

FORMALIZATION OF THE WASTE MANAGEMENT TASK IN UKRAINE FOR ENSURING THE ENVIRONMENTAL STABILITY OF EASTERN EUROPE

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ABSTRACT

The article outlines the current problems and contradictions in the waste management system in Ukraine from the standpoint of ensuring the ecological stability of the Eastern European region. The accepted paradigm of creating a recirculating economy is provided by a territorially balanced waste management system in the regions of Ukraine. The coefficient of territorial provision of utilization capacities has been proposed and tested, which allowed the evaluation of their existing potential integrally, and determined the formed regional disproportions between waste generation and utilization. In order to solve the existing imbalances in Ukraine in a comprehensive way, the stage of transition to recirculating recycling technologies of waste is proposed. The mathematical formalization of the problem of waste management in Ukraine specifies the space-time parameters of solving the problem of the system balance and provides the variability of input and output parameters for solving empirical problems.

Keywords: waste management, accumulation, utilization, territorial balance of the system, ecological stability, mathematical formalization of the problem

DOI: <http://dx.doi.org/10.15549/jeecar.v7i1.353>

PROBLEM DEFINITION

An integral part of a person's socio-economic life is the generation of wastes of industrial, economic and household origin, which in modern terms are being considered in economic, environmental, legal and other fields. The direct correlation between the dynamics of socio-economic development and the accumulation of waste requires adequate management systems. Imbalances in the

generation and disposal of waste with insufficient utilization capacity will cause accumulation with the corresponding negative consequences (especially environmental), and at excess utilization capacities without their proper raw material supply - negative economic consequences. Obviously, it is inappropriate to speak of excess utilization capacity in Ukraine at present, but the experience of some European countries testifies to the negative economic

consequences of underutilization of recycling facilities, forcing, for example, Swedish waste processing plants to import waste from other European countries, the annual amounts of which are almost 700 thousand tons of garbage.

Before the adoption of the National Waste Management Strategy by 2030, the Ukrainian attitude towards waste was quite unambiguous - neither was it addressed by owners nor producers, therefore waste was mainly directed straight to landfills, or stored temporarily on industrial sites. This has led to large-scale accumulations of these entities within the country, which have not been properly surveyed. The Ministry of Ecology and Natural Resources of Ukraine estimates the concentration of all types of waste in the amount of about 35 billion tons, with 2.6 billion tons being highly toxic. The total amount of household waste has increased annually by 50 million cubic meters or 14 million tons (300-400 kg per year per person), and industrial waste - 175 million cubic meters. In particular, for example, 12.5 million pieces of tires are accumulated each year. All of this waste occupies more than 7,000 hectares of land, which is a filtrate that causes irreparable harm to human health, as it pollutes the soil, poisons groundwater, and then rivers that flow through many countries and flow into the ocean. The ecosystem has no administrative boundaries and anthropogenic impact goes beyond the national problem of Ukraine and causes environmental risks for the entire Eastern European region.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Today, the foreign scientific environment sees the emergence of effective production management technologies, including recycling of waste that will promote the rational use of natural resources (Marshall & Farahbakhsh, 2013). Integrated waste management has become not only foundation of the EU sustainable development strategy but has also formed the basis of an action plan adopted by the European Commission on the transition to a cyclical economy by 2019. According to research conducted by the Center for European Policy Studies – CEPS (Rizos & Tuokko, 2017), the

implementation of the proposed economic innovations will reduce the negative environmental impact by reducing the amount of material and energy resources in the production process; reduce the level of production costs by saving primary resources; facilitate the emergence of new markets and, consequently, the creation of new jobs; and increase the well-being of the population.

In the waste management system of leading European countries, the concept of Zero Waste by (Murray, 2014) is particularly widespread, which is to return waste to the production cycle, to organize the circulation of substances used in technological cycles. Zero Waste, according to Murray "... represents the prevention of the very appearance of waste and the chains creation that slows down the entropy of energy and materials and enhances the natural processes of metabolism." (p. 208).

Waste management has always been the focus of domestic researchers, including: Berlinh (2006), Ihnatenko (2014), Samoylik (2014), Khyzhniakova (2003), Syvolap (2005), Rudenko (2011), Dovha (2012), Pylypiv (2010), Mishchenko (2011) and others. These studies relate mainly to individual aspects of governance without comprehensively addressing empirical problems. However, in Ukraine, the question remains of how to turn waste from a problem into a resource and, therefore, to return it to the production cycle. The mathematical formalization of the waste management problem in Ukraine specifies the space-time parameters of solving the problem.

FORMULATION OF OBJECTIVES FOR THE ARTICLE

Entire articles are formed on the basis of empirical studies of existing waste management issues in Ukraine. They are described in the include National Waste Management Strategy, in particular: rapid accumulation of waste in the industrial and household sectors; improper disposal and disposal of hazardous waste; neglect of environmental requirements in the disposal of household waste; low level of waste usage as secondary raw materials due to imperfection of organizational and economic principles of their involvement in production; inefficiency of economic instruments

implemented in the field of waste management. (On approval of the National Waste Management Strategy in Ukraine until 2030, 2017).

The purpose of this article is to develop conceptual approaches to waste management based on the formalization of the balance problem between the volume of their generation and disposal.

To achieve this goal, the following research objectives are outlined:

- to propose an indicator for integrated assessment and to investigate the formed territorial disparities between waste generation and utilization in Ukraine, and therefore, priority directions of capital investment for construction of utilization capacities;
- to identify the stages of the complex problem solution of existing imbalances between waste and utilization capacities in Ukraine;
- to formalize the problem of balancing the waste management system by constructing mathematical models that predict the variability of the initial conditions for solving empirical problems.

PRESENTATION OF KEY RESEARCH FINDINGS

Economic, environmental, legal, social and other aspects of waste management indicate its significant place and importance in human life, which requires the creation of adequate management systems. The objective inevitability of waste generation is to transform the modern management system from an environmental burden into a raw economic resource. In Ukraine, waste on the one hand is positioned as a polluter of the environment, and on the other – as a carrier of useful components and an energy source, i.e. secondary material and energy resources. If, in the former case, waste is found to be incompatible with the socio-economic development of the territories, then in the second image it is quite appealing to play a decisive role in achieving economic growth and ensuring the sustainable development of the territories, which requires the formation of adequate waste management systems based on territorial-balanced approach.

The balance of the system is equal between the amount of waste generated and its disposal. Waste generation is an ongoing process characterized by discretion and is accompanied by a process of storage and / or disposal of waste. Of course, there is a balance under any circumstances, but the key issue is the quality of that balance and the related environmental impacts that accompany it. It is possible to reduce waste generation if the economic development rate is reduced, which is unacceptable. There is a question: what to do with wastes which generation will be directly proportional to economic growth? There are several ways to solve this problem.

The first approach is the most rational and effective, but it requires a lot of time and considerable investment resources. It is the transition to modern resource-saving production technologies, which allow reducing significantly the volume of waste, both in the process of production of goods, and their further exploitation and utilization.

Another way is to modernize existing waste management facilities.

The territory of Ukraine is quite differentiated in terms of concentration on production capacity and level of urbanization, which affects the quantitative and specific composition of waste within individual territories. In order to provide economic performance in the waste management system, it is necessary to consider these features and concentrate the utilization capacity so that the logistical costs of moving waste streams can be minimized. It should be taken into account that a significant amount of hazardous waste is generated in the country, which displacement increases the risk of man-made accidents (Kravtsiv & Kolodiichuk, 2018).

Ensuring the territorial balance of waste management systems will reduce the man-made load on the environment, streamline existing unauthorized landfills, ensure their monitoring, control, concentrate potential raw materials for further processing (treatment, reuse), taking into account future prospects (Kravtsiv & Kolodiichuk, 2016). Therefore, territorial balance fills the waste management system with the content, as it is possible to define clear goals for its operation.

Table 1. Baseline data and calculation of territorial security by utilization capacity

Region	Area of the territory, thous.km ²	Average volume waste for 2015-2017, thous. tons	The amount of waste per 1 km ² territory $W/t, t / km^2$	Total number of authorized utilization capacity in 2017, thous. tons	Number of sanctioned utilizations Capacity per 1 km ² territory $Pt, t / km^2$	The coefficient of local availability of utilization capacity, Kp
AR Krym	26.1	-	-	-	-	-
Vinnitsia	26.5	2,073.2	78.2	562.4	21.2	0.271
Volyn	20.1	685.3	34.1	630.7	31.4	0.921
Dnipropetrovsk	31.9	225,347.2	7,064.2	189,877.0	5,952.3	0.842
Donetsk	26.5	19,839.3 ¹	748.7	20,990.2 ¹	792.1	1.058
Zhytomyr	29.8	539.7	18.1	289.9	9.7	0.536
Zakarpattia	12.8	154.2	12.0	170.4	13.3	1.108
Zaporizhzhia	27.2	5,211.2	191.6	4,709.3	173.1	0.825
Ivano-Frankivsk	13.9	2,003.0	144.1	1,653.4	118.9	0.825
Kyiv	28.1	1,495.8	53.2	1,156.4	41.2	0.774
Kirovohrad	24.6	35,125.4	1,427.9	37,342.2	1,518.0	1.063
Luhansk	26.7	1,882.9 ¹	70.5	680.8 ¹	25.5	0.362
Lviv	21.8	2,736.7	125.5	1,734.3	79.6	0.634
Mykolaiv	24.6	2,333.5	94.9	2,078.9	84.5	0.890
Odessa	33.3	663.3	19.9	600.0	18.0	0.905
Poltava	28.8	4,681.9	162.6	3,246.8	112.7	0.693
Rivne	20.1	671.4	33.4	286.2	14.2	0.425
Sumy	23.8	697.7	29.3	618.9	26.0	0.887
Ternopil	13.8	1,192.4	86.4	131.2	9.5	0.111
Kharkiv	31.4	1,822.5	58.0	960.6	30.6	0.528
Kherson	28.5	401.9	14.1	122.5	4.3	0.305
Khmelnitsk	20.6	1,062.9	51.6	638.0	31.0	0.601
Cherkasy	20.9	1,231.2	58.9	1,046.5	50.1	0.851
Chernivtsi	8.1	385.2	47.6	346.9	42.8	0.899
Chernihiv	31.9	773.5	24.2	431.4	13.5	0.558
Ukraine	603.5	324,730.6	538.1	270,922.2	449.3	0.835

¹ Excluding the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol, and the part of the temporarily occupied territories in Donetsk and Luhansk regions.

To assess the territorial proportionality between the volume of waste generation and the potential for its disposal, we will calculate the baseline. For this purpose, we will use not relative absolute figures, but relative volumes of waste generation per unit area of the territory of the region Wt (t / km²). Similarly, the availability of Pt utilization areas (t / km²) can be calculated. Comparing the value obtained with the relative value of waste generation, we obtain the coefficient of territorial security of utilization capacity:

$$Kp = \frac{Pt}{Wt} \quad (1)$$

The proposed index makes it possible to assess integrally the existing utilization capacity in the regions and to determine the existing disproportions, and therefore priority investment directions.

To estimate the volume of accumulated waste, we consider the relative indicators of its generation in the context of the regions of Ukraine Wt , for which we use the average values of the total indicators of all types of waste that have fallen to the utilization capacity over the last three years (Table 1). Note that utilization capacity means all authorized passive (designated areas or facilities) or active (sorting, recycling or incineration facilities) waste management facilities. Based on current forms of statistical reporting of Ukraine (Environment of Ukraine for 2017, 2018), the indicator shown in Table 1 is the sum of the values of recycled, incinerated and disposed waste in specially designated places or objects.

To find out the territorial features of the utilization capacity distribution, we will similarly perform the Pt calculation (see Table 1). Comparing the spatial localization of the waste generation and disposal areas, we obtain the coefficient Kp . To do this, we pre-group areas by the values of the calculated Kp values.

Using the method of equal intervals, we group according to the indicated sign, six groups of regions that are included in the formed closed intervals ($i = 0.1662$). To visualize the territorial security of Ukrainian regions with utilization capacities, we use a cartogram (Fig. 1).

If the coefficient Kp is one, then this means that all waste is recycled within the area in one way or another by the sanctioned capacity. This

assumption should be acknowledged, since the administrative boundaries of the areas are not an obstacle to the movement of waste, and it is natural that the waste generator can use the services of a utilization facility that is geographically close to it, even if it is in a neighboring area. This will certainly partially affect the value of the estimated coefficient. However, it should be borne in mind that the area from which the waste is being taken may come in counter-waste from neighboring areas where the waste generators also take advantage of the territorial proximity to the utilization capacity of the neighboring area and this will partially balance the proposed coefficient.

The most territorially balanced are waste management systems in Zakarpattia and Kirovohrad regions, where all generated waste is utilized at its own capacity. It should be noted that Donetsk region is also in the VI group, but the calculated indicators for it are not correct enough, since the initial value of the volume of waste (for two of the three studied years) and the number of sanctioned utilization capacities for the studied year were taken into account excluding the temporarily occupied territories and the whole territory of the region. This issue also applies to Luhansk region, which is caused by the peculiarities of the official statistical reporting of Ukraine

The lowest Kp value is in Ternopil region, where only 11.1% of the generated waste within the administrative territory can be utilized by its own capacity.

It is advisable to use mathematical methods to study the conditions of systems balance with the formation of

appropriate economic and mathematical characteristics of these processes, which will allow investigating their nature and critically determining measures for the systems improvement

Before proceeding to the formulation of the general and specific tasks of an economic and mathematical study of the conditions of waste management systems balance, we should clearly state the current situation in this field. Existing imbalances caused by the scarcity of utilization capacities in Ukraine for many years have led to the formation of catastrophic waste that is stored in unauthorized landfills. The

process of continuous increase in the volume of generated waste and the increase of anthropogenic load on the environment require immediate action for the primary stabilization of the situation with the further solution of the existing problem. This situation can be solved either by curtailing the economic activity of enterprises, or by commissioning new utilization facilities. The first way is inadmissible and the second one is too costly.

But there is another way in which the economies of highly developed countries are focusing – a the use of low- and non-waste production technologies with the use of recycling waste management systems. It is clear that these technologies are even more expensive and inaccessible to the national economy.

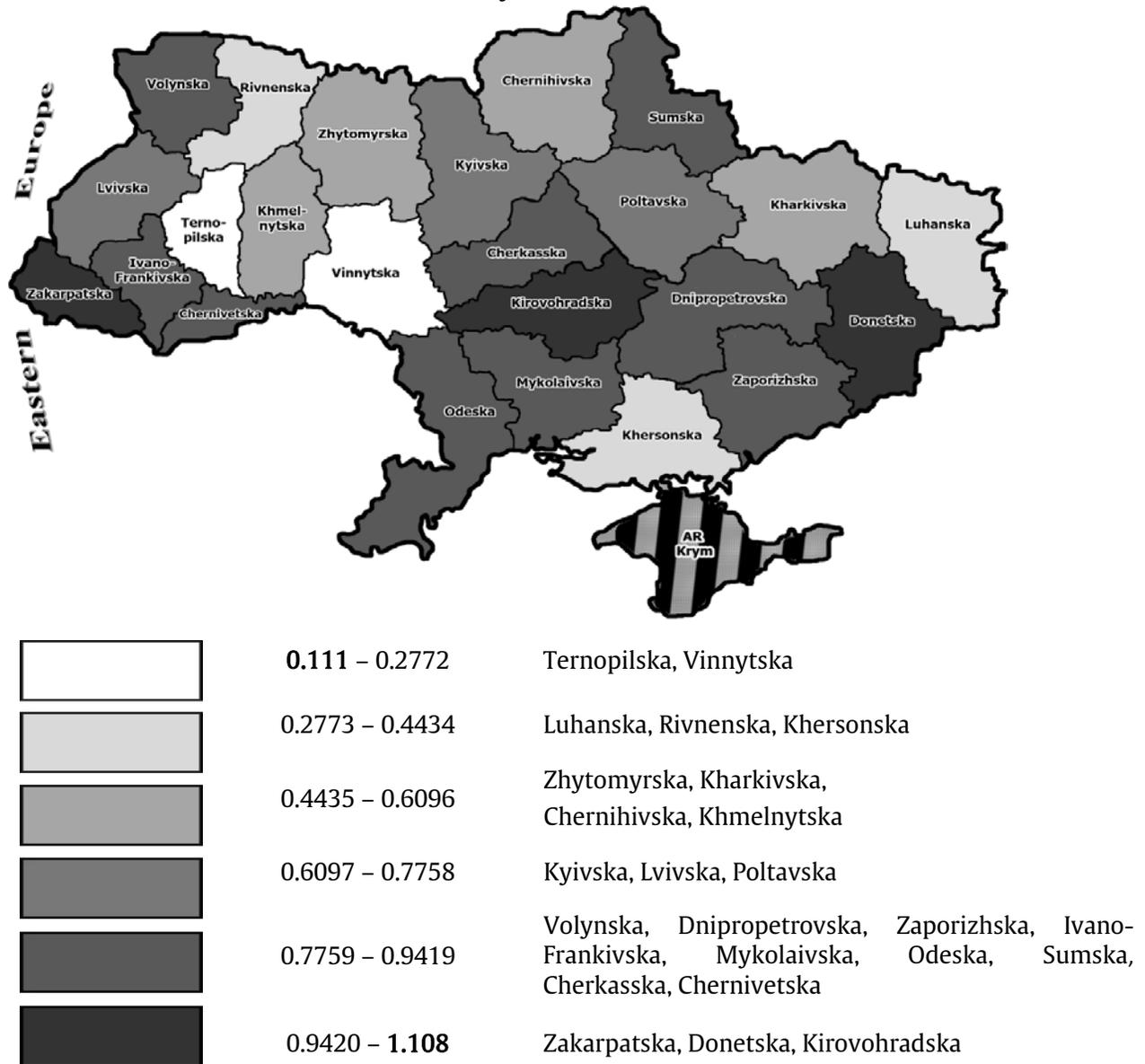


Fig. 1. Map of the grouping of regions of Ukraine by territorial security coefficient of utilization capacity, K_p

Based on the current state of economic development of Ukraine, we consider it

advisable the following stages of solving the waste management problem:

I phase. To monitor existing utilization facilities and reconstruct them to ensure anthropogenic safety during storage of accumulated waste.

II phase. To ensure the recycling of waste generated through the use of existing and the introduction of new utilization facilities.

III phase. To provide partial recycling of accumulated waste along with complete recycling of generated waste.

IV phase. To replace worn-out recycling facilities with modern recycling technologies.

Graphical interpretation of the set task is presented in Figure 2.

The implementation of the first phase involves the mobilization of all utilization capacities of Q_3 at the initial time T_1 after their preliminary monitoring and partial reconstruction. It should be noted that in this task we mean not only recycling or incineration plants, which are extremely scarce in Ukraine, but above all - places of authorized waste storage at adapted landfills or places of technological waste storage in the territories of enterprises. Static waste storage should neutralize the anthropogenic impact on the environment in order to stabilize

the environmental situation in the country. Existing and newly introduced utilization facilities should fully provide current waste disposal needs, the volumes of which Q_1 are sufficiently stable and predictable, and partially recycle previously accumulated waste (Q_2) awaiting recycling. In this case, the utilization capacities P must have an initial capacity Q_3 in excess of Q_1 by a certain amount ΔQ , that is, to provide the condition:

$$Q_3 = Q_1 + \Delta Q \quad (2)$$

In fact, the situation will be as follows: at some point in time, the processing facilities provide current needs for modifying the generated waste and for the partial processing of previously accumulated waste, which is safely stored until the appropriate time. As the accumulated waste will eventually be depleted, at some point T_n will completely recycle it, unloading and freeing up their static storage. It is clear that this is a rather idealized situation, the conditionality of which will allow us to carry out a mathematical formalization of the problem.

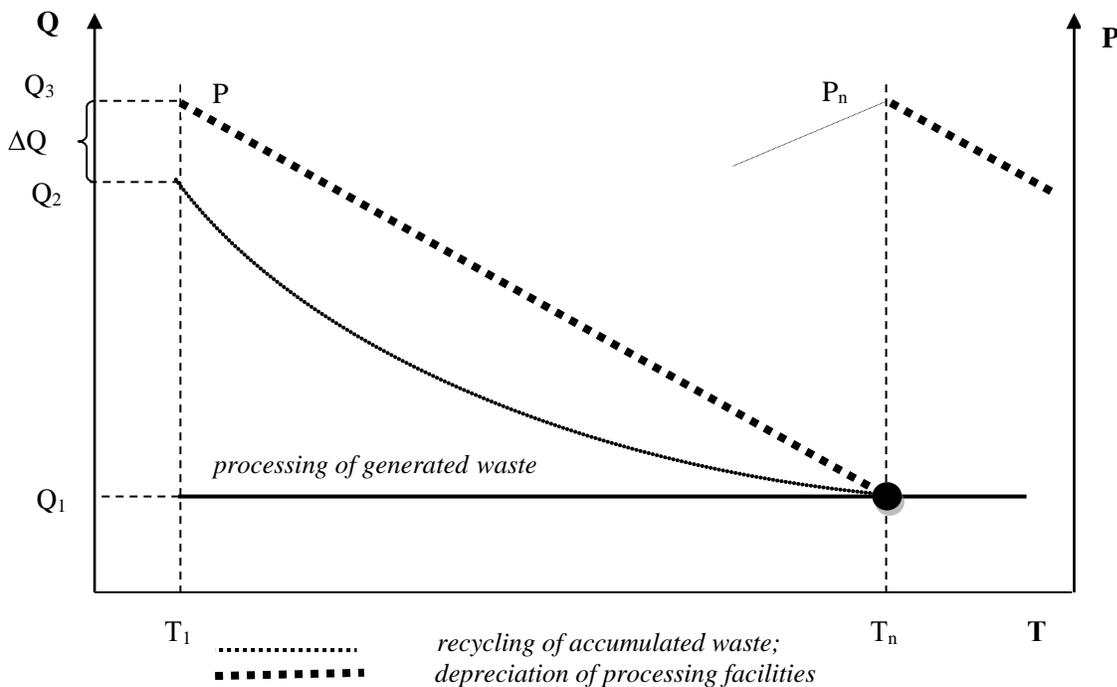


Fig. 2. Graphical interpretation of the balance problem of waste management systems

Capacities mobilized at time T_1 up to T_n will run out of resources and will require repair, replacement, upgrades and more. This period will last several years, which will cause not only physical but also moral obsolescence of the equipment. Existing utilization technologies, as well as the emergence of new NTPs, will set qualitatively new requirements for technologies and related technological equipment, based on a new paradigm of waste management, as they turn from the inevitable problem of finding ways to neutralize products of economic activity into a raw material source of recirculation. That is, the reserve of utilization capacity must be exhausted by the time of the accumulated waste disposal, while ensuring the needs of processing of the generated waste, and further these capacities should be replaced by modern processing enterprises of the innovative type. That is, time T_n is the point of bifurcation of the waste management system in Ukraine, which will further provide a new level of this system development. Of course, it is not possible to introduce innovative P_n capacities at one time T_n , but the process of replacing existing capacities should be based on systematically attracting investors. It should be preceded by a comprehensive state program of waste management system modernization with appropriate institutional, legislative and financial support. The mobilized resources should ensure the fastest transition to a new quality of waste management so that there is no capacity shortage at the time of replacement of obsolete ones.

The mathematical formalization of these processes has allowed us to carry out the economic and mathematical justification of our problem with the formulation of waste accumulation equations and their utilization, as well as a mathematical model of the waste management system balance.

The optimization of waste processing is reflected by the system of dependencies (3), (4) and the condition when the amount of waste generated (received) will be recycled $y = x$.

The equation system looks like this.

$$\begin{cases} x = x_1 \times e^{K \times t} & (3) \\ y = \frac{e^{K_1 \times t}}{K_1^2} - \frac{t}{K_1} - \frac{1}{K_1^2} & (4) \\ y = x, \text{ for } t = n, \text{ days} \end{cases}$$

Equation (3) demonstrates waste accumulation, i.e.:

$$x = x_1 \times e^{K \times t}$$

where x_1 is the initial accumulation, in the corresponding dimension;

e is an integer ($e = 2.71828$);

K is the waste growth factor that characterizes the technological conditions of accumulation.

Equation (4) is the final equation describing the processing of waste, i.e.:

$$y(t) = \frac{e^{K_1 \times t}}{K_1^2} - \frac{t}{K_1} - \frac{1}{K_1^2}$$

where K_1 is the coefficient characterizing the physical content of the waste processing production;

t is duration, days.

CONCLUSIONS AND RECOMMENDATIONS

The inevitable process of industrial and household waste generation requires adequate management systems capable to create environmentally friendly conditions for the storage of waste with subsequent disposal and, in the long term, to ensure the recycling of waste into raw materials. The paradigm of creating a recirculating economy should be based on the structural and functional support of waste management systems in the regions of Ukraine. The content of the waste management system is provided by their territorial balance, which is a condition of technogenic safety not only of Ukraine, but of the whole Eastern Europe, and a parametric base for the introduction of recycling technologies. The proposed coefficient of territorial security of utilization capacities allows us to assess integrally their existing potential and to determine the existing regional disparities

between waste generation and utilization, and therefore, priority directions of capital investment.

In our opinion, a comprehensive solution to the problem of existing imbalances between waste and utilization capacity in Ukraine involves four steps: 1) reconstruction of existing utilization capacities for accumulated waste; 2) technical and technological support of current processing of generated waste; 3) partial processing of the accumulated waste along with complete processing of the generated waste until the first is exhausted; 4) replacement of worn out recycling facilities with modern recycling technologies of waste processing.

Mathematical formalization of the balance problem of the waste management system involves the construction of models of type (3) and (4) and, depending on the formulation of the problem, determines either the timing of the implementation of the outlined stages, based on the available investment resources, or the amount of funds needed to provide time parameters for commissioning innovative utilization capacity.

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