DOI: 10.15587/978-617-7319-66-4.CH4

Sergey Rudenko, Tetiana Kovtun, Victoriya Smrkovska,
Tetiana Smokova, Kateryna Garbazhii, Dmytro Kovtun

CHAPTER 4

ASSESSMENT OF THE EFFICIENCY OF THE ECOLOGISTIC SYSTEM PROJECT TAKING INTO ACCOUNT THE TRANSFORMATIONAL CHANGES OF ITS LIFE CYCLE MODEL

ABSTRACT

The issue of evaluating the effectiveness of the ecological system project using the "discounted payback period" criterion, which takes into account transformational changes in its life cycle model, is considered.

The specific peculiarities of the life cycle of the ecological system project were studied, in which it is proposed to include, in addition to the generally accepted pre-investment, investment and operational phases, ecologically oriented phases. Regenerative and revitalization phases are considered to be ecologically oriented, that is, during which actions aimed at reducing the eco-destructive impact of the ecological system on the environment are performed. In the regenerative phase, an ecological product is created, which includes a complex of logistics services for the promotion of reverse recycling-utilization and related flows. The revitalization phase should end with the revival of the ecosystem damaged as a result of the creation and functioning of the ecological system.

The phases of the life cycle are divided into stages, between which serial and parallel connections are established. The life cycle of the project is divided into time intervals during which from one to three stages of different phases of the project can proceed in parallel. A model of the life cycle of the ecological system project was developed, which shows the relationships between time intervals and cash flows corresponding to the phases of the project life cycle. A mathematical formula for calculating the discounted life of the project is proposed, which takes into account the specific features of the formation of cash flows of individual phases of the life cycle of the ecological system project. The application of the formula is possible when the assumption of constancy of cash flows of the stages of operational and regenerative phases is fulfilled, which corresponds to the impossibility of their exact forecast at the beginning of the project.

Functional dependencies between the discounted payback period and cash flows during the phases of the project's life cycle were studied. Depending on the phase of the life cycle, the dependence is expressed as a linear, polynomial or power function. The detection of functional dependencies allows to study the dynamics of changes in the discounted payback period in response to changes in the project's cash flows, which can be used to predict the effectiveness of the ecological system project.

In order to take into account the uncertainty of the conditions for the implementation of the ecological system project, an approach based on the use of the tools of fuzzy set theory is proposed.

KEYWORDS

Ecological system, project, life cycle, cash flows, discounted term of totality, uncertainty.

Preservation of the environment today is one of the most important, urgent, and comprehensive problems on which the future of mankind and life on the planet as a whole depends. The high rate of growth of material production and population, which were the determining factors of civilization development in recent years, led to a dramatic increase in anthropogenic pressure on the environment. Natural assimilation potential no longer ensures the restoration of the status quo of the natural environment – significant changes have begun in ecosystems, which are irreversible in the near future.

Recently, there has been an intensive search for a new strategy for the survival of mankind under conditions of limited natural resources and the deterioration of the natural conditions of existence of humans as biological species. The problem of the future development of civilization, in general, has come to the forefront of scientific research and public awareness in general. The way out of the current situation is the application of the concept of sustainable development, which is a natural reaction of the world community to existing threats and provides for the harmonious coexistence of nature and society. The introduction of the principles of sustainable development involves taking into consideration environmental and social factors in all spheres of human life [1].

Logistics as a field of practical activity makes its negative contribution to the state of the environment, which is explained by an increase in the share of logistic services in the formation of logistic products and the significant eco-destructive component of these services [2].

Recently, ecological logistics (ecologistics, green logistics) has been used as a modern concept of logistics. Within the concept of sustainable development, ecologistics is considered as an effective approach to the management of material and associated flows in order to reduce environmental and economic damage to the environment [3, 4].

Ecologistics contributes to the prevention and elimination of the consequences of the negative eco-destructive impact on the environment through the transformation of logistic systems, which correspond to the modern linear model of the economy, into ecologistic systems [5]. Closed ecologistic systems make it possible to introduce the principles of the circular economy into economic activity [6, 7].

The transition to a circular economy is becoming global in nature, and the benefits of implementing this concept are getting increasingly apparent. According to experts, the introduction of a closed model will create huge opportunities for the developing of a country, providing annual GDP growth of up to 7 % [8].

Environmentally-oriented logistic systems are a tool for introducing a circular model of the economy. One of the main properties of an ecologistic system is the existence of closed logistic chains, which make it possible to increase the number of products that return to the production cycle in various forms.

As a result, the eco-destructive impact on the environment is reduced by minimizing the use of natural resources and reducing environmental pollution by production and consumption wastes [9].

Improvement of the effectiveness of projects of ecologistic systems requires the use of models and methods of modern management methodologies, in particular, project management. Taking into consideration the specific features of this category of projects, due to their environmental orientation, is a relevant issue that requires additional research.

4.1 LITERATURE REVIEW AND PROBLEM STATEMENT

The issues of designing and functioning of ecologistic systems are actively studied by modern scientists. The importance of taking into account environmental requirements in the optimization of logistic structures is noted in paper [10]. The authors propose to solve the problem of optimization of return material flows from consumers to places of production or disposal within the limits of reverse logistics in combination with traditional problems of logistics.

Paper [11] emphasizes the necessity of transition to the economy of the closed cycle, explores the issues of transformation of logistic systems, and develops the structure of a closed supply chain. In article [12], the peculiarities of functioning of direct and reverse material flows are considered, the expediency of introduction of reverse logistic tools into the logistic activity of an enterprise is substantiated. The authors formed the basic models of functioning of reverse material flows under modern economic conditions, revealed the peculiarities of the motion of return and disposable and recyclable reverse material flows.

In articles [10–12], more attention is paid to taking into consideration the technical and technological aspects of the functioning of ecologistic systems during their designing, the problem of the peculiarities of projects of ecologistic systems, which are substantiated by their ecological considerations, is not tackled.

It is possible to enhance the success of the implementation of projects of ecologistic systems through the use of models and methods of project management methodology [13]. From the standpoint of the project approach, an ecologistic system is considered as a unique result obtained from purposeful temporary activity. Thus, a project of creation of an ecologistic system is given a limited period of time from its beginning to completion, which is called the project life cycle [14].

The project approach involves dividing the project life cycle into phases that are characterized by obtaining a specific product. According to the requirements of the World Bank and the United Nations Economic Development Unit (UNIDO), the project life cycle is divided into pre-investment, investment, and operational phases. Paper [15] emphasized that the project life cycle includes the initial, intermediate, and final phases, which is an enlarged version of gradual project splitting. In paper [16], it is proposed to divide a project not only into phases but also into stages, between which a fuzzy correspondence is established. But in research [15, 16], the need to devote time to neutralizing the eco-destructive impact of a project and its products on the environment is not taken into consideration.

The growing importance of the problem of environmental protection and possible impacts associated with the products that are produced and consumed requires the extension of the life cycle through the addition of eco-oriented phases [17]. The life cycle stages should include the purchase of raw materials, production, and pre-processing usage after the end of service life, re-usage and residual disposal. In article [9], the life cycle is understood as successive and interconnected stages of products (or services), from purchasing raw materials or production from natural resources to disposal. The life cycle stages include the purchase of raw materials, designing, production, transportation/supply, use, final treatment, and/or processing, and final disposal. These papers take into consideration the environmental characteristics of a product but do not address the issues of environmental aspects in the life cycles of projects.

Recently, there have been positive trends of taking into consideration the environmental component in the project activity. The P5 standard includes such areas as "Personnel, Planet, Profit, Process, Product" [18]. In paper [19], the P5 standard was developed, a cognitive model of the project life cycle in the form of communications between the states of the project system was constructed, but not enough attention was paid to the environmental component of a project.

A change in views on the duration and composition of the life cycle phases affects the process of forming project parameters – specific characteristics, on the management of which depends on the project success and effectiveness. The authors of papers [20, 21] draw attention to the need to manage the temporal characteristics of life cycle phases. However, the authors of the research do not consider the issue of the impact of the environmental characteristics of project products on the project effectiveness.

In papers [22, 23], the issues of project time management are considered at the level of studying the formation of the project work schedule. In article [24], it is proposed to use the tools of artificial intelligence to form a schedule of project works. However, environmentally-oriented works of a project do not receive due attention in the time-table and schedule of works.

The method of static and dynamic planning of the characteristics of a project with limited resources is proposed in research [25]. Researchers in papers [26, 27] focus on taking into account the limited resources when determining the project parameters. It is proposed to make compromise decisions between the time and monetary characteristics of a project in case of limited resources in article [28]. But in the above research, the authors, while studying the relationship between limited resources and project parameters very thoroughly, do not separate the environmental component and do not explore its impact on the assessment of the project's effectiveness.

The performed analysis of scientific research on the subject of the project life cycle and formation of project parameters showed that researchers do not pay enough attention to the impact of the project life cycle characteristics on its effectiveness. The life cycle of a project of an ecologistic system has its own specific features, taking which into consideration will make it possible to determine more accurately the project parameters and their impact on the effectiveness of this type of project.

4.2 DETERMINING THE SPECIFIC FEATURES OF THE LIFE CYCLE OF A PROJECT OF AN ECOLOGISTIC SYSTEM

The tool of the introduction of a new, circular model of the economy is an ecologistic system, which implies a closed logistic system as a set of elements-links, interconnected in the process of managing the motion of logistic flows, which takes into account an eco-destructive impact on the environment [5].

An ecologistic system is based on the creation of recycling and disposal flows, which close logistic chains and ensure the circularity of a system. Recycling and disposal flow return products, their parts, components, materials to the process of production and consumption as secondary material resources, components, and products, which makes it possible to reduce consumption of primary resources and extend the service life of products. Thus, a product goes through certain stages of the life cycle to its full disposal. The product life cycle changes its structure and lasts longer due to the implementation of the process's characteristic of a circular model of economy proposed by the Ellen McArthur Foundation [8].

Changes in the life cycle of a product are reflected in the composition and duration of the life cycle of a project of its creation, as the life cycle of a product is an integral part of the life cycle of a project. The project life cycle is divided into separate phases, which, in turn, are divided into stages that end with the receipt of intermediate project results [29]. Project phases can differ not only quantitatively, but also qualitatively (having the same name, phases in different application areas may have different content load). Even in one application area, projects can differ in the number and duration of life cycle phases.

The project life cycle of an ecologistic system has differences from the project life cycle of a logistic system in its classical sense, based on the specific features of this type of project. It is proposed to divide the project life cycle of an ecologistic system into traditional pre-investment, investment, and operational phases, as well as environmentally-oriented regeneration and revitalization phases, on which circular processes and works on the ecosystem renewal will be carried out [17].

At the pre-investment phase, a documented project of an ecologistic system, which must meet all the requirements of project management standards, is designed. The classical definition of a document indicates: a document (from the Latin documentum – an instructive example, sample, proof) is a material object that contains particular information, intended to transmit it in time and space. During the pre-investment phase, project documentation, which is the material carrier of information about a project, is formed from separate documents. Work on project documentation is carried out throughout the phase and includes all project management processes. Based on the information reflected in it, further development of a project until its completion is carried out.

In the investment phase, an ecologistic system in the material representation is created. It is a complex, structured, dynamic system consisting of elements (subsystems, units), interconnected in the process of environmentally-friendly management of the motion of logistic flows. An ecologistic system differs from the logistic one by the existence of the elements that promote the return of material flows.

The creation of an ecologistic system in the investment phase makes it possible during the operational and regeneration phases to provide customers with a range of logistic services that contribute to the effective organization of the motion of material flows (direct and reverse). Logistic services (warehousing, transport, sales, supply, etc.) are the parts of a logistic product and are provided during the operational phase of a project. The complex of logistic services provided in the operational phase must ensure the motion of a material flow in compliance with the rules of ecologistics [5].

In the regeneration phase, recycling logistic services related to the maintenance of return material flows are provided. The logistic operations that form the return logistic services include: collection and return of goods, transportation, warehousing of returned goods and spare parts, recyclables, disassembly of damaged goods or of those with the finished service line, disposal, etc. [9]. To provide recycling logistic services, it is necessary to create an ecologistic system, which will include the appropriate infrastructure that will be the material basis for the promotion of recycling and disposal flow.

In the case of the organization of recycling and disposal flows and the closure of logistic chains, it is about short-term regeneration, in other words, rapid recovery of products or the formation of recyclable material resources. Establishment and operation of the facilities of the transport and logistic infrastructure of an ecologistic system: cargo terminals, warehousing complexes, distributing, repair centers, and other facilities, as well as the creation of communications between these facilities, have a negative effect on the environment. Negative consequences can appear in the short-term, medium-term, and more often in a long-term prospect. To perform a set of actions to eliminate eco-destructive consequences and restore an ecosystem requires time, which is determined by the duration of the latter, revitalization phase of a project of an ecologistic system [17] (**Fig. 4.1**).

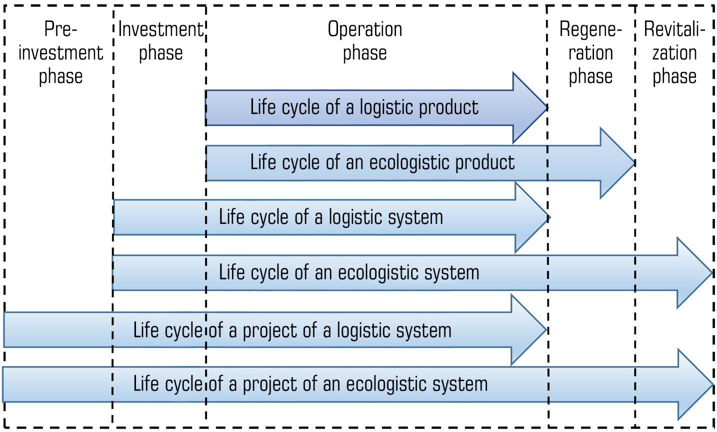


Fig. 4.1 Structure of life cycles of a project of logistic and ecologistic systems

Thus, the greening of a logistic system will result in an increase in the number of phases and the duration of the project life cycle.

4.3 MODEL OF THE LIFE CYCLE OF A PROJECT OF AN ECOLOGISTIC SYSTEM

The life cycle model is presented in the form of a sequence of stages that can overlap and (or) be repeated cyclically according to the project's field of application, size, complexity. In the projects of ecologistic systems, the phases of the life cycle can proceed both consecutively, one after another, and overlap. The investment phase occurs only after the end of the pre-investment phase. The regeneration phase begins before the end of the operational phase when a product from a final consumer enters the reverse flow of material resources. The revitalization phase begins together with the investment phase, proceeds during the operational and regeneration phases, and lasts until the project completion.

The phases of the life cycle of a project of an ecologistic system make up set C^f, $(f=\overline{1;F})$ are the project phases. Project phases are divided into stages that make up set S^{fj}, j $(j=\overline{1;J})$ are the stages of a project phase. The stages are characterized by obtaining intermediate results – intermediate project products.

Time intervals $[t_i;\ t_{i+1}]$ $(i=\overline{1;I-1})$, where t_i is the beginning, t_{i+1} is the end of a time interval of the duration of the stage of a project phase that are milestones correspond to the stages of project phases. It is proposed to separate the following significant events of a project that occur at a certain moment within the life cycle of a project of an ecologistic system:

– t_0 is the project beginning, the pre-investment phase;

– t_1 is the beginning of the investment and revitalization phases, completion of the pre-investment phase;

– t_2 is the beginning of the operational phase, completion of the investment phase;

– t_3 is the beginning of the regeneration phase;

– t_4 is the completion of the operation phase;

– t_5 is the completion of the regeneration phase;

– t_6 is the completion of a project, of a revitalization phase.

Thus, the life cycle includes set TI^i, $(i=\overline{1;I-1})$ of time intervals $[t_i;\ t_{i+1}]$ – periods of time, the beginning and the completion of which are the events that correspond to the beginning or the completion of a project phase.

The life cycle of an ecologistic system project includes the phases that differ in the number of stages in their composition:

– phase 1, pre-investment – $P^{11}_{[t_0;t_1]}$;

– phase 2, investment – $I^{21}_{[t_1;t_2]}$;

– phase 3, operation – $O^{31}_{[t_2;t_3]}$, $O^{32}_{[t_3;t_4]}$;

– phase 4, regeneration – $R^{41}_{[t_3;t_4]}$, $R^{42}_{[t_4;t_5]}$;

– phase 5, revitalization – $V^{51}_{[t_1;t_2]}$, $V^{52}_{[t_2;t_3]}$, $V^{53}_{[t_3;t_4]}$, $V^{54}_{[t_4;t_5]}$, $V^{55}_{[t_5;t_6]}$ [30] (**Fig. 4.2**).

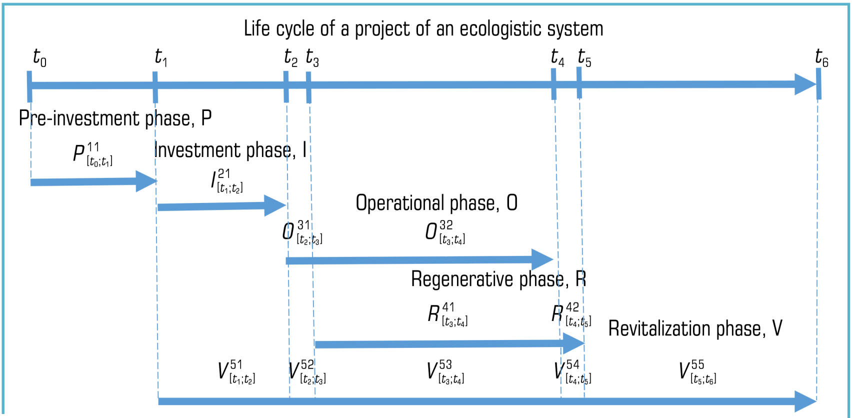


Fig. 4.2 Graphic model of the lifecycle of a project of an ecologistic system

The stages of the life cycle of a project of an ecologistic system are completed by obtaining a result – an intermediate phase product (in case of a single-stage phase) or a stage product (in case of a multi-stage phase), which belongs to a set of project products $R^{fj}_{[t_i;t_{i+1}]}$, $(f=\overline{1;F})$, $(j=\overline{1;J})$, $(i=\overline{1;I-1})$.

4.4 EVALUATION OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT USING THE DISCOUNTED PAYBACK PERIOD OF THE PROJECT

Obtaining project products $R^{fj}_{[t_i;t_{i+1}]}$ is characterized by corresponding cash flows $CF^{fj}_{[t_i;t_{i+1}]}$, $(f=\overline{1;F})$, $(j=\overline{1;J})$, $(i=\overline{1;I-1})$. To characterize cash flows in the life cycle of a project of an ecologistic system, a set of cash flows generated by intermediate project products is used:

$$CF^{fj}_{[t_i;t_{i+1}]}=\left\{\begin{matrix} CF^{11}_{[t_0;t_1]};\ CF^{21}_{[t_1;t_2]};\ CF^{31}_{[t_2;t_3]};\ CF^{32}_{[t_3;t_4]}; \\ CF^{41}_{[t_3;t_4]};\ CF^{42}_{[t_4;t_5]};\ CF^{51}_{[t_1;t_2]};\ CF^{52}_{[t_2;t_3]}; \\ CF^{53}_{[t_3;t_4]};\ CF^{54}_{[t_4;t_5]};\ CF^{55}_{[t_5;t_6]} \end{matrix}\right\}.$$

When calculating cash flows that arrive within time interval $[t_i;\ t_{i+1}]$, $(i=\overline{0;I-1})$, it is necessary to take into account the cash flows generated during the creation of phase products or products of the project's phases or stages that flow during the given interval of time:

$$CF_{[t_i;t_{i+1}]}=\sum_{f=1}^{F}\sum_{j=1}^{J}CF^{fj}_{[t_i;t_{i+1}]}, \tag{4.1}$$

where $CF^{fj}_{[t_i;t_{i+1}]}$ is the cash flows generated during stage j in phase f of the project that is completed within time interval $[t_i;\ t_{i+1}]$, $(i=\overline{0;I-1})$.

It is proposed to evaluate the effectiveness of a project of an ecologistic system using the criterion of the *Discounted Payback Period (DPP)* as an integrated indicator that takes into consideration the effectiveness of project management in each time interval of the life cycle.

Since modeling of cash flows is carried out at the beginning of a project when it is difficult to accurately predict their values, let's assume that the regeneration phase begins almost simultaneously with the operational phase, in other words, $\Delta t_{23}=(t_3-t_2)\rightarrow\min$ and $\Delta t_{45}=(t_5-t_4)\rightarrow\min$. In this case, it is possible to assume that cash flows during the operational and regeneration phases take conditionally constant values:

$$CF_{[t_2;t_3]}=CF_{[t_3;t_4]}=CF_{[t_4;t_5]}=CF^{\text{const}}_{[t_i;t_{i+1}]},\ \left(i=\overline{2;5}\right). \tag{4.2}$$

The discounted payback period corresponds to the point in time when the NPV (Net Present Value) of a project is equal to zero, that is, according to formula:

$$-I_0+\sum_{i=1}^{T}CF_i\cdot q^i=0, \tag{4.3}$$

where I_0 is the initial investment in a project; $q=1/(1+r)$ is the discount factor; r is the discount rate. According to [31], to calculate the discounted payback period at constant values of cash flows, let's use:

$$DPP=\log_q\left[1-\frac{I_0(1-q)}{CF_{\text{const}}\cdot q}\right], \tag{4.4}$$

where CF_{const} is the constant cash flows in a project.

Derive the formula of the *DPP* for a project of an ecologistic system, taking into account the specific features of the composition of its life cycle.

Since cash flows during the time interval $[t_2;\ t_5]$ have constant values, that is $CF_{[t_i;t_{i+1}]}=\text{const}$, $(i=\overline{2;4})$, formula (4.4) will take the form:

$$CF_{[t_0;t_1]}\cdot q^{t_1}+CF_{[t_1;t_2]}\cdot q^{t_2}+\sum_{i=2}^{T}CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}+CF_{[t_5;t_6]}\cdot q^{t_6}=0. \tag{4.5}$$

Hence, it follows:

$$\sum_{i=2}^{T}CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}=-CF_{[t_0;t_1]}\cdot q^{t_1}-CF_{[t_1;t_2]}\cdot q^{t_2}-CF_{[t_5;t_6]}\cdot q^{t_6}, \tag{4.6}$$

$$\sum_{i=2}^{T}q^{t_{i+1}}=\frac{-\left(CF_{[t_0;t_1]}\cdot q^{t_1}+CF_{[t_1;t_2]}\cdot q^{t_2}+CF_{[t_5;t_6]}\cdot q^{t_6}\right)}{CF^{\text{const}}_{[t_i;t_{i+1}]}}. \tag{4.7}$$

Convert the formula of the sum of the first terms of geometric progression and write it down:

$$\sum_{i=2}^{T} q^{t_{i+1}} = \frac{q^{t_i}\left(1-q^T\right)}{1-q}. \qquad (4.8)$$

Then,

$$\frac{q^{t_2}\left(1-q^T\right)}{1-q} = \frac{-\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)}{CF^{\text{const}}_{[t_i;t_{i+1}]}}, \qquad (4.9)$$

$$q^T = 1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}. \qquad (4.10)$$

The payback period can be calculated from the following formula:

$$DPP = T = \log_q\left[1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right], \qquad (4.11)$$

if conditions are satisfied:

$$1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}} > 0,\ q > 0,\ q \neq 1. \qquad (4.12)$$

The discounted payback period of a project depends on the values of cash flows in different time intervals $[t_i;\ t_{i+1}]$, $(i = \overline{0;I-1})$, the duration of these intervals, and the discount factor, the value of which depends on the discount rate.

4.5 DETERMINATION OF FUNCTIONAL DEPENDENCIES BETWEEN THE DISCOUNTED LIFETIME AND CASH FLOWS DURING THE LIFE CYCLE PHASES OF THE ECOLOGICAL SYSTEM PROJECT

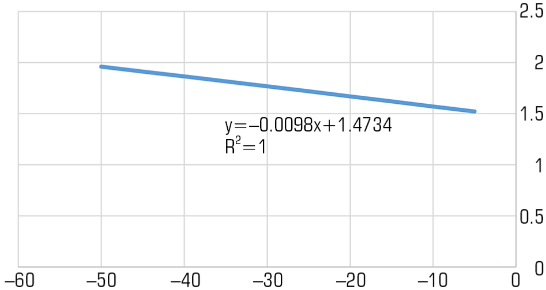
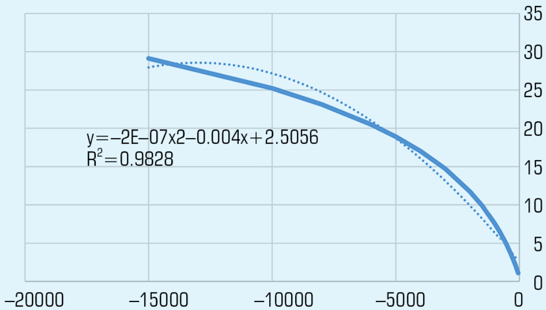
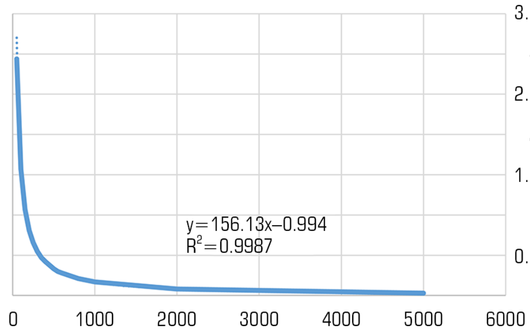
During the study, experimental calculations were performed, which made it possible to identify the dependences between cash flows during the project life cycle and the discounted payback period of a project on an ecologistic system. The obtained results are shown in **Table 4.1**.

The experimental data were approximated, as a result of which the mathematical equations that describe functional dependences between argument and the value of the function were obtained. The cash flow of pre-investment phase $CF_{[t_0;t_1]}$, cash flow of investment phase $CF_{[t_1;t_2]}$, cash flows of project's operational and regeneration phases $\sum_{i=2}^{5} CF^{\text{const}(O,R)}_{[t_i;t_{i+1}]}$, cash flows of revitalization phase

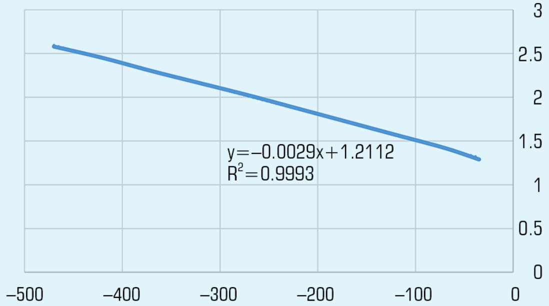
CHAPTER 4

$\sum_{i=1}^{5} CF^{V}_{[t_i;t_{i+1}]}$ are the arguments of the function. The value of the function is discounted payback period of a project of an ecologistic system *DPP*.

Table 4.1 Functional dependences between cash flows and a payback period of a project of an ecologistic system

<table>
<tr><th>Indicator</th><th>Chart of functional dependence</th></tr>
<tr><td>1</td><td>2</td></tr>
<tr><td>Cash flow of pre-investment phase $CF_{[t_0;t_1]}$</td><td>
</td></tr>
<tr><td>Cash flow of investment phase $CF_{[t_1;t_2]}$</td><td>
</td></tr>
<tr><td>Cash flows of project's operational and regeneration phases $\sum_{i=2}^{5} CF^{\mathrm{const}(O,R)}_{[t_i;t_{i+1}]}$</td><td>
</td></tr>
</table>

Continuation of Table 4.1

1	2
Cash flow of revitalization phase $\sum_{i=1}^{5} CF^{V}_{[t_i;t_{i+1}]}$	

For each of the analyzed parameters, the degree of approximation was determined with the help of approximation reliability R^2 and the most appropriate functional dependence was chosen.

The performed study showed that the dependence between the discounted payback period *DPP* and cash flow of the investment phase $CF_{[t_1;t_2]}$ is described by a polynomial (square trinomial) $y=-2E-07x^2-0.004x+2.5056$ at approximation reliability $R^2=0.9828$. Thus, the analytic expression to determine the dependence is the polynomial function of the form $y=ax^2+bx+c$ $(a\neq 0,\ b\neq 0)$ with the region of determining $(-\infty;\ 0)$. There is an inverse dependence between the payback period and the cash flows of the investment phase, an increase in the payback period gradually slows down at an increase in investment costs in the creation of an ecologistic system.

Dependence of the discounted payback period *DPP* on cash flows of the project's operational and regeneration phases $\sum_{i=2}^{5} CF^{\mathrm{const}(O,R)}_{[t_i;t_{i+1}]}$ is expressed by function $y=156.13x^{-0.994}$ with approximation reliability $R^2=0.9987$. The analytical expression to determine the dependence is the power function of the form $y=ax^n$ $(a\neq 0)$ with the region of determining $(0;\ +\infty)$. There is a direct relationship between the payback period and the cash flows of the operational and regeneration phases, the rate of an increase in the payback period slows down at an increase in cash flows.

The dependence that is observed between the discounted payback period and cash flows of the pre-investment and revitalization phases is linear and is expressed by function $y=-0.0098x+1.4734$ with approximation reliability $R^2=1$ and $y=-0.0029x+1.2112$ with approximation reliability $R^2=0.9993$, respectively. The dependence in both cases is expressed analytically by a linear function of the form of $y=kx+b$ $(k\neq 0)$ with the region of determining function $(-\infty;\ 0)$. There is an inverse dependence between the payback period and the costs of the pre-investment and investment phases.

The conducted study revealed the dependences between the criterion of project effectiveness – the discounted payback period and cash flows, which received functional expression. The dynamics of changes in the payback period are represented by various mathematical functions depending on the phase, to which the cash flows belong. Detection of this phenomenon will make it possible to predict the changes in the payback period of a project depending on the changes in cash flows of each phase of the project life cycle.

4.6 ESTIMATES OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT UNDER CONDITIONS OF UNCERTAINTY

In conditions of uncertainty, it is possible to evaluate the effectiveness of the project of the ecological system through a fuzzy defined DPP thanks to the application of the tools of the theory of fuzzy sets. In particular, by introducing fuzzy values of cash flows corresponding to certain time intervals of the project's life cycle. The reason for such actions is the lack of an opportunity to accurately forecast future values of cash flows in the pre-investment phase.

When calculating the DPP, it is suggested to take into account the impact of uncertainty by taking into account the fuzziness of the values of money $CF_{[t_i;t_{i+1}]}$, which are generated at time intervals $[t_i;t_{i+1}]$ and correspond to individual stages of the life cycle of the ecological system project. $CF_{[t_i;t_{i+1}]}=\left\{\left(CF^{n[t_i;t_{i+1}]}_{[t_i;t_{i+1}]};\, \mu_{CF_{[t_i;t_{i+1}]}}\left(CF^{n[t_i;t_{i+1}]}_{[t_i;t_{i+1}]}\right)\right)\right\},\ \left(n_{[t_i;t_{i+1}]}=\overline{1,N_{[t_i;t_{i+1}]}}\right)$ is a fuzzy set of cash flows of the time interval $[t_i;t_{i+1}]$, $(i=\overline{0;I-1})$, the life cycle of the ecological system project.

Cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ vary throughout the life cycle and take, depending on the inflows $IF^{fj}_{[t_i;t_{i+1}]}$ and outflows $OF^{fj}_{[t_i;t_{i+1}]}$, positive or negative values depending on the stage of the project.

The set of time intervals TI^i includes two subsets:

– a subset of time intervals $TI^i(OF)$ to which cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ correspond, consisting only of outgoing cash flows $IF^{fj}_{[t_i;t_{i+1}]}$, i.e.

$$TI^i(IF;OF)\in TI^i(IF=0;OF\neq 0),$$

$$TI^i(OF)=\{[t_0;t_1];[t_1;t_2];[t_5;t_6]\};$$

– a subset of time intervals $TI^i(IF,OF)$ to which cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ correspond, consisting of incoming $IF^{fj}_{[t_i;t_{i+1}]}$ and outgoing $IF^{fj}_{[t_i;t_{i+1}]}$ cash flows, i.e.

$$TI^i(IF;OF)\in TI^i(IF\neq 0;OF\neq 0),$$

$$TI^i(IF;OF)=\{[t_2;t_3];[t_3;t_4];[t_4;t_5]\}.$$

Cash flows are formed at time intervals that belong to set $TI^i(OF)$ outgoing cash flows for:

– pre-investment phase:

$$CF_{[t_0;t_1]}=CF^{11}_{[t_0;t_1]}=OF^{11}_{[t_0;t_1]}; \quad (4.13)$$

– investment phase:

$$CF_{[t_1;t_2]} = CF^{21}_{[t_1;t_2]} + CF^{51}_{[t_1;t_2]} = OF^{21}_{[t_1;t_2]} + OF^{51}_{[t_1;t_2]}; \tag{4.14}$$

– the last stage of the revitalization phase:

$$CF_{[t_5;t_6]} = CF^{56}_{[t_5;t_6]} = OF^{56}_{[t_5;t_6]}. \tag{4.15}$$

The time intervals $TI^i(IF;OF)$ of the life cycle, which are characterized not only by outgoing, but also by incoming cash flows, include cash flows:

– the first stage of operation and the second stage of the revitalization phase:

$$CF_{[t_2;t_3]} = CF^{31}_{[t_2;t_3]} + CF^{52}_{[t_2;t_3]} = IF^{31}_{[t_2;t_3]} + OF^{31}_{[t_2;t_3]} + IF^{52}_{[t_2;t_3]} + OF^{52}_{[t_2;t_3]}; \tag{4.16}$$

– the second stage of the operational, the first stage of the regenerative and the third stage of the revitalization phases:

$$\begin{aligned} CF_{[t_3;t_4]} &= CF^{32}_{[t_3;t_4]} + CF^{41}_{[t_3;t_4]} + CF^{53}_{[t_3;t_4]} = \\ &= IF^{32}_{[t_3;t_4]} + OF^{32}_{[t_3;t_4]} + IF^{41}_{[t_3;t_4]} + OF^{41}_{[t_3;t_4]} + IF^{53}_{[t_3;t_4]} + OF^{53}_{[t_3;t_4]}; \end{aligned} \tag{4.17}$$

– the second stage of the regenerative and the fourth stage of the revitalization phases:

$$CF_{[t_4;t_5]} = CF^{42}_{[t_4;t_5]} + CF^{54}_{[t_4;t_5]} = IF^{42}_{[t_4;t_5]} + OF^{42}_{[t_4;t_5]} + IF^{54}_{[t_4;t_5]} + OF^{54}_{[t_4;t_5]}. \tag{4.18}$$

The cash flows of the project $CF_{[t_i;t_{i+1}]}$ are formed from the incoming $IF_{[t_i;t_{i+1}]}$ and outgoing $OF_{[t_i;t_{i+1}]}$ flows corresponding to the time interval $[t_i;t_{i+1}]$, and in fuzzy defined conditions can be represented in the form of fuzzy sets:

– $IF_{[t_i;t_{i+1}]} = \left\{ \left(IF^{k_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]}; \mu_{IF_{[t_i;t_{i+1}]}} \left(IF^{k_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]} \right) \right) \right\}$, $\left(k_{[t_i;t_{i+1}]} = \overline{1, K_{[t_i;t_{i+1}]}} \right)$ – a fuzzy set of incoming cash flows during the time interval $[t_i;t_{i+1}]$, $\left(i = \overline{0; I-1} \right)$ of the life cycle of the ecological system project (**Table 4.2**);

– $OF_{[t_i;t_{i+1}]} = \left\{ \left(OF^{l_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]}; \mu_{OF_{[t_i;t_{i+1}]}} \left(OF^{l_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]} \right) \right) \right\}$, $\left(l_{[t_i;t_{i+1}]} = \overline{1, L_{[t_i;t_{i+1}]}} \right)$ – a fuzzy set of initial cash flows during the time interval $[t_i;t_{i+1}]$, $\left(i = \overline{0; I-1} \right)$ of the life cycle of the ecological system project (**Table 4.3**).

CHAPTER 4

Table 4.2 Incoming cash flows of the ecological system project

Time interval $[t_i;t_{i+1}]$	**Fuzzy value of incoming cash flows**
$[t_0;t_1]$	–
$[t_1;t_2]$	–
$[t_2;t_3]$	$IF_{[t_2;t_3]} = \left\{\left(IF_{[t_2;t_3]}^{k_{[t_2;t_3]}};\mu_{IF_{[t_2;t_3]}}\left(IF_{[t_2;t_3]}^{k_{[t_2;t_3]}}\right)\right)\right\},\ \left(k_{[t_2;t_2]} = \overline{1,K_{[t_2;t_2]}}\right)$ $IF_{[t_2;t_3]}^{31} = \left\{\left(IF_{[t_2;t_3]}^{31h};\mu_{IF_{[t_2;t_3]}^{31}}\left(IF_{[t_2;t_3]}^{31h}\right)\right)\right\},\ \left(h = \overline{1,H^{31}}\right)$ $IF_{[t_2;t_3]}^{52} = \left\{\left(IF_{[t_2;t_3]}^{52h};\mu_{IF_{[t_2;t_3]}^{31}}\left(IF_{[t_2;t_3]}^{52h}\right)\right)\right\},\ \left(h = \overline{1,H^{52}}\right)$
$[t_3;t_4]$	$IF_{[t_3;t_4]} = \left\{\left(IF_{[t_3;t_4]}^{k_{[t_3;t_4]}};\mu_{IF_{[t_3;t_4]}}\left(IF_{[t_3;t_4]}^{k_{[t_3;t_4]}}\right)\right)\right\},\ \left(k_{[t_3;t_4]} = \overline{1,K_{[t_3;t_4]}}\right)$ $IF_{[t_3;t_4]}^{32} = \left\{\left(IF_{[t_3;t_4]}^{32h};\mu_{IF_{[t_3;t_4]}^{32}}\left(IF_{[t_3;t_4]}^{32h}\right)\right)\right\},\ \left(h = \overline{1,H^{32}}\right)$ $IF_{[t_3;t_4]}^{41} = \left\{\left(IF_{[t_3;t_4]}^{41h};\mu_{IF_{[t_3;t_4]}^{41}}\left(IF_{[t_3;t_4]}^{41h}\right)\right)\right\},\ \left(h = \overline{1,H^{41}}\right)$ $IF_{[t_3;t_4]}^{53} = \left\{\left(IF_{[t_3;t_4]}^{53h};\mu_{IF_{[t_3;t_4]}^{53}}\left(IF_{[t_3;t_4]}^{53h}\right)\right)\right\},\ \left(h = \overline{1,H^{53}}\right)$
$[t_4;t_5]$	$IF_{[t_4;t_5]} = \left\{\left(IF_{[t_4;t_5]}^{k_{[t_4;t_5]}};\mu_{IF_{[t_4;t_5]}}\left(IF_{[t_4;t_5]}^{k_{[t_4;t_5]}}\right)\right)\right\},\ \left(k_{[t_4;t_5]} = \overline{1,K_{[t_4;t_5]}}\right)$ $IF_{[t_4;t_5]}^{42} = \left\{\left(IF_{[t_4;t_5]}^{42h};\mu_{IF_{[t_4;t_5]}^{42}}\left(IF_{[t_4;t_5]}^{42h}\right)\right)\right\},\ \left(h = \overline{1,H^{42}}\right)$ $IF_{[t_4;t_5]}^{54} = \left\{\left(IF_{[t_4;t_5]}^{54h};\mu_{IF_{[t_4;t_5]}^{54}}\left(IF_{[t_4;t_5]}^{54h}\right)\right)\right\},\ \left(h = \overline{1,H^{54}}\right)$
$[t_5;t_6]$	–

Table 4.3 Outgoing cash flows of the ecological system project

Time interval $[t_i;t_{i+1}]$	**Fuzzy value of outgoing cash flows**
1	**2**
$[t_0;t_1]$	$OF_{[t_0;t_1]} = \left\{\left(OF_{[t_0;t_1]}^{l_{[t_0;t_1]}};\mu_{OF_{[t_0;t_1]}}\left(OF_{[t_0;t_1]}^{l_{[t_0;t_1]}}\right)\right)\right\},\ \left(l_{[t_0;t_1]} = \overline{1,L_{[t_0;t_1]}}\right)$ $OF_{[t_0;t_1]}^{11} = \left\{\left(OF_{[t_0;t_1]}^{11g};\mu_{OF_{[t_0;t_1]}^{11}}\left(OF_{[t_0;t_1]}^{11g}\right)\right)\right\},\ \left(g = \overline{1,G^{11}}\right)$
$[t_1;t_2]$	$OF_{[t_1;t_2]} = \left\{\left(OF_{[t_1;t_2]}^{l_{[t_1;t_2]}};\mu_{OF_{[t_1;t_2]}}\left(OF_{[t_1;t_2]}^{l_{[t_1;t_2]}}\right)\right)\right\},\ \left(l_{[t_1;t_2]} = \overline{1,L_{[t_1;t_2]}}\right)$ $OF_{[t_1;t_2]}^{21} = \left\{\left(OF_{[t_1;t_2]}^{21g};\mu_{OF_{[t_1;t_2]}^{21}}\left(OF_{[t_1;t_2]}^{21g}\right)\right)\right\},\ \left(g = \overline{1,G^{21}}\right)$

Continuation of Table 4.3

1	2
$\left[t_2;t_3\right]$	$OF_{[t_2;t_3]}=\left\{\left(OF_{[t_2;t_3]}^{l_{[t_2;t_3]}};\mu_{OF_{[t_2;t_3]}}\left(OF_{[t_2;t_3]}^{l_{[t_2;t_3]}}\right)\right)\right\},\ \left(l_{[t_2;t_2]}=\overline{1,L_{[t_2;t_2]}}\right)$ $OF_{[t_2;t_3]}^{31}=\left\{\left(OF_{[t_2;t_3]}^{31g};\mu_{OF_{[t_2;t_3]}^{31}}\left(OF_{[t_2;t_3]}^{31g}\right)\right)\right\},\ \left(g=\overline{1,G^{31}}\right)$ $OF_{[t_2;t_3]}^{52}=\left\{\left(OF_{[t_2;t_3]}^{52g};\mu_{OF_{[t_2;t_3]}^{31}}\left(OF_{[t_2;t_3]}^{52g}\right)\right)\right\},\ \left(g=\overline{1,G^{52}}\right)$
$\left[t_3;t_4\right]$	$OF_{[t_3;t_4]}=\left\{\left(OF_{[t_3;t_4]}^{l_{[t_3;t_4]}};\mu_{OF_{[t_3;t_4]}}\left(OF_{[t_3;t_4]}^{l_{[t_3;t_4]}}\right)\right)\right\},\ \left(l_{[t_3;t_4]}=\overline{1,L_{[t_3;t_4]}}\right)$ $OF_{[t_3;t_4]}^{32}=\left\{\left(OF_{[t_3;t_4]}^{32g};\mu_{OF_{[t_3;t_4]}^{32}}\left(OF_{[t_3;t_4]}^{32g}\right)\right)\right\},\ \left(g=\overline{1,G^{32}}\right)$ $OF_{[t_3;t_4]}^{41}=\left\{\left(OF_{[t_3;t_4]}^{41g};\mu_{OF_{[t_3;t_4]}^{41}}\left(OF_{[t_3;t_4]}^{41g}\right)\right)\right\},\ \left(g=\overline{1,G^{41}}\right)$ $OF_{[t_3;t_4]}^{53}=\left\{\left(OF_{[t_3;t_4]}^{53g};\mu_{OF_{[t_3;t_4]}^{53}}\left(OF_{[t_3;t_4]}^{53g}\right)\right)\right\},\ \left(g=\overline{1,G^{53}}\right)$
$\left[t_4;t_5\right]$	$OF_{[t_4;t_5]}=\left\{\left(OF_{[t_4;t_5]}^{l_{[t_4;t_5]}};\mu_{OF_{[t_4;t_5]}}\left(OF_{[t_4;t_5]}^{l_{[t_4;t_5]}}\right)\right)\right\},\ \left(l_{[t_4;t_5]}=\overline{1,L_{[t_4;t_5]}}\right)$ $OF_{[t_4;t_5]}^{42}=\left\{\left(OF_{[t_4;t_5]}^{42g};\mu_{OF_{[t_4;t_5]}^{42}}\left(OF_{[t_4;t_5]}^{42g}\right)\right)\right\},\ \left(g=\overline{1,G^{42}}\right)$ $OF_{[t_4;t_5]}^{54}=\left\{\left(OF_{[t_4;t_5]}^{54g};\mu_{OF_{[t_4;t_5]}^{54}}\left(OF_{[t_4;t_5]}^{54g}\right)\right)\right\},\ \left(g=\overline{1,G^{54}}\right)$
$\left[t_5;t_6\right]$	$OF_{[t_5;t_6]}=\left\{\left(OF_{[t_5;t_6]}^{l_{[t_5;t_6]}};\mu_{OF_{[t_5;t_6]}}\left(OF_{[t_5;t_6]}^{l_{[t_5;t_6]}}\right)\right)\right\},\ \left(l_{[t_5;t_6]}=\overline{1,L_{[t_5;t_6]}}\right)$ $OF_{[t_5;t_6]}^{56}=\left\{\left(OF_{[t_5;t_6]}^{56g};\mu_{OF_{[t_5;t_6]}^{56}}\left(OF_{[t_5;t_6]}^{56g}\right)\right)\right\},\ \left(g=\overline{1,G^{56}}\right)$

The cash flows of the project $CF_{[t_i;t_{i+1}]}^{fj}$, which correspond to the stage j $(j=\overline{1;J})$ of the project phase f $(f=\overline{1;F})$, are formed from the input $IF_{[t_i;t_{i+1}]}^{fj}$ and outgoing $OF_{[t_i;t_{i+1}]}^{fj}$ flows and in fuzzy defined conditions can be represented in the form of fuzzy sets:

– $IF_{[t_i;t_{i+1}]}^{fjh}=\left\{\left(IF_{[t_i;t_{i+1}]}^{fjh};\mu_{IF_{[t_i;t_{i+1}]}^{fj}}\left(IF_{[t_i;t_{i+1}]}^{fjh}\right)\right)\right\},\ \left(h=\overline{1,H^{fj}}\right)$ – a fuzzy set of incoming cash flows corresponding to stage j of phase f of the project during the time interval of the life cycle of the ecological system project;

– $OF_{[t_i;t_{i+1}]}^{fjg}=\left\{\left(OF_{[t_i;t_{i+1}]}^{fjg};\mu_{OF_{[t_i;t_{i+1}]}^{fj}}\left(OF_{[t_i;t_{i+1}]}^{fjg}\right)\right)\right\},\ \left(g=\overline{1,G^{fj}}\right)$ – a fuzzy set of initial cash flows corresponding to stage j of phase f of the project during the time interval $\left[t_i;t_{i+1}\right]$ of the life cycle of the ecological system project.

To calculate fuzzy defined cash flows $CF_{[t_i;t_{i+1}]}$, incoming $IF_{[t_i;t_{i+1}]}$ and outgoing $OF_{[t_i;t_{i+1}]}$ cash flows corresponding to a time interval $[t_i;t_{i+1}]$, it is advisable to use trapezoidal fuzzy numbers. This assumption is based on the fact that the flows (input and output) are defined on the set of real numbers R. Fuzzy numbers used in the calculation of the fuzzy expressed DPP value of the ecological system project:

1. *Cash incoming flows*:

$$\left(IF_{[t_2;t_3]1},IF_{[t_2;t_3]2},IF_{[t_2;t_3]3},IF_{[t_2;t_3]4}\right)=\begin{pmatrix} IF^{31}_{[t_2;t_3]1}+IF^{52}_{[t_2;t_3]1},IF^{31}_{[t_2;t_3]2}+IF^{52}_{[t_2;t_3]2}, \\ IF^{31}_{[t_2;t_3]3}+IF^{52}_{[t_2;t_3]3},IF^{31}_{[t_2;t_3]4}+IF^{52}_{[t_2;t_3]4} \end{pmatrix}, \tag{4.19}$$

$$\left(IF_{[t_3;t_4]1},IF_{[t_3;t_4]2},IF_{[t_3;t_4]3},IF_{[t_3;t_4]4}\right)=\begin{pmatrix} IF^{32}_{[t_3;t_4]1}+IF^{41}_{[t_3;t_4]1}+IF^{53}_{[t_3;t_4]1}, \\ IF^{32}_{[t_3;t_4]2}+IF^{41}_{[t_3;t_4]2}+IF^{53}_{[t_3;t_4]2}, \\ IF^{32}_{[t_3;t_4]3}+IF^{41}_{[t_3;t_4]3}+IF^{53}_{[t_3;t_4]3}, \\ IF^{32}_{[t_3;t_4]4}+IF^{41}_{[t_3;t_4]4}+IF^{53}_{[t_3;t_4]4} \end{pmatrix}, \tag{4.20}$$

$$\left(IF_{[t_4;t_5]1},IF_{[t_4;t_5]2},IF_{[t_4;t_5]3},IF_{[t_4;t_5]4}\right)=\begin{pmatrix} IF^{42}_{[t_4;t_5]1}+IF^{54}_{[t_4;t_5]1},IF^{42}_{[t_4;t_5]2}+IF^{54}_{[t_4;t_5]2}, \\ IF^{42}_{[t_4;t_5]3}+IF^{54}_{[t_4;t_5]3},IF^{42}_{[t_4;t_5]3}+IF^{54}_{[t_4;t_5]4} \end{pmatrix}. \tag{4.21}$$

2. *Cash outgoing flows*:

$$\left(OF_{[t_0;t_1]1},OF_{[t_0;t_1]2},OF_{[t_0;t_1]3},OF_{[t_0;t_1]4}\right), \tag{4.22}$$

$$\left(OF_{[t_1;t_2]1},OF_{[t_1;t_2]2},OF_{[t_1;t_2]3},OF_{[t_1;t_2]4}\right), \tag{4.23}$$

$$\left(OF_{[t_2;t_3]1},OF_{[t_2;t_3]2},OF_{[t_2;t_3]3},OF_{[t_2;t_3]4}\right)=\begin{pmatrix} OF^{31}_{[t_2;t_3]1}+OF^{52}_{[t_2;t_3]1},OF^{31}_{[t_2;t_3]2}+OF^{52}_{[t_2;t_3]2}, \\ OF^{31}_{[t_2;t_3]3}+OF^{52}_{[t_2;t_3]3},OF^{31}_{[t_2;t_3]4}+OF^{52}_{[t_2;t_3]4} \end{pmatrix}, \tag{4.24}$$

$$\left(OF_{[t_4;t_5]1},OF_{[t_4;t_5]2},OF_{[t_4;t_5]3},OF_{[t_4;t_5]4}\right)=\begin{pmatrix} OF^{42}_{[t_4;t_5]1}+OF^{54}_{[t_4;t_5]1},OF^{42}_{[t_4;t_5]2}+OF^{54}_{[t_4;t_5]2}, \\ OF^{42}_{[t_4;t_5]3}+OF^{54}_{[t_4;t_5]3},OF^{42}_{[t_4;t_5]4}+OF^{54}_{[t_4;t_5]4} \end{pmatrix}, \tag{4.25}$$

$$\left(OF_{[t_3;t_4]1},OF_{[t_3;t_4]2},OF_{[t_3;t_4]3},OF_{[t_3;t_4]4}\right)=\begin{pmatrix} OF^{32}_{[t_3;t_4]1}+OF^{41}_{[t_3;t_4]1}+OF^{53}_{[t_3;t_4]1}, \\ OF^{32}_{[t_3;t_4]2}+OF^{41}_{[t_3;t_4]2}+OF^{53}_{[t_3;t_4]2}, \\ OF^{32}_{[t_3;t_4]3}+OF^{41}_{[t_3;t_4]3}+OF^{53}_{[t_3;t_4]3}, \\ OF^{32}_{[t_3;t_4]4}+OF^{41}_{[t_3;t_4]4}+OF^{53}_{[t_3;t_4]4} \end{pmatrix}, \tag{4.26}$$

$$\left(OF_{[t_5;t_6]1},OF_{[t_5;t_6]2},OF_{[t_5;t_6]3},OF_{[t_5;t_6]4}\right). \tag{4.27}$$

3. *Cash flows*:

$$\begin{pmatrix} CF_{[t_0;t_1]1}, CF_{[t_0;t_1]2}, \\ CF_{[t_0;t_1]3}, CF_{[t_0;t_1]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_0;t_1]1} - OF_{[t_0;t_1]4}, \\ IF_{[t_0;t_1]2} - OF_{[t_0;t_1]3}, \\ IF_{[t_0;t_1]3} - OF_{[t_0;t_1]2}, \\ IF_{[t_0;t_1]4} - OF_{[t_0;t_1]1} \end{pmatrix}, \tag{4.28}$$

$$\begin{pmatrix} CF_{[t_1;t_2]1}, CF_{[t_1;t_2]2}, \\ CF_{[t_1;t_2]3}, CF_{[t_1;t_2]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_1;t_2]1} - OF_{[t_1;t_2]4}, \\ IF_{[t_1;t_2]2} - OF_{[t_1;t_2]3}, \\ IF_{[t_1;t_2]3} - OF_{[t_1;t_2]2}, \\ IF_{[t_1;t_2]4} - OF_{[t_1;t_2]1} \end{pmatrix}, \tag{4.29}$$

$$\begin{pmatrix} CF_{[t_5;t_6]1}, CF_{[t_5;t_6]2}, \\ CF_{[t_5;t_6]3}, CF_{[t_5;t_6]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_5;t_6]1} - OF_{[t_5;t_6]4}, \\ IF_{[t_5;t_6]2} - OF_{[t_5;t_6]3}, \\ IF_{[t_5;t_6]3} - OF_{[t_5;t_6]2}, \\ IF_{[t_5;t_6]4} - OF_{[t_5;t_6]1} \end{pmatrix}, \tag{4.30}$$

$$\begin{pmatrix} CF^{\text{const}}_{[t_i;t_{i+1}]1}, CF^{\text{const}}_{[t_i;t_{i+1}]2}, \\ CF^{\text{const}}_{[t_i;t_{i+1}]3}, CF^{\text{const}}_{[t_i;t_{i+1}]4} \end{pmatrix} = \begin{pmatrix} IF^{\text{const}}_{[t_i;t_{i+1}]1} - OF^{\text{const}}_{[t_i;t_{i+1}]4}, \\ IF^{\text{const}}_{[t_i;t_{i+1}]2} - OF^{\text{const}}_{[t_i;t_{i+1}]3}, \\ IF^{\text{const}}_{[t_i;t_{i+1}]3} - OF^{\text{const}}_{[t_i;t_{i+1}]2}, \\ IF^{\text{const}}_{[t_i;t_{i+1}]4} - OF_{[t_i;t_{i+1}]1} \end{pmatrix}. \tag{4.31}$$

4. *Discounted cash flows*:

$$\left(CF_{[t_0;t_1]1} \cdot q^{t_1}, CF_{[t_0;t_1]2} \cdot q^{t_1}, CF_{[t_0;t_1]3} \cdot q^{t_1}, CF_{[t_0;t_1]4} \cdot q^{t_1}\right), \tag{4.32}$$

$$\left(CF_{[t_1;t_2]1} \cdot q^{t_2}, CF_{[t_1;t_2]2} \cdot q^{t_2}, CF_{[t_1;t_2]3} \cdot q^{t_2}, CF_{[t_1;t_2]4} \cdot q^{t_2}\right), \tag{4.33}$$

$$\left(CF_{[t_5;t_6]1} \cdot q^{t_6}, CF_{[t_5;t_6]2} \cdot q^{t_6}, CF_{[t_5;t_6]3} \cdot q^{t_6}, CF_{[t_5;t_6]4} \cdot q^{t_6}\right), \tag{4.34}$$

$$\left(CF^{const}_{[t_i;t_{i+1}]1} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]2} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]3} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]4} \cdot q^{t_2}\right). \tag{4.35}$$

5. *Amount of discounted cash flows*:

$$\begin{pmatrix} \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_1, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_2, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_3, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_4 \end{pmatrix} = \begin{pmatrix} CF_{[t_0;t_1]1}\cdot q^{t_1} + CF_{[t_1;t_2]1}\cdot q^{t_2} + CF_{[t_5;t_6]1}\cdot q^{t_6}; \\ CF_{[t_0;t_1]2}\cdot q^{t_1} + CF_{[t_1;t_2]2}\cdot q^{t_2} + CF_{[t_5;t_6]2}\cdot q^{t_6}; \\ CF_{[t_0;t_1]3}\cdot q^{t_1} + CF_{[t_1;t_2]3}\cdot q^{t_2} + CF_{[t_5;t_6]3}\cdot q^{t_6}; \\ CF_{[t_0;t_1]4}\cdot q^{t_1} + CF_{[t_1;t_2]4}\cdot q^{t_2} + CF_{[t_5;t_6]4}\cdot q^{t_6}; \end{pmatrix}. \tag{4.36}$$

6. *Cash flow ratio*:

$$\begin{pmatrix} \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_1, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_2, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_3, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_4 \end{pmatrix} = \begin{pmatrix} \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_1}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_4}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_2}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_3}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_3}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_2}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_4}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_1} \end{pmatrix}. \tag{4.37}$$

7. *Discounted payback period*:

$$\begin{pmatrix} DPP_1; \\ DPP_2; \\ DPP_3; \\ DPP_4; \end{pmatrix} = \begin{pmatrix} \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_1(1-q)\right)_1, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_2(1-q)\right)_2, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_3(1-q)\right)_3, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_4(1-q)\right)_4 \end{pmatrix}. \tag{4.38}$$

CHAPTER 4

Therefore, if at the beginning of the ecological system project it is possible to predict the value of cash flows for various stages, phases and time intervals of the life cycle, as well as to determine the value of the discount rate of cash funds, the *DPP* of the project is calculated according to formula (4.11). In conditions of uncertainty, it is proposed to calculate the fuzzy expressed *DPP* value of the project using a sequence of mathematical expressions represented by formulas (4.19)–(4.38).

4.7 EXPERIMENTAL CALCULATIONS REGARDING THE EVALUATION OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT

Input data for *DPP* calculations of the ecological system project are presented in **Table 4.4**. According to the data presented in **Table 4.4**, the value of the project equal to 1306 years was obtained.

In conditions of uncertainty, the effectiveness of the project of the ecological system is evaluated with the help of a fuzzy defined way of introducing fuzzy values of cash flows $CF_{[t_i;t+1]}$ that correspond to the time intervals $[t_i;t_{i+1}]$ of the life cycle of the project.

To calculate fuzzy defined $CF_{[t_i;t+1]}$ and *DPP* let's use trapezoidal fuzzy numbers (**Table 4.5**).

Table 4.4 Cash flows of the ecological system project

project phase	Cash flows, *CF*, c.u					
	Phase interval					
	$[t_0;t_1]$	$[t_1;t_2]$	$[t_2;t_3]$	$[t_3;t_4]$	$[t_4;t_5]$	$[t_5;t_6]$
Discounted cash flows, CF_{disc}	–3182	–438017	360631	327847	298042	–84671

Table 4.5 Fuzzy numbers for determining cash flows/discounted cash flows of an ecological system project

Cash flows			
$CF_{[t_0;t_1]}$	$CF_{[t_0;t_1]1}$	–4500	0
	$CF_{[t_0;t_1]2}$	–4100	1
	$CF_{[t_0;t_1]3}$	–3600	1
	$CF_{[t_0;t_1]4}$	–3200	0
$CF_{[t_1;t_2]}$	$CF_{[t_1;t_2]1}$	–550000	0
	$CF_{[t_1;t_2]2}$	–540000	1
	$CF_{[t_1;t_2]3}$	–520000	1
	$CF_{[t_1;t_2]4}$	–500000	0
$CF_{[t_2;t_3]}$	$CF^{const}_{[t_i;t_{i+1}]1}$	460000	0
$CF_{[t_3;t_4]}$	$CF^{const}_{[t_i;t_{i+1}]2}$	430000	1
$CF_{[t_5;t_6]}$	$CF^{const}_{[t_i;t_{i+1}]3}$	400000	1
	$CF^{const}_{[t_i;t_{i+1}]4}$	380000	0

Continuation of Table 4.5

$CF_{[t_5;t_6]}$	$CF_{[t_5;t_6]1}$	–180000	0
	$CF_{[t_5;t_6]2}$	–160000	1
	$CF_{[t_5;t_6]3}$	–130000	1
	$CF_{[t_5;t_6]4}$	–110000	0
Discounted cash flows			
$CF^{disc}_{[t_0;t_1]}$	$CF^{disc}_{[t_0;t_1]1}$	–4091	0
	$CF^{disc}_{[t_0;t_1]2}$	–3727	1
	$CF^{disc}_{[t_0;t_1]3}$	–3273	1
	$CF^{disc}_{[t_0;t_1]4}$	–2909	0
$CF^{disc}_{[t_1;t_2]}$	$CF^{disc}_{[t_1;t_2]1}$	–454545	0
	$CF^{disc}_{[t_1;t_2]2}$	–446281	1
	$CF^{disc}_{[t_1;t_2]3}$	–429752	1
	$CF^{disc}_{[t_1;t_2]4}$	–413223	0
$CF^{disc}_{[t_2;t_3]}$	$CF^{disc}_{[t_2;t_3]1}$	345605	0
	$CF^{disc}_{[t_2;t_3]2}$	323065	1
	$CF^{disc}_{[t_2;t_3]3}$	300526	1
	$CF^{disc}_{[t_2;t_3]4}$	285500	0
$CF^{disc}_{[t_3;t_4]}$	$CF^{disc}_{[t_3;t_4]1}$	314186	0
	$CF^{disc}_{[t_3;t_4]2}$	293696	1
	$CF^{disc}_{[t_3;t_4]3}$	273205	1
	$CF^{disc}_{[t_3;t_4]4}$	259545	0
$CF^{disc}_{[t_4;t_5]}$	$CF^{disc}_{[t_4;t_5]1}$	285624	0
	$CF^{disc}_{[t_4;t_5]2}$	266996	1
	$CF^{disc}_{[t_4;t_5]3}$	248369	1
	$CF^{disc}_{[t_4;t_5]4}$	235950	0
$CF^{disc}_{[t_5;t_6]}$	$CF^{disc}_{[t_5;t_6]1}$	–106444	0
	$CF^{disc}_{[t_5;t_6]2}$	–94617	1
	$CF^{disc}_{[t_5;t_6]3}$	–76876	1
	$CF^{disc}_{[t_5;t_6]4}$	–65049	0

Fuzzy numbers that represent operations on discounted cash flows corresponding to time intervals $\left[t_i;t_{i+1}\right]$, $(i=\overline{0;I-1})$ of the ecological system project life cycle are presented in **Table 4.6**.

Table 4.6 Fuzzy numbers for determining the amount of discounted cash flows/ratio of discounted cash flows/discounted payback period of the ecological system project

Amount of discounted cash flows		
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_1$	–565080.0	0
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_2$	–544624.8	1
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_3$	–509900.8	1
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_4$	–481181.1	0
Ratio of discounted cash flows		
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\mathrm{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_1$	–1.80	0
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\mathrm{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_2$	–1.65	1
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\mathrm{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_3$	–1.44	1
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\mathrm{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_4$	–1.27	0
Discounted payback period		
DPP_1	1.87	0
DPP_2	1.70	1
DPP_3	1.47	1
DPP_4	1.28	0

As a result of calculations using fuzzy numbers, a fuzzy trapezoidal number was obtained that reflects the value of the DPP of the project under conditions of uncertainty (**Fig. 4.3**) and is determined by formula (4.39):

$$\mu_A(DPP) = \begin{cases} 0, \ \ x < 1.28, \ \ x > 1.87; \\ \dfrac{x - 1.28}{1.47 - 1.28}, \ \ 1.28 \le x \le 1.47; \\ 1, \ \ 1.47 \le x \le 1.70; \\ \dfrac{1.87 - x}{1.87 - 1.70}, \ \ 1.47 \le x \le 1.28. \end{cases} \quad (4.39)$$

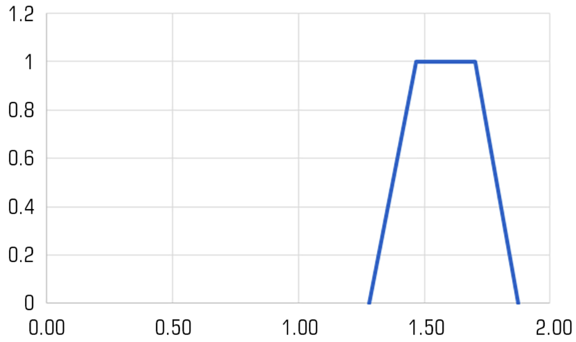


Fig. 4.3 Fuzzy meaning of the DPP of the ELS project

Thus, the evaluation of the effectiveness of the ecological system project was carried out using the proposed DPP calculation formula, which takes into account the cash flows of the project phases that occurred as a result of transformational changes in the life cycle of the ecological system project due to the greening of logistics. Experimental calculations confirmed the adequacy of the proposed DPP calculation mechanism in deterministic conditions and conditions of uncertainty.

CONCLUSIONS

1. The modern linear model of the economy is not perfect, as it constantly requires the involvement of additional primary resources, which passing through a man-made system as a result produce a large amount of waste. The tool for introducing a more humane circular model is an ecologistic system, which makes it possible to significantly reduce the eco-destructive impact on the environment through the creation of closed logistic chains. An ecologistic system has specific characteristics that distinguish it from a logistic system. In particular, the project life cycle of an ecologistic system includes ecologically-oriented phases, during which measures are taken to preserve and restore the ecosystem.

2. The model of the life cycle of a project of an ecologistic system includes five phases: pre-investment, investment, operational, regeneration, and revitalization, which take place over six time intervals. The pre-investment, investment, and operational phases are carried out sequentially, the regeneration phase begins immediately after the start of the operational phase, the revitalization phase proceeds in parallel with the investment, operational, and regeneration phases. The end of the revitalization phase means the end of a project. The model of the life cycle of an ecologistic system, in which the life cycle is divided into phases, stages, and time intervals, was presented.

3. A formula for calculating the discounted payback period of a project of an ecologistic system, which takes into consideration the specifics of cash flows of project phases, was developed. The application of the formula is possible on the condition that cash flows from the beginning of the operational phase to the end of the regeneration phase are conditionally constant. Due to the use of the proposed formula, the functional dependences between the discounted payback period and cash flows during the phases of the project life cycle were determined. It was found that the dependence of the project payback on cash flows has a different nature at different phases of the life cycle. There is a linear relationship between the discounted payback period and the cash flows of the pre-investment and revitalization phases. The dependence on the cash flows of the investment phase is expressed by the polynomial quadratic function, and the cash flows of the operational and regeneration phases are expressed by the power function. Identification of functional dependences makes it possible to explore the dynamics of changes in the discounted payback period and to predict its value in the event of changes in project cash flows.

4. Calculation formulas are proposed for determining the discounted payback period, which take into account the cash flows of ecologically oriented phases of the project under conditions of uncertainty. As a result of calculations using fuzzy numbers, a fuzzy trapezoidal number was obtained that reflects the value of the discounted term of the project under conditions of uncertainty. Experimental calculations have confirmed the adequacy of the proposed mechanism for evaluating the effectiveness of the ecological system project, which takes into account transformative ecologically oriented changes in the model of the project's life cycle, caused by the needs of modernity.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

REFERENCES

1. Kovtun, T. A. (2020). Determining the role of ecologization in achieving the goals of sustainable development. Development of Management and Entrepreneurship Methods on Transport, 2 (71), 63–81. doi: https://doi.org/10.31375/2226-1915-2020-2-63-81
2. Kovtun, T. A., Kovtun, D. K. (2021). Environmental product as a result of greening logistics activities. Transport Development, 3 (10), 19–29. doi: https://doi.org/10.33082/td.2021.3-10.02
3. Mishenin, Ye. V., Koblianska, I. I., Ustik, T. V., Yarova, I. Ye.; Mishenin, Ye. V. (Ed.) (2013). Ekolohooriientovane lohistychne upravlinnia vyrobnytstvom. Sumy: TOV "Drukarskyi dim "Papirus", 248.

4. Van Buren, N., Demmers, M., van der Heijden, R., Witlox, F. (2016). Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments. Sustainability, 8 (7), 647. doi: https://doi.org/10.3390/su8070647
5. Rudenko, S. V., Kovtun, T. A. (2020). Ekolohizatsiia lohistyky yak napriamok realizatsii kontseptsii staloho rozvytku. Proektnyi ta lohistychnyi menedzhment: novi znannia na bazi dvokh metodolohii. Vol. 3. Odesa: KUPRYIeNKO S. V., 7–24.
6. Potting, J., Hekkert, M., Worrell, E., Hanemaaijeret, A. (2017). Circular Economy: Measuring Innovation in the Product Chain. Netherlands Environmental Assessment Agency, 46. Available at: https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf
7. Ghisellini, P., Cialani, C., Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11–32. doi: https://doi.org/10.1016/j.jclepro.2015.09.007
8. Towards a Circular Economy: Business Rationale For An Accelerated Transition (2015). Ellen MacArthur Foundation, 20. Available at: https://kidv.nl/media/rapportages/towards_a_circular_economy.pdf?1.2.1
9. Kovtun, T. (2020). A model of closed circuits forming in a logistics system with feedback. Innovative Technologies and Scientific Solutions for Industries, 4 (14), 113–120. doi: https://doi.org/10.30837/itssi.2020.14.113
10. Kosenko, V., Gopejenko, V., Persiyanova, E. (2019). Models and applied information technology for supply logistics in the context of demand swings. Innovative Technologies and Scientific Solutions for Industries, 1 (7), 59–68. doi: https://doi.org/10.30837/2522-9818.2019.7.059
11. Bukrinskaia, E. M., Miasnikova, L. A. (2018). Logistika vzaimodeistviia uchastnikov sistemy obrashcheniia s otkhodami. Problemy sovremennoi ekonomiki, 3 (67), 152–157. Available at: https://cyberleninka.ru/article/n/logistika-vzaimodeystviya-uchastnikov-sistemy-obrascheniya-s-othodami
12. Dziubina, K. O. (2011). Mistse zvorotnoho materialnoho potoku u vyrobnycho-hospodarskii diialnosti pidpryiemstva. Visnyk Dnipropetrovskoho universytetu (im. O. Honchara). Seriia: Ekonomika, 5, 163–171.
13. Kovtun, T., Kovtun, D. (2022). Characteristics of ecologistic systems projects. Management of Development of Complex Systems, 50, 13–21. doi: https://doi.org/10.32347/2412-9933.2022.50.13-21
14. A Guide to the Project Management Body of Knowledge (PMBoK) (2017). PMI, 574. Available at: https://www.academia.edu/43014339/A_Guide_to_the_PROJECT_MANAGEMENT_BODY_OF_KNOWLEDGE_PMBOK_GUIDE_Sixth_Edition
15. Begiuli, F. (2002). Upravlenie proektom. Moscow: FAIR-PRESS, 208.
16. Rach, V. A., Antonenko, S. V., Cherepakha, G. S. (2004). Osobennosti vzaimodeistviia rukovoditelia i komandy na razlichnykh etapakh proekta. Upravlinnia proektami ta rozvitok

virobnitctva, 1, 160–170. Available at: http://www.pmdp.org.ua/index.php/ru/?option=com_content&view=article&id=917

17. Rudenko, S., Gogunskii, V., Kovtun, T., Smrkovska, V. (2021). Determining the influence of transformation changes in the life cycle on the assessment of effectiveness of an ecologistic system project. Eastern-European Journal of Enterprise Technologies, 1 (3 (109)), 6–14. doi: https://doi.org/10.15587/1729-4061.2021.225262
18. The GPM®Global P5TM Standard for Sustainability in Project Management. Ver. 1.5. GPM Global. Available at: https://www.greenprojectmanagement.org/the-p5-standard
19. Piterska, V., Kolesnikov, O., Lukianov, D., Kolesnikova, K., Gogunskii, V., Olekh, T. et al. (2018). Development of the Markovian model for the life cycle of a project's benefits. Eastern-European Journal of Enterprise Technologies, 5 (4 (95)), 30–39. doi: https://doi.org/10.15587/1729-4061.2018.145252
20. Onyshchenko, S. P., Arabadzhy, E. S. (2016). Creation of time management methods in the planning of execution for company development programs. Technology Audit and Production Reserves, 2 (3 (28)), 7–12. doi: https://doi.org/10.15587/2312-8372.2016.66674
21. Ahsan, K., Gunawan, I. (2010). Analysis of cost and schedule performance of international development projects. International Journal of Project Management, 28 (1), 68–78. doi: https://doi.org/10.1016/j.ijproman.2009.03.005
22. Herroelen, W., Leus, R. (2004). Robust and reactive project scheduling: a review and classification of procedures. International Journal of Production Research, 42 (8), 1599–1620. doi: https://doi.org/10.1080/00207540310001638055
23. Hyari, K., El-Rayes, K. (2006). Optimal Planning and Scheduling for Repetitive Construction Projects. Journal of Management in Engineering, 22 (1), 11–19. doi: https://doi.org/10.1061/(asce)0742-597x(2006)22:1(11)
24. Chang, C. K., Jiang, H., Di, Y., Zhu, D., Ge, Y. (2008). Time-line based model for software project scheduling with genetic algorithms. Information and Software Technology, 50 (11), 1142–1154. doi: https://doi.org/10.1016/j.infsof.2008.03.002
25. Artigues, C., Michelon, P., Reusser, S. (2003). Insertion techniques for static and dynamic resource-constrained project scheduling. European Journal of Operational Research, 149 (2), 249–267. doi: https://doi.org/10.1016/s0377-2217(02)00758-0
26. Cheng, M.-Y., Tran, D.-H., Wu, Y.-W. (2014). Using a fuzzy clustering chaotic-based differential evolution with serial method to solve resource-constrained project scheduling problems. Automation in Construction, 37, 88–97. doi: https://doi.org/10.1016/j.autcon.2013.10.002
27. Baradaran, S., Fatemi Ghomi, S. M. T., Mobini, M., Hashemin, S. S. (2010). A hybrid scatter search approach for resource-constrained project scheduling problem in PERT-type networks. Advances in Engineering Software, 41 (7-8), 966–975. doi: https://doi.org/10.1016/j.advengsoft.2010.05.010
28. Cheng, M.-Y., Tran, D.-H. (2014). Two-Phase Differential Evolution for the Multiobjective Optimization of Time-Cost Tradeoffs in Resource-Constrained Construction Projects.

IEEE Transactions on Engineering Management, 61 (3), 450–461. doi: https://doi.org/10.1109/tem.2014.2327512
29. Rudenko, S., Kovtun, T., Smrkovska, V. (2022). Devising a method for managing the configuration of products within an eco-logistics system project. Eastern-European Journal of Enterprise Technologies, 4 (3 (118)), 34–42. doi: https://doi.org/10.15587/1729-4061.2022.261956
30. Kovtun, T., Smrkovska, V. (2020). Development of a cash flow model for the eco-logistics system project. Technology Audit and Production Reserves, 6 (2 (56)), 26–33. doi: https://doi.org/10.15587/2706-5448.2020.220964
31. Boldyreva, T. V., Kovtun, T. A. (2009). Metodicheskii podkhod k initcializatcii parametrov produktov proekta transportnogo predpriiatiia. Visnik Odeskogo natcionalnogo morskogo universitetu, 22, 166–180.