Model of Socio-Ecological and Economic System: the Central Federal District Regions of the Russian Federation

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Abstract

This paper aims to present the model of socio-ecological and economic system for the regions of the Central Federal district and to make calculations related to the assessment of their state, functioning, management efficiency and harmony. We apply the author's methodological toolkit that includes the formation of individual and integrated indicators of the functioning and the management efficiency of complex systems, considered as socio-ecological and economic systems. The coefficient of harmony is a measure of the equilibrium of the region's functioning, which is constructed using the author's methodology. The paper results are as follows: The model is presented with 9 generalized performance indicators, 26 individual performance indicators and 49 factor indicators (state and impact factors) using open data from the Federal State Statistics Service of the Russian Federation for 2004–2015. Also the assessment of state, functioning, management efficiency and harmony of the Central Federal district are described. Included is also the analysis of the results.

Keywords

Regional economy, socio-ecological and economic systems, econometric modeling, integral indicators balance, efficiency

JEL code

C10, P25, R11, R15

INTRODUCTION

At the moment Russian economy is based on resource-exploration and resource-intensive sectors. It leads to a deterioration of the environmental health and the depletion of natural resources. At the same time, shifting the focus towards the economy without the social component support decreases the living standards, which should not be present in developing and developed countries, including the Russian Federation. Regions represent their territorial administrative units and they should be considered as complex socio-ecological and economic systems (SEES). Their management determines the economic growth and well-being of the entire state's population. However, the managerial efficiency is determined

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first of all by the validated assessment of the SEES's state and functioning as well as by studying the nature of the impact on the part of the management entity. It is the complexity of systems (socio-ecological-economic systems) that defines the diversity of approaches to their study. At the same time, most authors emphasize the social, environmental or economic aspects, applying various evaluation methods and using various models of the state and functioning of complex systems. The purpose of the article is to build a model for the functioning of the socio-ecological and economic system for the regions of the Central Federal District, and offer an assessment of the efficiency of their management. We are going to use the results of author's previous studies related to the research of individual components (social, environmental and economic).

The main method is supposed to be the author's approach presented in the part Data and Methods. It is based on the methods of system analysis, econometric modeling, correlation and regression analysis and the convolution algorithm of data.

1 SURVEY AND LITERATURE REVIEW

The socio-ecological and economic system is the unity of the social, ecological and economic subsystems (Tatarkin et al., 2016). This division is rather conventional as the terminological analysis revealed such systems in definitions that also correspond to other categories. For example, the social system contains economic factors, environmental - social elements, etc. Therefore, the term SEES allows to avoid these inaccuracies and form a general concept of a complex system comprising economic, social, environmental objects, processes, environments and projects.

Anopchenko and Murzin (2012) describe the socio-ecological and economy system as a set of structural components of nature, society and economy with different interconnection types. Meanwhile, they are the interconnections but not the components that are more significant. So it is partly true.

Davankov and Ezhova define the territorial socio-ecological and economy system (TSEES) as "an interconnected combination of natural, industrial, demographic, social and institutional components that function intentionally at the certain territory" (Tatarkin et al., 2016).

Rozanova (2001) determines TSEES as "part of the territory where the intensity of the links between the elements of nature and the economy greatly exceeds the intensity of the connections directed from outside and outwards the system, or assembly of elements itself".

Therefore, we conclude that socio-ecological and economy system is the integral set of interrelated objects, processes, systems and environments having social, ecological and economic relations, as well as their combinations. The system's functioning is aimed at ensuring its survival in the space-time continuum through production, distribution, exchange and consumption of material and non-material resources, substance, energy and information.

The different approaches to the study of socio-ecological and economic systems and the formation of SEES' conception started to develop in the 70's of the last century, when the "nature-population-economy" scheme was used as the basis for the study (Tatarkin et al., 2016). At that date, a number of studies describing the methodology of EES and SEES's research and modeling were published, among them you can find works by Jacobson and Jacobson (1987), Gurman (1981) and also co-authored by Ryumina (2001). Muhina et al. (1978) offered an analytical scheme of "impact – changes – consequences" for the study of complex systems. It correlated with socio-economic geography and suggested the use of the process approach. Bashirova (2010) comes up with the idea of targeted approach and studies SEES from the aspect of meeting the needs of system's elements within the framework of three components: environmental protection, protection and improvement of the human environment, and economic development. Achieving the goals ensures the balance of the state and functioning of SEES. Herewith, the object scheme "nature–man–economy" is used, similar to the Muhina and Preobrazhenskiy's triad presented in the late 1970's.

The study of the sustainable development of complex economic systems is based on the works of the founders of economic thought such as Leontiev (1997), Rothschild et Stiglitz (1976), Akerlof et al. (2001), Solow (1956), Schumpeter (1935), who determined the possibility of equilibrium growth. The issues of environmental safety are highlighted in the works by Zerkalov (2012) and other authors. At the same time, the studies concern only the social, ecological or economic component, although the presence of other different factors is supposed a priori. Summarizing the approaches presented above, we come to the conclusion that all of them use the basic methodology of system analysis in full or in part. The system analysis is based on 3 fundamental methodologies, including analysis, synthesis and behaviourism (Gharajedaghi, 2011).

The authors rely on a variety of models, applying them in compliance with the goals and objectives of the study.

The economic aspect of research at the regional level includes the following most known models of the regional economy.

Individual regional model. The authors use the economic growth models that exploit external demand (export base model) and also Keynes multiplier (multiplier multiplied by the initial change in investment gives the increment of GNP) as the basic factor. Nonlinear approaches (Zhulanov, 2016) are introduced within the framework of well-known Leontiev's input output model (Leontiev, 1997). A detailed analysis of models used by modern scientists, in particular input-output tables, is presented in (Baranov et al., 2016).

The Neumann model of economic growth (linear model of production) by J. von Neumann is also often applied. It describes the possibility of an object's outgate to a time-independent trajectory or a trajectory of equilibrium growth, and, unlike Leontiev's model, that used industries as production units, he relies on technological processes (Neumann, 1945–1946). The application of optimized interindustry models of the region offered by Kantorovich (1939) within the framework of his theory of optimum allocation of resources is widespread. They also take the advantage of Cobb-Douglas model to describe the results of economic system's production depending on labour and capital (Cobb and Douglas, 1928). A number of authors use regional econometric models, including for assessing the sustainability of socio-economic systems (Latypova and Chertykovtsev, 2008).

There are works that use an aggregated model of the regional economy functioning (6 blocks), with separate allocation models (cargo transportation, population migration, production location), as well as interregional models of the national economy (Larionov et al., 2017). Kondratiev's cyclic model (Kondratiev, 1993) is also known. The model presented in the report to the Club of Rome in 1972 by Meadows et al. (1972) is widely known too. It describes the limits of economic and demographic growth under the depletion of natural resources. It is a system of 16 nonlinear differential equations with more than 30 variables. It can be referred to the class of socio-ecological-economic models (Meadows et al., 2012).

Borodin (2006) took as a basis the notorious D. W. Pearce and R. K. Turner model describing the well-being of the population according to natural resources and services, which can be called the model of interaction between economic and ecological systems (Pearce and Turner, 1990). He related pollution (production waste) with the production and economic activities of the SEES, which results in a well-being of the population. These models are used to assess the equilibrium growth of complex systems as a factor in their steady state and functioning (Tatarkin et al., 2016). Partial or general indicators are used as efficiency indicators for evaluating complex systems, the latter of which are defined in the framework of a component analysis or an expert-statistical approach.

As for the first method the first principal component of private unified indicators is the integral indicator (Aivazian, 2003), with its informative value exceeding 55%. If it is impossible to figure out the first principal component, the weighted methodology is used. The squares of the lengths of the eigenvectors of the correlation matrix of the partial indices act as weight coefficients.

One of the options for dimension reduction, which is similar to Principal Components, is the Multidimensional Scaling (an alternative to factor analysis), taking into account the distances (proximity) between objects, but the latest data representations are difficult to interpret (Tolstova, 2006).

The expert-statistical method is supposed to execute an examination of weight coefficients value formation, which ultimately leads to compiling a rating of each of the individual indices significance.

An analysis of recent works on integral estimates has shown that most of them contain a calculation of averages of different types (arithmetic, geometric simple or weighted) and a weighted assessment that defines the importance of this or that partial indicator (subindex) is carried out mostly by expert methods.

Krivonozhko and Lychev (2010) present the Functioning Environment Analysis (FEA) method that develops Data Envelopment Analysis (DEA) by the research group of Charnes et al. (1978). The weighted coefficients of partial indicators that make part of summarized index are defined by solving the tasks of non-linear programming.

From the latter it can be concluded that a number of methods for constructing integral indicators can be used not only to assess the results rating of complex system's functioning, but also its efficiency, although the boundaries between these concepts, when using appropriate methods, are not generally defined.

The variety of existing approaches to the modeling and assessment of the complex systems' functioning led the authors to the idea of developing a methodology that would include the advantages of the presented studies and highlight the main characteristics of socio-ecological and economic systems.

2 DATA AND METHODS

As the model for the functioning of complex systems, a system of linear equations is chosen which are the standardized models of the additive form as the models for forming the norms $\hat{y}_i^*$:

$$\hat{y}_i^* = \sum_{j=1}^{n} C_{i,j} \cdot x_j^* + \sum_{s=1}^{s} D_{i,s} \cdot z_s^*, \tag{1}$$

where n is the number of state factors, s is the number of impact factors, $C_{i,j}$, $D_{i,s}$, are corresponding weight coefficients between i productive (result of functioning of system) and j and s standardized factors of x_j^* state and z_s^* impact. State factors present a set of essential properties that the system possesses at a given moment in time. Impact factors are a set of controlled properties that lead to changes in results of functioning of the system. Subjects of management can change the impact factors. When substituting actual values x_j^* and z_s^* in (1) for k region you can get a individual norm. Herewith:

$$x_j^* = \frac{x_j - M(x_j)}{\sigma(x_j)}, \tag{2}$$

$$z_s^* = \frac{z_s - M(z_s)}{\sigma(z_s)}, \tag{3}$$

where x_j, z_s are the actual values of factors of state and impact in absolute units of measurement.

At the same time, the assessment of the state and functioning of the SEES is determined by means of individual and generalized performance indicators, which describe the results of functioning of the system (Zhuravlev et al., 2013):

$$\xi_{k,i}(t) = \frac{y_{k,i}^0(t)}{\hat{y}_{k,i}^0(t)}, \tag{4}$$

where $y_{k,i}^0(t)$, $\hat{y}_{k,i}^0(t)$ are actual and normative values of standardized individual performance indicators which are specific for explored region, k is the region number, t is the time parameter ($t = 1..T$), $i = 1..m$,

m is the amount of individual performance indicators, the index "0" indicates that the normalization procedure has been carried out (bringing to the scale from 0 to 1), and after standardization:

$$y^0_{k,i}(t) = \frac{y^*_{k,i} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}{\max\{y^*_{k,i}, \hat{y}^*_{k,i}\} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}, \tag{5}$$

$$\hat{y}^0_{k,i}(t) = \frac{\hat{y}^*_{k,i} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}{\max\{y^*_{k,i}, \hat{y}^*_{k,i}\} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}. \tag{6}$$

Here $y^*_{k,i}$, $\hat{y}^*_{k,i}$ are standardized individual performance indicators, defined by the formulas:

$$y^*_{k,i}(t) = \frac{y_{k,i} - M(y_i(t))}{\sigma(y_i(t))}, \tag{7}$$

$$\hat{y}^*_{k,i}(t) = \frac{\hat{y}_{k,i} - M(\hat{y}_i(t))}{\sigma(\hat{y}_i(t))}, \tag{8}$$

where $M(y_i(t))$, $M(\hat{y}_i(t))$, $\sigma(y_i(t))$, $\sigma(\hat{y}_i(t))$ are expected value and standard deviation, respectively.

A generalized performance indicator is calculated as the ratio of individual performance indicators (actual and normative) (Zhukov, 2014):

$$\xi_k(t) = \frac{\sqrt{\sum_{p=1}^{m}\sum_{q=1}^{m} r_{pq} \cdot y^0_{k,p}(t) \cdot y^0_{k,q}(t)}}{\sqrt{\sum_{p=1}^{m}\sum_{q=1}^{m} \hat{r}_{pq} \cdot \hat{y}^0_{k,p}(t) \cdot \hat{y}^0_{k,q}(t)}}, \tag{9}$$

where r_{pq} and $\hat{r}_{pq}$ are the corresponding paired correlation coefficients.

If $\xi_k(t) \geq 1$, then we can assume them satisfactory otherwise we are to take measures aimed at the achievement of the norm that is calculated for each k of the object.

The application the proposed approach makes it possible to meet all the requirements for integrated assessment indicators.

The harmonic coefficient characterizing the balance of the system's functioning results can be determined by formula (Zhukov, 2016, 2017):

$$K_k = 1 - \frac{\sigma(\xi_{k,i})}{M(\xi_{k,i})}, \tag{10}$$

where $M(\xi_{k,i})$ is expected value, $\sigma(\xi_{k,i})$ is standard deviation. The closer to the one K_k, the more harmonic is the functioning of the object under research. This indicator does not characterize its specialization, but shows the degree of compliance of the indicators under consideration with the norms, taking into account specific conditions.

We introduce the notion of the effectiveness indicator. The effectiveness indicator is the ratio of the change in performance indicators to the change in the factors of the state (impact, generalized factor of state and impact) for the period under review.

A partial effectiveness indicator may be determined as:

$$Ef_{FPP,k}(t) = \frac{\Delta\xi_{k,i}(t)}{\Delta x_{k,i,j}(t)} = \frac{\xi_{k,i}(t) / \xi_{k,i}(t_o)}{x^0_{k,i,j}(t) / x^0_{k,i,j}(t_0)}, \tag{11}$$

where $\xi_{k,i}(t)$, $\xi_{k,i}(t_o)$ are determined by Formula (4) for current and base (previous) periods $x^0_{k,i,j}(t)$, $x^0_{k,i,j}(t_0)$ are normalized state factors correspondently; k is the region number; i is the index of partial performance indicators; j is index of state factor, FPP is Functioning, Partial indicator, Partial factor. Here and further "/" is the division operation, which is presented in this way for greater clarity of representation of the formula. The normalization procedure for $x^0_{k,i,j}(t)$, $x^0_{k,i,j}(t_0)$ is carried out by formula which is similar to Formula (5).

A partial effectiveness indicator of the functioning SEES by the generalized state factor is calculated as:

$$Ef_{FPG,k}(t) = \frac{\Delta\xi_{k,i}(t)}{\Delta x_{k,i,j}(t)} = \frac{\xi_{k,i}(t)/\xi_{k,i}(t_o)}{x^0_{k,i}(t/t_0)}, \tag{12}$$

where FPG is Functioning, Partial indicator, Generalized factor and $x^0_{k,i}(t/t_0)$ is determined by formula:

$$x^0_{k,i}(t/t_0) = \sqrt{\sum_{p=1}^{n}\sum_{q=1}^{n} r_{pq} \cdot \frac{x^0_{k,i,p}(t)}{x^0_{k,i,p}(t_0)} \cdot \frac{x^0_{k,i,q}(t)}{x^0_{k,i,q}(t_0)}}, \tag{13}$$

here r_{pq} is Pearson's correlation coefficient between p and q state factors, n is the amount of factors.

In case when state factors are independent then correlation matrix with r_{pq} are identity matrix and Formula (13) is simplified:

$$x^0_{k,i}(t) = \sqrt{\sum_{j=1}^{n}\left(\frac{x^0_{k,i,j}(t)}{x^0_{k,i,j}(t_0)}\right)^2}. \tag{14}$$

A generalized indicator of the effectiveness by partial and generalized state factors is determined as:

$$Ef_{FGP,k}(t) = \frac{\Delta\xi_k(t)}{\Delta x_{k,j}(t)} = \frac{\xi_k(t)/\xi_k(t_o)}{x^0_{k,j}(t)/x^0_{k,j}(t_0)}, \tag{15}$$

$$Ef_{FGG}(t) = \frac{\Delta\xi_k(t)}{\Delta x_k(t)} = \frac{\xi_k(t)/\xi_k(t_o)}{x^0_k(t/t_0)}, \tag{16}$$

where FGP is Functioning, Generalized indicator, Partial factor, FGG is Functioning, Generalized indicator, Generalized factor and $\xi_k(t)$, $\xi_k(t_o)$ are determined by Formula (9).

Similarly, an partial and generalized indicator of the effectiveness by partial and generalized impact factors is determined as:

$$Ef_{IPP,k}(t) = \frac{\Delta\xi_{k,i}(t)}{\Delta z_{k,i,s}(t)} = \frac{\xi_{k,i}(t)/\xi_{k,i}(t_o)}{z^0_{k,i,s}(t)/z^0_{k,i,s}(t_0)}, \tag{17}$$

$$Ef_{IPG,k}(t) = \frac{\Delta\xi_{k,i}(t)}{\Delta z_{k,i,j}(t)} = \frac{\xi_{k,i}(t)/\xi_{k,i}(t_o)}{z^0_{k,i}(t/t_0)}, \tag{18}$$

$$Ef_{IGP}(t) = \frac{\Delta\xi_k(t)}{\Delta z_{k,s}(t)} = \frac{\xi_k(t)/\xi_k(t_o)}{z^0_{k,s}(t)/z^0_{k,s}(t_0)}, \tag{19}$$

$$Ef_{IGG,k}(t) = \frac{\Delta\xi_k(t)}{\Delta z_k(t)} = \frac{\xi_k(t)/\xi_k(t_o)}{z^0_k(t/t_0)}. \tag{20}$$

Here s is the amount of impact factors, IP(G)P(G) is Impact, Particular (Generalized) indicator, Partial (Generalized) factor, $z_{k,i}^0(t/t_0)$ and $z_k^0(t/t_0)$ are defined similarly to Formula (13).

Partial and generalized indicators of management effectiveness are a generalization of performance and impact indicators, since they take into account the influence of both state and impact factors. The last of them change the state of the SEES, which is one of the management functions.

The main difference between the constructed indicators of SEES management effectiveness will be the presence in the denominator of the generalized state and impact factor:

$$Ef_{MPG}(t) = \frac{\Delta\xi_{k,i}(t)}{\{\Delta x_{k,i,j}(t), \Delta z_{k,i,j}(t)\}} = \frac{\xi_{k,i}(t)/\xi_{k,i}(t_o)}{\{x_{k,i}^0(t/t_0), z_{k,i}^0(t/t_0)\}}, \tag{21}$$

$$Ef_{MGG}(t) = \frac{\Delta\xi_k(t)}{\{\Delta x_{k,j}(t), \Delta z_{k,j}(t)\}} = \frac{\xi_k(t)/\xi_k(t_o)}{\{x_k^0(t/t_0), z_k^0(t/t_0)\}}, \tag{22}$$

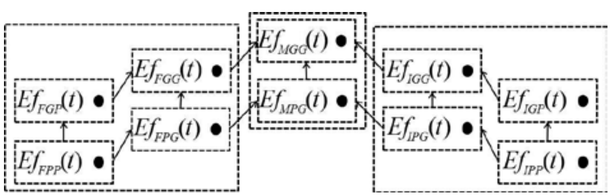
where M is Management and $\{x_k^0(t/t_0), z_k^0(t/t_0)\}$ is determined by the formula:

$$\{x_k^0(t/t_0), z_k^0(t/t_0)\} = \sqrt{\begin{array}{l} \sum_{p=1}^{n}\sum_{q=1}^{n} r_{pq} \cdot \frac{x_{k,i,p}^0(t)}{x_{k,i,p}^0(t_0)} \cdot \frac{x_{k,i,q}^0(t)}{x_{k,i,q}^0(t_0)} + \\ + \sum_{p=1}^{n}\sum_{q=1}^{s} r_{pq} \cdot \frac{x_{k,i,p}^0(t)}{x_{k,i,p}^0(t_0)} \cdot \frac{z_{k,i,q}^0(t)}{z_{k,i,q}^0(t_0)} + \\ + \sum_{p=1}^{s}\sum_{q=1}^{s} r_{pq} \cdot \frac{z_{k,i,p}^0(t)}{z_{k,i,p}^0(t_0)} \cdot \frac{z_{k,i,q}^0(t)}{z_{k,i,q}^0(t_0)} \end{array}}. \tag{23}$$

It should be noted that not all influencing factors determine the efficiency of management, but only those of them that are directly related to the purposeful influence on the system's functioning on the part of the subjects of management, for example, investments of various kinds, planned expenditures for the performance of an activity, etc.

The efficiency indicators formed this way represent an assessment of the functioning, impact and management of the SEES with various level of detail, and it allows to give a comprehensive assessment to the object of research (Figure 1).

Figure 1 Scheme of conformity of indicators of the effectiveness (functioning, impact and management) of SEES



Source: Own construction

Figure 1 shows that a set of efficiency assessment indicators represents step structure and provides a possibility of studying of SEES in various cuts.

The data of the research is represented by the Federal State Statistics Service of the Russian Federation (ROSSTAT) data for the regions of the Central Federal district in 2004–2015[2] (2004–2014 – social component, 2007–2014 – ecological component, 2007–2015 – economic component, number of observations for each variable made 187, 136, 153 for 17 CFD regions correspondently). The choice of different periods is related to the availability of open statistical data of ROSSTAT. The statistical data set has no outliers.

The description of the variables is represented in Table 1 to Table 8.

Table 1 The description of the variables of social assessment (generalized and private assessment indicators)

№	Variables	Description
1	$\hat{y}^*_{soc}$	Generalized social indicator
2	$\hat{y}^*_{2..9}$	Remaining life expectancy index
3	$\hat{y}^*_{5}$	Education index
4	$\hat{y}^*_{10.2/2}$	Per capita income

Note: Variable without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, fact values for No. 2,3,4 were calculated using technique of UNDP.[3]
Source: ROSSTAT, own construction

Table 2 The description of the variables of social assessment (state factors)

№	Variables	Description
1	$x^*_{2.8}$	Natural increase per 1 000 people
2	$x^*_{2.12}$	Net migration per 1 000 people
3	$x^*_{4,1}$	Percentage rates for real disposable income in comparison with the corresponding period of the year 2004
4	$x^*_{4.10}$	Social transfers as per cent of total income levels
5	$x^*_{4.19,5/1}$	Education expenditures of the general population generating inflation-adjusted positive and with the corresponding period of the year 2004
6	$x^*_{4.19,6/1}$	Health expenditures of the general population generating inflation-adjusted positive and with the corresponding period of the year 2004
7	$x^*_{4.22}$	Per capita consumption of meat and meat products
8	$x^*_{8.1}$	Number of crimes reported per 100 000 people
9	$x^*_{9.1}$	Air pollutants from stationary sources
10	$x^*_{9.5}$	Discharges of polluted waste water into surface water bodies

Note: * standardized variables.
Source: ROSSTAT, own construction

[2] Federal State Statistics Service of the Russian Federation (ROSSTAT) [online]. [cit. 20.6.2017]. <*http://www.gks.ru*>.
[3] The United Nations development programme (UNDP) [online]. [cit. 18.9.2017]. <*http://www.undp.ru*>.

Table 3 The description of the variables of social assessment (impact factors)

№	Variables	Description
1	$z^{*}_{1/1}$	Investments in fixed capital per capita (total) adjusted for inflation
2	$z^{*}_{1,5/1}$	Investments in fixed capital by education adjusted for inflation
3	$z^{*}_{1/2}$	Per capita investments in fixed capital (total) to purchasing power parity (PPP) in US dollars
4	z^{*}_{3}	Consolidated budget expenditures (total)

Note: * standardized variables.
Source: ROSSTAT, own construction

Table 4 The description of the variables of ecological assessment (generalized and private assessment indicators)

№	Variables	Description
1	$\hat{y}^{*}_{ecol}$	Generalized ecological indicator
2	$\hat{y}^{*}_{9,1}$	Generalized performance indicator for the assessment of the air
3	$\hat{y}^{*-1}_{9.1,1}$	Air pollutants
4	$\hat{y}^{*}_{9.2,1}$	Capture of air pollutants from stationary sources
5	$\hat{y}^{*}_{9,2}$	Generalized performance indicator for the assessment of the water source
6	$\hat{y}^{*}_{9.3,2}$	The use of fresh water
7	$\hat{y}^{*}_{9.4,2}$	Volume of circulating and consistently used water
8	$\hat{y}^{*-1}_{9.5,2}$	Discharges of polluted waste water into surface water bodies
9	$\hat{y}^{*}_{9,3}$	Generalized performance indicator for the assessment of the generation, disposal and use of waste
10	$\hat{y}^{*-1}_{9.6,3}$	Waste generation of production and consumption
11	$\hat{y}^{*-1}_{9.7,3}$	Waste storage and disposal
12	$\hat{y}^{*}_{9.8,3}$	Waste use and decontamination
13	$\hat{y}^{*-1}_{9.9,3}$	Waste intensity

Note: * standardized variables, ^ model (calculated) variables, –1 shows that the indicator is negative.
Source: ROSSTAT, own construction

In Tables 6 to 8 the variables that we use are grouped according to the division offered by Kolesnikov et Tolstoguzov (2016) and performance indicators (private assessment indicators) that include GDP by regions by economic activities (Russian Classification of Economic Activities (NACE (OKVED)) was used in the Russian Federation till 2015)[4] grouped by aggregate sector of the economy.

[4] Russian Classification of Economic Activities (NACE (OKVED)) [online]. [cit. 18.6.2017]. <*http://www.gks.ru/bgd/free/b02_60/Main.htm*>.

Table 5 The description of the variables of ecological assessment (state and impact factors)

№	Variables	Description
	State factors	
1	$x^*_{17.30}$	Passenger turnover (cars and public buses)
2	$x^*_{13.1}$	Sold goods of their own production and provided works and services by types of economic activity (total)
3	$x^*_{2.2}$	Average annual population
4	$x^*_{13.64}$	Electricity production
5	$x^*_{13.1,1.2}$	Sold goods of their own production and provided works and services by types of economic activity (mining and quarrying)
6	$x^*_{13.2}$	Industrial production index as % to the base year
	Impact factors	
7	$z^*_{9.1,3}$	Environmental expenditure in 2007 prices (air)
8	$z^*_{9.3,3}$	Environmental expenditure in 2007 prices (waste)

Note: * standardized variables.
Source: ROSSTAT, own construction

Table 6 The description of the variables of economic assessment (private assessment indicators)

№	Variables	Description	№	Variables	Description
1	$\hat{y}^*_1$	Commodity aggregate sector	4.3	$\hat{y}^*_{4.3}$	Section H. Transporting and storage. Section J. Information and communication (I)
1.1	$\hat{y}^*_{1.1}$	Section A. Agriculture, forestry and fishing (A)	4.4	$\hat{y}^*_{4.4}$	Section K. Financial and insurance activities (J)
1.2	$\hat{y}^*_{1.2}$	Section B. Mining and quarrying (C)	4.5	$\hat{y}^*_{4.5}$	Section L. Real estate activities. Section M. Professional, scientific and technical activities. Section N. Administrative and support service activities (K)
2	$\hat{y}^*_2$	Manufacturing aggregate sector	5	$\hat{y}^*_5$	Aggregate sector of non-market services
2	$\hat{y}^*_2$	Section C. Manufacturing (D)	5.1	$\hat{y}^*_{5.1}$	Section D. Electricity, gas, steam and air conditioning supply. Section E. Water supply; sewerage; waste management and remediation activities (E)
3	$\hat{y}^*_3$	Construction aggregate sector	5.2	$\hat{y}^*_{5.2}$	Section O. Public administration and defence; compulsory social security (L)
3	$\hat{y}^*_3$	Section F. Construction (F)	5.3	$\hat{y}^*_{5.3}$	Section P. Education (M)
4	$\hat{y}^*_4$	Aggregate sector of market services	5.4	$\hat{y}^*_{5.4}$	Section Q. Human health and social work activities (N)
4.1	$\hat{y}^*_{4.1}$	Section G. Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	5.5	$\hat{y}^*_{5.5}$	Section R. Arts, entertainment and recreation. Section S. Other services activities (O)
4.2	$\hat{y}^*_{4.2}$	Section I. Accommodation and food service activities (H)			

Note: * standardized variables, ^ model (calculated) variables, () NACE Rev. 1.1. sections.
Source: ROSSTAT, Zhukov (2018)

Table 7 The description of the variables of economic assessment (state factors)

№	Variables	Description	№	Variables	Description
6	The cost of fixed production assets at full accounting value at the end of the year by types of economic activity		7.4	$\overset{*}{x}_{3,2}$	Section F
6.1	$\overset{*}{x}_{1.1,1}$	Section A (A)	7.5	$\overset{*}{x}_{4.1,2}$	Section G (G)
6.2	$\overset{*}{x}_{1.2,1}$	Section B (C)	7.6	$\overset{*}{x}_{4.2,2}$	Section I (H)
6.3	$\overset{*}{x}_{2,1}$	Section C (D)	7.7	$\overset{*}{x}_{4.3,2}$	Sections H,J (I)
6.4	$\overset{*}{x}_{3,1}$	Section F (F)	7.8	$\overset{*}{x}_{4.5,2}$	Sections L, M, N (K)
6.5	$\overset{*}{x}_{4.1,1}$	Section G (G)	7.9	$\overset{*}{x}_{5.1,2}$	Sections D, E (E)
6.6	$\overset{*}{x}_{4.3,1}$	Sections H, J (I)	7.10	$\overset{*}{x}_{5.3,2}$	Section P (M)
6.7	$\overset{*}{x}_{5.1,1}$	Sections D,E (E)	8	$\overset{*}{x}_{2.2}$	Average annual population
7	Average annual number of persons employed by types of economic activities		9	Transport	
7.1	$\overset{*}{x}_{1.1,2}$	Section A (A)	9.1	$\overset{*}{x}_{4.1}$	Passenger turnover of public buses
7.2	$\overset{*}{x}_{1.2,2}$	Section B (C)	9.2	$\overset{*}{x}_{4.2}$	Departure of passengers by public railway transport
7.3	$\overset{*}{x}_{2,2}$	Section C (D)	10	$\overset{*}{x}_{5}$	Morbidity per 1 000 of population, registered diseases diagnosed in patients for the first time in life

Note: Variables without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, () NACE Rev. 1.1. sections.
Source: ROSSTAT, Zhukov (2018)

Table 8 The description of the variables of economic assessment (impact factors)

№	Variables	Description	№	Variables	Description
11	Investments in fixed capital by kinds of economic activities		12	$\overset{*}{z}_{2}$	Organic fertilizers per 1 ha of agricultural crops (in terms of 100% nutrients)
11.1	$\overset{*}{z}_{2,1}$	Section D (D)	13	Consolidated budget expenditures (by object)	
11.2	$\overset{*}{z}_{4.1,1}$	Section G (G)	13.1	$\overset{*}{z}_{5.2,3}$	Social policy
11.3	$\overset{*}{z}_{4.2,1}$	Section I (H)	13.2	$\overset{*}{z}_{5.3,3}$	Education
11.4	$\overset{*}{z}_{4.5,1}$	Sections L, M, N (K)			

Note: Variable without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, () NACE Rev. 1.1. sections.
Source: ROSSTAT, Zhukov (2018)

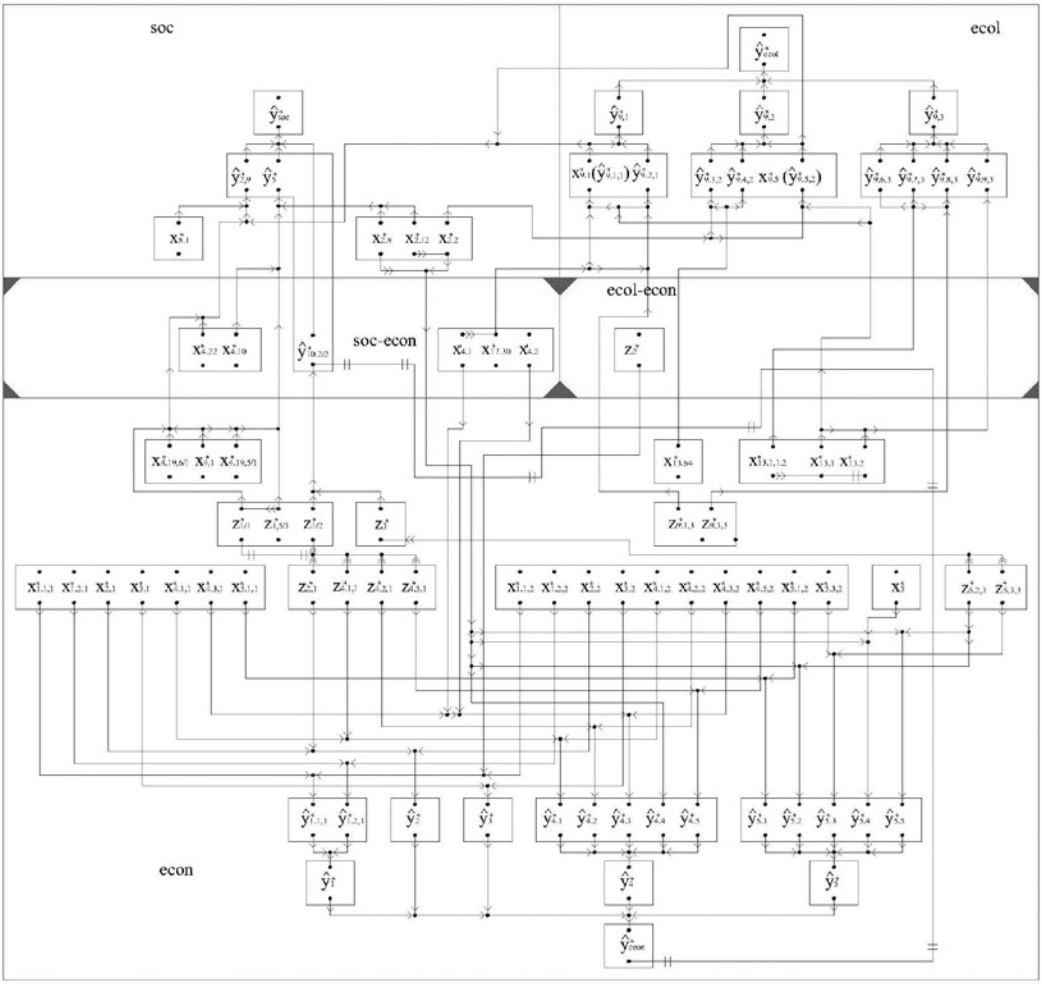
These tables include only substantial factors, significant at the level of no more than 5%. We used least square method (backward selection) to select included variables.

3 RESULTS AND DISCUSSION

The conducted research resulted in the corresponding models in forms (1), whose specification is represented in Tables 1 to 8 using author's expert system (beta version) (Zhukov, 2015). The corresponding formulas, which were reflected in the author's earlier investigations (Zhukov, 2016, 2017, 2018), are presented in the Annex.

The functioning model of SEES is included 26 equations with 49 state and impact factors. The visualization of the detected significant links is shown in Figure 2.

Figure 2 Model of socio-ecological and economic system for the CFD of the Russian Federation



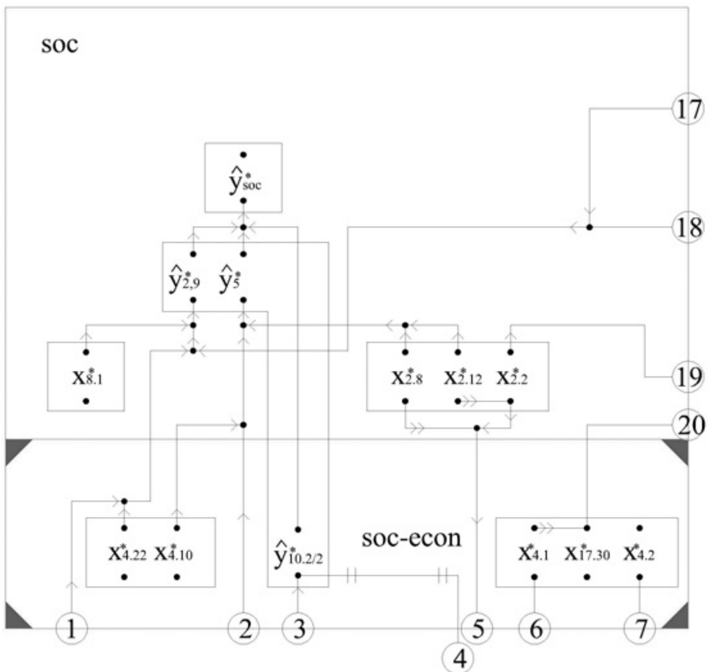
Note: Soc is social area; ecol is ecological area; econ is economic area; soc-econ is socioeconomic area; ecol-econ is ecological-economic area; > is direction of dependence of factors; >> shows that this indicator is part of the indicator with which it is associated (for example, the consolidated budget expenditures by education are part of the total consolidated budget expenditures); | | this indicator is derived from the associated indicator (for example, investments in fixed capital adjusted for inflation and investments in fixed capital (total) to purchasing power parity (PPP) in US dollars).

Source: Own construction

Figure 2 shows that some factors are socioeconomic and ecological-economic factors. At the same time, the environmental partial performance indicator $\hat{y}^*_{9,1}$ is state factor for remaining life expectancy index $\hat{y}^*_{2..9}$.

The detail visualization of the detected significant links is shown in Figures 3 to 5.

Figure 3 Detailing the social and socio-economic area of SEES model



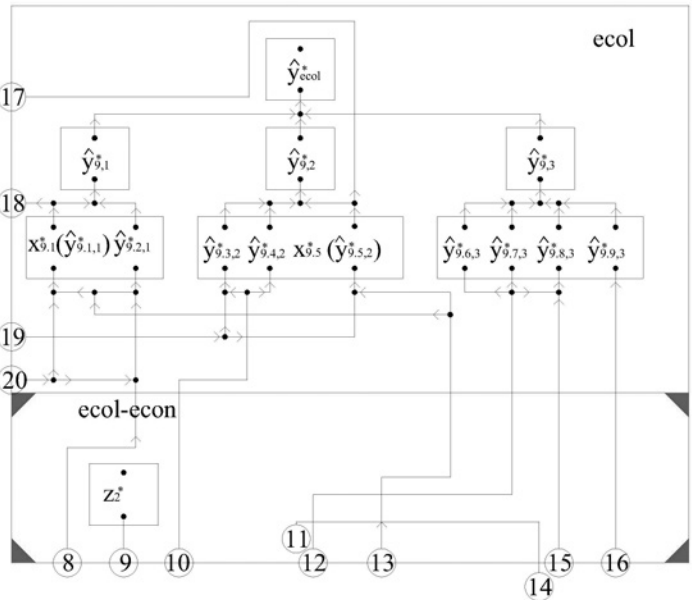
Source: Own construction

One of the performance indicators of ecological characteristic namely discharges polluted waste water into surface water bodies ($\hat{y}^*_{9.5,2}$) defines the state of social component; it also influences remaining life expectancy index ($\hat{y}^*_{2..9}$). The factors ($x^*_{2.8}$ and $x^*_{2.12}$) are components of the average annual population $x^*_{2.2}$ (Figure 3). The passenger turnover of public buses ($x^*_{4.1}$) are component passenger turnover (cars and public buses) ($x^*_{17.30}$). Also per capita income ($\hat{y}^*_{10.2/2}$) (Figure 3) belong to socioeconomic area and it is included in the generalized social indicator $\hat{y}^*_{econ}$ (Figure 5).

Figure 4 shows that organic fertilizers per 1 ha of agricultural crops (in terms of 100% nutrients) is included in ecological-economic area of SEES model.

The represented model that includes only the essential factors selected with the help of least square method (backward selection) is connected to the external environment through state and impact factors. Net migration per 1 000 people ($x^*_{2.12}$) and passenger turnover (cars and public buses) ($x^*_{17.30}$) are referred to such factors of state. Investments in fixed capital by kinds of economic activities ($z^*_{2,1}$) and other total (for example, $z^*_{1/1}$) can be referred to the factors of impact. All the rest factors of state and impact define the set of limitations. For example, regional budget revenues in the form of federal budget transfers impose restrictions to the structure and volume of consolidated budget expenses. All this requires a more detailed evaluation for a particular SEES. So the factors

Figure 4 Detailing the ecological and ecological-economic area of SEES model



Source: Own construction

of state and impact not included in the model can serve as the constraints imposed on the socio-ecological and economic system's functioning that allows to describe it within the framework of open systems.

To confirm the independence of the social, environmental and economic assessment, we will perform a factor analysis for the generalized SEES performance indicators. To do it we used the principal component analysis (PCA). The calculation was carried out by means of the analytical platform Deductor by BaseGroup Labs[5] (Table 9). The evaluation period was 2010–2014.

Table 9 shows that that the contribution of each component is significant so they can't be elicit from the model. It determines the possibility of constructing a relationship between them in the form of a linear or other communication model.

The first component gives the largest contribution to the result (46.25%).

We built three models showing the links between the social, ecological and economic performance indicators.

$$\xi_{\mathrm{soc}} = 0.940 + 0.071 \cdot \xi_{\mathrm{econ}}, \tag{24}$$

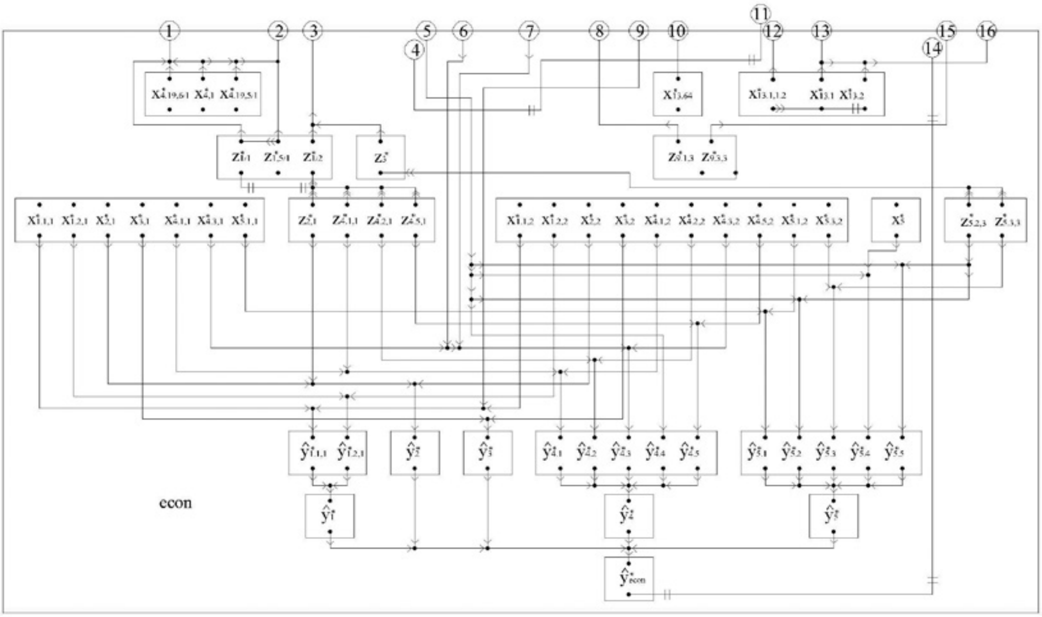
$$\xi_{\mathrm{ecol}} = 0.754 + 0.103 \cdot \xi_{econ}, \tag{25}$$

$$\xi_{\mathrm{econ}} = -1.115 + 1.677 \cdot \xi_{soc} + 0.590 \cdot \xi_{\mathrm{ecol}}, \tag{26}$$

where ξ_{econ}, ξ_{soc}, ξ_{ecol} are generalized social, ecological and economic performance indicators correspondently.

[5] Analytical platform Deductor Studio [online]. [cit. 23.1.2018]. <*https:// basegroup.ru*>.

Figure 5 Detailing the ecological and ecological-economic area of SEES model



Source: Own construction

Table 9 The results of principal component analysis (PCA)

N⁰	Principal component	Eigenvalues	% of the variance	Cumulative weight, %
1	Value 1	1.388	46.25	46.25
2	Value 2	1.044	34.82	81.07
3	Value 1	0.568	18.93	100

Source: Own construction

The standardized equation has the following form:

$$\breve{\xi}_{\text{soc}} = 0.339 \cdot \breve{\xi}_{econ}, \tag{27}$$

$$\breve{\xi}_{\text{ecol}} = 0.238 \cdot \breve{\xi}_{econ}, \tag{28}$$

$$\breve{\xi}_{\text{econ}} = 0.351 \cdot \breve{\xi}_{soc} + 0.255 \cdot \breve{\xi}_{\text{ecol}}. \tag{29}$$

For these models (Formulas 24–26) the coefficients of determination are $R^2_1 = 0.115$, $R^2_2 = 0.057$, $R^2_3 = 0.179$; the coefficients of multiple correlation are $R_1 = 0.339$, $R_2 = 0.238$, $R_2 = 0.424$; the standard errors are $\sigma_1 = 0.085$, $\sigma_2 = 0.181$, $\sigma_3 = 0.394$; the calculated values of F-test are $F_{calc1} = 10.741$, $F_{calc2} = 4.984$, $F_{calc3} = 8.961$, the critical values are $F_{cr1} = 3.956$, $F_{cr2} = 3.956$, $F_{cr3} = 3.108$, the statistical significance at 5% level with $(1, 83)_1$, $(1, 83)_2$, $(1, 82)_3$ degrees of freedom correspondently.

For the parameters of the model one (Formula 24) t-statistic is calculated (t_{calc}, in parentheses is the standard error) and, correspondently, values for the coefficients are $a_0 = 20.093$ (0.047), $a_1 = 3.164$ (0.022), the critical values are $t_{cr} = 1.989$ the statistical significance at 5% level with 82 degrees of freedom. The average relative errors of this model is $E_{rel} = 6.320\%$. For the model two (Formula 25) these evaluation parameters are $a_0 = 13.837$ (0.055), $a_1 = 2.232$ (0.046), $E_{rel} = 16.525\%$. For the model three (Formula 26) there are $a_0 = 2.073$ (0.538), $a_1 = 3.502$ (0.479), $a_2 = 2.544$ (0.232), $E_{rel} = 20.526\%$.

The model linking the economic indicator with the rest indicators turned out the most qualitative but its accuracy is lower in comparison with other models.

In this case the system of Formulas (24), (25) or (27), (28) or just one Formula (26) or (29) can be used to describe the functioning of SEES.

To construct the generalized performance indicator (ξ) we took 26 partial performance indicators and 51 factor attributes (the factors of state and impact). The results of calculations are shown in Table 10.

Table 10 The values of the integral performance indicators $\xi(t)$ for the regions of the CFD in 2010–2014 years

Nº	Region/Year	2010	2011	2012	2013	2014
1	Belgorod	0.972	0.995	0.960	0.984	1.064
2	Bryansk	1.082	1.126	1.220	1.154	1.224
3	Vladimir	0.892	0.964	0.976	0.966	0.984
4	Voronezh	0.750	0.877	0.907	0.842	0.886
5	Ivanovo	0.852	0.923	0.974	0.931	0.965
6	Kaluga	0.924	0.938	0.912	0.907	0.927
7	Kostroma	0.937	1.023	1.110	1.119	1.158
8	Kursk	1.070	1.028	1.025	1.037	1.041
9	Lipetsk	0.786	0.810	1.032	1.025	1.083
10	Moscow	0.923	0.918	0.942	0.899	0.903
11	Orel	0.968	1.007	1.035	0.933	0.986
12	Ryazan	1.004	1.017	1.054	1.055	1.256
13	Smolensk	1.009	0.956	0.982	0.997	1.014
14	Tambov	1.150	1.215	1.022	0.996	1.016
15	Tver	0.838	0.857	0.844	0.846	0.876
16	Tula	0.809	0.909	0.896	0.905	0.949
17	Yaroslavl	0.861	0.980	1.019	1.073	1.109

Source: Own construction

Table 10 shows that the maximum value of the indicator is observed in 2014 compared to previous years for the almost all CFD regions except Voronezh, Kursk, Moscow, Orel and Tambov regions.

The performance uniformity analysis of SEES functioning showed the differentiation of the harmonic coefficient (see Formula 10) for the CFD regions in 2010–2014 years (see Table 11).

Table 11 shows that in comparison with the harmonic coefficient values of the individual components (economic and social) that were presented in previous studies (Zhukov, 2016, 2017, 2018), the coefficient value is lower, for the ecological component the values above are observed for most regions except for the Bryansk, Kostroma, Tambov and Tula regions. That is, for allocated SEES the imbalance is not compensated by inclusion of the ecological component when calculating the harmonic coefficient.

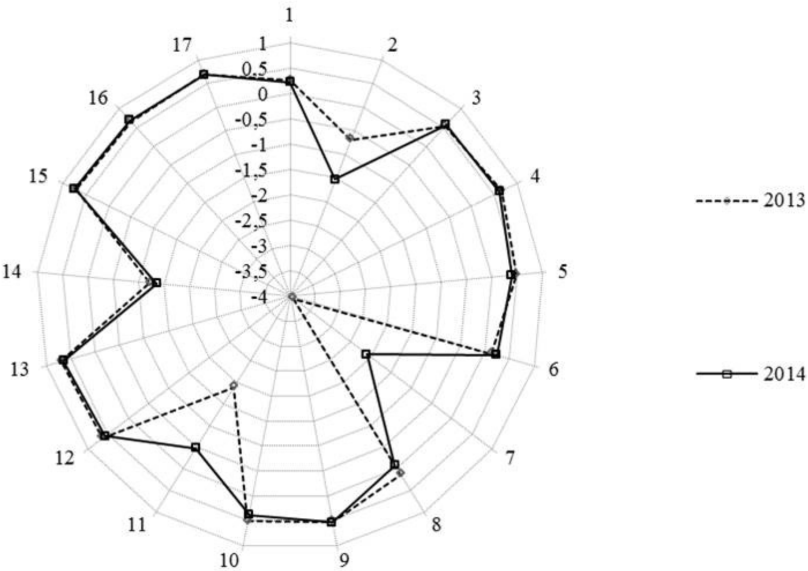
The visualization of the harmonic coefficient in 2013–2014 years is shown in Figure 6.

Table 11 The values of the harmonic coefficient for the regions of the CFD in 2010–2014 years

N⁰	Region/Year	2010	2011	2012	2013	2014
1	Belgorod	0.179	0.193	0.212	0.252	0.217
2	Bryansk	–0.099	–0.687	–0.632	–0.695	–1.534
3	Vladimir	0.699	0.151	0.439	0.532	0.570
4	Voronezh	0.685	0.653	0.677	0.653	0.622
5	Ivanovo	0.420	0.303	0.545	0.486	0.393
6	Kaluga	–0.040	0.035	0.043	0.138	0.235
7	Kostroma	–0.269	–0.782	–0.192	–3.919	–2.104
8	Kursk	–0.238	0.552	0.567	0.136	–0.072
9	Lipetsk	0.508	0.413	0.580	0.528	0.534
10	Moscow	0.573	–0.374	0.426	0.511	0.381
11	Orel	–2.424	–0.802	–1.192	–1.893	–0.476
12	Ryazan	0.328	0.579	0.642	0.636	0.577
13	Smolensk	0.648	0.682	0.702	0.688	0.645
14	Tambov	–0.908	–0.833	–2.445	–1.222	–1.358
15	Tver	0.604	0.709	0.694	0.716	0.746
16	Tula	0.509	0.601	0.688	0.661	0.694
17	Yaroslavl	0.668	0.629	0.638	0.683	0.679

Source: Own construction

Figure 6 Harmonic coefficient for the CFD regions in 2013–2014



Note: 1 – Belgorod, 2 – Bryansk, 3 – Vladimir, 4 – Voronezh, 5 – Ivanovo, 6 – Kaluga, 7 – Kostroma, 8 – Kursk, 9 – Lipetsk, 10 – Moscow, 11 – Orel, 12 – Ryazan, 13 – Smolensk, 14 – Tambov, 15 – Tver, 16 – Tula, 17 – Yaroslavl.
Source: Own construction

We can conclude that the decomposition of the social and economic harmonic coefficients into individual components worsens the value of the harmonic coefficient, which includes all three components, and the ecological coefficient, on the contrary, increases its value.

Analyzing the efficiency of SEES management we chose the following main factors influencing the generalized indicator of SEES functioning assessment: investments in fixed capital per capita (total) adjusted for inflation ($\Delta z^0_{1/1}$); investments in fixed capital by education adjusted for inflation ($\Delta z^0_{1,5/1}$); consolidated budget expenditures (total; Δz^0_3); environmental expenditure in 2007 prices (air; $\Delta z^0_{9.1,3}$); environmental expenditure (waste; $\Delta z^0_{9.3,3}$); investments in fixed capital by kinds of economic activities (D(D), G(G), H(I), K(L), M, N; $\Delta z^0_{2,1}$, $\Delta z^0_{4.1,1}$, $\Delta z^0_{4.2,1}$, $\Delta z^0_{5.1,1}$ sections correspondently).

Indicators of management effectiveness ($\Delta\xi$ / Δz^0_i) is calculated by Formula (19), where t, t_0 are current and previous periods correspondently (see Table 12).

Thus, in the Tula region the values of the effective indicators are more (less) than one for 5 (4) factors correspondently.

The least value (0.653) of the indicator is observed for the consolidated budget expenditures factor.

High efficiency for the generalized indicator by the factor of investment in fixed-capital assets per capita (total), adjusted for the inflation rate of the corresponding year ($\Delta z^0_{1/1}$) was observed for the Orel (29.228) and Smolensk (16.338) regions, and its value is out of the general trend for the rest of the regions. It can be caused by the following factors:. As for the Orel region, its investments in fixed capital changed insignificantly. In 2014 they were equal to 21 552.20 rubles (0.006 in the standardized variables), in 2013 – 23 148.90 rubles (0.179), i. e. they decreased by 1 596.70 rubles, and their ratio in standardized variables was 0.036.

Table 12 The values of the effective indicator for the regions of the CFD in 2014

Region/Indicator	$\Delta\xi / \Delta z^0_{1/1}$	$\Delta\xi / \Delta z^0_{1,5/1}$	$\Delta\xi / \Delta z^0_{3}$	$\Delta\xi / \Delta z^0_{9.1,3}$	$\Delta\xi / \Delta z^0_{9.3,3}$	$\Delta\xi / \Delta z^0_{2,1}$	$\Delta\xi / \Delta z^0_{4.1,1}$	$\Delta\xi / \Delta z^0_{4.2,1}$	$\Delta\xi / \Delta z^0_{5.1,1}$
Belgorod	1.933	1.178	1.4	0.701	1.102	2.145	1.298	2.202	1.374
Bryansk	1.126	0.696	1.378	1.065	0.62	1.253	1.061	1.024	1.074
Vladimir	0.674	1.384	0.722	1.149	0.555	0.219	0.683	0.789	1.171
Voronezh	1.034	1.148	0.928	20.46	1.152	0.678	0.815	0.478	0.849
Ivanovo	1.245	2.502	0.933	1.051	1.079	1.028	0.892	1.02	0.903
Kaluga	1.035	1.491	0.589	1.343	1.198	0.926	1.78	1.037	1.024
Kostroma	0.819	1.145	0.965	0.963	0.985	0.596	1.019	1.051	1.033
Kursk	2.084	7.792	0.983	1.173	0.675	1.075	0.889	1.366	0.905
Lipetsk	1.112	1.004	0.225	1.512	0.85	1.833	0.513	1.853	0.588
Moscow	1.312	0.971	0.885	1.412	1.286	0.866	0.657	0.892	0.755
Orel	29.228	1.065	1.042	1.034	1.187	0.957	0.947	1.049	1.017
Ryazan	2.95	0.538	2.028	3.03	0.991	4.895	1.349	1.194	1.255
Smolensk	16.338	2.309	1.39	1.075	1.052	0.831	0.964	0.925	0.956
Tambov	0.936	1.356	0.691	1.085	0.909	0.917	1.067	1.007	0.3
Tver	5.863	1.375	1.024	0.826	1.012	1.683	0.444	0.039	0.969
Tula	1.681	4.652	0.653	1.312	1.393	0.7	1.707	0.881	0.803
Yaroslavl	3.869	5.639	0.863	0.903	0.807	0.104	1.211	0.048	1.831

Source: Own construction

Meanwhile, the generalized performance indicator increased and amounted to 0.986 in 2014 against 0.933 in 2013, i.e. 1.057 times. Their ratio gives the value of 29.228. It means that at the decrease of investments in fixed capital the growth of the generalized performance indicator of functioning SEES is observed. A similar situation is typical for the Smolensk region.

High value of the effective indicator (20.460) by the factor of environmental expenditure in 2007 prices (air; $\Delta z^0_{9.1,3}$) is observed in the Voronezh region. The maximum value by the factor of investments in fixed capital by kinds of economic activities (Section D (C) Manufacturing) was identified in the Ryazan region (4.895), and minimum value was found in the Yaroslavl region (0.104). The minimum value of all the efficiencies is observed in the Tver region by the factor of investments in fixed capital by kinds of economic activities (Section H (I) Hotels and restaurants), i.e. they do not lead to the significant increase of the generalized efficiency indicator, that speaks of the poor performance of their usage.

Complex (generalized) effective indicator (by a generalized factor) can serve as an assessment for the cumulative analysis of the use of operating conditions and the impact factors on the part of the managerial subjects.

The values of the generalized effective indicator of generalized factor using Formulas (20) and (14) is presented in Table 13.

In 2014, the greatest efficiency was observed in the Ryazan region (0.557), and the lowest in the Moscow region (0.076). It shows that the change of generalized indicator of efficiency by 0.201 and 0.004 for these regions, respectively, demanded minor expenses from the management entity aimed at the development of SEES. So, for example, investments in fixed-capital assets (at current prices) in Ryazan region amounted

Table 13 The values of the generalized effective indicator of generalized factor for the regions of the CFD in 2011–2014 years

Nº	Region/Year	2010	2011	2012	2013	2014
1	Belgorod	-	0.218	0.291	0.263	0.345
2	Bryansk	-	0.292	0.338	0.358	0.341
3	Vladimir	-	0.314	0.310	0.304	0.322
4	Voronezh	-	0.121	0.098	0.284	0.376
5	Ivanovo	-	0.365	0.327	0.345	0.360
6	Kaluga	-	0.338	0.307	0.269	0.336
7	Kostroma	-	0.329	0.315	0.357	0.328
8	Kursk	-	0.243	0.379	0.364	0.281
9	Lipetsk	-	0.104	0.303	0.321	0.328
10	Moscow	-	0.301	0.256	0.294	0.076
11	Orel	-	0.131	0.345	0.276	0.325
12	Ryazan	-	0.133	0.238	0.088	0.557
13	Smolensk	-	0.298	0.226	0.286	0.354
14	Tambov	-	0.361	0.251	0.332	0.339
15	Tver	-	0.013	0.049	0.273	0.319
16	Tula	-	0.231	0.225	0.391	0.332
17	Yaroslavl	-	0.417	0.314	0.336	0.327

Source: Own construction

to 54 056 million rubles, and in Moscow region – to 640 320 million rubles, which is 11.8 times less, per capita – 47 720 rubles and 88 018 rubles respectively. So, it can be confirmed that the Moscow region was to expect even greater changes in Generalized effectiveness because the region's potential is much higher than the Ryazan region has. And, it indicates the significance of generalized efficiency method. I.e., despite the fact that Moscow is more attractive from the point of view of investments, the Ryazan region is ahead in relative terms. Drawing a parallel with economic effects, one can speak of lower return on investment. Similar arguments can be made for other regions.

CONCLUSION

The main result of the study is the model specification of functioning of socio-ecological and economic system for the regions of the Central Federal district using author's approach. The results of the generalized assessment of the CFD regions functioning, their degree of balance, as well as the efficiency of their management are presented. The functioning model of SEES included 26 equations with 49 state and impact factors from social, ecological and economic areas.

The results of the research may be of interest for specialists in the field of economics, ecology, sociology, state and municipal management, students and graduate students of the relevant fields, as well as for general readers studying the problems of sustainable development of the SEES, including the regional and international levels.

ACKNOWLEDGMENTS

The reported research was funded by the Russian Foundation for Basic Research and the government of the Tula region of the Russian Federation, grant № 18-410-710001 (r_a).

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ANNEX

The equations for description of model of functioning of socio-ecological and economic systems by CFD regions:

$$
\begin{array}{lllll}
\hat{y}^*_{2..9} = & 0.336 \cdot x^*_{4,1} + & 0.146 \cdot x^*_{4.19,6/1} + & 0.300 \cdot x^*_{4.22} - & 0.251 \cdot x^*_{8.1} - \\
& (0.004) & (0.003) & (0.010) & (0.000) \\
& -0.099 \cdot x^*_{9.1} - & 0.230 \cdot x^*_{9.5} + & 0.115 \cdot z^*_{1/1}, & (R^2 = 0.740), \\
& (0.001) & (0.001) & (0.000) &
\end{array} \tag{30}
$$

$$
\begin{array}{lllll}
\hat{y}^*_{5} = & 0.732 \cdot x^*_{2.8} - & 0.536 \cdot x^*_{2.12} - & 0.201 \cdot x^*_{4,1} + & 0.122 \cdot x^*_{4.10} - \\
& (0.001) & (0.000) & (0.000) & (0.000) \\
& -0.159 \cdot x^*_{4.19,5/5} - & 0.288 \cdot z^*_{1,5/1}, & (R^2 = 0.623), & \\
& (0.000) & (0.001) & &
\end{array} \tag{31}
$$

$$
\begin{array}{llll}
\hat{y}^*_{10.2/2} = & 0.735 \cdot z^*_{1/2} + & 0.292 \cdot z^*_{3}, & (R^2 = 0.804) \\
& (0.107) & (0.002) & ,
\end{array} \tag{32}
$$

$$
\begin{array}{llll}
\hat{y}^*_{9.1,1} = & 0.635 \cdot x^*_{17.30} + & 0.278 \cdot x^*_{13.1}, & (R^2 = 0.918) \\
& (0.000) & (0.000) &
\end{array} \tag{33}
$$

$$
\begin{array}{lllll}
\hat{y}^*_{9.2,1} = & -0.484 \cdot x^*_{17.30} + & 0.793 \cdot x^*_{13.1} + & 0.558 \cdot z^*_{9.1,3}, & (R^2 = 0.585) \\
& (0.000) & (0.004) & (0.626) &
\end{array} \tag{34}
$$

$$
\begin{array}{llll}
\hat{y}^*_{9.3,2} = & 0.417 \cdot x^*_{2.2} + & 0.466 \cdot x^*_{13.64}, & (R^2 = 0.537) \\
& (0.029) & (0.130) &
\end{array} \tag{35}
$$

$$
\begin{array}{lll}
\hat{y}^*_{9.4,2} = & 0.867 \cdot x^*_{13.64}, & (R^2 = 0.751) \\
& (0.340) &
\end{array} \tag{36}
$$

$$\hat{y}^*_{9.5,2} = \underset{(0.012)}{0.474} \cdot x^*_{2.2} + \underset{(0.000)}{0.483} \cdot x^*_{13.1}, \quad (R^2 = 0.878) \tag{37}$$

$$\hat{y}^*_{9.6,3} = \underset{(0.042)}{0.958} \cdot x^*_{13.1,1.2}, \quad (R^2 = 0.918) \tag{38}$$

$$\hat{y}^*_{9.7,3} = \underset{(0.046)}{0.921} \cdot x^*_{13.1,1.2}, \quad (R^2 = 0.849) \tag{39}$$

$$\hat{y}^*_{9.8,3} = \underset{(0.018)}{0.774} \cdot x^*_{13.1,1.2} + \underset{(1.202)}{0.172} \cdot z^*_{9.3,3}, \quad (R^2 = 0.736) \tag{40}$$

$$\hat{y}^*_{9.9,3} = \underset{(0.000)}{0.473} \cdot x^*_{13.1} + \underset{(0.003)}{0.322} \cdot x^*_{13.2}, \quad (R^2 = 0.378) \tag{41}$$

$$\hat{y}^*_{1.1} = \underset{(0.001)}{0.668} \cdot x^*_{1.1,1} + \underset{(0.001)}{0.259} \cdot x^*_{1.1,2} + \underset{(0.035)}{0.611} \cdot z^*_{2}, \ (R^2 = 0.874) \tag{42}$$

$$\hat{y}^*_{1.2} = \underset{(0.001)}{0.604} \cdot x^*_{1.2,1} + \underset{(0.025)}{0.346} \cdot x^*_{1.2,2}, \ (R^2 = 0.889) \tag{43}$$

$$\hat{y}^*_{2} = \underset{(0.001)}{0.396} \cdot x^*_{2,1} + \underset{(0.002)}{0.395} \cdot x^*_{2,2} + \underset{(0.001)}{0.226} \cdot z^*_{2,1}, \ (R^2 = 0.964) \tag{44}$$

$$\hat{y}^*_{3} = \underset{(0.001)}{0.170} \cdot x^*_{3,1} + \underset{(0.003)}{0.786} \cdot x^*_{3,2}, \ (R^2 = 0.888) \tag{45}$$

$$\hat{y}^*_{4.1} = \underset{(0.001)}{0.715} \cdot x^*_{4.1,1} + \underset{(0.003)}{0.168} \cdot x^*_{4.1,2} + \underset{(0.001)}{0.121} \cdot z^*_{4.1,1}, \ (R^2 = 0.966) \tag{46}$$

$$\hat{y}^*_{4.2} = \underset{(0.001)}{0.758} \cdot x^*_{4.2,2} + \underset{(0.001)}{0.229} \cdot z^*_{4.2,1}, \ (R^2 = 0.942) \tag{47}$$

$$\hat{y}^*_{4.3} = \underset{(0.001)}{0.171} \cdot x^*_{4.3,1} + \underset{(0.004)}{0.553} \cdot x^*_{4.3,2} + \underset{(0.001)}{0.138*} \cdot x^*_{4,1} + \underset{(0.001)}{0.141*} \cdot x^*_{4.2}, \ (R^2 = 0.968) \tag{48}$$

$$\hat{y}^*_{4.4} = \underset{(0.001)}{0.969} \cdot x^*_{2.2}\,, (R^2 = 0.940) \tag{49}$$

$$\hat{y}^*_{4.5} = \underset{(0.004)}{0.576} \cdot x^*_{4.5,2} + \underset{(0.001)}{0.408} \cdot z^*_{4.5,1}\,, (R^2 = 0.959) \tag{50}$$

$$\hat{y}^*_{5.1} = \underset{(0.001)}{0.567} \cdot x^*_{5.1,1} + \underset{(0.004)}{0.418} \cdot x^*_{5.1,2}\,, (R^2 = 0.929) \tag{51}$$

$$\hat{y}^*_{5.2} = \underset{(0.001)}{0.250} \cdot x^*_{2.2} + \underset{(0.001)}{0.749} \cdot z^*_{5.2,3}\,, (R^2 = 0.979) \tag{52}$$

$$\hat{y}^*_{5.3} = \underset{(0.001)}{0.225} \cdot x^*_{5.3,2} + \underset{(0.001)}{0.781} \cdot z^*_{5.3,3}\,, (R^2 = 0.982) \tag{53}$$

$$\hat{y}^*_{5.4} = \underset{(0.001)}{0.993} \cdot x^*_{2.2} + \underset{(0.001)}{0.054} \cdot x^*_{5}\,, (R^2 = 0.962) \tag{54}$$

$$\hat{y}^*_{5.5} = \underset{(0.001)}{0.466} \cdot x^*_{2.2} + \underset{(0.001)}{0.518} \cdot z^*_{5.5,3}\,, (R^2 = 0.958) \tag{55}$$

Here is denoted: () standard errors, R^2determination coefficient.

For these models the coefficient of determination are statistical significant at 1% level. For assessment the F-test was used. For the assessment of coefficients of models we is used t-test. All coefficients are statistical significant at 5% level.