Comprehensive monitoring of the territorial technosphere for environmental and economic accounting

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Abstract. This paper discusses the use of integrated monitoring of the territorial technosphere to collect primary environmental information for the work of the system of environmental and economic accounting and maintenance of the system of national accounts. An information-measuring system is given, which includes this subsystem and collects this information. It was proposed to integrate environmental factors of the territorial technosphere objects into environmental-economic groups depending on the similarity of the technological processes used at the territorial technosphere objects, production equipment, raw materials and materials, taking into account the standards for the cost of their environmental impact.

1. Introduction

The concept of environmental and economic accounting for Russian enterprises is new and not regulated by domestic legislation. At the same time, when fulfilling the requirements for improving the environmental safety of the territorial technosphere (TT), enterprises have questions about how one could present objective environmental costs in their economic reporting, i.e. for maintaining environmental and economic accounting. The purpose of environmental and economic accounting is to provide the decision maker (DM) with objective information on various environmental protection costs (E) integrated into the financial statements of the company. Expenditures on environmental protection measures, reduction (elimination) of the consequences of negative impact on the environment, mitigation of climate change, other types of environmental activities today include such costs. For individuals, impacts on the environment that are subject to accounting are [1] the emissions of pollutants (pollutants) from vehicles owned by citizens and the volume of emissions of pollutants from individual heating of houses.

The use of this information assumes the existence of a separate accounting of environmental costs in the framework of production and non-production activities by types and locations, as well as linking to specific products, works, services when calculating costs by product, i.e. conducting a detailed analysis and accounting of environmental costs.

When preparing environmental and economic information, it is advisable to correlate the production activity of an enterprise with its financial and environmental indicators, since all environmental costs (except for fines) are taken into account in the cost of products or services. This requires the adaptation of the economic system of the enterprise to account for the economic
consequences of the impact on the environmental of waste, emissions, discharges (hereinafter environmental factors) generated in the production process and obtaining reliable information about the volumes of their formation.

2. Materials and Methods
The System for Integrated Environmental and Economic Accounting was proposed by the Statistics Division of the UN Secretariat [1], which was aimed at recording the interaction of TT objects with environmental ones in national statistics. This system establishes the relationship between the state of the environmental and the economy of the country. This system is associated with the UN system of national accounts (SNA) [2], which takes into account the use of natural resources by TT objects and the formation of environmental factors. An SEEA is needed to take into account the parameters of qualitative and quantitative interaction between the TT and the environmental (see Figure 1).

![Figure 1. Parameters of the system of environmental-economic accounting [1].](image)

Regular compilation by countries of environmental and economic accounts contributes to the international comparability of statistical data and provides scientifically based information on the environmental status and environmental management at the national, regional, and international levels. In addition, it provides a deeper understanding of the impact of TT on the environmental.

SEEA provides information related to a wide range of environmental and economic issues, including, in particular, an assessment of trends in the use and availability of natural resources, the extent of environmental factors in TT, and the volume of economic activities for environmental purposes.

In accordance with [1], the primary source data necessary for the construction of an environmental account in the SNA take into account the anthropogenic impacts on the environment and are determined by the method of assessment (calculation), not measurement. Despite the simplicity of the method, the calculation method is based on the use of theoretical or empirical values of the parameters and, consequently, is less objective.

The advantages of measuring methods of data collection for the formation of primary source data for calculating environmental accounts are the accuracy and objectivity of the assessment, the expression of results in generally accepted units of measurement, comparability and reproducibility of the results. The high costs of testing are characteristic of making measurements that require equipped testing laboratories and auxiliary equipment, sometimes very expensive, as well as highly qualified personnel.

Accounts are implemented in accordance with the approaches to the implementation of the SEEA at the national level in stages and take into account the following environmental factors: emissions of pollutants into the atmosphere, waste generation, total costs for environmental protection [2].
The total emissions of pollutants into the air is calculated by the formula:

\[ V_{total} = V_1 + V_2 + V_3, \]

where \( V_{total} \) is the total emissions of pollutants into the air; \( V_1 \) – the emissions of pollutants by industry; \( V_2 \) – the volume of emissions of pollutants from households; \( V_3 \) – the emissions of pollutants from controlled landfills for solid municipal waste.

The volume of emissions of pollutants by industry is defined as the aggregate of emissions of pollutants from all types of economic activity:

\[ V_1 = \sum_{i=1}^{n} V_i, \]

where \( V_i \) is the emissions of pollutants from agriculture, transport, mining, manufacturing and other industries.

The volume of emissions of pollutants from households are determined from the expression:

\[ V_2 = V_{HV} + V_{HH}, \]

where \( V_{HV} \) is the emission of pollutants from household vehicles; \( V_{HH} \) is the volume of emissions of pollutants from household heating.

To determine the emissions of pollutants from household vehicles, we use the formula:

\[ V_{HV} = \frac{S_{vehicles}}{p_{av.price}} \cdot k, \]

where \( V_{HV} \) is the emission of pollutants from household vehicles; \( S_{vehicles} \) – the amount of expenditure on fuel and lubricants for personal vehicles of households; \( p_{av.price} \) – the average annual retail price for a certain type of fuel; \( k \) – emission factor.

The volume of emissions of pollutants from household heating is determined by the formula:

\[ V_{HH} = \frac{S_{heating}}{p_{av.price}} \cdot k \]

where \( V_{HH} \) is the volume of emissions of pollutants from household heating; \( S_{heating} \) is the volume of household heating expenses; \( p_{av.price} \) is the average annual retail price for a certain type of fuel; \( k \) – an emission factor.

The total waste generated is used as follows:

\[ V = V_{pr} + V_{cons} + V_{import}, \]

where \( V \) is the total amount of waste generated; \( V_{pr} \) – the volume of educated waste production by industry; \( V_{cons} \) – the amount of waste generated by consumption; \( V_{import} \) – the import volume of waste.

The following formula is used to determine the total cost of environmental protection:

\[ V_{fix.cap} = V_{invest} + V_{cur.exp}, \]

where \( V_{fix.cap} \) is the volume of investments in fixed capital, aimed at environmental protection; \( V_{cur.exp} \) is the volume of current expenses aimed at environmental protection.

To obtain reliable calculations using the above methodology, large amounts of data are needed, which characterize the intensity of work of economic objects and, as a result, the intensity of environmental factors.

The integration of environmental and economic information requires an interdisciplinary approach that combines information about the reserves of various natural resources, the intensity of work of economic objects and the volume of environmental factors into a single system. For each of these...
areas, a specific and detailed measurement and assessment procedures should be developed, which are integrated into the SEEA Central Framework in such a way as to give a complete and reliable picture of the state of affairs. A large number of classical economic methods exist for assessing the reserves of various natural resources in the economy, and economic methods are just beginning to be developed to take into account environmental factors of TT. An example of such a document is the “Experimental Ecosystem Accounts of the SEEA” [3]. Successful application of this document requires complex statistical data, including the state of the environment, which can be used to estimate the degradation of the environment, its cost estimate and the share in the total costs of any technospheric object, as shown in Figure 2.

![Generalized indicators of the system of environmental-economic accounting.](image)

**Figure 2.** Generalized indicators of the system of environmental-economic accounting.

The need for reliable information about the quality of the environmental is growing rapidly with the new requirements for its condition. Environmental statistics covers a wide range of information and is interdisciplinary. Primary information about the state of the environment is dispersed over a large number of sources: special databases (DB), design and regulatory documents (RD). Therefore, special resources are needed to collect and reliably present environmental information.

3. **Results and Discussion**
An information-measuring system (IMS) can become such a special resource, including subsystems of complex monitoring of TT and decision support (DSS), i.e. a computer-aided automated system, the purpose of which is to help the decision maker in a complete and objective analysis of all incoming information (see Figure 3).
Figure 3. Environmental Information Management System.

Databases can become sources of environmental TT status data including a large number of unprocessed measurement results of environmental parameters and related processes. Environmental statistics that describe, aggregate, and structure environmental data in accordance with the requirements of the RD, environmental indicators used to present complex statistical data in order to summarize, simplify, and transmit information.

All this information is converted by IMS into environmental and economic groups (EEG); parameters that group environmental factors are formed based on the similarity of technological processes used at enterprises, production equipment, raw materials and materials, taking into account the standards of the cost of their impact on the environmental.

The EEG parameters are combined into blocks: conditions and quality of the environmental; natural resources and their use; the resulting environmental factors; emergency situations and natural disasters; sanitary condition of the environmental in human settlements; environmental protection measures.

And, thus, the IMS has preliminary information about what impact this TT object has on environmental, that is, there is a list of environmental factors characteristic of this TT object (qualitative analysis).

In addition, one needs information about the actual state of the environmental at the moment and its dynamics in time and space. Such information can be provided by the complex monitoring subsystem of the TT, which, in accordance with [1], needs to collect information on forty-nine indicators combined into the following groups: air pollution, water resources, land and soil, destruction of the ozone layer, climate change, biodiversity, waste generation, financing of environmental protection measures, the impact on the environment of energy and transport as the most environmentally significant components of the TT.

These parameters can be collected by the complex monitoring subsystem of the territorial technosphere (CMS TT) shown in Figure 4 [4].

Sensors for measuring concentrations of pollutants collect data and measure the concentration of pollutants directly from sources of pollution. Weather station collects meteorological data (wind speed, air temperature, pressure, humidity). High-speed gas sensors for environmental monitoring of the state of the atmosphere collect information about the state of the atmosphere. The GPS system
tracks the coordinates of the measurement site with an accuracy of several meters. The first and second groups of environmental monitoring sensors measure the concentrations of pollutants, spatial, temporal and probabilistic parameters of contaminated areas, characteristics of pollution sources and form a typical message.

Figure 4. Subsystem for integrated monitoring of the territorial technosphere.

The simulation center, which includes a special software and hardware complex, is intended for mapping the fields of pollutant concentrations. Simulation assumes the availability of reliable data on meteorological features and parameters of the impact on the environment and allows to reliably predict how a particular situation could develop. The applicability of models to real conditions is checked according to specially organized observations.

The entire set of collected data is transmitted via a secure communication channel to the data comparison processing centers for further analysis, structuring, processing.

The second data processing and comparison center and the analysis unit of the structuring and data processing algorithm are introduced into the integrated monitoring subsystem of the territorial technosphere to improve the reliability of operation. Both centers are interchangeable. We show an increase in the reliability of the system in the interaction of two data processing and storage centers.

Based on the Markov processes, we compile a CMS TT state graph (see Figure 5), consisting of two processing centers and data comparison.
Figure 5. The integrated monitoring subsystem of the territorial technosphere.

Consider the four states of the processing center and data comparison center (PC and DC): Y0 - the 1st and 2nd PC and DC are healthy; Y1 - 1st PC and DC are faulty, 2nd PC and DC are healthy; Y2 - 1st PC and DC are healthy, 2nd PC and DC are faulty; Y3 - 1st and 2nd PC and DC are faulty. The probability of these states at the moment t is denoted by P0 (t), P1 (t), P2 (t), and P3 (t). We will make a marked state graph (see Figure 5). A similar solution is used for two data processing and data comparison centers.

The system of differential equations for the probabilities of states is as follows:

\[
\begin{align*}
\frac{dP_{Y0}}{dt} &= \mu_1 \cdot P_{Y1}(t) + \mu_2 \cdot P_{Y2}(t) - (\lambda_1(t) + \lambda_2(t)) \cdot P_{Y0} \\
\frac{dP_{Y1}}{dt} &= \lambda_1 \cdot P_{Y0}(t) + \mu_2 \cdot P_{Y3}(t) - (\mu_1(t) + \lambda_2(t)) \cdot P_{Y1} \\
\frac{dP_{Y2}}{dt} &= \lambda_2 \cdot P_{Y0}(t) + \mu_1 \cdot P_{Y3}(t) - (\mu_2(t) + \lambda_1(t)) \cdot P_{Y2} \\
\frac{dP_{Y3}}{dt} &= \lambda_1 \cdot P_{Y2}(t) + \lambda_2 \cdot P_{Y1}(t) - (\mu_1(t) + \mu_2(t)) \cdot P_{Y3}
\end{align*}
\] (8)

To find the probabilities, we equate to zero the left parts of the equations of state (suppose that all derivatives \(\frac{dP_k(t)}{dt}\) are equal to 0) and solve the resulting system of linear equations:

\[
\begin{align*}
\mu_1 \cdot P_{Y1}(t) + \mu_2 \cdot P_{Y2}(t) - (\lambda_1(t) + \lambda_2(t)) \cdot P_{Y0} &= 0 \\
\lambda_1 \cdot P_{Y0}(t) + \mu_2 \cdot P_{Y3}(t) - (\mu_1(t) + \lambda_2(t)) \cdot P_{Y1} &= 0 \\
\lambda_2 \cdot P_{Y0}(t) + \mu_1 \cdot P_{Y3}(t) - (\mu_2(t) + \lambda_1(t)) \cdot P_{Y2} &= 0 \\
\lambda_1 \cdot P_{Y2}(t) + \lambda_2 \cdot P_{Y1}(t) - (\mu_1(t) + \mu_2(t)) \cdot P_{Y3} &= 0
\end{align*}
\] (9)

Initial conditions for solving the system of equations:

\[P_{Y0} + P_{Y1} + P_{Y2} + P_{Y3} = 1\] (10)

From Figure 5, it follows that the probabilities of the states Y1 and Y2 will be equal, i.e. \(P_{Y1} = P_{Y2}\); \(P_{Y0} + 2P_{Y1} + P_{Y3} = 1\).

At \(t \to \infty\), there will be a stationary mode of CMS TT operation with state probabilities:
\[
\begin{aligned}
P_Y &= 1 - 2P_Y - P_Y \\
P_Y &= \frac{1}{\lambda + 2\mu} \lambda \\
P_Y &= \frac{\lambda P_Y}{\mu}
\end{aligned}
\] (11)

Substituting the values of \( \lambda \) and \( \mu \), we get:

\[ P_Y = 0.66; P_Y = 0.15; P_Y = 0.04. \]

The results suggest that the probability of failure in the two processing centers and data comparison is \( \approx 4\% \).

The central control room is designed to collect information about the environmental status of the TT, its registration and presentation using technical means in both automatic and dialog modes.

By combining this information with data from regulatory and project sources, it is presented in an easily understandable form of decision makers, i.e. it forms the reporting within the framework of the SEEA in the form of SNA.

4. Conclusions

Thus, the proposed IMS allows one to collect environmental and economic information and present it to the decision maker in a convenient form.

References

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