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METHODOLOGICAL FOUNDATIONS OF ECONOMIC EVALUATION OF TECHNOGENIC LOSSES OF NATIONAL ECONOMY

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Abstract. The article considers world's modern approaches of evaluation of technogenic losses from permanent and emergency environmental contamination (emissions, discharges, wastes), and investigates their advantages and disadvantages. The article justifies methods of fuzzy sets theory for complex economic evaluation of technogenic losses of national economy and necessity of these methods under the circumstances of vagueness and lack of information. The article also suggests the heterodox approach to economic evaluation of anticipated technogenic losses of industry branches by analyzing the risks of possible losses by means of fuzzy logic and neural networks.

Key words: economic evaluation, technogenic losses, fuzzy sets theory, national economy, risks of possible losses.

The problem of effective management of the national economy is directly related to the problem of economic evaluation of the losses, harm and damages (in actual and costly forms) that are caused by constant destructive influence of economic activities on the environment and society. In addition, morally outdated production technologies create high degree of system pollution (under normal management conditions) and extremely high degree emergency environmental damage (the onset of an emergency), the decline in the viability of labour resources or destruction of main productive assets. All this leads to an increase in technogenic losses in the national economy. Of particular **topicality** is the problem of constructing a modern approach to the economic evaluation of technogenic losses in the national economy and the formation of the appropriate methodology in the management system of the national economy.

Analysis of recent researches and publications shows that the prominent contribution to the formation of the theory of the national economy function and the theory of economic damage was done by such world's scientists: A. Afanasiev, K. Hoffmann, A. Gusiev, G. Daly, P. Drucker, A. Enders, C. Kuzniets, V. Leontiev, A. Marshall, J. Meadows, G. Motkin, I. Potravny, R. Coase, T. Panayiotou, V. Pareto, F. Perroux, A. Pigou, R. Richter, W. Rostow R. Hawtrey and others. An important contribution to the solution of problems of economic damage evaluation was conducted by leading Ukrainian economists: A. Amosha, A. Balatskiy, B. Burkynsky, J. Vytvytsky, V. Gejets, B. Danylyshyn, S. Doroguntsov, S. Illyashenko, A. Zahorodniy, O. Kraynyk, O. Kuzmin, L. Melnyk, E. Mishenin, J. Petrovych, V. Soloviov, Y. Stadnitskii, V. Tregobchuk, J. Tunytsya, A. Fedoryshcheva, L. Fedulova, S. Kharichkov, V.Shevchuk and others.

However, despite the significant amount of the works on the economy and national economy management, the issues of economic evaluation of technogenic losses caused by economic activity of enterprises and the consequences of technogenic emergencies have been studied insufficiently. Research of opportunities of the fuzzy sets theory methods and means of neural networks for prediction of risks of potential losses due to extreme (emergency) situations in the system of economic management are fragmented.

The research of theoretical and applied methodology basis of loss evaluation leads to the statement of such **objectives of the work**: the formation of the modern approach to the complex

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economic evaluation of technogenic losses of the national economy.

Scientists of Lviv Scientific School under the guidance of prof. Kuzmina, O.E in the work [1, p.73-106] view the development of evolutionary economics based on the theory of growth returns by P. David and B. Arthur (theory of positive feedback), where the success of the company depends on the previous development path. At the end of the twentieth century, scientists of Sumy Scientific School under the guidance of prof. Balatskiy O.F laid the foundation for determining the damage caused to the environment in fundamental scientific works [2, 3], where they substantiated the necessity of considering the impact of atmospheric and water on the main indicators of the national economy. It is obvious that the damage inflicted by economic activity in previous time periods affects the national economy in the future. That is why today in the world the search is conducted for new approaches to complex economic evaluation of technogenic losses in the national economy.

The source of technogenic losses is the productive and economic activities of enterprises. This enterprise itself as a system at micro-level is at the same time a subsystem at macro-level, so the development of such complex organizational and productive systems is diverse and varied. Mostly the development of these organizational systems is connected with the development of innovational, productive, supply and marketing activities of a business entity. As proved in the work [4, p. 12–15], a key role in solving classical problems of capacity utilization is played by “methodological approaches of target-oriented planning of their use improvement and bases of forming of economic mechanism of their use.” In the past century there were found laws of national economies development, examining the relationship between economic dynamic factors [5, p. 222–225]: 1) the development of STP, 2) existing natural resources, 3) population growth, 4) characteristics of investment (fluctuations in investment, its impulse nature of the investment), 5) a function of consumption and so on. It allowed to form a theory of uneven shocks [6, p. 122–125], where the economic system is characterized by fading fluctuations of income, and its equilibrium is disturbed by external stimulus (the Schumpeter impulse). In his outstanding research work, S. Kuznets [6, p. 124–128] studied the relationship between the release of the final product, capital formation and savings and income distribution among different segments of the population. The author established the existence of a cyclic component in the dynamics of production and prices, determined its time as greater than normal duration of the economic cycle, but less than the period of the Kondratiev’s long waves.

In 1995 it was first examined environmental component in predicting of trends in the national economies of states. For example, Grossman and Krueger established the converse domed relationship between the pollution and income per capita. This curve is called the environmental Kuznets curve in honor of his achievements in the study of the laws of economical growth of national economies. Environmental Kuznets curve resembles an inverse parabola between the income growth and the environmental quality. In low-income countries the environmental quality gets worse with increasing incomes of population, while in high-income countries on the contrary – the environmental quality improves according to population income growth [7].

Installation of such relationship between economic growth and deterioration (improvement) of the environment determined, on the one hand, the need to find ways of developing the national economy, including: 1) technological restructuring of production, 2) the elimination of outdated primary means, which threaten accidental pollution of the environment, 3) implementation of eco-innovations of technical and organizational nature, 4) the development of high-tech industrial technologies etc. On the other hand, in the collective monograph [8, p. 18–22, 309] the problem of the national economy development is solved by constructing a concept of prognosis and evaluation of the structure of the national economy efficiency by aspects of economic activity.

Therefore, the modern trends of national economy are connected with prognostication of economic phenomena that are of evolutionary nature and cannot always be merely described by traditional instruments. To solve the problem of evaluation of such parameters as stability and risk of the economic systems functioning, the authors of the work [9, p. 6–25] consider that there should be applied modern instruments of systems theory, catastrophe theory, chaos theory and the concept of synergetic interaction of evolutionary systems. There arises a need for new approaches and methods for description of real economic processes

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of organizing and self-organizing of economic systems, evaluation of technogenic losses from pollution, influence of harmful factors on economy, nature and population. As emphasized in the work [10], an instrumental basis for solving the specified problems of the practical economic are concepts and models, borrowed from nonlinear thermodynamics, the theory of fractal analysis, self-organizing, regularities of fuzzy logic patterns and properties of neural systems, adapted to existing conditions of heterodox economics.

This property of self-organizing was used at the end of the past century by S. Bir in the work [11, p. 222–225] to construct a model of economic viability of the economic system along with the properties of integrity and coherence of all the elements and availability of feedback in it. Such management system was defined by S. Bir as a system that has the ability to store and maintain an independent existence infinitely. The main property of socio-economic systems, considered by the authors of the work [12], is their resistance to external influences, as well as internal disturbances inherent to any changes of system elements and relations between them.

Let us compare the advantages and disadvantages of the classical approaches and heterodox (unconventional) approaches to economic evaluation of technogenic losses according to their methodological foundations. The damage done to the environment and society by economic activities of enterprises creates aggressive external influences as for the business entities itself, and for the national economy in general. This, in turn, determines disruption of stability of economic systems functioning, reduction of technological safety levels and, consequently, increases risk of emergencies or accidents occurrence. The consequences of such emergency contamination are described in economics as amounts of technogenic losses. Economic evaluation of technogenic losses and their levels allows also to establish levels of the national economy stability.

Let us consider classical approaches to economic evaluation of technogenic losses of the national economy, which can be divided into two classes: the approaches that evaluate the damage to the primary recipients and approaches, that determine damage experienced by the national economy and its branches as a result of aggressive environmental factors activity.

The classic example of sustainability definition on the level of industrial and economic system is a technological approach [13], which deals with external factors of environment and internal factors of main productive assets functioning (resources, equipment, etc.).

At the level of the national economy of Ukraine economic evaluation of destructive influence of economic activity of enterprises on the environment, the economy and the population is based on two main alternative approaches, where the first takes into account the actual (full) evaluation of damage done, and the second – preliminary costs to prevent possible damage. In addition, the methods for estimating technogenic losses from systemic disorders, conned with usual economic activity differ from the methods for estimating technogenic losses from random dangerous technogenic processes (as a result of emergencies or accidents). Among the classical approaches to economic evaluation of technogenic losses of the national economy the most common are approaches of direct and indirect calculation.

The nature of each of these approaches is considered in detail in previous works of the author [14–18], the advantages and disadvantages are presented in Table 1.

Comparison of classical approaches to the economic evaluation of technogenic losses in the national economy

The name of the approach	Advantages	Disadvantages
Direct calculation	1. Determination of actual, factorial and recipient losses. 2. Establishing of root cause relationships between factors of influence and indexes of the national economy and the environment development.	1. Large volumes of output value. 2. Cumbersome calculations. 3. Expert surveys of damage amount.
Indirect calculation	1. Using of multivariate analysis 2. Linking of variables losses (functional and factorial). 3. Calculation of average and specific values of economic losses (losses on damaged or destroyed unit of 1 m^2 area, on 1 km length of connecting line, etc.).	1. The generalized nature. 2. Generating of source of output statistics data on the results of damage evaluation. 3. Limited application.

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The international organization UNEP [19] recommends to use two separate types of waste streams for the evaluation of amount of region's solid wastes (in natural and valuable forms) – solid wastes created by economic systems (production, research institutions, treatment plants) and municipal management (catering, building companies, etc.). The advantage of this approach is to determine the amount of solid waste in quantitative measures and their average values that can predict future volumes separately for each industry branch (service). Disadvantages of the approach of solid waste streams are its separation and the need to calculate the ratio of solid waste at the input and output of the manufacturing process.

Economic evaluation of technogenic losses caused to the national economy is concerned with the evaluation of damage from pollution, harmful factors influence on the economy, nature and population. Developing the idea previously outlined in the work [20], in terms of the classical approach there should be used a modern method of evaluating technogenic loss in industry in terms of total streams technogenic waste. The concept of technogenic wastes [20] is defined as air emissions, discharges into water bodies, pollution, liquid and solid industrial waste, business waste and wastes generated by consumption of enterprise, and describes all kinds of lost substances, materials or energy, which are formed as a result of any economic activity and the action of natural forces, and cannot be used fully with their primary purpose in given place and at given time.

Method of evaluation of tecnogenic damages in the national economy in terms of total tecnogenic waste streams of separate industries is built on previous works of the author [20, 23] on the basis of the classification system of economic activities, which is used in Ukraine since 2012 (NACE 2010 DK 009:2010) [24] and meets requirements of International Standard Industrial Classification (ISIC) [25]. The advantage of the method previously proposed by the author in [20, 23] is calculation of the total tecnogenic waste streams of the national economy, which is held in physical and of value terms, and in terms of energy. The disadvantage of the proposed approach is the need for additional expert researches of technologies to calculate the weight coefficient with the coordination of quantities in physical, valuable and energy forms.

It is obvious that to evaluate the appropriate level of technogenic security of economic sectors, of the reliability and efficiency of the national economy, the quality of society life and good environmental features, the classical approaches are insufficient. It is necessary to evaluate the entire amount of both incurred and projected technogenic losses, damages and costs in various industries. Heterodox approach to complex evaluation of technogenic losses in the national economy can be based both on the results of the evaluation of technogenic losses on total anthropogenic waste streams of the specific sectors of the economy, and on the achievements of the theory of fuzzy sets and neural networks for evaluation of the predicted technogenic losses.

Therefore, in order to form heterodox approach to the evaluation of projected technogenic damage in the national economy, first there should be define the basic concepts of the fuzzy sets theory and their economic content.

Environmental management system, as described in [26, p. 389], is usually formed considering in the direct relationship of the environmental risk with the environmental damage, the result of which they are. Simply, the determination of the risk index, that is the occurrence of certain damages, in [26, p. 393] is described by the formula (1):

$$R_i = p_i \times Q_i, \text{ where } i = 1, \quad m,$$

where p_i – probability of the i-th species loss; Q_i – value of possible losses of the i-th species; m – number of species loss.

Thus, the problem of complex evaluation of technogenic losses (both systemic and non-systemic) in the case of violations of environmental, economic or social status of economic systems (national economy, enterprise) can be considered as a probabilistic process. Theory of probability, according to [27, p. 122], is based on the probabilistic measure and is a partial case of fuzzy sets, and fuzzy sets theory uses as fuzzy membership function the distribution of fuzzy set possibility and is a partial case of fuzzy sets theory. Thus, the theory of fuzzy sets provides more opportunities to build methodological foundations of evaluation of technogenic losses.

Fuzzy sets allow considering not only the uncertainties of the statistical, but also of linguistic nature. Fuzzy description is formed by a set of rules,

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which for the smallest possible list make the fullest description of the system, with no need of full coordination. Another advantage of the fuzzy description is the ability to process data, received for the short time period (fuzzy numbers) and work with linguistic variables, that is variables whose values are words or expressions of natural or artificial language, thanks to a discovery made by the founder of the fuzzy logic theory Lutfi Zadeh in [28].

Therefore, based on the foregoing, let us suggest for the formation of methodical bases of evaluation of technogenic losses, caused by accidental violations at the objects of the national economy, for application of heterodox approach based on fuzzy logic and fuzzy sets, which allows real (quantitative and qualitative) evaluation of the economic, environmental and social disruptions of the national economy.

In the scientific literature in economics there are known successful attempts of using fuzzy logic to solve similar problems, in particular the authors of the work [9, p. 57–65] used fuzzy logic for solving the problem of accidents risk at the landfill of solid wastes.

To construct an approach to the evaluation of technogenic losses, arising from the operation of the facilities of the national economy, let us use the basic principles and laws of fuzzy sets theory, which are set out in the basic works on this problem [28, p. 17–63, 29, p. 117–191, 30, p. 12–84]. The feature of heterodox approach is the use of fuzzy-logical result, and its main stages we considering the following (Fig. 1).

1. The stage of definition of linguistic values of variables and membership functions, required for formalization, called fuzzyfication of variables.

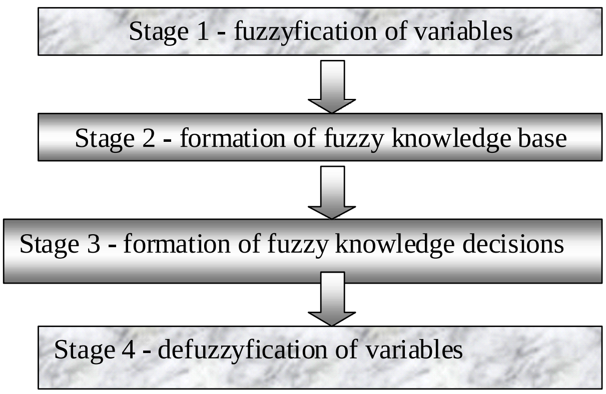

Fig. 1. Main stages of fuzzy-logical result in heterodox approach to the evaluation of technogenic losses in the national economy

2. The stage of formation fuzzy knowledge base, which creates fuzzy conditional rules for conversion fuzzy data into fuzzy action (controlling influences), according to the principle of "if-then".

3. The stage of fuzzy decision-making, where a fuzzy output after the fuzzy control actions according to fuzzy rules from the knowledge base.

4. The stage of transformation of fuzzy data from the output stage of fuzzy decision into precise quantities (quantitative or qualitative) used in the economic environment, called defuzzyfication of variables.

Let us briefly consider each stage of fuzzy-logical conclusion in heterodox approach to the evaluation of technogenic losses.

1. The stage of definition of linguistic values of variables and functions corresponding for their formalization of membership functions requires the selection of elements (and their sets) with the whole problem area. Let the set P – a complete set, covering the entire problem area (the formation of technogenic losses in the national economy). Fuzzy subset F of the set of P factors of technogenic losses is determined by the membership function $\mu^F(p)$, where p – an element of the universal set, that is $p \in P$.

The function of reflecting elements of the set P on the set of numbers in the range [0, 1], which characterize the degree of membership of each element $p \in P$ to a fuzzy set F, whereby $F \subset P$. If the full set P covers finite number of sets of elements $p_1, p_2, \ldots, p_n$, then the fuzzy subset F can be represented as (2):

$$F = \mu^F(p_1)/p_1 + \mu^F(p_2)/p_2 + \ldots + \mu^F(p_m)/p_m = \sum \mu^F(p_i)/p_i \,. \quad (2)$$

In our case, the object of study is the factor formation of technogenic losses in the national economy, which are described at the input n variables $x_1, x_2, \ldots x_n$, and at the output – in one variable y (the level of technogenic losses, or technogenic loss ratio) by the formula (3):

$$y = f_y(x_1, x_2, \ldots x_n), \quad (3)$$

where $x_1, \ldots x_n$ – set of input variables; y – the corresponding value of the output variable.

To solve the problem of economic evaluation of technogenic losses in the national economy it is necessary to develop a method of fuzzy decision making as a result of all the stages of fuzzy-logical conclusion (see Figure 1). For this a specialist in

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the delineated area of research (expert analyst) creates a separate set of parameters $X = \{x_i\}$, where $i = 1, \ldots, N$, which is the most important indicator for the evaluation of technogenic losses (otherwise the index of risk of emergency pollution or systemic damage application). In formalized language, that means to a fixed vector of input variables $\vec{X} = \langle \vec{x}_1, \vec{x}_2, ..., \vec{x}_n \rangle$, $\vec{x}_i \in P_i$ it should be definitely put in correspondence a solution $\vec{y} \in Y$ (for an object with a discrete output). The expert analyst must choose values according to their significance for the evaluation of technogenic losses; take into account various sources of losses, the impact of different recipients of influence (environment, society, economy) and others. Thus, the set of all indices to assess complex measure of losses may include both qualitative and quantitative criteria and x_1, x_2, … x_n.

Fuzzy descriptions of the structure of the method of technogenic losses evaluation from emergencies occur in connection with the expert's uncertainty arising during the various classifications. The expert creates a linguistic variable with its term-set values. In our case, the variable "level of damage" can be described as term-set of values {Very Low, Low, Medium, High, Very High}. For structural description of the linguistic variables, the expert selects the corresponding quantitative feature – for example, a designed in a definite way specified index value risk of danger that takes the value from zero to one. Then the expert chooses the corresponding quantitative trait for a linguistic variable, in our case, it may be an indicator of the value of technogenic losses of certain danger occurrence (harmful effects, pollution, etc.). Among the known functions after the recommendations of Nedosyekina A.O. set out in [31], there are mainly used trapezoidal membership functions. Then the trapezoidal membership function is written in an analytical form (expression or expression system). This is the end of the first phase of fuzzyfication of variables.

2. The stage of formation of fuzzy knowledge base is to construct formal fuzzy conditional rules for converting formed in the first stage fuzzy data into fuzzy actions (controlling influences) according to the principle of "if-then". Forming a set of rules, in fact, is created by an expert system based on fuzzy knowledge, where the adoption of fuzzy-logical conclusion will be made. In this case, there will be made the conclusion about the level of losses, arising as a result of the functioning of the national economy on the basis of all the necessary initial information received in the course of research. At this stage, the formation of fuzzy knowledge is being held. The process of fuzzy-logical conclusion is important itself. In the simpler cases, this can be a table with a set of decision rules, and in more complex cases – fuzzy-integral convolution. It is important, that the mathematical framework, which lays in the mechanism of the conclusion, identifies features of all the other stages of expert system. Notable examples of expert shells, as a mechanism of fuzzy-logical conclusion, as described in [32] is used a sequence (in terms of hierarchy of knowledge base) of fuzzy-integral convolution after Sugeno. Each fuzzy integral is a mechanism of elementary comparison. It receives input from one side – expertise knowledge (a standard) as a distribution point for a given fuzzy set, on the other hand – the current expert review as a distribution of membership function in this set. This feature of the use of Sugeno fuzzy integral defines the benefits of expert shell, suggested in [32].

3. The stage of fuzzy decision-making, in our case, is done with the help of a table of decision rules for the system of fuzzy knowledge from the knowledge base.

4. The stage of transformation of fuzzy data from the output stage of fuzzy decision into precise quantities (quantitative or qualitative) used in the economic environment, is done in the opposite direction to the stage fuzzyfication for linguistic variable of the damage level Y.

Accordingly, in order to develop appropriate methodological basis of an assessment of technogenic losses in the national economy there were conducted the following studies:

1. Study of the advantages and disadvantages known in the world classical approaches to the evaluation of technogenic losses from environmental pollution (emissions, discharges, wastes). Particular attention is paid to the research of capabilities of the approach recommended by the International Organization of the United Nations Environment Program (UNEP), for evaluation of the streams of solid wastes, which are determined by the production technology in each industry and national economy.

2. Suggestion of modern approaches to economic evaluation of possible (in terms of total

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technogenic wastes streams) and projected (in terms of the risk of non-systemic (emergency) situations occurrence) technogenic losses to the national economy sectors. Herewith, the notion of technogenic wastes is considered as a complex, which includes air emissions, discharges into water bodies, pollution, liquid and solid industrial wastes, business wastes and wastes consumption of products of enterprises, etc. The stages of each of the proposed approaches, their advantages and disadvantages were characterized.

3. Substantiation of expediency of methodological foundations forming of economic evaluation of technogenic losses in the national economy by means of fuzzy sets theory and neural networks.

4. There was described the heterodox approach to predicting of damage caused by accident (emergency) situations.

5. Building of the fuzzy-logical conclusion for damage levels evaluation of the functioning of the national economy.

The suggested methodological principles can be used for different sectors of the national economy in future studies for building of the evaluation methodology of technogenic losses.

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