CHAPTER 1
INNOVATION-ORIENTED ENVIRONMENTAL MANAGEMENT IN THE AGRICULTURAL SECTOR OF THE UKRAINIAN ECONOMY

DOI https://doi.org/10.30525/978-9934-26-632-4-1

1.1 Theoretical and Methodological Foundations of Innovation-Oriented Environmental Management in the Agricultural Sector of the Ukrainian Economy

The development of sustainable competitive advantages in the contemporary agricultural sector is intrinsically linked to its capacity to integrate economic, environmental, and innovation imperatives within a unified management system [1]. Achieving this integration requires the establishment of a clear conceptual and categorical framework that captures the synergistic interplay between managerial practices, technological advancement, and environmental responsibility [2]. At the heart of this framework lies a triad of key concepts: «environmental management», «innovation» and «competitiveness». The logical interrelation of these concepts gives rise to a novel, comprehensive category – innovation-oriented environmental management.

Environmental management in the agricultural sector is defined as a systematic managerial activity aimed at optimizing the interaction between agricultural production and the natural environment, minimizing negative anthropogenic impacts, ensuring the sustainable use of natural resources, and complying with environmental standards and regulations [3]. It extends beyond mere control and risk mitigation, encompassing a proactive approach to managing resource efficiency (land, water, biological resources) and waste reduction. In the context of this study, environmental management serves as the foundational basis for establishing ecological constraints and target benchmarks for economic activity.

Innovation, as an economic construct, denotes the capacity of a system – be it an enterprise or an entire sector – to generate, adopt, and effectively commercialize novel solutions. Within the agricultural sector, innovation is manifested through the deployment of new technologies (precision agriculture, biotechnology, alternative energy), organizational arrangements (cooperatives, digital management platforms), marketing strategies (organic certification, short supply chains), and products (new crop varieties, high value-added goods). Innovation functions as a driving force, enabling not only adaptation to environmental constraints but also their transformation into sources of enhanced efficiency [4].

Competitiveness in the agricultural sector represents a resultant category, reflecting its ability to produce and deliver goods that are more attractive to consumers in terms of price and non-price attributes compared to alternatives, while simultaneously ensuring the sustainable development of the sector. Competitive advantages emerge from both lower-order factors (natural resources, low-cost labor) and higher-order factors (technology, quality, brand, innovation). Notably, innovations directed at addressing environmental challenges generate the most resilient higher-order competitive advantages [5].

The logical and inseparable connection among these three dimensions underpins the concept of innovation-oriented environmental management – an integrated system for managing agricultural enterprises or sectors [6]. This system is grounded in the proactive identification and implementation of technological, organizational, and product innovations aimed not only at achieving compliance with environmental standards but also at creating long-term competitive advantages through improved resource efficiency, product differentiation, and the mitigation of eco-economic risks.

Thus, innovation-oriented environmental management is not merely the sum of environmental management and innovative activities. It represents a qualitatively new managerial paradigm in which environmental challenges function not as burdensome constraints but as catalysts for innovation, which in turn form the foundation of competitiveness. This logical sequence – «environmental challenge → innovative solution → competitive advantage» – constitutes a central element of our study [7].

The primary objective of environmental management in agriculture is the governance of eco-economic interactions. This implies that every managerial decision (for example, the choice of soil cultivation technology, fertilization system, or crop protection method) is assessed not only in terms of its impact on yield and production costs but also through the lens of its consequences for soil quality, water resources, biodiversity, and human health. Consequently, the management system integrates environmental criteria directly into the operational, tactical, and strategic activities of agricultural enterprises.

The functioning of the environmental management system is based on a set of interrelated principles adapted to the specific characteristics of agricultural production (Table 1.1).

Therefore, environmental management in the agricultural sector transforms the traditional approach to management, reorienting it from maximizing short-term profits to achieving long-term sustainability through the harmonization of economic interests and environmental safety.

Competitiveness in the agricultural sector is a complex economic category reflecting its ability to produce and deliver goods and services that meet consumer demands more effectively than competing alternatives, while simultaneously ensuring the sustainable development of the sector itself and enhancing societal well-being. Competitiveness can be analyzed at multiple levels [8]:

– micro-level (enterprise level) – the capacity of an individual agricultural enterprise to utilize resources efficiently, implement innovations, adapt to market changes, and maintain profitability over the long term;

– meso-level (industry/region level) – the ability of a group of enterprises within a sector or region to compete effectively in national and international markets. Key factors at this level include infrastructure development, cluster initiatives, and access to knowledge and technologies;

– macro-level (national level) – the capacity of the national agricultural sector to maintain and strengthen its position in the global market, determined by agricultural policies, the investment climate, institutional quality, and macroeconomic stability.

Traditionally, the factors shaping competitiveness in the agricultural sector have been classified as [9]:

– price-related factors – associated with the ability to produce goods at lower costs than competitors, achieved through economies of scale, access to inexpensive resources, and favorable natural and climatic conditions;

– non-price factors – related to product quality, uniqueness, safety, branding, service level, and reliability of supply.

Table 1.1

Fundamental principles of environmental management in the agricultural sector

Principle	Content	Manifestation in Agricultural Production
Systemicity	Considering the enterprise and its environment as a single, interconnected system. Management decisions are made taking into account both direct and indirect links.	Taking into account the impact of crop rotation not only on current yields but also on long-term soil fertility, phytosanitary condition of fields, and water resource requirements.
Preventiveness	Prioritizing the prevention of negative environmental consequences over their elimination. Focus on identifying and addressing the causes of environmental problems rather than their symptoms.	Implementation of precision farming systems to avoid excessive use of fertilizers and pesticides instead of investing in costly technologies for cleaning contaminated groundwater.
Integration	Incorporating environmental goals, objectives, and criteria into the overall management system of the enterprise at all levels (strategic, tactical, operational).	Environmental indicators (e.g., humus content, CO_2 emission levels) are included in the system of key performance indicators (KPI) alongside financial indicators (profit, profitability).
Continuous Improvement	Ongoing process of analyzing, assessing, and improving environmental aspects of activities based on the Deming cycle.	Regular monitoring of soil conditions, analyzing the effectiveness of applied agricultural technologies, and adjusting them to gradually reduce the use of agrochemicals.
Responsibility	Awareness and acceptance by the enterprise of responsibility for the environmental consequences of its activities to society, the state, and future generations.	Voluntary certification of products according to environmental standards, publication of non-financial reports on environmental impact.
Scientific Justification	Making management decisions based on scientific data, objective research, and advanced knowledge in the fields of agroecology, agrochemistry, and economics.	Selection of plant varieties based on data on disease resistance and adaptability to the climatic conditions of the region, minimizing the use of fungicides.

Source: compiled by the authors

However, in contemporary conditions, this classification is supplemented by a new group of factors emerging from the concept of sustainable development. Innovation-oriented environmental management has become a powerful source of sustainable competitive advantages, influencing both price and non-price dimensions.

The effectiveness of innovation-oriented environmental management is determined not merely by the presence of individual environmental or innovative elements, but by their systemic, integrated interaction [10]. This interaction forms a unified, inseparable block in which each component simultaneously serves as both a cause and an effect for the others, creating a closed-loop positive feedback system. The structure of this interaction can be described as follows [11]:

– environmental imperatives as drivers of innovation – increasing ecological constraints (resource depletion, soil degradation, heightened climate risks, etc.) exert pressure on the agricultural sector. Traditional extensive development models become economically unviable and environmentally hazardous. This pressure acts as a trigger for innovation demand, compelling enterprises to seek new business approaches that reduce anthropogenic impact:

– technological innovations – water scarcity stimulates the adoption of drip irrigation; soil degradation encourages no-till farming and precision fertilization technologies; energy crises foster the deployment of biogas facilities;

– organizational innovations – the need to manage complex environmental data drives the implementation of digital monitoring systems; product traceability requirements encourage blockchain solutions;

– product innovations – consumer demand for environmentally friendly products promotes a transition to organic production and the development of new products with appropriate labeling.

– innovative solutions as instruments of ecological optimization – innovations act as direct tools for achieving the objectives of environmental management. They enable a shift from passive adaptation to active management of environmental parameters in production:

– enhanced resource efficiency – precision agriculture technologies optimize the use of fertilizers, crop protection agents, and fuel, reducing both costs and chemical loads on agroecosystems;

– minimization of waste and emissions – the implementation of zero-waste technologies (e.g., biomass conversion to energy or fertilizers) transforms waste from a problem into a resource;

– preservation of biodiversity and soil fertility – agroecological innovations, such as green manuring, crop rotation, and biological pest control, support the restoration of natural capital.

– competitive effects as a result of synergy – the synergy of environmental and innovative components generates sustainable competitive advantages that are difficult to replicate. These advantages manifest across multiple levels:

– economic efficiency (direct benefits):

– cost reduction – savings on resources (water, energy, fertilizers) directly lower production costs;

– increased yield – optimized technologies enhance productivity per unit of land;

– new revenue streams – sales of surplus energy from biogas plants, premium pricing for organic products.

– market positioning (indirect benefits):

– product differentiation – «eco» or «organic» labeling allows access to niche markets with higher margins;

– enhanced image and reputation – environmental responsibility strengthens loyalty among consumers, investors, and partners;

– access to new markets – compliance with international environmental standards opens export opportunities.

– strategic resilience (long-term benefits):

– reduced regulatory risks – proactive implementation of environmental standards minimizes future fines and restrictions;

– increased climate resilience – crop diversification and water-saving technologies reduce business vulnerability;

– preservation of core capital – maintaining soil fertility represents an investment in the long-term productivity of agricultural enterprises.

This integrated structure forms a cycle of reinforced competitiveness: environmental challenges stimulate innovation, innovations improve economic efficiency and environmental performance, generating additional profit that can be reinvested into further ecological innovations. This inseparable block serves as the foundation for developing methodologies for assessment and modeling [12].

Effective use of environmental management as a source of competitive advantage is impossible without its deep integration into the overall corporate strategy. Isolated environmental initiatives that are not aligned with core business objectives often remain ineffective and costly. Integration requires a systemic approach, in which environmental and innovative aspects are considered at all levels of decision-making.

The integration process can be represented as a series of sequential steps [13]:

1) strategic awareness and leadership – enterprise management must recognize that environmental sustainability is not a threat but an opportunity. This requires a shift in mindset from «environmental costs» to «investment in sustainable development». Leadership from top management is critically important to promote this new philosophy throughout the organization;

2) context and stakeholder analysis – the enterprise should analyze both the external environment (legislation, market trends, consumer demands) and the internal environment (resources, technologies, competencies). Identifying key stakeholders (investors, consumers, communities, government bodies) and their expectations regarding environmental performance is essential;

3) formulation of an integrated strategy – based on the analysis, a strategy is developed in which environmental and innovation objectives are integral to overall business goals. The strategy should be formalized through long-term plans and specific, measurable indicators;

4) implementation of structural and process changes – integration requires modifications to organizational structures and business processes:

– structural changes – a dedicated sustainability department may be established, or environmental responsibilities may be assigned to managers of all key units (production, marketing, finance);

– process changes – environmental criteria are incorporated into all key processes:

a) new product development – applying a life cycle assessment (LCA) approach to minimize the environmental footprint of products;

b) procurement – introducing green procurement criteria when selecting suppliers of raw materials and components;

c) production – continuous process improvement to enhance resource efficiency and minimize waste;

d) human resource management – developing incentive and training systems that promote environmentally responsible behavior;

e) investment activities – incorporating environmental risks and opportunities into the evaluation of investment projects.

– monitoring, evaluation, and reporting – it is necessary to establish a system to track both environmental and economic indicators. Regular evaluation of goal achievement enables strategy adjustments. Non-financial reporting (sustainability reports) is a key element that enhances company transparency and strengthens stakeholder trust.

The key to successful integration is finding synergies between environmental and innovative practices [14]. For example, investing in a biogas facility (technological innovation) not only addresses waste management issues (environmental goal) but also provides the enterprise with its own energy and fertilizers (economic goal), thereby creating a closed-loop production cycle that forms the basis of a circular economy. Such deep integration enables the creation of a sustainable business model that is adaptive, efficient, and competitive in the long term.

For an objective analysis and modeling of the impact of innovation-oriented environmental management on competitiveness, it is necessary to develop a comprehensive system of indicators that adequately reflects the effectiveness of this process. Such a system should be logically aligned with the conceptual framework and the interaction structure described above, forming a continuous methodological basis for subsequent economic and mathematical modeling [15]. The indicator system can be structured into four hierarchical levels: resource provision indicators, process indicators, performance indicators, and impact indicators.

Level 1: Resource Provision Indicators (Input Parameters) – this group of indicators characterizes the volume and quality of resources mobilized for the implementation of innovation-oriented environmental management. They serve as the input data for any modeling framework.:

1) financial indicators:

– volume of investments in environmental innovations $\left(I_{env}\right)$, UAH;

– share of expenditures on environmental measures in the total structure of expenditures $\left(P_{ec}\right)$, %;

2) material and technical indicators:

– level of equipment for precision farming $\left(T_{pa}\right)$, %;

– capacity of renewable energy installations (P_{re}), Kw;

3) human and Information Indicators:

– costs for training personnel in environmental management and innovation (C_{hr}), UAH;

– availability of a certified environmental management system (e.g. ISO 14001) – binary indicator $S_{iso} \in \{0,1\}$.

Level 2: Process indicators (management efficiency) – this group assesses the effectiveness of the direct implementation of innovative and environmental measures:

1) indicators of resource conservation:

– specific water consumption per unit of production (W_u), m^3 / t;

– specific energy consumption per unit of production (E_u), kW * hour / t;

– fertilizer utilization rate (ratio of applied and absorbed elements) (K_f);

2) indicators of reducing the load on the environment:

– the level of reduction of greenhouse gas emissions by 1 hectare (GHG_r), t CO2-eq/ha;

– the share of waste that goes to recycling or disposal (R_w), %;

3) indicators of Innovation Activity:

– the number of implemented environmental innovations for the period (N_{inn}), units.

– share of areas under organic farming (A_{org}), %.

Level 3: Performance indicators (direct effects) – this group reflects the direct environmental and economic results from the implementation of innovation-oriented environmental management:

4) economic results:

– profitability of production of environmentally oriented products (R_{eco}), %;

– cost savings from the introduction of resource-saving technologies (S_{cost}), UAH/ha;

– additional income from the sale of environmentally friendly products or services (I_{add}), UAH;

5) environmental results:

– integral indicator of the ecological state of the agricultural landscape $\left(I_{es}\right)$;

– improvement of soil fertility indicators (humus content, structure) (�F_{soil});

– reducing the pesticide load on the agroecosystem $\left(L_{pest}\right)$, kg a.i./ha.

Level 4: Impact indicators (formation of competitive advantages) – this group of indicators assesses the long-term impact of environmental management on competitiveness:

1) market indicators:

– market share occupied by ecological products of the enterprise $\left(MS_{eco}\right)$, %;

– premium price for ecological products compared to traditional products $\left(P_{prem}\right)$, %;

– export volume of certified products $\left(V_{exp}\right)$, t;

Integral indicators:

– Integral Eco-Efficiency Index $\left(IEE\right)$, which is calculated as the ratio of the aggregate economic result to the aggregate environmental load;

– Integral Competitiveness Index $\left(ICI\right)$, that takes into account economic, market and environmental indicators.

This four-level indicator system provides a logical foundation for the development of economic and mathematical models:

– level 1 indicators serve as input variables and model parameters;

– levels 2 and 3 indicators function as intermediate (endogenous) variables and optimization criteria;

– level 4 indicators represent the ultimate objective functions to be maximized.

This structure ensures a continuous transition from theoretical justification to practical modeling tools.

Summarizing the theoretical and methodological foundations of the study, it can be concluded that a coherent and logically interconnected conceptual basis has been established for analyzing innovation-oriented environmental management as a driver of competitive advantages in the agricultural sector. The starting point is the definition of innovation-oriented environmental management as an integrated managerial paradigm that transforms environmental challenges into catalysts for innovation, and innovations into the foundation of competitiveness. This approach overcomes the traditional perception of environmental requirements as burdensome costs, treating them instead as a strategic resource for development.

A key element of the proposed methodology is the elucidation of the systemic interaction among environmental imperatives, innovative solutions, and competitive effects. This interaction operates as a unified block that generates synergy: environmental pressures stimulate innovation demand, which in turn enhances resource efficiency and opens new market niches [16]. The outcome is the creation of sustainable higher-order competitive advantages, manifested not only in cost reduction but also in product differentiation, improved market positioning, and enhanced strategic resilience of agribusiness.

To bridge the gap between theoretical principles and applied analysis, a comprehensive four-level indicator system has been developed to operationalize the examined categories. The structure, encompassing resource provision, process, performance, and impact indicators, forms a continuous methodological platform for subsequent economic and mathematical modeling. This hierarchical approach logically connects input investment parameters with intermediate eco-efficiency indicators and ultimate competitiveness criteria.

1.2 Toolkit for Economic and Mathematical Modeling of Environmental Management in the Agricultural Sector of the Economy of Ukraine

The complexity and multifactorial nature of innovation-oriented environmental management in the agricultural sector necessitate the use of formalized methods for analysis and decision-making. Economic and mathematical modeling serves as a powerful tool that enables quantitative assessment of the interrelations among production, economic, and environmental parameters, facilitates the analysis of alternative scenarios, and supports the justification of optimal strategies.

The main groups of economic and mathematical models used for the study of environmental management can be systematized in the form of a Table 1.2.

Table 1.2

Classification of economic-mathematical models used in environmental management of the agricultural sector

Model Type	Purpose and Essence	Application Examples
Optimization Models	Finding the best solution according to given criteria (maximizing profit, minimizing costs, minimizing pollution) while considering constraints (resources, technologies, environmental regulations).	**Linear Programming** – optimizing crop area allocation to maximize profit under constraints on water, fertilizers, and pesticides.
		Nonlinear Programming – modeling production functions with nonlinear yield responses to fertilizer application to determine the optimal dose.
		Goal Programming – solving problems with multiple conflicting objectives (profit, soil conservation, water savings).
		Dynamic Programming – developing multi-year crop rotation strategies considering soil fertility.
Simulation Models	Reproducing the behavior of complex systems over time to analyze "what-if" scenarios. They do not find an optimal solution but show process dynamics and consequences of actions.	**System Dynamics** – modeling the impact of agricultural intensification on soil quality, water, and biodiversity.
		Agent-Based Models – simulating farmer behavior in response to government policies (environmental subsidies, taxes).
		Process-Oriented (Biophysical) Models – modeling plant growth and nutrient flows (APSIM, DSSAT) to assess the effects of agrotechnologies.
Stochastic Models	Accounting for uncertainty and risk (weather, prices, diseases) in decision-making. They use probability distributions instead of fixed values.	**Stochastic Programming** – production planning resilient to weather and market fluctuations.
		Monte Carlo Method – estimating probable financial outcomes from new technologies through repeated simulations.
		Game Theory – analyzing interactions between farms sharing common environmental resources.
Econometric Models	Quantitative assessment of relationships between economic and environmental variables based on statistical data.	**Regression Analysis** – evaluating the impact of investments in environmental measures on profitability.
		Production Function Analysis – determining the effect of soil quality and pollution levels on production efficiency.
		Panel Data Models – studying the impact of environmental policies on the agricultural sector over time.

Source: compiled by the authors

The use of this toolkit enables a transition from qualitative descriptions to quantitatively grounded managerial decisions. It allows for the assessment of the potential impact of implementing eco-innovations, determination of the optimal level of environmental investments, risk management, and ultimately the development of a sustainable business model that harmoniously combines economic efficiency with environmental responsibility [17].

Moving from theoretical justification to practical management of innovation-oriented environmental management effectiveness requires the application of formalized methods capable of quantitatively assessing the influence of various factors on final outcomes. Multivariate analysis, including regression models and scenario analysis, represents a logical tool for systematically identifying the key determinants of both environmental and economic performance, which is intrinsically linked to the indicator system developed in the previous section.

The purpose of regression analysis is to build a mathematical model that describes the dependence of the resulting indicator (for example, the integral eco-efficiency index (IEE), or the level of profitability (R_{eco})) from a set of factor variables (indicators of resource provision and processes). This allows not only to state the presence of a connection, but also to quantify the strength and direction of influence of each factor.

The general view of a multivariate regression model can be presented as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon$$

where

Y – dependent variable (resultant indicator, e.g., IEE or (S_{cost}); $X_{1,2,\supset,n}$ – independent variables (factors, e.g. the volume of investments I_{env}, share of area under no-till farming A_{nt}, specific energy consumption (E_u); β_0 – free term of the equation (constant);

$\beta_{1,2,\ldots,n}$ – regression coefficients, indicating the average change in Y for a one-unit change in the corresponding X_i, assuming all other factors remain constant;

ϵ – stochastic error, which takes into account the influence of random and unaccounted factors.

For the agricultural sector, it is often advisable to use nonlinear functional forms, in particular, a Cobb–Douglas production function modified to include environmental and innovation factors. For example, the model describing the dependence of the output of eco-friendly products (Q_{eco}) can be expressed as [18]:

$$Q_{eco} = A \cdot K^{\alpha} \cdot L^{\beta} \cdot I_{env}^{\gamma} \cdot T_{pa}^{\delta}$$

where

K, L – traditional factors: capital and labor; I_{env} – investing in environmental innovation;

T_{pa} – the level of implementation of precision farming technologies;

$A, \alpha, \beta, \gamma, \delta$ – model parameters evaluated on the basis of statistical data. The coefficients γ and δ show the elasticity of output by eco-innovative factors.

The constructed and verified regression model becomes the basis for conducting a scenario analysis, which allows you to assess the potential consequences of management decisions [18]. Scenario analysis is a logical continuation of regression modeling and consists in calculating the forecast values of the resulting indicator for different combinations of values of factor variables [19].

As part of scenario analysis, the following scenarios are usually considered:

– basic (inertial) scenario – forecasting results provided that current trends in investment and innovation are maintained;

– optimistic (innovation) scenario – modeling the situation with an increase in investments in innovation-oriented environmental management (for example, an increase I_{env} of 20%) and accelerating the introduction of resource-saving technologies;

– pessimistic (risky) scenario – assessment of the consequences of funding cuts, tightening of environmental restrictions (for example, the introduction of a carbon tax, which implicitly increases the cost of resources).

The results of the scenario analysis make it possible to substantiate the priority areas of investment and develop a strategy of innovation-oriented environmental management aimed at maximizing eco-economic efficiency. Thus, multivariate analysis performs diagnostic and prognostic functions, creating a solid analytical basis for the transition to optimization tasks [20].

While multivariate analysis answers the questions "how and why?", optimization modeling addresses the question "how to achieve the best outcome?". The construction of optimization models represents a logical extension of multivariate analysis, as it utilizes identified relationships and quantitative estimates to determine the optimal allocation of limited resources (financial, land, water) in order to achieve the maximum economic outcome while adhering to specified environmental constraints.

The classical formulation of a linear or nonlinear programming problem in the context of integrating the principles of innovation-oriented environmental management can be expressed as follows.

The target function (optimality criterion) can be represented as:

– profit:

$$P_p = \sum_{i=1}^{n}(p_i - c_i\left(X\right) * q_i\left(X\right) \rightarrow max;$$

– profitability:

$$R = \frac{P_p}{\sum_{i=1}^{n} c_i\left(X\right) * q_i\left(X\right)} \rightarrow max,$$

where i – type of activity or technology (e.g. traditional farming, organic farming, growing energy crops); p_i – sale price of products of the i-type;

$c_i\left(X\right)$ – cost function, which depends on the set of innovations applied X;

$q_i\left(X\right)$ – function of the volume of production, which also depends on innovation X.

System of constraints – the optimal plan must satisfy a number of constraints that are inextricably linked with the previous results of the study and the system of indicators [21]:

1) resource constraints:

– land resources – the total area under all activities should not exceed the total available area:

$$\sum_{i=1}^{n} A_i \leq A_{total}$$

– financial resources – total investments in various technologies should not exceed the total investment budget:

$$\sum_{i=1}^{n} I_i \leq I_{total} ;$$

– water resources – total water consumption should not exceed the established limit:

$$\sum_{i=1}^{n} W_i * q_i\left(X\right) \leq W_{limit} ;$$

2) agrotechnological restrictions – requirements for crop rotation, structure of sown areas, etc.;

– environmental restrictions:

– limits on greenhouse gas emissions – useless emissions must not exceed the established norm:

$$\sum_{i=1}^{n} GHG_i * A_i \leq GHG_{max} ;$$

– restrictions on pesticide load – requirements for maintaining soil fertility: for example, the requirement that the weighted average balance of humus on the farm be integral:

$$\sum_{i=1}^{n} L_{pest,\,i} * A_i \leq L_{pest,\,max} .$$

Classical optimization models are deterministic. However, agricultural production largely depends on stochastic (random) factors, such as weather conditions, market price fluctuations, and disease outbreaks. To account for this uncertainty, stochastic programming models are employed.

In such models, some parameters (for example, productivity q_i, price p_i) are considered not as fixed values, but as random variables with a certain distribution law. The target function in this case can be formulated as maximizing the mathematical expectation of profit:

$$E\left[P_p\right] = E\left[\sum_{i=1}^{n} (\tilde{p}_i - c_i\left(X\right) * \tilde{q}_i\left(X\right)\right] \rightarrow max ,$$

where

$\tilde{p}_i$ and $\tilde{q}_i$ – random variables. Additionally, risk constraints may be imposed, for example, requiring that the probability of loss not exceed a given α level:

$$P_p(P < 0) \leq \alpha .$$

The solution to such an optimization problem provides not merely a set of indicators, but a concrete optimal production plan: which area to allocate to each crop, which technologies (innovations) to implement, and how to distribute investments to achieve maximum profit while complying with all environmental and resource constraints.

A generalized assessment of a company's level of innovation-oriented environmental orientation is a complex task, as this phenomenon has a multidimensional nature and encompasses various aspects of activity – from resource utilization to organizational capacity [22]. The use of individual indicators provides only a partial view, whereas an integral index allows for the synthesis of heterogeneous information into a single value suitable for comparison and monitoring.

The construction of an integral index involves a series of sequential steps:

– formation of the indicator system;
– normalization of indicators;
– determination of weighting coefficients;
– aggregation of indicators;
– interpretation of the integral index.

In the first step, indicators that most comprehensively characterize the company's innovation-oriented environmental orientation are selected. Indicators may cover different groups (economic, technological, environmental, organizational). It is essential that they meet the criteria of relevance, measurability, and comparability.

Formally, the system of indicators for enterprise j is written as a vector:

$$X_j = \{x_{1j}, x_{2j}, \ldots, x_{nj},\}, x_{ij} \in \mathrm{R},$$

where

x_{1j} – value of the i-th indicator for the j-th enterprise.

Indicators are further classified into stimulants:

(S) – indicators whose increase reflects positive changes (e.g., increased efficiency) and disincentives;

(D) – indicators whose increase is undesirable (e.g., increased costs or negative impact).

$$S \cup D = \{1, 2, \ldots, n\}, S \cap D = \varnothing .$$

Such a division is necessary for the correct interpretation of further calculations.

Since indicators are measured in different units and have different ranges of values, direct comparison is not correct. Therefore, normalization is used, which reduces all values to a single scale – usually [0;1].

– for stimulants

$$x'_{ij} = \frac{x_{ij} - min_j(x_i)}{max_j(x_i) - min_j(x_i)}, i \in S ;$$

– for disincentives:

$$x'_{ij} = \frac{max_j(x_i) - x_{ij}}{max_j(x_i) - min_j(x_i)}, i \in D .$$

As a result of normalization, all values take on a dimensionless form:

$$0 \le x'_{ij} \le 1 .$$

This means that 0 corresponds to the worst result in the sample and 1 to the best. This allows for aggregation.

Not all indicators carry the same weight in forming the integrated assessment. When constructing an integrated index, it is important to consider that different indicators have varying significance for evaluating a company's innovation-ecological orientation. Some reflect more critical characteristics, while others are secondary. For example, technological factors may have a greater impact on the outcome than administrative ones, or vice versa. To reflect this, weighting coefficients w_i are introduced [23].

Formally, the weight vector is given as follows:

$$W = (w_2, w_2, \ldots, w_n), w_i \ge 0, \sum_{i=1}^{n} w_i = 1 .$$

Ways to determine weights:

– expert (for example, the method of analytic hierarchies) – advantage in taking into account practical experience, but subjectivity is possible. A comparison matrix $A = (a_{ij})$, is formed, where:

– a_{ij} – relative advantage of indicator;

– i over indicator j .

Properties:

$$a_{ij} = 1, a_{ij} = \frac{1}{a_{ji}}, a_{ij} > 0 .$$

The weights vector is defined as the normalized eigenvector corresponding to the largest eigenvalue of the matrix A:

$$Aw = \lambda_{max} w, w_i = \frac{w_i}{\sum_{k=1}^{n} w_k} .$$

Additionally, the consistency index (CI) and consistency coefficient (CR) are checked. If $CR < 0{,}1$, the matrix is considered consistent.

– statistical (variance method, principal component method, correlation method) – provide formal objectivity, since weights are derived from the internal properties of the data.

The idea behind the variance method is that indicators with greater variation have a greater impact [24]:

$$w_i = \frac{\sigma_i}{\sum_{k=1}^{n} \sigma_k}, \sigma_i = \sqrt{\frac{1}{m} \sum_{j=1}^{m} \left(x_{ij}^{`} - \overline{x_i^{`}} \right)^2} .$$

The principal component method is used to construct a covariance matrix:

$$C = \frac{1}{m} X^{`T} X^{`} .$$

Here, the weights are defined as the coefficients of the first principal component (the one with the largest variance):

$$C_v = \lambda_{max} v, W = \frac{v}{\sum_{k=1}^{n} v_k} .$$

The idea behind the correlation method is that if the integral score has a target variable (e.g., overall rating), then the weights can be defined as normalized Pearson correlation coefficients:

$$w_i = \frac{|p_{iY}|}{\sum_{k=1}^{n} |p_{kY}|} ;$$

– combined approaches – it is often practical to combine expert and statistical methods. For example [25]:

$$w_i = \alpha * w_i^{(exp)} + (1 - \alpha) * w_i^{(stat)}, 0 \le \alpha \le 1$$

Here

α determines the degree of confidence in the expert method.

Weighing properties:

if $w_i = \frac{1}{n}$, all indicators have the same weight;

if $w_i \to 1$, then the integral index actually reduces to a single indicator;

if weights are determined using PCA or correlations, they reflect the internal structure of the data, not subjective judgments.

At the stage of indicator aggregation, normalized and weighted values are combined into an integral index:

– additive model (the simplest and most common) – interpreted as the weighted average value of normalized indicators:

$$ICI = \sum_{i=1}^{n} w_i * x_{ij}^{`};$$

– multiplicative model (takes into account the interdependence of indicators) – the advantage of such a model is that a zero value of any indicator reduces the index to zero, which reflects the «bottleneck effect»:

$$ICI = \prod_{i=1}^{n} \left(x_{ij}^{`} \right)^{w_i};$$

– taxonomic model (based on distance to the standard) – in this case, the integral assessment is determined by the degree of proximity of the enterprise to a conditional ideal object with all indicators equal to 1.

$$ICI = 1 - \frac{d_j}{max_k d_k}, d_j = \sqrt{\sum_{i=1}^{n} w_i * \left(x_{ij}^{`} - 1 \right)^2}.$$

Interpretation of the integral index – the obtained values of the integral index always belong to the interval [0;1]:

$ICI \to 1$ – the enterprise is characterized by a high level of innovative and ecological orientation;

$ICI \to 0$ – the company has a low level of orientation;

intermediate values allow you to detail strengths and weaknesses.

Thanks to this, the index serves several functions simultaneously:

– comparative – ranking enterprises by the level of innovation-ecological development;

– diagnostic – identifying problem areas (for example, strong results in technological indicators and weak ones in organizational aspects);

dynamic – enabling the tracking of changes over time and assessing progress in implementing the eco-innovation strategy.

If the assessment is carried out in a time frame $t = 1, 2, \ldots, T$ then we have a matrix:

$$ICI = \left\{ ICI_{jt} \right\}, j = 1, \ldots, m; t = 1, \ldots, T.$$

In this case, it is advisable to determine:

average growth rate:

$$g_j = \left(\frac{ICI_T}{ICI_{j1}} \right)^{\frac{1}{T-1}} - 1$$

stability Index:

$$\sigma_j^2 = \frac{1}{T-1} \sum_{t=1}^{T} \left(ICI_{jt} - \overline{ICI_j} \right)^2.$$

These characteristics allow for assessing not only the current state but also the dynamics and stability of development. Thus, the integrated assessment of the level of innovation-ecological orientation can be presented as a formalized procedure:

$$ICI_{jt} = F\left(N, \left(X_j \right), W \right),$$

where

N – normalization operator,

W – weight vector,

F – Aggregation function.

Thus, the method of integral assessment is a universal tool that allows you to transform a complex system of indicators into a compact and informative form. It combines mathematical rigor and applied value for managerial decision-making.

1.3 Innovation-Oriented Environmental Management as a Factor in Generating Competitive Advantages: a Conceptual Model and Directions for its Implementation

The basis of the model is the definition of the dependent variable that characterizes competitiveness and the independent variables that reflect the results of the innovation-oriented approach to the implementation of environmental management. These variables logically follow from the scorecard developed above.

Dependent variable – integral competitiveness index (ICI). This index is a complex value that aggregates key aspects of competitive advantages: economic efficiency, market positions and strategic stability. Its value is the ultimate goal of modeling [26].

Independent (explanatory) variables: these variables are the initial data, in particular:

1) indicators of economic efficiency:

– X_1 – Profitability of production (R_{eco}), %;

– X_2 – savings in unit costs due to the introduction of innovations (S_{cost}), UAH/t;

2) environmental performance indicators (indirectly affect market attractiveness and risks):

– X_3 – Integral Eco-Efficiency Index (IEE), arb. units. This indicator aggregates data on resource conservation and reduction of anthropogenic load;

3) market Advantage Indicators:

– X_4 – share of eco-labelled products in total sales (MS_{eco}), %;

– X_5 – premium price for eco-friendly products (P_{prem}), %;

4) indicators of innovation activity:

– X_6 – volume of investments in environmental innovations per 1 hectare $\left(\frac{I_{env}}{A_{total}}\right)$, UAH/ha.

Taking into account the multiplicative effect of the synergy of various factors, it is advisable to use a model in the form of a power function (Cobb-Douglas type), which allows you to assess the elasticity of competitiveness for each of the factors. The model will look like:

$$ICI = A \cdot X_1^{\alpha_1} * X_2^{\alpha_2} * X_3^{\alpha_3} * X_4^{\alpha_4} * X_5^{\alpha_5}.$$

After logarithm, this model is reduced to linear, which simplifies the estimation of its parameters using the method of least squares:

$$\ln(ICI) = \ln(A) + \alpha_1 \ln(X_1) + \alpha_2 \ln(X_2) + \ldots + \alpha_6 \ln(X_6),$$

where

A – proportionality coefficient, reflecting the influence of factors not taken into account in the model;

α_1 – each α_i coefficient shows by how many percent the integral competitiveness index (ICI) will change when the corresponding factor X_i changes by 1 %.

Assessment of α_i coefficients allows us to draw important conclusions about strategic priorities [27]:

– for example, if α_4 (elasticity with respect to the share of eco-products) and α_1 (elasticity with respect to the price premium) turn out to be significantly higher than

– α_2 (elasticity with respect to cost savings), this indicates that market advantages (differentiation, branding) play a greater role in shaping competitiveness than direct resource savings;

– a high value of α_3 (elasticity with respect to the eco-efficiency index) would confirm the hypothesis that improving objective environmental performance is an independently significant factor in competitiveness, possibly through its impact on reputation and access to «green» financing.

This inseparable model, logically following from the previous stages of analysis, makes it possible to quantify the impact of innovation-oriented environmental management on competitiveness, transforming a set of disparate indicators into a holistic system for strategic decision-making.

The results of economic and mathematical modeling require further systematization and visualization for strategic analysis. To visualize the positioning of agricultural enterprises based on the results of the implementation of the principles of innovation-oriented environmental management, it is advisable to build a matrix, the axes of which are two key aggregate indicators [14]:

X-axis – integral index of economic efficiency $(IEcE)$. This index can be calculated as a weighted sum of normalized indicators of profitability, labor productivity, return on capital, etc;

Y-axis – integral environmental efficiency index (IEE).

The matrix divides the analytical space into four quadrants, each of which characterizes a specific strategic position (Table 1.3).

Table 1.3

Strategic Positioning Matrix "Eco-Economic Efficiency"

IEE	Low IEcE	High IEcE
High IEE	Quadrant II: "Environmental Enthusiasts" Strategy: Commercialization of environmental achievements, targeting niche markets.	Quadrant I: "Sustainable Development Leaders" Strategy: Maintaining and strengthening leadership positions, fostering innovative development.
Low IEE	Quadrant III: "Stagnation Zone" Strategy: Survival, seeking ways to improve efficiency, risk of market exit.	Quadrant IV: "Traditional Leaders" Strategy: Implementing environmental innovations to reduce risks and maintain market positions.

Source: compiled by the authors

Positioning specific enterprises within the matrix allows for diagnosing their strengths and weaknesses and developing differentiated development strategies. For example, enterprises in Quadrant I ("Sustainable Development Leaders") are characterized by a combination of high economic and environmental efficiency. This indicates their ability not only to achieve stable financial results but also to cultivate a positive environmental image, which ensures long-term competitiveness. For such enterprises, the development strategy should focus on maintaining and strengthening leadership positions, expanding innovative activities, and integrating sustainability principles into all business processes.

Enterprises in Quadrant II ("Environmental Enthusiasts") demonstrate high environmental efficiency but exhibit insufficient economic returns. Their strength lies in the focus on "green" technologies and compliance with environmental standards, which can serve as a foundation for unique competitive advantages. At the same time, their weaknesses include low profitability or limited financial resources. In this case, the key task is the commercialization of environmental achievements, identification of niche markets, and development of products that consumers choose specifically based on environmental criteria.

Quadrant III ("Stagnation Zone") represents enterprises with low economic and environmental efficiency. This is the most problematic category, as these business entities do not generate sufficient value and fail to meet modern environmental production standards. They typically have few strengths, with high operational risk, lack of innovation, and limited access to investments as primary characteristics. The strategy in this case should focus on survival, business model reassessment, reduction of inefficient expenditures, and gradual improvement of performance. Without structural transformation, such an enterprise may face bankruptcy or be pushed out of the market.

Finally, enterprises in Quadrant IV ("Traditional Leaders") are characterized by high economic performance but low environmental efficiency. Their strength is a stable financial base that enables business development and scaling. However, their weakness lies in environmental risks: reputational losses, potential regulatory sanctions, and decreased customer loyalty. For these enterprises, the development strategy should include gradual implementation of environmental innovations, modernization of production, and a transition to more environmentally friendly technologies. This approach helps mitigate risks, strengthen public trust, and preserve competitive positions in the long term.

As mentioned above, ICI is a dependent variable, but it also needs to be calculated for model verification and for benchmarking. It is built on the basis of factors identified as key determinants of competitiveness and is the logical conclusion of the scorecard [28].

The calculation can be carried out according to the additive or multiplicative convolution model. For example, according to the additive model:

$$ICI = w_1 * K_{econ} + w_2 * K_{eco} + w_3 * K_{market} + w_4 * K_{innov},$$

where $K_{econ}, K_{eco}, K_{market}, K_{innov}$ – group (sub-) indices that characterize economic efficiency, environmental performance, market positions and innovation potential, respectively. Each sub-index is calculated based on normalized primary indicators; w_i – Weighting coefficients of significance of each group of factors, $\sum w_i = 1$. The scales can be determined expertly or based on (α_i) elasticity coefficients from the regression model, ensuring the continuity and objectivity of the assessment.

This approach enables the derivation of a single quantitative criterion for ranking enterprises (or sectors) by their level of competitiveness, taking into account the full range of environmental, economic, and innovation-related factors. Systematizing the results in the form of matrices and integral indices transforms a complex data set into a practical tool for strategic planning and for monitoring the effectiveness of implementing innovation-oriented environmental management [29].

The construction of a conceptual model of innovation-oriented environmental management is based on the idea of synergistically combining environmental priorities with the enterprise's strategic innovation objectives. In the modern economy, a company aiming to ensure long-term competitiveness must not only comply with environmental regulations but also actively develop its own environmental policy through the implementation of advanced technologies, digital monitoring and management tools, and integrated methods for assessing the environmental impact of production. The conceptual model aims to demonstrate the logic of implementing a set of organizational, technological, and managerial solutions that ensure sustainable environmental performance while simultaneously enhancing market competitiveness.

The foundation of the model is a systemic approach, according to which environmental management is not treated as an isolated function but as an integrated component of the overall enterprise development strategy. The key elements of the conceptual model include: environmental strategy, innovative technologies, institutional and regulatory environment, organizational management structure, information-analytical systems, performance assessment mechanisms, as well as a block of competitive advantages generated through the application of the model [30]. Their interrelations form a dynamic system capable of adapting to changes in the external environment, responding to risks, and leveraging new opportunities (Table 1.4).

The operational logic of innovation-oriented environmental management involves a multi-level construction of managerial processes, where each level performs specific tasks while simultaneously forming the foundation for subsequent actions. This approach ensures the coherence of management, aligns strategic intentions with tactical tools and operational procedures, and creates conditions for achieving competitive advantages. The sequence of transitions from the formation of strategic guidelines to their specification and implementation in managerial practices is presented in Table 1.5.

Table 1.4

Structure of the conceptual model of innovation-oriented environmental management

Model Element	Content	Expected Outcome
Environmental Strategy	Setting goals and objectives that integrate environmental and economic interests	Reduction of negative environmental impact, enhanced reputation
Innovative Technologies	Implementation of energy-saving, zero-waste, and digital solutions	Cost reduction, improved resource efficiency
Institutional and Regulatory Environment	Compliance with international standards and national legislation	Access to external markets, certification compliance
Organizational Management Structure	Integration of environmental management into corporate governance	Coordinated actions, improved managerial efficiency
Information and Analytical Systems	Monitoring, processing, and analysis of environmental data	Informed decision-making, increased transparency
Performance Assessment Mechanisms	Use of quantitative and qualitative indicators of environmental performance	Timely adjustment of actions, enhanced control
Competitive Advantage Block	Formation of reputational, innovative, and market capital	Increased competitiveness, sustainable development

Source: compiled by the authors

An essential component of the model's logic is the creation of a feedback mechanism that allows for the comparison of actual results with planned outcomes and timely adjustment of strategy. This ensures not only the system's adaptability but also the potential for generating a cumulative innovation effect, which, in the long term, transforms into competitive advantages. Thus, the model is not limited to environmental efficiency alone but aims to create added value through enhancing reputational capital, entering new market segments, and attracting environmentally conscious consumers and partners.

The implementation of an innovation-oriented environmental management model in a competitive environment requires the development of clear methodological foundations that allow for the measurement of its effectiveness and the achievement of managerial performance. In this context, indicators, tools, and criteria that form the basis for managerial decision-making are of critical importance [31].

Table 1.5

Levels of implementation of the logic of the functioning of innovation-oriented environmental management

Implementation Level	Characteristics	Key Tools and Actions	Expected Outcomes
Strategic	Formation of the enterprise's core environmental policy goals and their integration into the overall development strategy	Defining strategic guidelines, combining economic and environmental priorities (emission reduction, resource optimization, development of environmentally safe products)	Establishment of long-term development directions and focus on sustainable growth
Tactical	Specification of strategic guidelines through the implementation of innovative solutions	Energy-efficient technologies, digital emission monitoring platforms, circular economy tools, environmentally optimized production processes	Achievement of defined environmental and economic goals, reduction of environmental impact
Operational	Implementation of daily management procedures and control over environmental tasks	Integration of management procedures, information and analytical systems, continuous monitoring and adjustment of decisions	Improved management efficiency, prompt response to deviations, ensured process stability

Source: compiled by the authors

Primarily, it is advisable to consider a system of indicators that reflect the model's effectiveness. This system should include both quantitative and qualitative parameters. Quantitative indicators enable the assessment of reductions in greenhouse gas emissions, decreases in resource consumption, and the increase in the share of innovative technologies within the overall production process. Qualitative indicators reflect reputational effects, stakeholder satisfaction levels, and the growth of trust among consumers and partners. Importantly, the indicator system should be integrated into the enterprise's strategic planning framework so that environmental performance directly influences overall business outcomes.

The methodological toolkit of the model encompasses a set of strategic and operational management instruments. Among the strategic tools, environmental auditing holds a prominent place, providing an assessment of the enterprise's compliance with regulatory requirements and identifying areas for innovative improvements. Equally important is the implementation of an environmental certification system (e.g., ISO 14001), which confirms high standards of environmental management and facilitates access to international markets. Operational tools include digital monitoring and resource management systems, product life-cycle models, and analytical dashboards for real-time control of key environmental indicators [32].

The methodological framework of the model also incorporates criteria that enable a comprehensive assessment of performance. These criteria are divided into three main groups: economic, environmental, and social (Table 1.6).

Table 1.6

Indicators of Assessment of Innovation-Oriented Environmental Management

Indicator Group	Examples	Impact on Competitiveness
Economic	Share of innovative technologies in production, reduction of costs per unit of output	Increased profitability
Environmental	Reduction of CO_2 emissions, level of waste recycling	Compliance with international standards
Social	Employee satisfaction, community engagement	Enhancement of reputational capital

Source: compiled by the authors

Economic criteria take into account indicators such as profitability, reduction of production costs, and growth in the enterprise's market value. Environmental criteria relate to the dynamics of emission reductions, energy efficiency levels, and volumes of resource recycling. Social criteria encompass employee satisfaction, enhancement of corporate responsibility, and strengthening ties with local communities. The combination of these criteria allows for a comprehensive assessment of the model's impact on the enterprise's competitive position [33].

In the context of sustainable development, the integration of economic, environmental, and social criteria into management processes necessitates the formation of an innovation-oriented environmental management system. Such a system serves as a strategic platform for aligning ecological priorities with business objectives, ensuring that resource efficiency, technological modernization, and stakeholder engagement become integral components of enterprise development. The implementation of innovative practices – ranging from eco-design and waste minimization to the introduction of green technologies – creates conditions for systemic transformation rather than isolated improvements. This approach enhances both the resilience and adaptability of the enterprise in a competitive environment characterized by rapid technological and regulatory changes.

The functioning of innovation-oriented environmental management follows the principle of sequential interaction across management levels, where each stage creates prerequisites for subsequent actions while simultaneously generating its own results. The strategic level lays the foundation by defining policies and objectives, the tactical level specifies these guidelines in the form of programs and technologies, the operational level ensures their practical implementation and control, and the final outcome is the formation of competitive advantages. This logic demonstrates how the management system transforms long-term intentions into tangible results in market performance (Table 1.7).

At the strategic level, long-term objectives of environmental and innovation policies are defined, determining development priorities and expected outcomes in terms of environmental safety and competitiveness. The tactical level of model implementation focuses on specifying strategic goals through the introduction of innovative technologies, resource optimization, and the development of programs to enhance production environmental efficiency.

The operational level encompasses management procedures, control mechanisms, and information-analytical systems that provide continuous monitoring of key indicators and allow for timely adjustments in case of deviations from planned results. Overall, this multi-level approach creates a coherent logic for translating abstract strategic intentions into concrete competitive advantages, such as reduced production costs, enhanced reputational capital, improved market position, and increased investment attractiveness [34].

Table 1.7

The idea of the model's functioning: from strategic guidelines to competitive results

Level	Key Actions	Tools	Results
Strategic	Formulation of environmental policy	Strategies, ISO standards	Long-term objectives
Tactical	Implementation of innovation programs	Energy-efficient technologies	Cost reduction
Operational	Monitoring and control	IoT, analytical systems	Minimization of environmental impact
Competitive Outcome	Creation of advantages	Green marketing	Strengthening market position

Source: compiled by the authors

Thus, representing the interrelationships between the model's implementation levels enables clear tracking of how each element of the conceptual system influences the enterprise's final outcomes, as well as the assessment of the effectiveness of integrating innovative and environmental approaches. This logic and the connection between strategy, tools, and results are summarized in the following table.

For a comprehensive assessment of the effectiveness of innovation-oriented environmental management, comparison with the traditional approach to environmental management is of particular importance. Such a comparison allows not only the evaluation of quantitative and qualitative results but also the assessment of the degree of integration of innovative and environmental practices into the enterprise's overall strategy (Table 1.8).

Table 1.8

Comparison of the results of traditional and innovation-oriented models of environmental management

Evaluation Parameter	Traditional Model	Innovation-Oriented Model
Compliance with regulations	Minimal compliance	Proactive implementation of standards
Resource usage	High resource consumption	Optimized, energy-efficient use
Innovation component	Limited application	Systematic integration of technologies and digital solutions
Economic outcomes	Short-term cost reduction	Long-term profitability and market value growth
Reputational effect	Low, limited to local market	High, supports international reputation and attracts investors
Social impact	Partial consideration of community interests	Full integration of corporate social responsibility principles

Source: compiled by the authors

In the traditional approach, environmental management is primarily focused on minimal compliance with regulatory requirements, which ensures basic standard adherence but limits the potential for gaining competitive advantages. Economic, social, and reputational aspects in such systems are considered fragmentarily, often preventing the realization of a synergistic effect.

The innovation-oriented approach, on the other hand, involves a systematic integration of strategic priorities with innovative technologies, information-analytical tools, and comprehensive performance evaluation. This enables enterprises to proactively respond to changes in the external environment, reduce resource consumption, enhance reputational capital, and create additional market-based competitive advantages [35].

Thus, comparing traditional and innovation-oriented approaches clearly highlights the qualitative differences in management outcomes, assesses the degree of integration of innovations, and identifies potential for enhancing competitiveness. The innovation-oriented model allows enterprises to move beyond a purely regulatory approach to environmental management, transforming it into a strategic instrument for strengthening competitive positions. Such an approach generates a comprehensive effect, encompassing economic, environmental, and social dimensions, ensuring long-term sustainability and increased attractiveness to investors and partners.

The conceptual model of innovation-oriented environmental management ensures the integration of environmental priorities into the strategic and operational management of the enterprise. It combines long-term objectives, innovative technologies, organizational and informational tools, as well as performance evaluation mechanisms, enabling the creation of competitive advantages and enhancing operational resilience. The model establishes dynamic interactions between strategic planning, tactical decisions, and operational processes, contributing to improved resource efficiency, reduced environmental impact, and strengthened market positions.

Implementation of the model involves the development of internal programs for environmental innovations, integration of international standards, and digital monitoring and control technologies, along with active engagement with social groups and local communities [36]. The use of economic, environmental, and social performance indicators allows for comprehensive evaluation of activities and improves the quality of managerial decision-making.

For practical application, it is advisable to implement systemic measures aimed at increasing energy efficiency, optimizing resource use, developing «green» technologies, and supporting innovative processes in production. Special attention is given to building a positive corporate image, enhancing reputational capital, and attracting environmentally conscious partners and consumers.

The innovation-oriented environmental management model fosters the emergence of a new type of enterprise that combines innovative approaches with environmental responsibility. This creates conditions for enhancing competitiveness in a globalized market, ensuring sustainable development, and strengthening positions at both national and international levels.

List of References to the Chapter 1

1. Kaletnik, G., & Lutkovska, S. (2020). Innovative environmental strategy for sustainable development. *European Journal of Sustainable Development*, 9(2), 89-98. DOI: https://doi.org/10.14207/ejsd.2020.v9n2p89

2. Khomenko, O. (2015). Types of strategies and tools for choosing the enterprise development strategy. *Development Management*, 3(181), 131-137.

3. Kaletnik, G., Honcharuk, I., & Okhota, Y. (2020). The waste-free production development for the energy autonomy formation of Ukrainian agricultural enterprises. *Journal of Environmental Management and Tourism*, 11(3), 513-522. DOI: https://doi.org/10.14505//jemt.v11.3(43).02

4. Sytnyk, H. P., Zubchyk, O. A., & Orel, M. H. (2022). Conceptual Understanding of the Peculiarities of Managing Innovation-Driven Development of the State in the Current Conditions. *Science and Innovation*, 18(2), 3-15. DOI: https://doi.org/10.15407/scine18.02.003

5. Lutkovska, S., Koval, N., Lozova, O., Okhrimenko, I., Shatskaya, Z., & Vytrykhovskyi, Y. (2024). Project management of innovatively structures in the smart economic model. *Financial and Credit Activity: Problems of Theory and Practice*, 6(59), 613-632. DOI: https://doi.org/10.55643/fcaptp.6.59.2024.4631

6. Petrushina, T.O. (2020). Sociological understanding of the modernization of modern Ukrainian society. *Science and Innovation*, 16(5), 3-20.

7. Klius, Y., & Syvochka, V. (2023). Ensuring the competitiveness of regional enterprises on an innovative basis. *Visnik of the Volodymyr Dahl East Ukrainian National University*, 2 (278), 50-55. DOI: https://doi.org/10.33216/1998-7927-2023-278-2-50-55

8. Okhota, Y., Chikov, I., & Bilokinna, I. (2024). Conceptual polycomponent model of an innovative mechanism for improving the competitiveness of agro-industrial complex enterprises. *Baltic Journal of Economic Studies*, 10(2), 196-210. DOI: https://doi.org/10.30525/2256-0742/2024-10-2-196-210

9. Nitsenko, V., Tepliuk, M., Velychko, O., Koliadenko, S., Hanzhurenko, I., Melnichenko, O., & Moskvichenko, I. (2025). Revitalization of stevedoring activities, risk management and relocation of logistics processes in Ukrainian agribusiness. *Scientific Journal of Silesian University of Technology. Series Transport*, 126, 171-188. DOI: https://doi.org/10.20858/sjsutst.2025.126.11

10. Chikov, I., & Titov, D. (2023). Ecological balance and innovation: the role of biotechnology in modern realities. *Agrosvit*, (14), 37-45. DOI: https://doi.org/10.32702/2306-6792.2023.14.37

11. Honcharuk, I., & Tomashuk, I. (2023). Influence of innovative processes on increase of competitiveness of agricultural enterprises. *Economy, Finance, Management*, (1), 30-47. DOI: https://doi.org/10.37128/2411-4413-2023-1-3

12. Chang, S. (2020). Development of methods for integrated assessment of the level of innovative potential of companies. *Economic Bulletin of NTUU «KPI»*, 17, 421-438. DOI: https://doi.org/10.20535/2307-5651.17.2020.216387

13. Vishnevsky, V.P., Garkushenko, O.M., Knyazev, S.I. (2020). Technological gaps: concept, models, ways to overcome. *Science and Innovation*, 16(2), 3-19.

14. Chikov, I., Radko, V., Marshalok, M., Tepliuk, M., Petrenko, O., Sharko, I., & Sitkovska, A. (2022). Economic development of agricultural food enterprises on an innovative basis. *Financial and Credit Activity: Problems of Theory and Practice*, 1(42), 98-106. DOI: https://doi.org/10.55643/fcaptp.1.42.2022.3672

15. Chikov, I., Khaietska, O., Okhota, Y., Titov, D., Prygotsky, V., & Nitsenko, V. (2023). Modeling of the synthetic indicator of competitiveness of agricultural enterprises: methodological approach to neural network tools. *Financial and Credit Activity: Problems of Theory and Practice*, 5(52), 222-242. DOI: https://doi.org/10.55643/fcaptp.5.52.2023.4149

16. Kwak, M.V. (2020). Determinants of the formation of the trajectory of innovative development of the state in the modern economic space. *Economic space*, 155, 20-24.

17. Shpykuliak, O., & Bilokinna, I. (2019). «Green» cooperatives in the formation of an institutional mechanism of development of alternative power engineering in the agrarian sector of the economy. *Baltic Journal of Economic Studies*, 5(2), 249-255. DOI: https://doi.org/10.30525/2256-0742/2019-5-2-249-255

18. Chikov, I. A., Koliadenko, S. V., Supryhan, V. A., Tabenska, O. I., Nitsenko, V. S., & Holinko, O. V. (2023). Smart contracts and business process automation: the technical aspect. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 186-192. DOI: https://doi.org/10.33271/nvngu/2023-5/186

19. Pidvalna, O., Kachala, T., & Romashchenko, K. (2022). Organizational, methodological and economic imperatives of developing an innovation strategy of a region's sustainability on the basis of intellectual capacity building. *Baltic Journal of Economic Studies*, 8 (1), 118-125. DOI: https://doi.org/10.30525/2256-0742/2022-8-1-118-125

20. Chikov, I., & Denys, T. (2025). Expert system for determining strategic directions for ensuring the stable functioning of agricultural enterprises and rural areas. *Baltic Journal of Economic Studies*, 11(4), 238-251. DOI: https://doi.org/10.30525/2256-0742/2025-11-4-238-251

21. Chikov, I., & Vovk, V. (2023). Theoretical and practical aspects of using waste ecologistics in sustainable supply chains of agricultural enterprises. In *Scientific Monograph* (pp. 57-136). Riga: Baltija Publishing. DOI: https://doi.org/10.30525/978-9934-26-286-9-2

22. Rayets, M., Tkachuk, V., Buryk, M., Kubitskyi, S., & Kasimova, N. (2023). The Role of Leadership in Stimulating Innovation and the Creative Potential of the Team. *Economic Affairs*, 68(03), 1601-1610. DOI: https://doi.org/10.46852/0424-2513.3.2023.26

23. Chikov, I. (2021). Assessment of the level of competitiveness of agricultural enterprises based on neural network modeling. *Economy, Finances, Management*, 4(58), 83-99. DOI: https://doi.org/10.37128/2411-4413-2021-4-6

24. Chikov, I., & Yaroshchuk, R. (2024). Innovative activity as a system-forming factor in increasing competitiveness of agricultural enterprises. *Economy and Society*, (61). DOI: https://doi.org/10.32782/2524-0072/2024-61-78

25. Pakhucha, E. (2018). Influence of internal and external factors on the competitiveness of agricultural enterprises. *Efektyvna ekonomika*, 7.

26. Dotsiuk, S., Chikov, I., Shevchenko, O., Nitsenko, V., Gerasymchuk, N., & Demydova, M. (2024). Evaluation of the institutional development of innovative activities to ensure the economy of the state. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (3), 171-180. DOI: https://doi.org/10.33271/nvngu/2024-3/171

27. Chikov, I. (2024). Innovative potential of enterprise: conceptual and categorical apparatus and model of valuation. *Economy and Society*, (68). DOI: https://doi.org/10.32782/2524-0072/2024-68-55

28. Kaletnyk, H.M., & Goncharuk, T.V. (2013). Innovation provision of development of the bio-fuel industry: world and domestic experience. *Business inform,* 9, 155-160.

29. Sakhno, A., Salkova, I., Abuselidze, G., Yanchuk, T., & Buha N. (2023). Evaluation of Efficiency of Small Agricultural Enterprises Economic Activity Under Sustainable Development Conditions. *Lecture Notes in Networks and Systems*, 2(575), 2262-2271.

30. Chikov, I.A. (2024). Theoretical and methodological foundations of forming an innovative mechanism to improve competitiveness of agricultural enterprises. *Business Inform*, (7), 221-239. DOI: https://doi.org/10.32983/2222-4459-2024-7-221-239

31. Dubas, R.G. (2018). Management of innovation and investment development of the national economy of Ukraine. *Problems of innovative investment development*, 16, 4-13.

32. Tokarchuk D., Pryshliak N., Shynkovych A., & Mazur K. (2021). Strategic Potential of Agricultural Waste as a Feedstock for Biofuels Production in Ukraine. Rural Sustainability research, 46, 341. DOI: https://doi.org/10.2478/plua-2021-00121-12

33. Sakhno, A., Boltovska, L., Chikov, I., & Dotsiuk, S. (2024). Economic assessment of efficiency of environmental protection activities in Ukraine. *Economy, Finances, Management*, 4(70), 144-163. DOI: https://doi.org/10.37128/2411-4413-2024-4-10

34. Chikov, I. (2024). Theoretical and methodological aspects of approaches to assessing efficiency of agricultural enterprises. *Entrepreneurship and Trade*, (41), 104–117. DOI: https://doi.org/10.32782/2522-1256-2024-41-14

35. Furman, D., Shchokin, R., Kubitskyi, S., Chaplinskyi, V., Strochenko, N., & Dorosh, I. (2023). Motivation and incentives for employees of domestic enterprises. *Journal of Law and Sustainable Development*, 11(3), e815-e815. DOI: https://doi.org/10.55908/sdgs.v11i3.815

36. Chikov, I., & Kovalchuk, P. (2024). Theoretical basics of enterprise competitiveness in horticulture. *Economy and Society*, (59). DOI: https://doi.org/10.32782/2524-0072/2024-59-76