (QIM) and harmonization models; the use of sequential pattern mining algorithm for identification of relationships in TRV QIM allowed to disclose practicable correlations between the indexes; the statistical data distribution is based on KVEED DK 009:2005 and KVEED DK 009:2010 classifiers of economic activities. Application of these methods will improve efficiency of managerial decisions in the technogenic regional production management, maximize benefits from the use innovations and define strategic innovative directions for regional development.

Introduction, relevance and justification

In today's difficult conditions and with the development of the modern economy there is a need to reconsider the problems of sustainable development. This is due to the increasing impact on the economy and performance of individual countries and regions of globalization and uncertainty and risk factors. The concept of sustainable and safe development of the state as a whole and individual regions allows to ensure stable and balanced development of four sectors: economic, environmental, social and spiritual and moral unity on the basis of innovative socio-humanitarian technologies, combining the principles of economic efficiency, social security and environmental safety.

At present, the issues of environmental-economic and socio-humanitarian safe and sustainable development of civilization have come to the forefront of scientific research and public consciousness in general. Mankind has reached the point where modern civilization, often called technogenic-consumer, has found its hopelessness, when it is necessary to seriously reconsider its basis and consciously choose another, spiritual and environmental, development strategy, otherwise humanity may be destroyed from Earth due to global systemic crises that have erupted in recent years. To solve this problem, humanity needs to abandon a number of stereotypes and direct the vector of civilizational development to the formation of the sphere of mind ("noosphere" according to V. I. Vernadsky). The formation of the noosphere-environmental imperative is associated with the formation of a society that is able to ensure the coevolutionary and viable development of civilization for planetary integrity. Sustainable and safe development is impossible without the spiritual, cultural and educational improvement of man himself. The new model of civilizational development, which implements non-traditional environmental, economic and demographic imperatives, must have a deeply humanistic social orientation. Such an approach to understanding the noosphere requires the creation of a new model of science, which should be based not only on a rational-intellectual approach to the ecosystem, but also based on its spiritual and cultural components. At the same time, the most important problem is the integration of science, education and innovative technology based on the noosphere paradigm of sustainable development.

Why integration? In the history of mankind, in the history of countries in the Eurasian space, there have been many different crises, conflicts, wars, cataclysms that have threatened the existence of life on Earth. But each time Mankind found the strength to combine intellectual, material and spiritual capabilities, which ensured the preservation and development of life on Earth in all sorts of challenges.

Now the world is once again in a global crisis, and once again the integration of opportunities is needed, especially the important accounting in the integrated system of humanitarian components.

Why, first of all, do we need the integration of science, education and technology?

As a result of this integration, we get the answer to the question "How?" to preserve the development of mankind in the conditions of various and multidimensional external (space), internal and hybrid threats. The answer to the question "How?" provides for the development of a developed system of measurement (measures) that combines science, education and technology.

Fundamental rules of integration of values of science, education and technologies are:

a) harmonization: science - education - technologies are integrated and form a holistic system, if compliance with their basic principles and laws is ensured by eliminating gaps in the dimension; b) innovation; c) fundamentality: the use of fundamental knowledge and results of the noosphere paradigm of sustainable development.

All the world's scientific schools aim to preserve the Earth for future generations. However, to achieve this goal, they offer different methods. For example, the western school is the control of population growth (the strategy of the "*golden billion*"), the eastern school is the observance of dogmas (the strategy of *Eternal Life*), and our school is the transition to the *noosphere*, i.e. the strategy of creating a noosphere model of sustainable development.

The innovative model of sustainable and safe development of societies and the world as a whole must be built on the basis of an integrated paradigm of socio-environmental and economic unity and socio-humanitarian technologies. The object of study of systems analysis, synthesis, innovative technologies of modeling and management in this case is the system "*Creator - Man - socio-humanitarian-environmental-economic environment*" [1].

The problem of studying the sustainable and safe development of the state as a whole and individual regions in socio-environmental and economic systems with humanitarian components, i.e. on the basis of integration of 4 spheres of activity and functioning of modern complex systems in innovative economy (presented both in phase space and in ESTI space - "*education - science - technology - innovation*"), as well as in modern science in general, is the main and relevant. Only the integration of methods of modeling socio-economic, environmental, cultural, spiritual and other processes can ensure the sustainability and viability of the entire system [1-7].

The general scheme of the integrated model of sustainable and socio-humanitarian development of the global (world) system, which the author calls the noosphere model of development, can be represented as an integrator: $S = E_n \oplus E_c \oplus S_o \oplus H_u \oplus ESTI$, i.e. as an integrated "4-single" system in which the subsystems are E_c - economic system, E_n - environmental system, S_o - social system, H_u - humanitarian system; $X(t,r)$ - state of the integrated system S; in the space of variables $(t,r) \in [T \times R^3]$; X_0 - the state of the system S at the initial time t_0; W is the set of disturbing environmental factors; $ESTI$ - education, science, technology, innovation or, in particular, R&D [3-7].

Thus, the system (model) of sustainable development is the integration of 1 + 2 + 3 + 4, and *NMSD* - can be called a noosphere model of sustainable development ("civilization model") and is defined as a set (1.4-1.2), (1.2- 2.3), (2.3-3.4), (1.4-3.4), which defines a system with integral properties [2, 3].

It should also be borne in mind that at present the evolution of humanity as a global system, as well as the evolution of any open nonequilibrium system, obeys the laws of nonlinear dynamics and synergetics. The merger of technologies of artificial intelligence, robotics, the Internet of Things, autonomous means, 3-D printing, blockchain, biotechnology causes the fourth industrial revolution, i.e. "Industry 4.0" [4, 5, 7, 9, 13].

Important technological bases for the development of "Industry 4.0" are computer-integrated systems (CIS), computer-integrated production, application systems: CAD, CAE, CAM, CAPP and others, as well as important issues of digitalization of the industry, strategy, criteria and the principles of creating intellectualized and integrated systems. In [8] an intelligent integrated information logistics system of environmental and economic monitoring, modeling and management (*SEEMM*) of a technogenic industrial enterprise (production system, which is presented in the form of 3 aligned management structures), operating in conditions of instability, was developed.

The digital economy has created favorable conditions for the implementation of the concept of "Industry 4.0" as a new level of organization of production and management of the value chain throughout the life cycle of products. The fourth industrial revolution is a mixture of technologies of the physical, digital and biological worlds, which creates new opportunities and affects political, social and economic systems. According to the German economist K. Schwab, *the qualitative difference between the fourth revolution and the third is the synergetic effect that arises from the merging of different technologies: computer, information, nanotechnology, biotechnology, and others. This leads to the blurring of the boundaries between the physical, digital and biological (including human) worlds* [4, 9, 13]. The favorites of the "Industry 4.0" concept will be biotechnology, nanotechnology, robotics and mechatronics, new medicine and new nature management, development and use of the capabilities of the individual and the team at a new, higher level. About development, reforms, modernizations, about innovative technologies and that today the world is moving, moving to the sixth technological mode, i.e. to the NBIC (nanotechnology, biotechnology, information technology, cognitive technology) [4]. The phrase "*convergent technologies*" refers to a synergistic combination of the four main "*NBIC*" (*nano-bio-info-cognies*) areas of science and technology, each of which is currently progressing rapidly.

But socio-humanitarian technologies (SH) refer to man, to practice, to society ... to morality, morality, values, to culture. And these are more philosophical problems. That is, now we must focus on *NBIK* + *SH* - technology. As well as at those that will be able to organize and ensure this breakthrough into the future [2, 6, 7].

Thus, on the basis of the system-synergetic approach the question of aggravation of the global crises caused by technogenic civilization is considered, the question arises: whether it is possible to leave these crises, without changing the basic system of values of technogenic culture? Mankind has a chance to find a way out of global crises, but this will have to go through an era of spiritual reformation and the development of a new system of values. The modern paradigm of the world community's exit from the systemic crisis and the transition to safe and sustainable development is, first of all, an innovative way of development based on modern innovative, information and convergent technologies, based on new knowledge as the main resources of development, based on socio-humanitarian technologies, and also on the basis of active transition according to the 6th, and then to the 7th technological ways of development and "Industry 4.0".

The purpose of the work

The purpose of this work is to study the problem of sustainability of integrated man-made system in an innovative economy and "Industry 4.0" and the development of methods and methodologies for assessing the level of sustainable development of the state as a whole and individual regions allows stable and balanced development of four sectors: economic, environmental, social and spiritual and moral unity on the basis of innovative socio-humanitarian technologies, combining into a holistic system the principles of economic efficiency, social security and environmental security.

Presentation of the main material

Carrying out a comprehensive analysis of the sustainability of regional development involves the use of criteria and indicators that allow to obtain a reliable assessment of its level, direction and intensity of change. However, to date, economics has not finally developed approaches to justify their choice, methods of calculation, determination of patterns of development, etc. The main disadvantage of the existing methodological provisions is that they do not allow to fully assess the sustainability of the region, the degree of influence of various factors on the level of its change and discrepancies with the limit values. Different views among scholars dealing with the problem of sustainable development of the region are manifested in the choice of criteria that should be the basis for assessing the sustainability of development.

We will note that the general scheme of integration model of steady safe environmental and economic and social and humanitarian development of system is presented in [1-3, 6, 7].

The main factors of sustainable development of the region. The paradigm of sustainable development, which provides for a dynamic process of successive positive changes that ensure the balance of economic, social and environmental aspects, should be the basis for the formation of approaches to solving the problems of territorial entities. This is especially relevant today, when the focus of economic reforms is shifting to the level of regions and strengthening their role in the implementation of economic policy. The priority approach in the implementation of reforms at the regional level should be the belief that the development of the territory should not be equated with its economic development. It is impossible to consider the region developing steadily only on the basis of increase of economic indicators. Sustainable development should be aimed at achieving a high quality of life, with a positive dynamics of the set of indicators. The priority of the new stage of economic change is the innovative modernization of the regional economy.

It is believed that the term "*sustainable development*" is inherently innovative, because for the continuous, stable operation of any system in changing environmental conditions, it must constantly increase the degree of organization, adapting to these changes, i.e. generate new forms and mechanisms of stability support.

The transition to sustainable development requires radical transformations, at the center of which is the socialization, greening and humanization of all major human activities, changing his consciousness and creating a new "sustainable society". Such changes must take place purposefully, consciously, taking into account socio-economic, political, technical and other conditions. In general, the level of sustainable development of the technogenic region is due to the interaction of a number of groups of factors of socio-economic, environmental and innovative nature.

Socio-economic factors include: production and resource potential (labor, material, financial, raw materials, fixed capital, etc.), market (factors of demand, supply and distribution; interpenetration of regional, national and world markets), strengthening the social function of the state, income level (propensity to consume, save, invest), education and health care, social protection, level and quality of life, level of environmental awareness.

The environmental aspect of sustainable development implies the rational use of natural resources (subsoil, extraction of natural resources, forest, water, land fertility, wildlife) on the principles of their economy, efficiency of recreational capacity and investment in environmental activities. This approach to sustainability means the maximum reduction of their use, the search for substitutes, the widespread introduction of resource-saving technologies.

Innovative factors include intellectual potential (ideas and knowledge, which later turn into new sources of raw materials and power; information), scientific and technical potential (substitution technologies, technological activity), investment in innovation.

Thus, sustainable development means that the socio-economic system ensures the dynamic stability of its properties, applying, at the same time, the whole set of factors that affect the level of competitiveness of the region's economy.

As criteria for assessing the above factors can be identified a system of indicators that characterize the sustainable development of the man-made region.

Leading international organizations are developing indicators of sustainable development: the United Nations, the World Bank, the Organization for Economic Cooperation and Development (OECD), the European Commission, the Scientific Committee on the Environment (SCOPE), and others. Among individual countries, the experience, scale, duration and complexity of developing a system of sustainable development indicators in the United States and the United Kingdom should be particularly noted. These countries began this work at the governmental level in the mid-1990s.

Recent developments include research and implementation of sustainability indicators for countries such as Denmark (sustainable development indicators), Germany (environmental indicators for public information) and Canada (sectoral sustainability indicators for agriculture).

In Germany, a special "environmental barometer" (EB) has been developed, which covers only 6 key indicators. EB is intended for both the public and high-ranking officials. On the basis of 6 EB indicators the aggregate indicator - an index of a condition of environment (DUX) by means of which it is easy to analyze a condition of environment for the general public is constructed. This index is regularly (monthly) shown on one of the leading German TV channels. It is also included in the annual economic reports of the German Government (Ministry of Finance) and in the environmental reports.

Although the development of indicators of sustainable development is still far from complete, but already proposed draft indicators for systems of different scales: global, regional, national, local, sectoral, even for individual settlements and enterprises.

The concept of sustainable development and some research results. Theory and practice show that at the turn of the century the teachings of V. I. Vernadsky on the noosphere proved to be a necessary platform for the development of a threefold concept of sustainable environmental, socio-economic development. Generalizations of this concept were made at the UN World Summits in 1992 and 2002, which were attended by more than 180 countries, many international organizations and leading scientists. Thus, the new concept systematically combines three main components of sustainable development of society: economic, environmental (environmental) and social.

The economic approach is to optimize the use of limited resources and apply natural, energy and resource-saving technologies to create a flow of total income that would ensure at least the preservation (not reduction) of the total capital (physical natural or human) with which this total income is created. At the same time, the transition to the information society leads to a change in the structure of total capital in favor of human capital, increasing the intangible flows of Finance, information and intellectual property. Already these flows exceed the volume of movement of material goods by 7 times [ru.wikipedia.org].

The development of a new, "weightless" economy (knowledge economy) is stimulated not only by the scarcity of natural resources, but also by the growth of information and knowledge that acquire the value of a sought-after commodity. From the point of view of ecology, sustainable development must ensure the integrity of biological and physical natural systems, their viability, on which depends the global stability of the entire biosphere. Of particular importance is the ability of such systems to self-renew, and adapt to various changes, instead of maintaining a certain static state or degradation and loss of biological diversity. The social component is focused on human development, on maintaining the stability of social and cultural systems, on reducing the number of conflicts in society. Man must become not an object but a subject of development. He must take part in the processes of formation of his life, making and implementing decisions, monitoring their implementation. Equitable distribution of benefits among people (reduction of the so-called GINI index), pluralism of opinion and tolerance in relations between them, preservation of cultural capital and its diversity, especially the heritage of non-dominant cultures, are important to ensure these conditions.

Systematic coordination and balancing of these three components is a huge task. In particular, the relationship of social and environmental components leads to the need to preserve the equal rights of present and future generations to use natural resources. The interaction of social and economic components requires the achievement of justice in the distribution of material goods among people and the provision of targeted assistance to the poor. Finally, the relationship between environmental and economic components requires a cost assessment of man-made impacts on the environment. Solving these challenges is the most important challenge today for national governments, authoritative international organizations and all the progressive people of the world.

The problem of sustainable development on the basis of the "hexagon" of fixed assets (capital), supported by the activities of SEEMM. The main assets that support the viability of integrated SEEandHS are the following 7 factors: S - Social capital; Φ - Financial capital; N - Natural capital (land, water, etc.); K - Physical capital (fixed assets); L -Labor resources (labor); H - Human (intellectual) capital; I - Institutional factor (resource).

The generalized production-technological function (PTF) can be represented in general as a nonlinear function:

$$Y(t) = F[K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t); \vec{c}].$$

It can be used to study sustainable development.

<u>*The level of sustainable development (SDL)*</u> will be assessed using the index I_{sdl}, which is calculated as the sum of indices for four dimensions (areas): economic

(I_{eco}), environmental (I_{ecl}), social (I_{soc}) and humanitarian (I_{hum}) with the appropriate weighting coefficients, that is:

$$I_{sdl} = \alpha_1 I_{eco} + \alpha_2 I_{ecl} + \alpha_3 I_{soc} + \alpha_4 I_{hum}, \ \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1, \alpha_i \geq 0.$$

In turn, each of the indices I_{eco}, I_{ecl}, I_{soc} and I_{hum} will be calculated using well-known in international practice indices and indicators.

When using the arithmetic mean form of construction of the generalizing indicator at decrease in social and economic indicators and increase in environmental it is possible leveling of a threatening situation. Therefore, the content of the considered indicator is more consistent with the geometric mean value, which reflects the proportionality between the indicators. In addition, the considered indicators will reflect the real situation in the region. The level of sustainability of economic development of the region can be calculated by the following formula:

$$I_{sdl} = \sqrt[4]{[\alpha_1 I_{eco} \times \alpha_2 I_{ecl} \times \alpha_3 I_{soc} \times \alpha_4 I_{hum}]}.$$

In particular, for example, the level of sustainability of economic development of the region can be determined by the following formula:

$$I_{eco} = \sqrt[5]{I_n \times I_u \times I_{\Phi} \times I_m \times I_{np}},$$

where I_{eco} - the level of sustainability of economic development of the region; I_n - level of production component of regional development: innovation, labor, financial and natural resources; I_u - the level of innovation component of regional development; I_{Φ} - the level of the financial component of regional development; I_m - the level of the labor component of regional development; I_{np} - the level of natural resource component of regional development.

This construction of the indicator will reflect the importance of each of the considered components: environmental-environmental and socio-humanitarian subsystems (spheres) in the performance of the target function. A change in any of the private indicators leads to a change in the value of the aggregate indicator and captures a change in the steady state of the region. In the general case, all indicators change over time, i.e. have a certain dynamics.

Simple conditions for sustainable development (SD) are defined as follows.

1) Condition of weak stability:

$$\frac{dF[\cdot]}{dt} \geq 0 \qquad \text{or} \qquad F_{t+1}[\cdot] \geq F_t[\cdot],$$

where

$$F_t[\cdot] \equiv F[K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t), \vec{c}].$$

2) Condition of strong stability:

$$\frac{dF[\cdot]}{dt} \geq 0, N = N^C + N^S \quad \text{and} \quad \frac{dN^C}{dt} \geq 0 \quad \text{or} \quad N_{t+1}^C + N_t^C,$$

where N^C - critical part of natural capital, and N^S - natural capital, which can be replaced by artificial.

For example, given critical natural capital N^C, sustainable development can be supplemented by a time limit on depletion of this value. For a time-decreasing production function, the arguments of which are aggregated variables: labor - *L*, capital - *K* and natural - resource N, we will have the ratio:

$$F_t(K, L, N) \leq F_{t+1}(K, L, N)$$

or, in the general case

$$F(K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t), \vec{c}) \leq$$
$$F(K(t+1), L(t+1), H(t+1), N(t+1), \Phi(t+1), S(t+1), I(t+1), \vec{c})$$’

and it also requires compliance with the condition of not decreasing in time the value of N^C, i.e. $N_t = N_t^C + N_t^S$, as well as the condition of partial replacement of natural capital N by artificial N^S (or non-renewable resource for renewable resource): $N_t = N_t^C + N_t^S$.

The integrated level of sustainable development for all capital (resources) can be defined, for example, *in the case of linear dependence* as

$$Y_{sdl}(t) = c_1 K(t) + c_2 L(t) + c_3 H(t) + c_4 N(t) + c_5 \Phi(t) + c_6 S(t) + c_7 I(t),$$

where $c_1, c_2, c_3, c_4, c_5, c_6, c_7$ weighting (normalizing and scaling) coefficients.

In the general case, the integral level of sustainable development can be represented as a nonlinear function:

$$Y_{sdl}(t) = F_{sdl}[K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t); \vec{c}] \cdot$$

Private versions of the PTF model:

a) Mankiw–Romer–Weil model. Option of accounting for human capital *H* in the production function (*PF*), along with physical capital (*K*), labor (*L*) and natural (*N*) resources:

$$Y(t) = K^{\alpha}(t) \cdot H^{\beta}(t) \cdot [A(t) \cdot L(t)]^{1-\alpha-\beta},$$

where $\alpha, \beta > 0$, $\alpha + \beta < 1$; H; $A(t)$ - function of scientific and technological progress. Note that α - the share of capital provided by investment growth (capital costs); similarly β.

b) Model of accounting for all fixed assets:

$$Y(t) = A(t) K^{\alpha}(t) \cdot L^{\beta}(t) \cdot H^{\gamma}(t) \cdot S^{\rho}(t) \cdot \Phi^{q}(t) \cdot N^{\tau}(t) \cdot I^{\upsilon}(t),$$

where $\alpha, \beta, \gamma, \rho, q, \tau, \upsilon > 0$ and $\alpha + \beta + \gamma + \rho + q + \tau + \upsilon = 1$ The following notations are also used here: *K* - physical capital, *L* - labor (labor), *H* - human capital, *S* - social capital, *F* - financial capital, *N* - natural resources (land, water, etc.), *A(t)* is a function of the level of scientific, technical and technological development, for example, $A(t) = aT^{S}(t)$, where $T(t)$ - volume of innovative technologies (resources).

The system of global dimensions of sustainable development (in the designations of the authors) [10]. An important problem in implementing the concept of sustainable development is the formation of a system of measurements (indices and indicators) for quantitative and qualitative assessment of this very complex process. The main requirements for this system of measurements are its completeness of information and the adequacy of the presentation of the interconnected triad of components of sustainable development. Well-known international organizations and numerous scientific teams are currently working in this direction, but unambiguous coordination of this system of measurements has not been achieved yet.

Here is a system of measurements of sustainable development, proposed by the Institute of Applied Systems Analysis of NTU "KPI" [10].

The level of sustainable development will be assessed using the corresponding I_{sdl} index, which is calculated as the sum of indices for three dimensions: economic (I_{eco}), environmental (I_{ecl}) and social (I_{soc}) with the appropriate weighting coefficients. In turn, each of the indices I_{eco}, I_{ecl} and I_{soc} will be calculated using well-known in international practice indices and indicators.

Of course, all indicators that affect the components of these indices, as well as these indices themselves, are measured in different units and have different interpretations. Therefore, they are reduced to a normalized form so that their changes, as well as changes in the indices themselves, were in the range from 0 to 1. In this case, the worst values of these indicators will correspond to numerical values close to 0, and the best - will bring these values closer to 1. This rationing allows you to calculate each of the indices I_{eco}, I_{ecl}, I_{soc} and I_{hum} in the form of the average sum of its components with the appropriate weighting coefficients.

1. The index of economic dimension (I_{eco}) will be formed from two global indices:

- the index of competitive development (hereinafter - the index of competitiveness - I_c), developed by the organizers of the World Economic Forum (World Economic Forum). This index is calculated annually for 117 economies of the world and is published in the form of the so-called "Global Competitiveness Report". We will use this report for 2005 - 2006 [www.weforum.org]). The competitiveness index is formed from the following three indicators: the indicator of technological development of the country; indicator of civic institutions and indicator of macroeconomic environment. In turn, these three indicators are calculated based on the use of 47 data sets on the state of technology transfer and innovation development, the level of information and communication technology development, the level of R&D spending, the level of foreign investment, the level of business independence from government, the level of corruption in the country, etc.;

- index of economic freedom (I_{ef}), which was developed by the intellectual center of the Heritage Foundation [www.heritage.org/research/features/index]. It is published annually in the Wall Street Journal. The index of economic freedom is formed from the following ten indicators: the country's trade policy; fiscal burden from the government; government intervention in the economy; monetary policy; capital flows and foreign investment; banking and financial activities; pricing and remuneration policies; private property rights; regulatory policies; informal market activity. These ten indicators are calculated based on the use of 50 sets of various economic, financial, legislative and administrative data.

According to the results of data processing for 2005, we present a list of the ten best countries in the world, based on the index of economic measurement (table 1 look [10, 11] and [www.weforum.org]).

The achievements of these countries are due to the optimal combination of such important factors of economic development as the level and quality of innovation, priority research support, significant foreign investment, with perfect legislation in the field of business taxation and high technology, effective protection of private property, especially intellectual, low corruption, the orientation of countries' policies to create economies on the model of "welfare for all" instead of the model of "indifference to the natural market". Finland, Denmark, Iceland and Sweden demonstrate this development strategy most clearly.

The G8 countries, with the exception of the United States and the United Kingdom, are inferior to the group of leaders in terms of qualitative characteristics of economic development. In particular, they lose significantly to leaders in the quality and scale of innovation, levels of commercialization of science, almost twice less funding for research in high technology, have relatively outdated and less flexible legislation in the field of taxation and development of high-tech business. According to the efficiency and progressiveness of their economies, they are quite compactly placed (except for Russia) in the following sequence: USA – the 5th place (I_{eco} = 0.537), Great Britain – the 9th place (I_{eco} = 0.542), Canada – the 15th place (I_{eco} = 0.525), Germany – the 16th place (I_{eco} = 0.510), France – the 19th place (I_{eco} = 0.438), Italy – the 20th place (I_{eco} = 0.410), Russia – the 98th place (I_{eco} =0.319).

The group of post-socialist countries, which at the beginning of their independence had approximately equal starting conditions, as of 2005 turned out to be quite "scattered" in the rating table according to the index of economic dimension. Thus, Estonia ranks the 12th (I_{eco} = 0.533), the Czech Republic – the 29th (I_{eco} = 0.459), Slovakia – the 37th (I_{eco} = 0.428), Hungary – the 40th (I_{eco} = 0.423), Latvia – the 41st place (I_{eco} = 0.420), Poland – the 46th place (I_{eco} = 0.400), Bulgaria – the 61st place (I_{eco} = 0.366), Moldova – the 87th place (I_{eco} = 0.325), Ukraine – the 91st place (I_{eco} = 0.319). Naturally, these countries are in the process of restructuring all components of their economic and social systems. Those of them who quickly transformed production, science, education, business into a market, innovative model of the economy, are more likely to show positive changes. These are, first of all, Estonia, the Czech Republic, Slovakia, Hungary, Latvia, Poland. As for Bulgaria, Moldova and Ukraine, this process is slower.

2. Environmental Measurement Index (I_{ecl}) will be assessed using the well-known ESI (Environmental Sustainability Index), calculated by the Center for Environmental Law and Policy at Yale University (USA) for 146 countries as of 2005 [www.yale.edu/esi]. The ESI index is formed of 21 environmental indicators, which, in turn, were calculated based on the use of 76 sets of environmental data on the state of natural resources in the country, the level of environmental pollution in the past and today, the country's efforts to manage environmental conditions characteristics and more.

The ESI index quantifies a country's ability to protect its environment, both in the current period and in the long run, based on the following five criteria: the existence of a national environmental system; possibility to counteract environmental influences; reducing people's dependence on environmental influences; the country's social and institutional capacity to respond to environmental challenges; the possibility of global control over the environmental state of the country. In addition, this index can be used as a powerful tool for decision-making on an analytical basis, taking into account the social and economic dimensions of sustainable development.

The G8 countries, with the exception of Canada, are not world leaders in terms of environmental protection and have rather mediocre ESI index values. In particular, Canada ranks the 6th place (ESI = 0.644), Japan – the 30th place (ESI = 0.573), Germany – the 31st (ESI = 0.569), Russia – the 33rd (ESI = 0.561), France – the 36 (ESI = 0.552), USA – the 45th (ESI = 0.529), Great Britain – the 65th (ESI = 0.502), Italy – the 69th (ESI = 0.501). This is due to the priority desire of these countries to increase GDP, compared to environmental measures, and the rather intensive use of natural resources.

It is interesting to compare a group of post-socialist countries that were in approximately the same environmental conditions in the late 1980s. Now Latvia is in the 15th place (ESI = 0.604), Estonia - in the 27th (ESI = 0.582), Slovakia - in the 48th (ESI = 0.528), Hungary - in the 54th (ESI = 0.520), Moldova - on the 58th (ESI = 0.512), Bulgaria - on the 70th (ESI = 0.500), the Czech Republic - on the 92nd (ESI = 0.466), Poland - on the 102nd (ESI = 0.450), Ukraine - at the 108th (ESI = 0.447).

From the above data we see that there are significant differences between countries both in the state of the environment and in long-term trends in its changes. The level of economic development of a country, expressed in terms of GDP per capita at purchasing power parity, does not necessarily guarantee a better state of its environment. In this regard, significant factors were: low population density, economic capacity to overcome environmental challenges and the quality of management of environmental measures and development of natural deposits.

3. The index of the social dimension (I_{SOC}) is formed by averaging three global indices:

- Index of Quality and Safety of Life (I_q), developed by the international organization Economist Intelligence Unit [www.en.wikipedia.org]. This index is formed using the following nine indicators: GDP per capita at purchasing power parity; average life expectancy of the population; rating of political stability and security of the country; the number of divorced families per 1,000 population; level of public activity (activity of trade unions, public organizations, etc.); differences in latitude between warmer and colder regions of the country; unemployment rate in the country; the level of political and civil liberties in the country; the ratio between the average wages of men and women.
- Human Development Index (I_{hd}), used by the United Nations Development Program [www.hdr.undp.org/reports/global/2005]. It is formed with the help of the following three indicators: the average life expectancy of the country's population; level of education and standard of living of the country's population, measured by GDP per capita at purchasing power parity (GDP per capita).
- Index of a knowledge-based society, or K-society (I_{ks}), developed by the United Nations Department of Economic and Social Development - UNDESA [UN publication No.E.04.II.S.1,2005]. This index is determined by three main indicators: intellectual assets of society; prospects for the development of society and the quality of society, which, in turn, are formed by 15 data sets on the level of youth education and information, investment climate in the country, corruption, inequality

of material and social benefits (GINI-index), the level of child mortality, etc. The list of the ten best countries in the world according to the index of social dimension is given in [10].

The success of this group of countries in achieving the best social standards of living is formed not only by high welfare (expressed in terms of GDP per capita at purchasing power parity). More importantly, these countries pursue consistent policies aimed at harmonizing the main factors influencing social development. They reached 1.2-1.5 times lower than in the G8 countries, inequality of society (expressed by the GINI index). These countries have very low defense spending and some of the world's highest spending on health, education, media and communications. As a result, they have a high rating of political stability, a significant level of political and civil liberties, a very low level of corruption, low infant mortality, and a relatively high life expectancy.

We see that, with the exception of Japan, the G8 countries are not among the top ten in the index of social development. They are located quite compactly in the first - third tens of the rating table. The only exception was Russia. We have the following sequence of countries: Japan - 8th place (I_{SOC} = 0.792), USA - 14th place (I_{SOC} = 0.779), Canada - 15th place (I_{SOC} = 0.777), Germany - 16th place (I_{SOC} = 0.776), Great Britain - 17th place (I_{SOC} = 0.773), Italy - 21st place (I_{SOC} = 0.759), France - 24th place (I_{SOC} = 0.754), Russia - 81st place (I_{SOC} = 0.520). The concentration of great wealth in these countries does not automatically ensure high social standards of living. They are characterized by higher defense spending, much higher than the preliminary group, inequality of society, lower rating of political stability and lower average level of education, except for Japan, 1.3-1.5 times higher infant mortality (in Russia it is higher four times compared to other members of this group).

The group of post-socialist countries over the past 20 years has been characterized by significant stratification in the level of social development. They have the following ratings: Czech Republic – the 28th place (I_{SOC} = 0.702), Hungary – the 32nd place (I_{SOC} = 0.686), Slovakia - 34th place (I_{SOC} = 0.673), Poland - 36th place (I_{SOC} = 0.664), Estonia - 44th place (I_{SOC} = 0.657), Latvia - 47th place (I_{SOC} = 0.649), Bulgaria - 49th place (I_{SOC} = 0.627), Ukraine - 72nd place (I_{SOC} = 0.554) , Moldova - 78th place (I_{SOC} = 0.553).

It is fundamentally important that the countries of this group, which became members or candidates for EU membership, achieved much higher social standards of living, compared to Ukraine and Moldova, which moved up in the ranking table, respectively, to 72nd and 78th place. Due to the low rating of political stability, uncertain social and economic policies of the last two countries, they are significantly behind the first in almost all indicators of the social dimension, except for some educational indicators and indicators related to civil liberties.

Comparison of countries according to the index of sustainable development from 3-indices. The Sustainable Development Index (I_{sd}) will be calculated by the formula:

$$I_{sd} = 0.43 \cdot I_{eco} + 0.37 \cdot I_{ecl} + 0.33 \cdot I_{soc},$$

in which scaling factors are used to ensure equal weight of economic, environmental and social dimensions in the index of sustainable development.

Methods of forming the humanitarian index (IDX^{HUM} or I_{hum}) [11,12]. The problem of forming an assessment of the level of sustainable development of regions, enterprises or the country as a whole using indices and indicators does not leave the pages of domestic and foreign publications, but to date in this direction has not been developed a single concept.

An urgent problem is the formation of a methodology for calculating the humanitarian index, which has an available statistical basis and, along with other indices, can be used in modeling and to assess the level of sustainable development of regions. Therefore, the task is to develop a methodology for forming a humanitarian index to assess the level of sustainable development of the region.

The scheme of formation of the humanitarian index is shown in fig. 1. The basis for the formation of the humanitarian index are directly the input data, which in some way are aggregated into parameters. The parameters are aggregated into indicators, and the indicators already make up the humanitarian index:

{Incoming data} $\Rightarrow$ *{Parameters}* $\Rightarrow$ *{Indicators}* $\Rightarrow$ ***Humanitarian index***

Fig. 1. Humanitarian index formation scheme

Here symbol "$\Rightarrow$" means the algorithm of transformations (aggregation, calculations).

The information base for the formation of the humanitarian index was the data of the State Statistics Service of Ukraine for the period from 2000 to 2014. 87 items of input data were selected, which were aggregated into 22 parameters. The parameters were aggregated into 10 indicators, and the indicators, in turn, were aggregated into one humanitarian index.

In order to be able to compare regions without being too subjective, the values of all input data were calculated per capita of the permanent population (p.p.) of a particular region for a particular year.

Input standardization was performed, after which the "worst" value of the input data corresponded to the value "0", and the "best" - the value "1". When the "best" value of the input data corresponds to their largest value, standardization is carried out according to the formula:

$$ID_i^{ST}(REG_j YR_k) = \frac{ID_i^{OR}(REG_j YR_k)}{\max\limits_{REG_j}(ID_i^{OR}(REG_j YR_k))} \qquad (1)$$

$$i = 1...87, j = 1...27, k = 2000...2014,$$

where ID^{ST} – standardized input data values, ID^{OR} – original input data values, REG – region, YR – year.

In the case when the best values of input data correspond to their smallest values, standardization is carried out according to the formula:

$$ID_i^{ST}(REG_j YR_k) = 1 - \frac{ID_i^{OR}(REG_j YR_k)}{\max\limits_{REG_j}(ID_i^{OR}(REG_j YR_k))} \quad (2)$$

$$i = 1...87, j = 1...27, k = 2000...2014$$

where ID^{ST} – standardized input data values, ID^{OR} – original input data values, REG – region, YR – year.

"Preliminary" weighting coefficients were calculated for the input data $WC^{PR}(ID_j^{ST}(REG_j))$ using the principal components method. The "preliminary" weighting coefficients were reduced to a single value by the mean formula:

$$WC(ID_i^{ST}) = \frac{\sum\limits_j WC^{PR}(ID_i^{ST}(REG_j))}{27}, i = 1...87, j = 1...27, \quad (3)$$

where WC – input data weighting coefficients, WC^{PR} – "preliminary" weighting coefficients of input data, ID^{ST} – standardized input data values, REG – region. The sum of the input data weighting coefficients for each parameter is always equal to one.

Regarding the calculation of parameter values, the parameter value is equal to the sum of the values of all input data included in it, multiplied by the corresponding weighting coefficients.

For example:

$$PRM_1(REG_j, YR_k) = \sum_{i=1}^{3} ID_i^{ST}(REG_j YR_k) \cdot WC(ID_i^{ST}), \quad (4)$$

$$PRM_4(REG_j, YR_k) = \sum_{i=9}^{18} ID_i^{ST}(REG_j YR_k) \cdot WC(ID_i^{ST}), \quad (5)$$

$$PRM_{12}(REG_j, YR_k) = \sum_{i=40}^{44} ID_i^{ST}(REG_j YR_k) \cdot WC(ID_i^{ST}), \quad (6)$$

$$j = 1...27, k = 2000...2014,$$

where PRM – parameter, ID^{ST} – the standardized values of the input data, WC – the weighting coefficients of the input data, REG – region, YR – year.

A total of 22 parameters are used. As with the input data, "preliminary" weighting coefficients $WC^{PR}(PRM_i(REG_j))$ were calculated for the parameters using the principal component method. The "preliminary" weighting coefficients were also reduced to a single value by the mean formula:

$$WC(PRM_j) = \frac{\sum_j WC^{PR}(PRM_i(REG_j))}{27}, \tag{7}$$

$$i = 1...22,\ j = 1...27,$$

where WC – weighting coefficient of the parameter, WC^{PR} – the "preliminary" weighting coefficient of the parameter, PRM – parameter, REG – region. The sum of the weighting coefficients of the parameters for each indicator is always equal to one.

By calculating the values of the parameters according to the scheme shown in fig. 1, the calculation of indicator values follows.

The values of the indicator are the values of the parameters included in it, multiplied by the corresponding weighting coefficients. Here are some of the formulas:

$$IDT_1(REG_j, YR_k) = \sum_{i=1}^{3} PRM_i(REG_j, YR_k) \cdot WC(PRM_i), \tag{8}$$

$$IDT_4(REG_j, YR_k) = \sum_{i=10}^{14} PRM_i(REG_j, YR_k) \cdot WC(PRM_i), \tag{9}$$

$$IDT_{10}(REG_j, YR_k) = \sum_{i=21}^{22} PRM_i(REG_j, YR_k) \cdot WC(PRM_i) \tag{10}$$

$$j = 1...27, k = 2000...2014,$$

where WC – the weighting coefficient of the indicator, WC^{PR} – the "preliminary" weighting coefficient of the parameter, IDT – indicator, REG – region, YR – year.

For the indicators, "preliminary" $WC^{PR}(IDT_i(REG_j))$ weighting coefficients were calculated using the principal components method. The "preliminary" weighting coefficients were reduced to a single value using the average value formula:

$$WC(IDT_i) = \frac{\sum_j WC^{PR}(IDT_i(REG_j))}{27}, \quad (11)$$

$$i = 1...10,\ j = 1...27,$$

where WC – the weighting coefficient of the indicator, WC^{PR} – the "preliminary" weighting coefficient of the indicator, IDT – indicator, REG – region. The sum of the weighting coefficients of the indicators that make up the humanitarian index is always equal to one.

The value of the humanitarian index is equal to the sum of the values of all indicators included in it, multiplied by the corresponding weighting coefficients, and is calculated by the formula:

$$IDX^{HUM}(REG_j, YR_k) = \sum_{i=1}^{10} IDT_i(REG_j YR_k) \cdot WC(IDT_i), \quad (12)$$

$$j = 1...27, k = 2000...2014,$$

where IDX^{HUM} – humanitarian index, IDT – indicator, WC – weighting coefficient of the indicator, REG – region, YR – year. For the regions of Ukraine for the period from 2000 to 2014, the values of humanitarian indices IDX^{HUM} were calculated, and for five regions of Ukraine the values of the indices are given in [11, 12].

Conceptual model of sustainable development index and harmony index formation, that is shown in fig. 2, connects the indices that are part of it with mathematical relations and performs their algebraic "convolution".

The conceptual model of formation of regional economy indices in the context of components (fig. 3) combines data of different nature, i.e. economic, environmental, social and humanitarian.

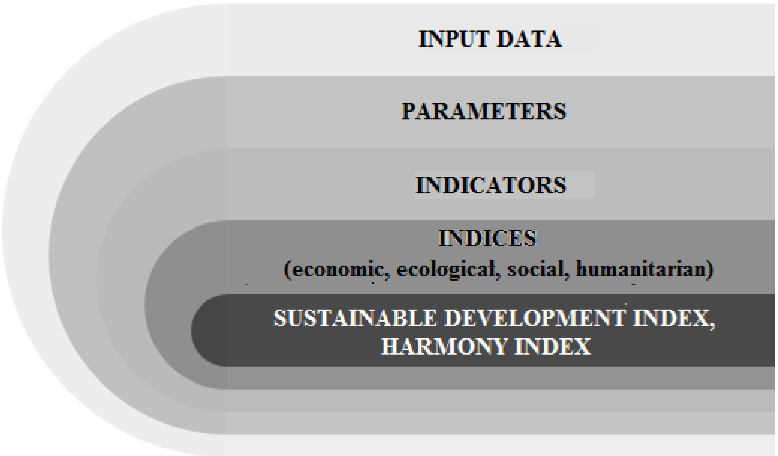

Fig. 2. Conceptual model of sustainable development index and harmony index formation

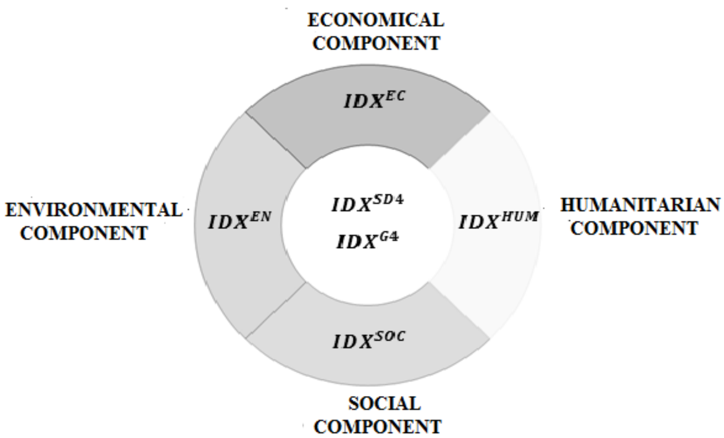

Fig. 3. Conceptual model of formation of regional economy indices in the context of four components

In this way, it reflects the interrelationship and balance between these four inseparable components of the regional economy. The IDX^{SD3} or IDX^{SD4} Sustainability Index and the IDX^{G3} or IDX^{G4} Harmony Index are calculated by their IDX^{EC}, IDX^{EN}, IDX^{SOC} and / or IDX^{HUM} components.

The algorithm for forming the IDX^{SD4} Sustainable Development Index and the IDX^{G4} Harmony Index for the regional economy, which contains four components:

economic, environmental, social and humanitarian, is similar to the algorithm for forming indices, which contains three components and is given in [2, 11].

If we modify this formula and apply it for a regional economy that has four components, we get:

$$IDX^{G4} = \arccos[0.5)IDX^{EC} + IDX^{EN} + IDX^{SOC} + IDX^{HUM})] / [(IDX^{EC})^2 + (IDX^{EN})^2 + (IDX^{SOC})^2 + (IDX^{HUM})^2], \quad (13)$$

where IDX^{G4} is the harmony index, IDX^{EC} is the economic index, IDX^{EN} is the environmental index, IDX^{SOC} is the social index, and IDX^{HUM} is the humanitarian index.

To determine the values of weighting coefficients during the formation of TRV indices, preference was given to the calculation method of the main components, because, unlike expert methods, it lacks a subjective component and its use does not require the cost of expert services.

When modeling indices for a regional economy containing three components, three indices are used: economic IDX^{EC}, environmental IDX^{EN} and social IDX^{SOC}, and if we consider a regional economy with four components, then the humanitarian index IDX^{HUM} is added to the above three indices. These three or four indices are used to calculate the values of the IDX^{SD3} or IDX^{SD4} sustainable development indices and the IDX^{G3} or IDX^{G4} harmony indices.

IDX indices and WC_3 weighting coefficients for calculating the sustainable development index for the regional economy, which contains three components, the following: economic index IDX^{EC}, $WC_3(IDX^{EC}) = 0.3438$; environmental index IDX^{EN}, $WC_3(IDX^{EN}) = 0.3396$; social index IDX^{SOC}, $WC_3(IDX^{SOC}) = 0.3166$.

In turn, if the regional economy contains four components, then the weighting coefficients of WC_4 change: economic index IDX^{EC}, $WC_4(IDX^{EC}) = 0.2608$; environmental index IDX^{EN}, $WC_4(IDX^{EN}) = 0.2463$; social index IDX^{SOC}, $WC_4(IDX^{SOC}) = 0.2607$; humanitarian index IDX^{HUM}, $WC_4(IDX^{HUM}) = 0.2322$.

The assessment of the level of sustainable development of the regional economy is based on the fact that it contains four components - economic, environmental, social and humanitarian. Therefore, the total array of input statistics is also divided into four components. The basis for the distribution were the types of economic activity of the subjects according to the NACE. It should be noted that the source of input data was the data of the State Statistics Service of Ukraine.

Input statistics cover the period from 2000 to 2014. Over these years, the structure of NACE has changed: until 2012 there was a valid NACE DK 009: 2005, and since 2012 and to this day a valid NACE DK 009: 2010. Comparison of input statistics for modeling by two classifiers requires a redistribution of economic activities that correspond to the components of the regional economy. Therefore, the following method of comparing NACE DK 009: 2005 and NACE DK 009: 2010 for the correct formation of the arrays of input data corresponding to the components of TRV [2, 12].

When calculating the sum of the weighting coefficients of economic IDX^{EC}, environmental IDX^{EN}, social IDX^{SOC} and humanitarian IDX^{HUM} indices, which make up the index of sustainable development IDX^{SD3} or IDX^{SD4}, is equal to one.

The values of the IDX^{SD3} and IDX^{SD4} sustainable development indices are calculated as the sum of the values of their constituent indices multiplied by the respective weighting coefficients. For a regional economy containing three components, the formula is as follows:

$$\begin{aligned} &IDX^{SD3}(REG_jYR_k) = IDX^{EC}(REG_jYR_k)\cdot WC_3(IDX^{EC}(REG_jYR_k)) + \\ &+IDX^{EN}(REG_jYR_k)\cdot WC_3(IDX^{EN}(REG_jYR_k)) + \\ &+IDX^{SOC}(REG_jYR_k)\cdot WC_3(IDX^{SOC}(REG_jYR_k)). \end{aligned} \tag{14}$$

For a regional economy containing four components:

$$\begin{aligned} &IDX^{SD4}(REG_jYR_k) = IDX^{EC}(REG_jYR_k)\cdot WC_4(IDX^{EC}(REG_jYR_k)) + \\ &+IDX^{EN}(REG_jYR_k)\cdot WC_4(IDX^{EN}(REG_jYR_k)) + IDX^{SOC}(REG_jYR_k)\cdot \\ &WC_4(IDX^{SOC}(REG_jYR_k)) + IDX^{HUM}(REG_jYR_k)\cdot WC_4(IDX^{HUM}(REG_jYR_k)). \end{aligned} \tag{15}$$

In formulas (14) - (15) IDX^{EC} - economic index; IDX^{EN} - environmental index; IDX^{SOC} - social index; IDX^{HUM} - humanitarian index; WC_3 and WC_4 - weighting coefficients; REG_j - region, $j = 1...27$; $YR_k = year$, $k = 2000...2014$.

For the regions of Ukraine for the period from 2000 to 2014, the values of the IDX^{SD3} and IDX^{SD4} sustainable development indices and the IDX^{G3} and IDX^{G4} harmony indices were calculated. For five regions of Ukraine, the selective values of the indices are given in [2, 12]. Note that the higher the value of the harmony index, the more uneven development of the components of the regional economy, i.e. in some priority areas.

Conclusions

The integration model of sustainable development is shown as a family of models for the creation of integrated information systems of environmental, economic and socio-humanitarian management of various socio-organizational systems and especially economic objects of man-made nature to ensure sustainable and viable development. The economic approach to modeling sustainable development is considered, which consists in the optimal use of limited resources and applies natural, energy and resource-saving technologies to generate aggregate income. At the same time, the transition to the information society leads to a change in the structure of aggregate capital in favor of human, increasing intangible flows, flows of information and intellectual property.

The problem of sustainable development through 7 main assets (capital) that support the viability of socio-environmental and economic systems is considered. The concept of sustainable development, the system of global dimensions of sustainable development and the level of sustainable development are defined.

The method of formation of the humanitarian component of TRV with the use of available statistics, which is described by the humanitarian index and is included in the models of quality condition indices (IQC), is presented; the method of searching for sequential templates for determining the dependencies in the TRV IQC, which allowed to identify useful patterns in the indices; the method of distribution of statistical data according to the components of the TRV on the basis of the types of economic activity of economic entities according to NACE DK 009:

2005 and NACE DK 009: 2010. The use of methods will increase the efficiency of solutions in the management of man-made regional production, increase the efficiency of the use of innovations and identify areas of innovation strategies of the regions.

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