I.J. Information Engineering and Electronic Business, **2026, 1, 56-70**
Published Online on February 8, 2026 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijieeb.2026.01.04

Mathematical Model of Strategic Diagnostics of Enterprise in the Circular Economy Adaptation Process

Oleksandr Trukhan
Zhytomyr Institute PrJSC "Higher Educational Institution "Interregional Academy of Personnel Management (IAPM)"/Department of fundamental training, management and administration, Zhytomyr, 10003, Ukraine
Email: alex1979zt@gmail.com
ORCID iD: https://orcid.org/0000-0001-7986-0297

Zarina Poberezhna
State University "Kyiv Aviation Institute"/Department of Economics and Business Technologies, Kyiv, 03058, Ukraine
Email: zarina_www@ukr.net
ORCID iD: https://orcid.org/0000-0001-6245-038X

Maksym Zaliskyi*
State University "Kyiv Aviation Institute"/Department of Telecommunication and Radioelectronic Systems, Kyiv, 03058, Ukraine
Interregional Academy of Personnel Management/Department of Computer Science and Intelligent Systems, Kyiv, 03039, Ukraine
E-mail: maximus2812@ukr.net
ORCID iD: https://orcid.org/0000-0002-1535-4384
*Corresponding Author

Yanina Goncharenko
Dragomanov Ukrainian State University/Department of Higher Mathematics, Kyiv, 01001, Ukraine
E-mail: ya.v.honcharenko@udu.edu.ua
ORCID ID: https://orcid.org/0009-0009-2541-7631

Received: 26 August, 2025; Revised: 25 October, 2025; Accepted: 07 January, 2026; Published: 08 February, 2026

Abstract: The article considers the development of strategic diagnostics of an enterprise in the condition of adaptation to a circular economy. In the context of global economic and environmental changes, strategic diagnostics is an important tool for assessing the effectiveness of the implemented changes and adapting to new challenges. The authors emphasize the importance of implementing the principles of a circular economy, which involve minimizing waste and reusing resources. It is obvious that in the process of adapting an enterprise to the conditions of a circular economy, strategic diagnostics plays an important role, which allows assessing the enterprise readiness to transition to a new economic model, determining its competitive advantages and developing effective development strategies. A set of strategic diagnostics tools with their adaptation to the conditions of a circular economy is systematized. It is substantiated that the proposed tools allow enterprises to effectively adapt to the conditions of a circular economy, reduce environmental impact, increase competitiveness, and find new opportunities for sustainable economic development. An algorithm for using strategic diagnostics of the enterprise in the context of adaptation to circular economy is developed. The presented algorithm allows enterprises to effectively adapt to the conditions of the circular economy, increase competitiveness, and ensure long-term business sustainability.

Index Terms: Strategic Diagnostics, Circular Economy, Sustainable Industry, Sustainable Economic, Strategic Management, Strategic Development, Business Process, Life Cycle Analysis, Resource Saving, Principal Component Analysis, Closed Loop Recycling

1. Introduction

The development of the economy, society, and modern world industry requires the creation of a single system of values and coordinated actions to ensure sustainable improvement [1, 2]. The result of this was the Sustainable Development Goals [3]. These goals are intended to prevent future crises that threaten the survival of humanity, as well as to direct global development on the path of the environmental preservation, social equality, sustainable industry, and sustainable economic [4, 5].

The current problems of the economy in the light of the Sustainable Development Goals relate to the need to combine environmental, social, and economic interests into a single development of management system [6]. Based on this, it can be argued that the main task of the modern economy is the synthesis of a model of sustainable growth, which can be based on innovation, resource efficiency, social justice, and continuous improvement [7, 8].

The current economic challenges in this framework include ensuring a compromise between economic growth and environmental sustainability [9]. This problem can be considered in the context of the eighth, twelfth and thirteenth goals of sustainable development. At the same time, the economies and industries of the vast majority of countries are currently focused on increasing gross domestic product, which is usually achieved at the expense of significant consumption of natural resources, damage to ecological systems, and increased greenhouse gas emissions [10, 11]. The basis for solving this problem is the transition to a circular economy, where waste from production and consumption can become resources, and energy can be produced from renewable sources [12, 13].

The main means for implementing a circular economy today include not only economic, but also technological, organizational, legal, and educational tools, the purpose of which is to increase the efficiency of resource consumption and minimize waste [14, 15].

One of the approaches to solving the problem of implementing a circular economy is:

– development of products that have the properties of further processing, repairability, and reuse [16];
– reduction of consumption of electricity, water, raw materials, spare parts, and others [17];
– implementation of a comprehensive system of collection, sorting, and processing of waste in the production life cycle [18];
– merger of different enterprises, in which the waste of one enterprise is converted into resources for another [19];
– life cycle analysis in order to create a system of effective resource management [20].

These approaches can be considered within the framework of strategic diagnostics of enterprises. The purpose of strategic diagnostics of enterprises is to determine the efficiency of resource use based on the waste generation indicator and the environmental performance of technological processes. The result of the implementation of strategic diagnostics of enterprises is the assessment of opportunities, obstacles, and main ways of transforming the linear model into the circular economy [21, 22].

In the current conditions of global economic and environmental changes, strategic diagnostics of the enterprise is gaining particular importance. It allows to assess the current state of the business, identify potential risks, and adapt the strategy to new challenges. Therefore, one of the key trends of the modern economy is the transition to a circular model, which involves minimizing waste and using resources efficiently. In this regard, enterprises are forced to rethink their production processes, logistics chains, and business models [23].

Strategic diagnostics in the conditions of the circular economy is becoming an indispensable tool for assessing the effectiveness of the implemented changes. It helps to determine how ready the enterprise is for environmental standards and requirements of sustainable economic development. In addition, such diagnostics allows to identify prospects for reducing costs by reusing materials and introducing innovative technologies. Particular attention should be paid to analyzing the competitive environment and the dynamics of the market for environmentally friendly products [24].

Strategic diagnostics in the circular economy can help to solve the following tasks:

– assess the current state of the enterprise in terms of resource efficiency, calculation of production costs, environmental impact, and the effectiveness of the quality management system;
– determine strategic potential by studying the state of application of innovative technologies, assessing human resources and financial capabilities for transformation to a circular economic model;
– detect threats and obstacles;
– determine target indicators of the enterprise’s activities;
– monitor key performance indicators and formulate corrective and preventive actions [25, 26].

The implementation of the principles of a circular economy requires a comprehensive approach to enterprise management. This applies not only to technological changes, but also to the transformation of organizational culture and the decision-making system. It is strategic diagnostics that allows to identify key barriers and opportunities for such a transition. It contributes to the development of flexible business strategies that help the enterprise remain competitive in the long term [27, 28].

Therefore, the development of strategic diagnostics is an important factor in the adaptation of enterprises to new economic realities. It ensures effective planning, risk management, and the implementation of innovations. As a result, enterprises can not only increase their own efficiency, but also make a significant contribution to environmental protection.

This article consists of five sections. Section 1 is background information. Section 2 deals with state of the art and problem statement. Section 3 considers methodological features of the use of strategic diagnostics of the enterprise for implementing circular economy approach. Section 4 presents step-by-step method description and numerical example. Section 5 concentrates on the conclusions.

2. Literature Review and Problem Statement

The issue of developing strategic diagnostics of the enterprise in the conditions of circular economy is extremely relevant and attracts the attention of many scientists. In particular, many scientists have been engaged in the study of individual issues of the impact of the circular economy on the processes of developing strategic diagnostics. The authors of paper [29] investigate the relationship between strategic planning and the implementation of the principles of the circular economy. Based on the analysis of four Canadian companies with established strategies of environmental sustainability, they emphasize the importance of involving internal and external stakeholders to exchange knowledge and use formal tools of strategic planning.

The scientific publication [30] focuses on the problems of the circular economy as a result of strategic management, which ensures social sustainable industry development through adherence to its principles. The authors substantiate the principles of the circular economy as determinants of strategic management to ensure social development, suggesting directions for directing strategic management efforts in accordance with the determinism of the circular economy.

The paper [31] considers the strategic development of the circular economy business in established companies. The author proposes a process model that describes how circular business strategy, business model innovation, and collaboration dynamically interact in the process of strategic development of circular business. In article [32], the authors present an expert system for modeling business in a circular economy. The system provides recommendations to manufacturing companies on the development of business models that allow separating value creation from resource consumption. The study emphasizes the importance of strategic thinking and systematic approaches for the successful implementation of circular business models.

It must be stated that the multi-directionality and ambiguity of the presented approaches require further in-depth research to create a balanced and substantiated methodology in the chosen context. As a result, we consider the study of the issues of developing strategic diagnostics of an enterprise in the process of adapting to the conditions of a circular economy to be key to increasing the efficiency of management in the enterprise as a whole.

The article [33] examines how management factors affect the functioning of small businesses in a developing economy. The authors identify a positive correlation between the availability of resources, the availability of services, and the formalization of business activities. From a practical point of view, the study provides recommendations for developing integrated strategies to increase the availability and improve the quality of resources and services for small businesses. The authors of the article [34] apply evolutionary game theory to complex networks in order to model the choice of strategies for digital transformation of enterprises. The contribution of the article is to integrate models of interaction of enterprises in the network environment, as well as to take into account the results of monitoring information flows in order to understand the path of enterprises digitalization. The authors also recommend that enterprise managers develop infrastructure, differentiated services and decision-making skills through strategic diagnostics of enterprise activities.

The article [35] investigates how corporate strategy influences the innovative performance of the enterprise based on risk analysis. The authors proved that moderate strategic aggressiveness stimulates innovation, while risk-taking partially explains this effect. However, further research is needed to expand the model to take into account organizational culture, resources, and environmental factors as additional mechanisms of influence. The article [36] is devoted to the analysis of the impact of systemic strategic planning and business innovation on sustainable economic and enterprise productivity. From a practical point of view, the results of the study indicate the need to strengthen the synergistic unity between planning and innovation strategies.

The authors of the article [37] explored an interdisciplinary theoretical framework for a circular economy roadmap that integrates strategic management, systems thinking, sustainability, and ISO standards. The proposed framework provided an opportunity to develop a step-by-step guide to implementing a circular economy from goal setting to implementation and monitoring. The contribution of the article is to create a flexible methodology for developing a circular economy. The article [38] considers the issue of modernization of the repair system for the aviation enterprise to save the resource fund in terms of spare parts for equipment and repair personnel. The article provides recommendations on the deployment of the infrastructure of repair centers to ensure the sustainable development of aviation in terms of optimizing the logistical support during equipment life cycle analysis.

The authors of the article [39] analyze the development trends and correlation between Industry 4.0, the circular economy, and the global sustainable development goals based on the analysis of 478 articles on the given topic. As a result, the authors emphasize the need to create an integrated management system with further explanation of the influence of political mechanisms, cross-national comparisons, and models of the use of development strategies. A similar analysis was also conducted in the article [40], where the authors conducted a scientific review of 188 publications to identify trends, drivers, barriers, and strategies for implementing the circular economy.

The authors of the article [41] used 18 circular economy parameters and the relative taxonomic measure method to analyze the degree of implementation of the circular economy in 27 EU countries for the period 2013–2022. In general, the article states that the transition to a circular model is slow. The main contribution of this research is the identification of weak elements during the implementation of the circular economy.

The article [42] is devoted to the analysis of 77 circular design tools. The authors concluded that most of the tools are physical, qualitative, and cross-sectoral, focusing on the early stages of development. The main significance of the article is to create a catalog of methods for the development of the circular economy.

The article [43] analyzes the application of circular economy principles in modular construction through interviews with experts. The contribution of the research is to identify key barriers and formulate a strategy to overcome them, which causes the theoretical and practical advancement of the circular model in construction.

The authors of the article [44] explore six principles of a circular economy for biobased products, including reducing dependence on fossil resources, efficient use of resources, waste disposal, and others. The principles presented complement existing circular economy approaches, taking into account the specifics of biobased systems.

The article [45] examines the specifics of implementing circular economy principles in the electrical and electronic equipment industry, paying attention to a detailed analysis of the benefits, barriers, and incentives that arise in this process. The results of the study emphasize the need to overcome technical, economic, and regulatory challenges for an effective transition to circular models. The article [46] uses a systemic approach to the circular economy as a practical framework for meeting the needs of society and the economy while preserving the environment.

There is a wide range of research on aviation operations management and signal processing of technical equipment, which is directly related to increasing resource efficiency and extending the life cycle of equipment [47, 48]. Such approaches can be applied in the context of the circular economy to optimize the use of aviation resources, reduce waste, and minimize energy costs in the transport system [49].

Today, many researchers use statistical analysis, machine learning, and artificial intelligence methods to study the problems of the circular economy. The article [50] is devoted to the development of a methodology for assessing the efficiency of production processes, monitoring overall performance, and formulating recommendations for priority areas of development. This was based on the statistical computation of the circular economy index to determine the current state of the community. As a continuation of the research [50], the authors of the article [51] combine the results of surveys with objective socio-economic and environmental data. The main mathematical tool was correlation and regression analysis, on the basis of which authors determined the dependence between the circular economy index and population density, unemployment rate, gross domestic product, and others.

The article [52] discusses the basic metrics for assessing the level of the circular economy. Author paid sufficient attention to the main elements of this process that are life cycle analysis and material flow analysis. The authors of the article [53] applied multivariate statistical analysis based on correlation to establish the dependence between circular economy indicators and parameters of economic and environmental processes. The basic mathematical tool of the article [54] is a combination of Generative AI and Principal Component Analysis. The first of them was used to model and generate data on changes in trends of parameters of circular economy systems. The second method was used to reduce the dimensionality of the feature space and to form a generalized index of the circular economy, which reduces the set of initial variables to several principal components. The use of two methods made it possible to take into account nonlinearity, complex interaction and variability of data on the functioning of circular economy systems.

The literature review showed that current research on the circular economy covers both theoretical foundations and approaches, as well as practical methods for implementing sustainable strategies in various sectors, including manufacturing, industry, aviation, and others. The main trends indicate the importance of integrating digital technologies, strategic diagnostics, and innovations to increase resource efficiency and minimize waste. Further research should focus on developing models of the circular economy components and forming quantitative indicators of strategic diagnostics.

The main hypothesis of this study is the possibility to determine the importance of strategic diagnostics for the enterprise when adapting it to the conditions of a circular economy, taking into account the appropriate set of instruments for this diagnosis. The purpose of this article is to develop a mathematical model for strategic diagnostics of an enterprise in the process of adaptation to a circular economy. The objectives of achieving the mentioned purpose are:

– to form an algorithm for conducting strategic diagnostics of the enterprise, in contrast to the existing ones with the use of digital technologies when conducting diagnostics;

– to develop a mathematical model for determining the integral index of adaptation of the enterprise to the circular economy, which includes several indicators: resource efficiency R, waste level W, innovation index I, financial stability F, environmental compliance E, market competitiveness M, legislative compliance L, and the level of use of digital technologies T, which will then allow to form a number of measures for the enterprise depending on the determined level;

– to offer practical recommendations for the enterprise when conducting strategic diagnostics and a number of measures for its further effective functioning and adaptation to the conditions of the circular economy, which will ensure its long-term sustainability.

The research methods used are the methods of general scientific cognition, along with synthesis and analysis, methods of probability theory and mathematical statistics, machine learning methods, the method of separating the essential from the general, and the method of critical analysis of literature sources, which made it possible to obtain new scientific results.

3. Material and Methods

In the process of scientific research on the issues of developing strategic diagnostics of an enterprise during the adapting to the conditions of a circular economy, it is advisable to use a combination of quantitative and qualitative methods. The combination of these approaches allows to get a comprehensive view of the processes of adapting enterprises to a new economic paradigm.

Quantitative methods make it possible to assess the effectiveness of implementing strategic decisions, measure the impact of the circular economy on the financial indicators of the enterprise, and analyze market dynamics. At the same time, qualitative methods help to identify hidden problems, risks, and opportunities for adapting an enterprise to the circular economy. The combination of quantitative and qualitative methods makes the study more substantiated, since it takes into account both accurate data and expert assessments and real cases. This contributes to the development of effective strategic decisions for enterprises that seek to successfully adapt to the conditions of the circular economy and adapt their business processes. The efficiency estimation for technological and business processes can be considered in terms of information technologies usage, possibility of digital transformation and processes automation, assessing customer experience, innovations level, digitalization strategies, and others [55].

Strategic diagnostics of the enterprise is the process of analyzing and assessing the internal and external environment of an enterprise in order to determine its strategic position, potential, and possible development paths. The main goal of strategic diagnostics is to identify the strengths and weaknesses of the organization, as well as to identify possible threats and opportunities for its further development [56].

The circular economy is a concept based on the principles of resource saving, reuse, and recycling of materials. It offers an alternative to the traditional linear model of production, which involves the use of resources, their transformation into products, and the disposal of waste. The circular economy is based on the idea of minimizing waste and maximizing the efficiency of the use of material resources. This approach involves the creation of closed cycles, where products and materials find a new life through reuse or recycling. In addition, the circular economy helps reduce environmental impact, as it reduces the need for new natural resources and minimizes pollution. This model of economic development has great potential for a sustainable future, contributing to the growth of innovation and economic efficiency [57, 58].

Circular processes play an important role in the development of strategic diagnostics of the enterprise, as they change approaches to resource management and the formation of business strategies. The transition to the circular economy requires new methods of assessing the effectiveness of the enterprise, taking into account not only financial indicators, but also environmental and social aspects. In general case, economic, social, and environmental factors improve as a result of intensified innovation. At the same time, these feature changes cause to the accumulation of funds, knowledge, and skills to spread innovation processes in the country [59].

Strategic diagnostics in such conditions should provide a deep analysis of closed-cycle processes, optimize resource use, and determine long-term competitive advantages. To use the modern technologies can quickly and accurately process huge amounts of information. This capability helps companies respond to market changes, identify new opportunities for business growth, and improve the efficiency of their internal operations [60]. The importance of comprehensive product life cycle analysis and environmental auditing as important components of strategic diagnostics is growing. In addition, enterprises must adapt their business models to new regulatory requirements and consumer demands for environmental responsibility. The implementation of circular processes requires a flexible approach to strategic planning, which helps to increase the competitiveness of enterprises in the global market. Thus, the circular economy stimulates the development of strategic diagnostics, making it more dynamic and multidimensional.

In the process of adapting the enterprise to the conditions of the circular economy, strategic diagnostics plays an important role, which allows assessing the enterprise readiness to transition to a new economic model, identifying its competitive advantages and developing effective development strategies. For this purpose, it is advisable to use appropriate strategic diagnostics tools [55, 57, 60]:

1. Analytical diagnostic methods:

- PESTEL analysis – assessment of the impact of political, economic, social, technological, environmental, and legal factors on the activities of the enterprise;

- SWOT analysis – identification of the strengths and weaknesses of the enterprise, as well as opportunities and threats in the context of the circular economy;
- VRIO analysis – resources uniqueness assessment and ability to create long-term competitive advantages.

2. Life cycle and environmental efficiency assessment methods:

- LCA (life cycle analysis) – analysis of the life cycle of products to determine the environmental impact at all stages: from raw material extraction to disposal;
- business model circularity matrix – helps to assess the level of implementation of the principles of the circular economy in production processes;
- carbon and ecological footprint analysis – measurement of the enterprise's impact on the environment.

3. Digital tools and intelligent systems:

- Big Data and artificial intelligence – analysis of large volumes of data to predict the effectiveness of circular business models;
- IoT (Internet of Things) – monitoring resource use and improving the efficiency of production processes;
- Blockchain – ensuring transparency of supply chains and tracking resources in a circular economy.

4. Financial and economic tools:

- sustainable finance analysis – assessing the possibilities of attracting "green" investments;
- calculation of the return on investment of environmental innovations (ROI for circular investments) – assessing the effectiveness of investments in circular business models;
- benchmarking of circular strategies – comparing the enterprise's indicators with leaders in the circular economy.

5. Organizational and management methods:

- delfi-method – surveying experts to determine promising directions for the company's development;
- business process mapping – optimizing internal processes in accordance with the principles of circularity;
- balanced scorecard (BSC) – a strategic map that includes environmental, social and financial indicators.

The use of these tools allows enterprises to effectively adapt to the conditions of the circular economy, reduce environmental impact, increase competitiveness, and find new opportunities for sustainable development. Digital tools usage in management can help to determine a certain approach to the client, which improves the level of customer satisfaction and loyalty. This approach causes the sales increasing and customer losses reducing [62].

Strategic diagnostics of the enterprise in the conditions of the circular economy is a multi-stage process that allows to assess the enterprise's readiness to transition to closed production and consumption cycles, identify strengths and weaknesses, and formulate effective strategic solutions. The algorithm for using strategic diagnostics of an enterprise in the conditions of adaptation to a circular economy is presented in Fig. 1.

The importance of digital technologies in all processes of enterprise activity should be taken into account, including in the concept of circular economy and when conducting strategic diagnostics. The authors of this article offer appropriate tools, which are directly based on digital technologies, such as Big Data and artificial intelligence, Internet of Things, and Blockchain. It should be noted that modern conditions encourage the digitalization of all areas of enterprise activity. The algorithm developed by the authors (Fig. 1) also includes at stage 3.3. – determination of the level of digital maturity and the possibility of using innovations (Big Data, IoT, and blockchain), which will be directly calculated in the proposed mathematical model. The presented algorithm allows enterprises to effectively adapt to the conditions of the circular economy, increase competitiveness, and ensure long-term business sustainability.

4. Results and Discussion

The proposed model is designed as a multi-level quantitative framework that integrates internal enterprise indicators, external environmental drivers, dynamic simulation, and optimization of strategic measures.

The mathematical model of strategic diagnostics of the enterprise in the process of adaptation to a circular economy consists of the following steps:

Step 1. General structure of the model.

The proposed model is multi-level and consists of the following blocks:

- A. Block of internal indicators (resources, innovations, and finances).

- B. Block of external influences (market, legislation, and environmental trends).
- C. Integral index of adaptation to the circular economy.
- D. Optimization module of strategic decisions.

Step 2. Formalization of variables.
For a mathematical description of the problem, we introduce the following variables:

- R is the level of resource efficiency – an integral indicator that reflects the ability of the enterprise to minimize the use of natural resources (raw materials, energy, and water) in the production of products or provision of services, while ensuring non-reduction or improvement of the quality of the result. It is calculated as the ratio of the volume of the final obtained product to the volume of spent resources, $R \in [0;1]$.
- W is the level of waste generation – the part of material resources that are converted into waste in the production process, $W \in [0;1]$.

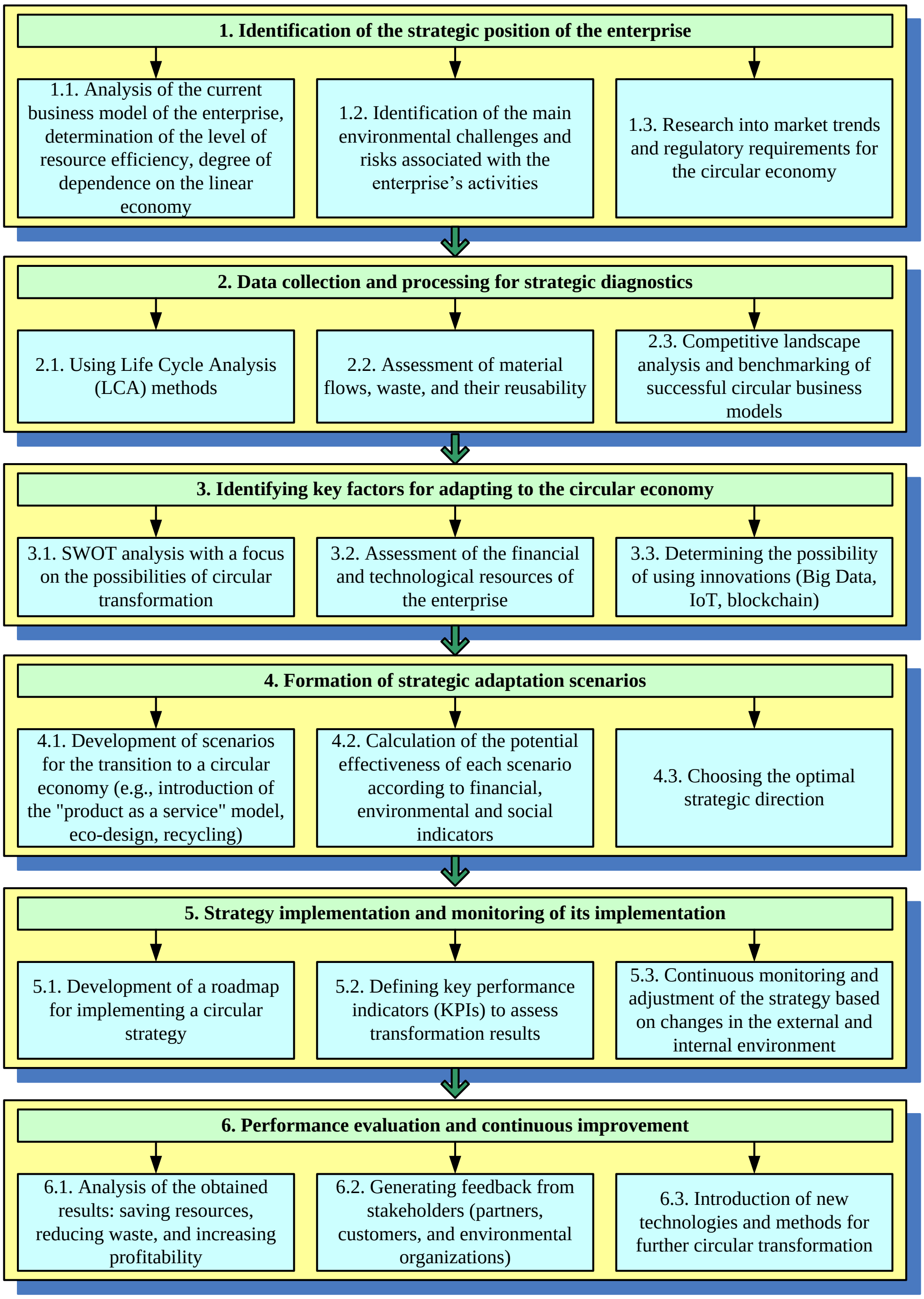

Fig. 1. Algorithm for using strategic diagnostics of an enterprise in the context of adaptation to a circular economy

- I is the innovation index – an indicator of the enterprise's readiness and ability to introduce new technologies, products and processes to increase efficiency and competitiveness, $I \in [0;1]$.
- F is the financial stability of the enterprise (cost-to-investment ratio) – an indicator of the enterprise's ability to cover its investment costs through operating profit or external stable sources of financing: $F = \text{Operating profit} / \text{Investment costs}$, $F \geq 0$. If $F > 1$, then the level of financial stability is high, if $F < 1$ – low, $F = 1$ – the equilibrium point.
- E is the compliance with environmental norms and standards (national and international), $E \in [0;1]$.
- M is the indicator of market competitiveness, determined by the growth of sales of the enterprise's products.
- L is the compliance with legislation, $L \in [0;1]$.
- T is the indicator of the use of AI, Big Data, IoT, Blockchain technologies, $T \in [0;1]$.

Step 3. Modeling the integrated index of enterprise adaptation to the circular economy CEAI (Circular Economy Adaptation Index).

Let $x = (R, W, I, F, E, M, L, T)^T$ represent the vector of normalized indicators for each enterprise, where all variables are transformed to the interval $[0;1]$. To capture the directional contribution of each indicator, we transform W into its complementary form, where lower waste increases adaptation performance: $z = (R, 1-W, I, F, E, M, L, T)^T$. Let $w = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \beta_1, \beta_2, \beta_3)^T$ denote the weight vector for internal and external indicators, subject to constraints: $\sum_{i=1}^{5} \alpha_i = 0.6$ and $\sum_{i=1}^{3} \beta_i = 0.4$, $\alpha_i \geq 0$, $\beta_i \geq 0$. Then, the Circular Economy Adaptation Index (CEAI) is defined as:

$$CEAI = w^T z = \alpha_1 R + \alpha_2 (1-W) + \alpha_3 I + \alpha_4 F + \alpha_5 E + \beta_1 M + \beta_2 L + \beta_3 T, \tag{1}$$

where α_i are weight coefficients of internal indicators, β_i are weight coefficients of external indicators.

The value of the weight coefficients was determined by the method of principal component analysis (PCA). In this case, additional conditions were imposed on the weight coefficients: $\sum_{i=1}^{5} \alpha_i = 0.6$ and $\sum_{i=1}^{3} \beta_i = 0.4$, which reflected the total relative weight of the influence of internal and external indicators.

Since all elements of $z \in [0;1]$ and weights are non-negative and sum to 1, we have: $0 \leq w^T z \leq 1$. Hence,

$$0 \leq CEAI \leq 1. \tag{2}$$

The distribution of weights between internal (0.6) and external (0.4) dimensions was derived using a structured expert judgment approach. In particular, a two-stage Delphi procedure was conducted involving five experts in enterprise sustainability, digital transformation, and circular economics. Each expert independently assessed the relative contribution of internal vs. external drivers to adaptation readiness, based on four criteria: measurability, managerial controllability, strategic importance, and temporal sensitivity.

The assessments were aggregated using weighted median scores, and the consistency ratio (CR) was evaluated following the Analytic Hierarchy Process (AHP) approach, resulting in $CR = 0.08 < 0.1$, indicating acceptable agreement. Based on the consensus ranking, internal indicators (resources, innovation, financial stability, and environmental compliance) were assigned a collective weight of 0.6, while external drivers (market, legislation, and digital infrastructure) accounted for 0.4.

This approach aligns with previous research where internal capabilities are considered primary determinants of circular transition readiness [63, 64].

The PCA method was applied not as a normative weighting method, but as a data-driven exploratory tool to reveal latent relationships between indicators and identify the most influential variables based on variance contribution. The dataset includes actual values from 3 logistics enterprises (2022–2024) and a simulated extension of 100 synthetically generated enterprises, constrained within empirically valid bounds. Such use is consistent with empirical studies that develop composite indices using PCA to identify structural importance.

The main operations of the PCA method:

1. Formation of the data matrix. Based on the statistical data collected for 10 enterprises, the matrix $A = \|a_{ij}\|$, $i = \overline{1,10}$, $j = \overline{1,8}$ was formed, where rows are individual enterprises, columns are indicators R, W, I, F, E, M, L, T.

2. Normalization of values. Normalization of values was carried out by the method of natural normalization. As a result, the matrix $A' = \|a'_{ij}\|$ was obtained, all elements of which acquire values in the range $[0;1]$. To automate the

calculations, the class: *sklearn.preprocessing.StandardScaler()* of the *sklearn.preprocessing* module of the Python programming language was used.

3. Calculation of loads. The PCA method was applied to the normalized matrix, with the help of which the first principal component was selected, which describes the largest share of the total variation, and the principal components – new variables, which are linear combinations of the initial ones and describe the largest data variance. The *sklearn.decomposition.PCA()* class of the *sklearn.decomposition* module of the Python programming language was used to implement the algorithm.

4. Determining the importance of each indicator. The obtained principal components were normalized to the sum of one, and then distributed between internal and external indicators. The following coefficient values were obtained:

$$R = 0.15, W = 0.1, I = 0.12, F = 0.08, E = 0.15, M = 0.14, L = 0.13, T = 0.13. \quad (3)$$

Step 4. Determination of adaptation thresholds.

Thresholds are used to classify enterprises by the level of adaptation to the conditions of the circular economy. A model with two thresholds – T_1, T_2 and the scale given in Table 1 was considered.

Table 1. Description of the Levels of Adaptation of Enterprises to the Conditions of the Circular Economy

Adaptation category	**Description**
Low (0 – T_1)	Initial level, no or minimal adaptation
Medium (T_1 – T_2)	There are some elements of circularity, but no systemic transformation
High (T_2 – 1.0)	Full or almost full integration of circular economy principles

To empirically determine T_1 and T_2, we used the following approach:

1. CEAI was calculated for a certain number of enterprises. In our case, modeling was conducted for ten real enterprises, and then data for one hundred similar enterprises were simulated.
2. The distribution of CEAI values was plotted.
3. Percentiles were determined:

- Lower – 33% of enterprises – low level of adaptation,
- Average – 34-66% of enterprises – medium,
- Upper 66-100% of enterprises – high.

The CEAI value, which is the median for low and medium-level enterprises, determines the lower threshold of T_1, and the value, which is the median for medium and high-level enterprises, determines the upper threshold of T_2.

The modeling of threshold values was carried out using the *NumPy* library. The Seaborn library in Python was used to visualize the results (Fig. 2).

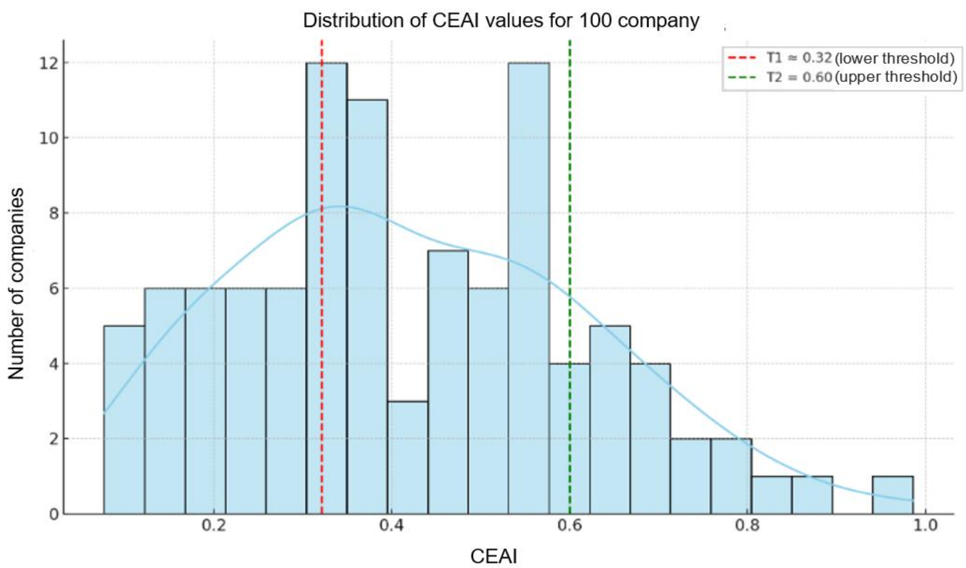

Fig. 2. Threshold value simulation

Step 5. Dynamic model of development.
To simulate changes over time, a model of the form:

$$\frac{d(CEAI)}{dt} = \gamma_1 \Delta R + \gamma_2 (1 - \Delta W) + \gamma_3 \Delta I + \gamma_4 \Delta F + \gamma_5 \Delta E + \delta_1 \Delta M + \delta_2 \Delta L + \delta_3 \Delta T - \eta , \quad (4)$$

where: ΔX is a change in the indicator X per unit of time, η is an inertia coefficient of the system (takes into account the difficulty of changes).

The values of the increments $d(CEAI)$ were simulated using a dynamic model for different sets of parameters in three scenarios. The simulation results for the initial values $CEAI = 0.5$, $\eta = 0.02$ and random values of increments, which have a uniform distribution on such intervals $R \in [0; 0.03]$, $W \in [-0.03; 0]$, $I \in [0; 0.025]$, $F \in [0; 0.02]$, $E \in [0; 0.025]$, $M \in [0; 0.02]$, $L \in [0; 0.015]$, $T \in [0; 0.03]$, are shown in Fig. 3.

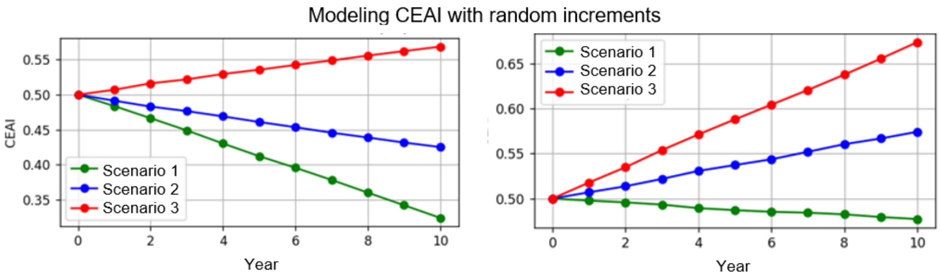

Fig. 3. Results of modeling CEAI increments using a dynamic model

Step 6. Optimization problem for strategic development.
To formulate the optimization problem, the CEAI function was chosen as the objective function under budget and time constraints. Mathematical model of the problem is (5) with restrictions (6):

$$\max_{x_i} CEAI(x_1, x_2, ..., x_n), \quad (5)$$

$$\begin{cases} \sum_{i=1}^{n} c_i x_i \le B, \\ \sum_{i=1}^{n} t_i x_i \le T_{\max}, \end{cases} \quad (6)$$

where x_i is the intensity of the optimization measure, which is defined as the part of the total amount of resources that are planned to be spent on improving the quality of the *i*-th factor (for example, implementing LCA analysis, upgrading equipment, and others); c_i is the cost of the optimization measure; t_i is the time of implementation of the optimization measure; B is the available budget; $T_{\max}$ is the permissible time horizon.

Stage 7. Practical implementation of the model for specific enterprises.
Three enterprises were selected for analysis: SC “KUEHNE & NAGEL” [65], SC “SCHENKER” [66], LLC “ZAMMLER UKRAINE” [67]. For each of them:

- An initial diagnosis was carried out and data on the variables R, W, I, F, E, M, L, T was collected (corresponding data is presented in Table 2).
- The initial value of CEAI was calculated.
- A development trajectory for 3 years (2022-2024) was built, changing the intensity of strategic measures.
- The set of measures was optimized to achieve $CEAI \ge T_2$, taking into account resource constraints.

Table 2. Initial Data

Parameter	SC “KUEHNE & NAGEL”	SC “SCHENKER”	LLC “ZAMMLER UKRAINE”
Resource efficiency R	0.55	0.5	0.5
Waste level W	0.35	0.4	0.35
Innovation index I	0.6	0.55	0.6
Financial stability F	0.65	0.7	0.6

Environmental compliance E	0.7	0.7	0.65
Market competitiveness M	0.65	0.65	0.6
Legislative compliance L	0.8	0.85	0.8
Use of digital technologies T	0.65	0.6	0.65
CEAI	0.595	0.581	0.569

The simulation results for the optimal parameter sets are shown in Fig. 4. The optimal measures and timing for achieving the upper CEAI threshold level for the three enterprises are given in Table 3.

Table 3. Optimal Measures and Timing of Achieving the Upper Threshold Level of CEAI for Three Enterprises

Enterprise	**Main measures**	**Deadline for reaching the upper threshold level**
SC “KUEHNE & NAGEL”	Expanding IoT solutions for transportation	Up to 2 months
SC “SCHENKER”	Reducing waste generation	Up to 34 months
LLC “ZAMMLER UKRAINE”	Increasing innovation through green solutions in logistics	Up to 16 months

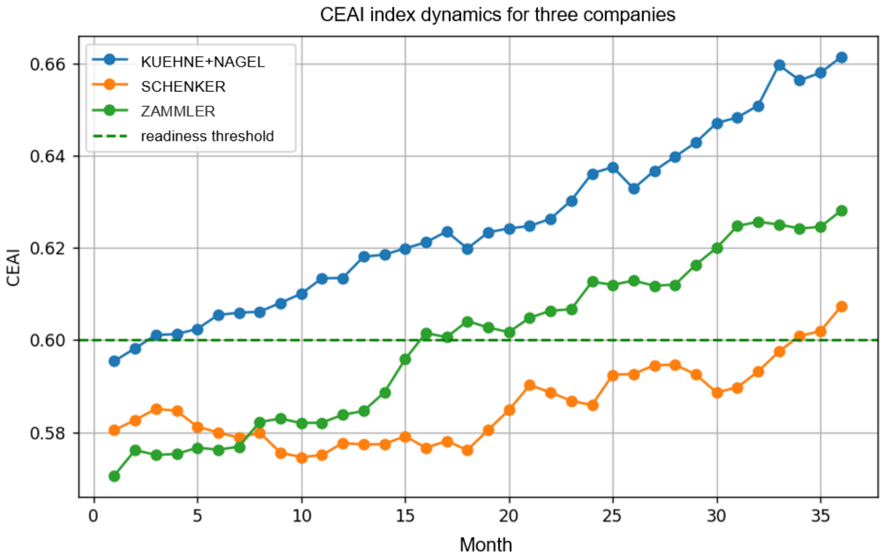

Fig. 4. The simulation results for the optimal parameter sets

The developed CEAI digital tool enables full automation of data normalization, PCA-based weight estimation, CEAI calculation, threshold modeling, and multi-scenario adaptation forecasting. The tool can be accessed at repository [68].

The analysis of the results allows concluding following:

1. Each of the studied enterprises requires a different set of measures to achieve the target CEAI (integral index of enterprise adaptation to the circular economy). This indicates the importance of adapting the model to the specifics of a particular business.
2. The fastest achievement of the threshold level is predicted for the enterprise “KUEHNE & NAGEL”, which, thanks to the implementation of IoT solutions for transport, can achieve the desired CEAI level within 2 months. This indicates the high effectiveness of digitalization as an adaptation tool.
3. The enterprise “ZAMMLER UKRAINE” needs up to 16 months to achieve the target level. At the same time, the best strategy for this enterprise is to increase innovation by integrating environmental solutions into logistics processes. This indicates the potential for sustainable development through innovation.
4. SC “SCHENKER” has the longest time to achieve the goal – up to 34 months, despite higher initial values of some indicators (in particular, financial stability and legal compliance). The main reason for this is the emphasis on a gradual reduction in waste levels, which requires a longer time to implement.

The proposed mathematical model allows determining the level of adaptation of enterprises to the conditions of the circular economy, through the definition of the proposed index (CEAI). Depending on the indicator given in Table 2, the enterprise can use a number of measures given in Table 3. The main emphasis in the proposed model is on the importance of implementing the principles of circular policy in the activities of enterprises, which allows to reduce costs for raw materials and energy, increase competitiveness, stimulate innovation, increase financial stability, reduce waste, and moving to sustainable resource use.

The model allows for effective combination of available resources with sustainable development goals, ensuring optimization of measures taking into account the constraints, strengths and risks of enterprises.

Despite its promising results, the proposed model has several limitations. First, the empirical analysis is based on a relatively small sample of logistics enterprises operating in a specific regional context. Consequently, the estimated weights and thresholds may not be directly generalizable to other sectors or countries. Second, while PCA was purposefully used as a data-driven exploratory tool for revealing latent structure among variables, it does not replace normative multi-criteria decision-making approaches (e.g., AHP, ANP, or TOPSIS). Therefore, the resulting CEAI values should be interpreted as indicative rather than prescriptive. Third, several indicators (such as innovation index and digitalization maturity) partially rely on expert judgments and secondary reports, which may introduce measurement bias. Future studies should replace these proxies with more standardized, survey-based, or real-time digital metrics. Finally, the dynamic and optimization components of the model use assumed parameter values, which limits their predictive robustness. Integrating stochastic differential modeling, Monte Carlo simulations, and robust or multi-objective optimization techniques would significantly enhance the applicability of the model.

Although the current version of the model is exploratory, its architecture demonstrates strong potential for further refinement and cross-sectoral application. Due to its modular structure, the model can be extended by integrating ESG indicators, carbon footprint accounting, digital maturity metrics, or sector-specific sustainability criteria. Future research may enhance the CEAI framework by incorporating machine learning for adaptive threshold estimation, stochastic simulation for scenario robustness, or multi-objective optimization for strategic decision support. Thus, the proposed CEAI model can evolve into a comprehensive digital tool for enterprise diagnostics, strategic planning, and policy evaluation within circular economy transitions.

5. Conclusions

Considering the factors influencing the development of strategic diagnostics of an enterprise in the context of adaptation to a circular economy, it can be concluded that for the successful integration of the principles of the circular economy into the enterprise strategy, it is necessary to review existing approaches to resource management, processes, and innovations. The circular economy sets new requirements for the efficiency of material use and waste reduction, which requires enterprises to change their resource management strategy, investments in recycling and reuse.

Strategic diagnostics in such conditions must take into account new environmental, technological, and social aspects, which allows not only to increase competitiveness, but also to contribute to the natural resources saving and reduce the negative impact on the environment. In addition, adaptation to a circular economy requires constant monitoring of changes in the external environment, in particular in legislation relating to environmental standards, as well as a review of internal processes and opportunities for innovation.

The article calculates the CEAI index for real data on the activities of three logistics companies over a period of 36 months. The calculation results showed that KUEHNE+NAGEL consistently shows the highest CEAI index values and clearly exceeds the readiness threshold with values in the range of 0.6...0.66. In general, this company demonstrates uniform growth, which indicates systemic development and a high level of digital maturity. SCHENKER fluctuates in the range of 0.58...0.61 and only at the end of the observation period demonstrates noticeable growth. This may indicate slower rates of innovation implementation or periods of instability. ZAMMLER starts with the lowest values at 0.57, but shows the fastest growth to 0.63. In the second half of the period, the company confidently crosses the readiness threshold, which indicates active transformation processes. Overall, the calculation of the CEAI index allowed to quantitatively assess the level of readiness and dynamics of the implementation of circular economy principles in three logistics companies. The obtained values showed that the CEAI index effectively reflects the current state of digital and operational innovations, as well as the pace of their progress over time.

Thus, the development of strategic diagnostics is a necessary condition for the effective adaptation of an enterprise to new conditions and the creation of long-term sustainability in the context of a circular economy.

References

[1] S. D. Sever, E. Tok, and A. L. Sellami, "Sustainable development goals in a transforming world: Understanding the dynamics of localization," in *Sustainability,* vol. 17(6):2763, 2025. doi: 10.3390/su17062763.

[2] N. Shahid and N. Sheikh, "Impact of Big Data on innovation, competitive advantage, productivity, and decision making: Literature review," in *Open Journal of Business and Management*, vol. 9, 2021, pp. 586–617. doi: 10.4236/ojbm.2021.92032.

[3] D. Firoiu, G. H. Ionescu, C. M. Cismaș, M. P. Costin, L. M. Cismaș, S. C. F. Ciobanu, "Sustainable production and consumption in EU member states: Achieving the 2030 sustainable development goals (SDG 12)," in *Sustainability,* vol. 17(4):1537, 2025. doi: 10.3390/su17041537.

[4] S. M. Ali, et al., "Development goals towards sustainability," in *Sustainability*, vol. 15:9443, 2023. doi: 10.3390/su15129443.

[5] K.Y.H. Lim, P. Zheng, and C.H. Chen, "A state-of-the-art survey of digital twin: Techniques, engineering product lifecycle management and business innovation perspectives," in *Journal of Intelligent Manufacturing*, vol. 31, 2020, pp.1313–1337. doi: 10.1007/s10845-019-01512-w.

[6] F. A. F. Alazzam, H. J. M. Shakhatreh, Z. I. Y. Gharaibeh, I. Didiuk, and O. Sylkin, "Developing an information model for e-commerce platforms: A study on modern socioeconomic systems in the context of global digitalization and legal compliance," in *Ingenierie des Systemes d'Information*, vol. 28(4), 2023, pp. 969–974. doi: 10.18280/isi.280417.

[7] A. Ardanza, A. Moreno, A. Segura, M. de la Cruz, and D. Aguinaga, "Sustainable and flexible industrial human machine interfaces to support adaptable applications in the Industry 4.0 paradigm," in *International Journal of Production Research*, Vol. 57(12), 2019, pp. 4045–4059. doi: 10.1080/00207543.2019.1572932.

[8] N. Mironova, H. Koptieva, I. Liganenko, A. Sakun, and D. Chernyak, "Modeling the selection of innovative strategy for development of industrial enterprises," in *WSEAS Transactions on Business and Economics*, vol. 19, 2022, pp. 278–291. doi: 10.37394/23207.2022.19.26.

[9] R. Kostyrko, T. Kosova, L. Kostyrko, L. Zaitseva, and O. Melnychenko "Ukrainian market of electrical energy: Reforming, financing, innovative investment, efficiency analysis, and audit," in *Energies*, vol. 14(16):5080, 2021; doi: 10.3390/en14165080.

[10] O. Kovalko, T. Eutukhova, and O. Novoseltsev, "Energy-related services as a business: Eco-transformation logic to support the low-carbon transition," in *Energy Engineering: Journal of the Association of Energy Engineering*, vol. 119(1), 2022, pp. 103–121. doi: 10.32604/EE.2022.017709.

[11] A. Zaporozhets, V. Babak, V. Isaienko, and K. Babikova, "Analysis of the air pollution monitoring system in Ukraine," in *Studies in Systems, Decision and Control*, vol. 298, 2020, pp. 85–110. doi: 10.1007/978-3-030-48583-2_6.

[12] D. Atstaja, V. Koval, J. Grasis, I. Kalina, H. Kryshtal, and I. Mikhno, "Sharing model in circular economy towards rational use in sustainable production," in *Energies*, vol. 15(3), 2022. doi:10.3390/en15030939.

[13] Y. Voronina, et al., "Economic and environmental component in the field of sustainable development management," in *Quality - Access to Success*, vol. 25(201), 2024, pp. 7–14. doi: 10.47750/QAS/25.201.02.

[14] J. Andre, *Industry 4.0: Paradoxes and Conflicts*. New York: Wiley, 2019, 310 p.

[15] M. Zaliskyi, O. Solomentsev, Z. Poberezhna, O. C. Okoro, B. Chumachenko, and S. Chumachenko, "Information technologies of data processing for linear deterioration process during aviation equipment operation," in *CEUR Workshop Proceedings*, vol. 3732, 2024, pp. 32–44.

[16] O. Solomentsev, et al., "Efficiency analysis of current repair procedures for aviation radio equipment," in I. Ostroumov and M. Zaliskyi (eds.), Proceedings of the 2nd International Workshop on Advances in Civil Aviation Systems Development. ACASD 2024. *Lecture Notes in Networks and Systems*, vol. 992, 2024, pp. 281–295. doi: 10.1007/978-3-031-60196-5_21.

[17] A. O. Dvigun, O. I. Datsii, N. M. Levchenko, G. A. Shyshkanova, and R. M. Dmytrenko, "Rational use of fresh water as a guarantee of agribusiness development in the context of the exacerbated climate crisis," in *Science and Innovation*, vol. 18(2), 2022, pp. 85–99. doi: 10.15407/scine18.02.085.

[18] R. Santos and M. J. Abreu, "Impact assessment and product life cycle analysis of different jersey fabrics using conventional, post-industrial, and post-consumer recycled cotton fibers," in *Sustainability*, Vol. 17(13):5700, 2025. doi: 10.3390/su17135700.

[19] I. Lee and G. Mangalaraj, "Big data analytics in supply chain management: A systematic literature review and research directions," in *Big Data and Cognitive Computing*, Vol. 6(1):17, 2022. doi: 10.3390/bdcc6010017.

[20] J. Stark, *Product Lifecycle Management*. Vol. 1: 21st Century Paradigm for Product Realisation. London: Springer, 2019. doi: 10.1007/978-3-030-98578-3.

[21] S. Bondarenko, A. Bratko, V. Antonov, R. Kolisnichenko, O. Hubanov, and A. Mysyk, "Improving the state system of strategic planning of national security in the context of informatization of society," in *Journal of Information Technology Management*, vol. 14, 2022, pp. 1–24. doi:10.22059/jitm.2022.88861.

[22] M. Sillanpaa and C. Ncibi, *The circular economy: Case studies about the transition from the linear economy*. New York: Academic Press, 2019. doi: 10.1016/C2017-0-02916-6.

[23] M. Zaliskyi, V. Ivannikova, O. Solomentsev, I. Ostroumov, and N. Kuzmenko, "The approach to optimization of the structure of the repair process of aviation radio equipment," in *Transport*, Vol. 40(1), 2025, pp. 50–63. doi: 10.3846/transport.2025.24012.

[24] L. N. T. Cam, "A rising trend in eco-friendly products: A health-conscious approach to green buying," in *Heliyon*, vol. 9, no. 9, 2023. doi: 10.1016/j.heliyon.2023.e19845.

[25] L. Lelyk, V. Olikhovskyi, N. Mahas, and M. Olikhovska, "An integrated analysis of enterprise economy security," in *Decision Science Letters*, vol. 11(3), 2022, pp. 299–310. doi: 10.5267/j.dsl.2022.2.003.

[26] V. Ivannikova, M. Zaliskyi, O. Solomentsev, I. Ostroumov, and N. Kuzmenko, "Statistical data processing technologies for sustainable aviation: A case study of Ukraine," in *Sustainability*, vol. 17, no. 13, 2025. doi: 10.3390/su17135781.

[27] L. Agostini, A. Nosella, R. Sarala, and C. Nkeng, "Emerging trends around strategic flexibility: a systematic review supported by bibliometric technique," in *Management Decision*, vol. 63, no. 6, 2025, pp. 1835–1881. doi: 10.1108/MD-02-2023-0135.

[28] N. M. Zayed, F. O. Edeh, S. Darwish, K. M. A. Islam, H. Kryshtal, V. Nitsenko, and O. Stanislavyk, "Human resource skill adjustment in service sector: Predicting dynamic capability in post COVID-19 work environment," in *Journal of Risk and Financial Management*, vol. 15(9), 2022. doi: 10.3390/jrfm15090402.

[29] A. G. Ferrari, D. Jugend, F. Armellini, and B. M. R. P. Seles, "Opportunities and challenges of strategic planning in the context of circular economy: an exploratory analysis," in *Management of environmental quality*, vol. 36(3), 2025, pp. 833–854. doi: 10.1108/MEQ-05-2024-0183.

[30] A. Pohrebniak, I. Chaikovska, O. Yushkevych, O. Kolesnyk, S. Nikolaienko, and O. Holubiev, "Circular economy as a determinant of strategic management," in *Management theory and studies for rural business and infrastructure development*, vol. 46(3), 2024, pp. 362–371. doi: 10.15544/mts.2024.34.

[31] J. Kaipainen, *Strategic development of circular economy business in established companies: A process approach to business strategy, business model innovation, and collaboration*. Tampere: Tampere University Dissertations, vol. 922, 2023. Available at: https://trepo.tuni.fi/bitstream/handle/10024/152862/978-952-03-3198-6.pdf.

[32] M. P. Pieroni, T. C. McAloone, Y. Borgianni, L. Maccioni, and D. C. A. Pigosso, "An expert system for circular economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption," in *Sustainable production and consumption*, vol. 27, 2021, pp. 534–550. doi: 10.1016/j.spc.2021.01.023.

[33] U. I. Aguado-Riveros, et al., "Strategic business management and its role in the formalization of micro and small enterprises in emerging economies," in *World*, vol. 6(2):41, 2025. doi: 10.3390/world6020041.

[34] Q. Huang and Y. Tang, "Enterprise digital transformation strategy: The impact of digital platforms," in *Entropy*, vol. 27(3):295 2025. doi: 1010.3390/e27030295.

[35] R. Li, Y. Cui, and Y. Zheng, "The impact of corporate strategy on enterprise innovation based on the mediating effect of corporate risk-taking," in *Sustainability*, vol. 13(3):1023, 2021. doi: 10.3390/su13031023.

[36] S. Y. Dwikat, D. Arshad, and M. N. Mohd Shariff, "The influence of systematic strategic planning and strategic business innovation on the sustainable performance of manufacturing SMEs," in *Sustainability*, vol. 14(20):13388, 2022. doi: 10.3390/su142013388.

[37] H. Abu-Bakar and F. Charnley, "Developing a strategic methodology for circular economy roadmapping: A theoretical framework," in *Sustainability*, vol. 16(15):6682, 2024. doi: 10.3390/su16156682.

[38] M. Zaliskyi, et al., "Methodology for substantiating the infrastructure of aviation radio equipment repair centers," in *CEUR Workshop Proceedings*, vol. 3732, 2024, pp. 136–148.

[39] M. Baca-Neglia, et al., "Industry 4.0, circular economy and Sustainable Development Goals: Future research directions through scientometrics and mini-review," in *Sustainability*, vol. 17(14):6468, 2025. doi: 10.3390/su17146468.

[40] A. Chakraborty, D. De, and P. K. Dey, "Circular economy in small and medium-sized enterprises – current trends, practical challenges and future research agenda," in *Systems*, vol. 13(3):200, 2025. doi: 10.3390/systems13030200.

[41] A. Marciniuk-Kluska and M. Kluska, "An attempt to assess the implementation of the circular economy in the EU-27 as an important element of sustainable development," in *Sustainability*, vol. 17(11):4942, 2025. doi: 10.3390/su17114942.

[42] B. Rotondo, C. Bakker, R. Balkenende, and V. Arquilla, "Integrating circular economy principles in the new product development process: A systematic literature review and classification of available circular design tools," in *Sustainability*, vol. 17(9):4155, 2025. doi: 10.3390/su17094155.

[43] S. Senaratne, E. Saysanavongpheth, and M. Samaratunga, "Exploring challenges and strategies in circular economy applications in modular construction: The case in Australia," in *Buildings*, vol. 15(9):1515, 2025. doi: 10.3390/buildings15091515.

[44] I. Vural Gursel, B. Elbersen, K. P. H. Meesters, and M. van Leeuwen, "Defining circular economy principles for biobased products," in *Sustainability*, vol. 14(19):12780, 2022. doi: 10.3390/su141912780.

[45] M. Zoka and R. Korez Vide, "Circular economy implementation in the electric and electronic equipment industry: Challenges and opportunities," in *Sustainability*, vol. 17(17):7700, 2025. doi: 10.3390/su17177700.

[46] C. Scheel and E. Aguinaga, "A systems view of circular economy," in *Sustainability*, vol. 17(3):1268, 2025. doi: 10.3390/su17031268

[47] I. Ostroumov, et al., "A probability estimation of aircraft departures and arrivals delays," in O. Gervasi, et al. (eds.), Computational Science and Its Applications – ICCSA 2021. *Lecture Notes in Computer Science*, vol. 12950, 2021, pp. 363–377. doi: 10.1007/978-3-030-86960-1_26.

[48] O. Solomentsev, M. Zaliskyi, Yu. Nemyrovets, and M. Asanov, "Signal processing in case of radio equipment technical state deterioration," in Signal Processing Symposium (SPS). Debe, Poland, 2015, pp. 1–5. doi: 10.1109/SPS.2015.7168312.

[49] I. Ostroumov, V. Ivannikova, N. Kuzmenko, and M. Zaliskyi, "Impact analysis of Russian-Ukrainian war on airspace," in *Journal of Air Transport Management*, vol. 124, 2025, pp. 1–14. doi: 10.1016/j.jairtraman.2025.102742.

[50] D. Atstaja, I. Liepa, A. Vembris, B. Rivza, S. Osipova, and N. Cudecka-Purina, "Circular economy index: A new methodology for evaluating circularity in municipalities," in *Sustainability*, Vol. 17: 4867, 2025. doi: 10.3390/su17114867.

[51] I. Liepa and D. Atstaja, "A Comparative analysis of circular economy index in urban and rural municipalities," in *Urban Science*, Vol. 9: 321, 2025. doi: 10.3390/urbansci9080321.

[52] W. C. Munonye, "Towards circular economy metrics: A systematic review," in *Circular Economy and Sustainability*, Vol. 5, 2025, pp. 4093–4135. doi: 10.1007/s43615-025-00604-5.

[53] F. Figueiredo and A. Figueiredo, "Multivariate analysis of some circular economy indicators," in *Research in Statistics*, Vol. 3(1), 2025. doi: 10.1080/27684520.2025.2519288

[54] P. K. Patro, A. Acquaye, R. Jayaraman, and K. Salah, "Circular economy indexing with Generative AI and PCA," in International Conference on Computers and Industrial Engineering. Sydney, Australia, 2024, pp. 817–825.

[55] O. Arefieva, Z. Poberezhna, S. Petrovska, S. Arefiev, and Y. Kopcha, "Devising approaches to modeling enterprise business processes under conditions of modern digital technologies," in *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 13(127), 2024, pp. 69–79. doi: 10.15587/1729-4061.2024.298143.

[56] O. Zham, V. Rudyka, T. Voronko-Nevidnycha, S. Bebko, C. Shikovets, and H. Kvita, "Diagnostics of the strategic management of the financial and economic development of the enterprise," in *Financial and credit activity: problems of theory and practice*, vol. 5(52), 2023, pp. 162–172. doi: 10.55643/fcaptp.5.52.2023.4214.

[57] A. Kuzior, O. Arefieva, Z. Poberezhna, and O. Ihumentsev, "The mechanism of forming the strategic potential of an enterprise in a circular economy," in *Sustainability*, vol. 14, (2022, pp. 32–58. doi: 10.3390/su14063258.

[58] H. Lehtimaki, V.V. Piispanen, and K. Henttonen, "Strategic decisions related to circular business model in a forerunner company: challenges due to path dependency and lock-in," in *South Asian journal of business and management*, vol. 9(3), 2020. doi: 10.1177/2277977920957957.

[59] S. Smerichevska, Z. Poberezhna, O. Mykhalchenko, Y. Shtyk, and Y. Pokanevych, "Modeling and evaluation of organizational and economic support for sustainable development of transport enterprises: innovative and ecological aspects," in *Financial and Credit Activity: Problems of Theory and Practice*, vol. 4, 2023, pp. 218–229. doi: 10.55643/fcaptp.4.51.2023.4121.

[60] S. Smerichevskyi, Z. Poberezhna, O. Mykhalchenko, Y. Petrova, and V. Smilyanets, "Ensuring the sustainable development of the aviation enterprise in the context of forming innovative potential using digital technologies," in *CEUR Workshop Proceedings*, vol. 3732, 2024, pp. 174–185.

[61] J. A. Mesa, A. González-Quiroga, "Development of a diagnostic tool for product circularity: a redesign approach," in *Research in Engineering Design*, vol. 34, 2023, pp. 401–420. doi: 10.1007/s00163-023-00415-5.

[62] S. Smerichevskyi, Z. Poberezhna, I. Kryvovyazyuk, L. Ivanenko, and D. Malnov, "Formation of principles of a customer-oriented approach by transport enterprises in conditions of sustainable development," in E3S Web of Conferences. International Scientific and Practical Conference Innovations in Construction and Smart Building Technologies for Comfortable, Energy Efficient and Sustainable Lifestyle, 2024, vol. 534. doi: 10.1051/e3sconf/202453401022.

[63] T. Li, H. Zhang, C. Yuan, Z. Liu, and C. Fan, "A PCA-based method for construction of composite sustainability indicators," in *The International Journal of Life Cycle Assessment*, Vol. 17(5), 2012, pp. 593–603. doi: 10.1007/s11367-012-0394-y.

[64] Jain, N., and G. Mohapatra, "A comparative assessment of composite environmental sustainability index for emerging economies: A multidimensional approach," in *Management of Environmental Quality*, Vol. 34(2), 2023, pp. 425–446. doi: 10.1108/MEQ-04-2022-0086.

[65] Financial statements of the enterprise SC “KUHNE & NAGEL”, 2025. URL: https://clarity-project.info/edr/24596990/finances.
[66] Financial statements of the enterprise SC “SHENKER”, 2025. URL: https://clarity-project.info/edr/24382029/finances.
[67] Financial statements of the enterprise LLC “ZAMMLER UKRAINE”, 2025. URL: https://clarity-project.info/edr/35007717/finances.
[68] Streamlit application for Circular Economy Adaptation Index (CEAI), 2025. URL: https://doi.org/10.5281/zenodo.17720643.

Authors’ Profiles

Oleksandr Trukhan, PhD
Date and place of birth: 1979, Zhytomyr, Ukraine.
Education: Zhytomyr Institute of Engineering and Technology, 2001.
Affiliation and functions: PhD of economic sciences since 2006, associate professor of Economics Department at the Zhytomyr Institute of Engineering and Technology since 2007.
Research interests: strategic diagnostics of the enterprise, formation of business resilience of enterprises, digital business transformations.
Publications: more than 50 papers.

Zarina Poberezhna, Doctor of Sciences (DSc)
Date and place of birth: 1985, Kyiv, Ukraine.
Education: National Aviation University, 2008.
Affiliation and functions: DSc in economic sciences since 2023, professor of Economics and Business Technologies Department at the State University “Kyiv Aviation Institute” since 2023.
Research interests: development of business models of enterprises; increasing the efficiency of air transportation; development of a strategy for the functioning of airlines.
Publications: more than 140 papers.

Maksym Zaliskyi, Doctor of Sciences (DSc)
Date and place of birth: 1984, Kyiv, Ukraine.
Education: National Aviation University, 2007.
Affiliation and functions: DSc in technical sciences since 2021, professor of Telecommunications and Radioelectronic Systems Department at the State University “Kyiv Aviation Institute” since 2021.
Research interests: signal and data processing, equipment operation and reliability analysis.
Publications: more than 300 papers.

Yanina Goncharenko, PhD
Date and place of birth: 1974, Kyiv, Ukraine.
Education: Dragomanov Ukrainian State University, 1996, Institute of Mathematics of NASU, 2001.
Affiliation and functions: PhD in Probability Theory and Mathematical Statistics since 2004, Professor of the Department of Higher Mathematics at Dragomanov Ukrainian State University since 2018.
Research interests: mathematical modeling, statistics, probability theory.
Publications: more than 150 papers.

How to cite this paper: Oleksandr Trukhan, Zarina Poberezhna, Maksym Zaliskyi, Yanina Goncharenko, "Mathematical Model of Strategic Diagnostics of Enterprise in the Circular Economy Adaptation Process", International Journal of Information Engineering and Electronic Business(IJIEEB), Vol.18, No.1, pp. 56-70, 2026. DOI:10.5815/ijieeb.2026.01.04