ARCHITECTING THE ECONOMIC RECOVERY MANAGEMENT SYSTEM IN THE NEW BIOECONOMIC REALITY: DETERMINANTS AND MODERN CLUSTER SOLUTIONS

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INTRODUCTION

In the process of a profound transformation of the national economy (which goes beyond the classical theory of structural shifts[1] and acquires the features of revolutionary changes[2]),caused by large-scale destruction of the material and technical base of economic entities, in particular those related to the bioeconomy sectors, structural imbalances, socio-economic shocks and crisis deformations of the institutional and regulatory landscape in the conditions of the war economy and the post-war period, sprouts of a new management paradigm appear in Ukraine, conceptually oriented on bioeconomic principles of development, regeneration and self-regulation of socio-economic systems.

Modern recovery dynamics require not only the reactivation (redesign) of operational and financial flows, but above all, a rethinking of the foundations of the economic growth paradigm itself, including its energy-resource, social, cognitive, and environmental determinants. In this context, architecting the economic recovery management system appears not as a technocratic process of restructuring institutions, but as an intellectual and institutional modelling and design of a new economic architecture based on the principles of bio-oriented rationality and ecosystem balance, thereby forming a modern bioeconomic reality.

Bioeconomic reality materialises in a multidimensional socio-natural construct, within which natural, technological, social and managerial subsystems interact, united by a common logic of sustainable and comprehensive (inclusive) reproduction. Its essence lies in the integration of bioresource potential, human capital and cognitive assets within a single business model, where the main factor of development is not material resources, but knowledge, trust, innovative capacity and social cooperation. The bioeconomy, as a renewable paradigm, is based on the principles of circularity, energy efficiency, decentralisation of management, responsible consumption, and the reproducibility of natural capital. Under such conditions, economic recovery is a multi-level process involving the coherent combination of socio-economic determinants that form systemic dependencies

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[1] Петруха Н., Петруха С. До питання природи та ідентифікації структурних зрушень в економіці: методологічний аспект. *Економіст*. 2013. № 8. С. 23–26.; Webster A., Dunning J. Structural Change in the World Economy (Routledge Revivals). Taylor & Francis Group, 2013. 244 p.

[2] Петруха С. В., Петруха Н. М. Економіка харчової промисловості України: «перша хвиля» світової фінансово-економічної рецесії. *Економіка харчової промисловості* : наук. журн. 2013. № 2 (18). С. 5–16.

between resource capabilities, technological adaptability, institutional capacity, and social cohesion within society.

From the standpoint of a systemic-synergistic approach, the architecture of economic recovery management in the bioeconomic paradigm acquires a two-dimensional nature. On the one hand, it is an epistemological system of scientific knowledge that reveals the ontological foundations of development determinants, determines the mechanisms of their interaction and typology in the process of forming management decisions. On the other hand, it is a practical-institutional construction that materialises in the form of organisational and economic mechanisms, cluster models, bioinnovation networks and production systems that ensure self-sustaining, adaptive and regenerative economic growth based on bioresource, intellectual and technological synergy.

The architecture of such a management system requires a high level of coherence between macroeconomic policy, sectoral strategies, local initiatives and mechanisms of public-private interaction. Its functioning involves a transition from linear, hierarchical management schemes to network, integrated, and polycentric models, within which the interests of the state, bioeconomy sectors, educational and scientific institutions, and rural territorial communities are coordinated to achieve agreed-upon environmental, social, and economic goals.

The methodological quintessence of this section is the integration of three interconnected levels of analytics and management that determine the architecture of bioeconomic recovery:

The first level (1) is epistemological. It aims to conceptualise the nature, structure, and typology of socio-economic determinants that influence the trajectory of economic recovery. At this level, a theoretical and methodological basis is formed for understanding the role of social, institutional, cognitive and behavioural factors in the transformation of the development model from resource-exhausting to bio-oriented;

The second level (2) is organisational and economic. It reveals the mechanisms of institutionalisation of the bioeconomic paradigm in the practice of strategic management, the central element of which is the biocluster as an institutional form of coordination that unites entities from different sectors of the bioeconomy, ensuring a combination of economic efficiency with environmental expediency. At this level, the principles, functions, tools and algorithms for managing cluster interaction as a form of adaptive (initially to the conditions of the war economy, later to early post-war recovery, and at the final stage – post-war recovery) economic integration are determined;

The third level (3) is the approximation-industry level. It focuses on the mechanisms of diffusion and adaptation of bioeconomic principles in industry-based processing and production systems. At this level, it is investigated how organisational and economic determinants affect productivity growth, energy efficiency, optimisation of resource supply, technological flexibility and the implementation of circular and low-carbon production models in various sectors of the bioeconomy.

1. The epistemology and typology of socio-economic determinants of economic recovery in the bioeconomy paradigm

In modern economic theory[3], the category of "determinants" (Latin: determinare – to determine, to condition) denotes a system-organised complex of factors and conditions that set the parameters, trajectory, and intensity of socio-economic processes. Within the bioeconomic paradigm, this category assumes a synergistic-structural meaning, that is, it is not about a set of isolated factors, but about an interconnected network of economic, social, institutional, managerial, environmental, and cognitive-technological variables, whose interaction shapes the dynamics of regenerative growth and the controllability of recovery cycles. Therefore, the epistemological status of the concept of "determinants" is associated with the knowledge of deep cause-and-effect relationships in systems that evolve towards circularity, low-carbon and resource efficiency.

Researchers view bioeconomic recovery[4] as a multifaceted, polycentric process in which natural and human capital, institutional quality, and technological capacity mutually reinforce one another, forming a development ecosystem. In this perspective, determinants are not only "what influences," but also "how, through what channels, and with what elasticity of influence." Natural resource constraints, information asymmetries, regulatory settings, social capital and trust, human and innovation potential, spatial and cluster architecture, the degree of digitalisation, and knowledge infrastructure all determine the configuration of recovery, its sustainability, speed, and inclusiveness. However, to capture the profound logic of interactions, it is advisable to consider determinants as vector variables in a multi-level management model, where each level (macro/meso/micro) has its own set of tools and feedback loops, as well as its own performance indicators (economic, social, environmental, institutional, etc.).

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[3] Blaug M. Economic theory in retrospect. 5th ed. Cambridge ; New York : Cambridge University Press, 1997. 725 p.; Zhang W.-B. The Time for a Grand Economic Theory. The General Economic Theory. Cham, 2020. P. 1–17. DOI: https://doi.org/10.1007/978-3-030-56204-5; Петруха С. В. Державне антикризове регулювання аграрного сектору економіки України : монографія; Інститут економіко-правових досліджень. Центр учбової літератури, 2018. 524 с.

[4] Anderson L. G., Seijo J. C. Bioeconomics of Fisheries Management. Wiley & Sons, Incorporated, John, 2011. 320 p.; Flichman G., Louhichi K., Boisson J. M. Modelling the Relationship Between Agriculture and the Environment Using Bio-Economic Models: Some Conceptual Issues. Bio-Economic Models applied to Agricultural Systems. Dordrecht, 2011. P. 3–14. DOI: https://doi.org/10.1007/978-94-007-1902-6_1; Brears R. C. Urban Bioeconomy: Advancing Circular Economy, Renewable Energy, Waste Management, Sustainable Agriculture, Green Infrastructure, and Biotechnology in Cities. Global Climate Solutions, 2025. 107 p.; Volodin S., Petrukha S. Science park as a management system for the transfer of innovation. Entrepreneurial Dimensions of Management and Innovation: Strategic, Educational and Socio-Economic Perspectives: Scientific Monograph. Przeworsk, Poland : Higher School of Social and Economic in Przeworsk. 2025. P. 160–177. URL: https://www.wssgprzeworsk.edu.pl/wp-content/uploads/2025/09/Monografia-WSSG-10.09.2025-r.pdf; Petrukha N., Demydonok I., Hubanov O. Ethical Aspects of Bioeconomy in Post-War Reconstruction Projects in Ukraine. *Economics, Finance and Management Review*. 2024. № 4 (20). P. 4–17. DOI: https://doi.org/10.36690/2674-5208-2024-4-4-17; Petrukha N., Petrukha S., Shapovalov O., Ushchenko P. The Role of the Bioeconomy in the Post-War "Greening" of Economic Policy. *Investytsiyi: praktyka ta dosvid*. 2025. № 10. P. 104–115. DOI: https://doi.org/10.32702/2306-6814.2025.10.103

To ensure the manageability of the analytical process and correct approximation to specific management decisions, the following hierarchical typology of determinants of bioeconomic recovery is proposed[5]:

I. By levels of influence:

macro level, determinants of state policy and regulatory environment (circularity standards, guarantees of origin of energy and bioproducts, eco-regulation, tax and financial incentives), financial and monetary and investment framework, national innovation system, scientific policy, security parameters, technological structure and geo-economic constraints;

meso level, spatial and cluster determinants (bioclusters as institutional forms of coordination of actors; logistics and energy infrastructure; regional value chains; network interactions between business, science, communities and the state; mechanisms for sharing resources and data);

micro level, managerial, technological and behavioural factors at the level of enterprises and production systems (innovative activity, technological flexibility, energy efficiency, organisational culture, personnel competencies, decision-making models, eco-design and lean-circulation practices);

II. By origin:

endogenous (internal to the system) – management decision-making procedures, technological regimes, cost and productivity structure, social capital within the organisation/territory;

exogenous (external) – regulatory changes, market conditions, price shocks to resources/energy, climate risks, institutional shifts outside the system;

III. By content of manifestation:

economic (capital structure, access to "green" financing, pricing of eco-services, investment climate);

social (quality of life, social cohesion, trust, human capital, demographic dynamics);

institutional and managerial (rules of the game, standards and protocols, capacity of management bodies, coordination mechanisms);

environmental (state of natural capital, biodiversity, renewable resources, externalities and their internalisation);

cognitive and technological (information infrastructure, digitalisation, R&D, education, innovation culture).
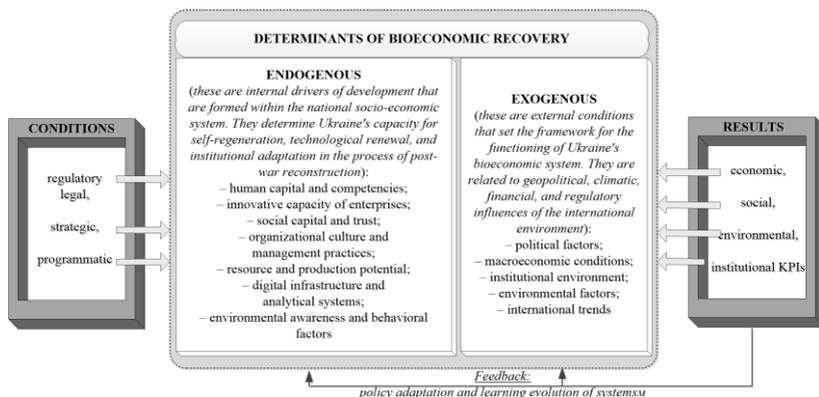
Fig. 1. Circularity (predictors and responses) of the bioeconomic recovery of bioeconomy sectors

Source: compiled by the authors based on[6].

The traditional model of economic recovery[7] is organised around a resource-intensive logic, i.e., extensive output growth, high transaction costs to offset negative externalities, and low levels of environmental damage. The determinants in such a model primarily focus on technical and economic parameters, including capital intensity, return on assets, and productivity, while social and institutional factors play a secondary role.

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[6] Gülşah Yilan. Circular Bioeconomy: Theories and Tools for Economists and Sustainability Scientists. Cambridge University Press, 2023. 300 p.; Pan A. Bioeconomy. Singapore : Springer Nature Singapore, 2023. 294 p. DOI: https://doi.org/10.1007/978-981-19-6164-9; Green, Closed Loop, Circular Bio-Economy. MDPI, 2021. 288 p. DOI: https://doi.org/10.3390/books978-3-0365-0211-3; Klymenko K., Petrukha N., Petrukha S. "Green" Marshall Plan For Ukraine: Financial, Economic and Regulatory Context. *RFI Scientific papers*. 2024. № 1 (106). P. 20–49. DOI: https://doi.org/10.33763/npndfi2024.01.020; Globalization, Income Distribution and Sustainable Development / ed. by R. Chandra Das. Emerald Publishing Limited, 2022. DOI: https://doi.org/10.1108/9781801178709

[7] Мельников О. В., Петруха С. В., Петруха Н. М. Економічне відновлення сільських територій: співвідношення фундаментального та прикладного аспектів наукового дослідження. *Вчені записки Університету «КРОК»*. 2021. № 1 (61). С. 176–193. DOI: https://doi.org/10.31732/2663-2209-2021-61-176-193; Petrukha S., Stakhov B., Petrukha N. Ukraine's public finance: denerminants, institutional transformation and directions in development of budgetary regulation. Pandemic economic crisis: challenges to society. Sofia, Bulgaria : VUZF Publishing House "St. Grigorii Bogoslov", 2020. P. 271–301. URL: https://philarchive.org/archive/BRIPEC-3; Classical Political Economy and Modern Theory: Essays in Honour of Heinz Kurz / I. Steedman et al. Taylor & Francis Group, 2013. 384 p.

In contrast, the bioeconomic model[8] presents a regenerative logic of recovery, in which natural capital is viewed not as an input resource to be exploited, but as a factor of long-term sustainability to be managed. In such a model, socio-economic and institutional determinants become dominant, since they form a triad due to which: the motivational and behavioural regime of economic agents is formed (willingness to invest in energy efficiency, accept circular technologies, ability to form clusters), institutional predictability is ensured (standards and guarantees of origin, stability of rules, coordination mechanisms), information asymmetry is reduced and trust is increased, without which network forms of interaction do not have the institutional capacity to reproduce.

Therefore, we position the transition from the traditional to the bioeconomic model not simply as technological modernisation, but as an institutional and social transformation with a recapitulation of the set of determinants and the predominance of socio-economic features in determining growth trajectories (economic recovery).

In the context of forming bioeconomic management architecture, socio-economic determinants become the fundamental structural factors that ensure the real implementation of restorative models in national economic practice. Their significance lies in the fact that they not only correlate with economic results but also determine the parameters of the entire system of institutional, managerial, and technological interactions. In post-crisis Ukrainian realities, it is the socio-economic dimension that sets the boundary conditions for the possibility of reforms, as it shapes the ability of society to perceive, support and reproduce innovative management solutions based on trust, partnership and shared responsibility.

Social capital and trust are key elements of the "fabric" of the bioeconomic space, which reduce the transaction costs of horizontal cooperation, increase the efficiency of communications between cluster entities, accelerate the diffusion of bioinnovations, and create the prerequisites for collective investment in common infrastructure, in particular logistics, energy and digital. In countries undergoing a reconstruction phase, including early ones, it is the level of public trust that determines the stability of institutions and the legitimacy of policies, without which any technocratic models remain declarative.

Human capital and competence capacity shape the technological elasticity of bio-oriented production systems. Relatively speaking, bioeconomic transformation is possible to the extent that human resources structures possess digital data management skills, biotechnological knowledge, project thinking and a systemic understanding of environmental constraints. For Ukraine, this determinant is critical, since demographic depopulation, the outflow of specialists and the destruction of the vocational education environment during the war period create an institutional gap between the innovative potential and the human capacity to implement it.

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[8] Morris E. J., Virgin I. Creating Sustainable Bioeconomies: The Bioscience Revolution in Europe and Africa. Taylor & Francis Group, 2016. 296 p.; Будякова О. Ю., Дервіш Д. С. Інвестиції в біоекономіку для повоєнного відновлення України. *Трансформаційна економіка*. 2023. № 4 (04). С. 9–13. DOI: https://doi.org/10.32782/2786-8141/2023-4-2; Bio#Futures / ed. by E. Koukios A. Sacio-Szymańska. Cham : Springer International Publishing, 2021. 644 p. DOI: https://doi.org/10.1007/978-3-030-64969-2

Institutional quality and management capacity ensure predictability, feedback and adaptability of management circuits. A bioeconomic system cannot exist in conditions of fragmented regulation or political volatility, as it requires stable norms, transparent monitoring procedures, effective KPI analytics, and mechanisms for self-correction of policies in response to environmental, social, or financial disturbances. The Ukrainian experience[9] demonstrates that even under conditions of limited resources, it is the institutional coherence and managerial competence of local and regional authorities that enable the reproduction of sustainable development models.

Economic incentives, including the system of "green" financing, tax and credit instruments, and energy supply guarantees, are effective only if there are corresponding socio-institutional prerequisites. In the absence of trust, human capital, and effective institutions, even the best economic mechanisms fail to generate the expected effects, as confirmed by both international practice[10] and Ukrainian cases of ineffective implementation of environmental investment programs or state support for the agricultural sector[11].

In conclusion, we can state that socio-economic determinants play the role of an "architectural framework" of bioeconomic recovery, setting the coefficient of realisation of all other determinants – technological, environmental, and financial. They form the implementation threshold of the system, that is, they determine whether the theoretically constructed model can become a practical institutional reality or

[9] Консолідація державних фінансів України : кол. моногр. / [Луніна І. О., Булана О. О., Степанова О. В. та ін.] ; за ред. д.е.н. І. О. Луніної ; НАН України, ДУ «Ін-т екон. та прогнозув. НАН України». Електрон. дані. К., 2017. 344 с.; Фіскальна та монетарна безпека національної економіки в умовах глобальних викликів і загроз [Електронний ресурс] / за ред. Т. І. Єфименко. Київ : ДННУ «Акад. фін. управління», 2023. 1157 с.; Петруха Н. М., Петруха С. В. Державне регулювання інтегрованих корпоративних об'єднань в умовах структурно-інституціональної та функціональної трансформації сільської економіки: проблеми методології, теорії, соціально-економічної та секторальної політики : монографія. Київ : ТОВ «Видавничий дім «Професіонал», 2020. 496 с. + 1 електрон. опт. диск.; Petrukha S., Petrukha N., Gasanov S., Miakota R., Konovalenko D. Public Debt and Public Debt Administration Under Martial Law in the Process of Post-War Reconstruction. *Jornal of Law and Political Sciences*. 2025. Vol. 47/2 (Special Issue). P. 341–376. DOI: https://doi.org/10.5281/zenodo.17240064

[10] Winiecki J. Institutional Barriers to Economic Development: Poland's Incomplete Transition. Taylor & Francis Group, 2002. 128 p.; Дяченко М. О., Нігородова С. А., Петруха С. В. Міжнародне фінансування для вирішення глобальних екологічних проблем у проектах сталого розвитку. Світове господарство та міжнародні економічні відносини : сучасні трансформації та перспективи розвитку: монографія / за ред. С. Г. Мізюк. Київ : Видавничий дім «Кондор», 2019. С. 228–244. URL: https://er.nau.edu.ua/bitstream/NAU/41119/1/%D0%9C%D0%9E%D0%9D%D0%9E%D0%93%D0%A0%D0%90%D0%A4%D0%98%D0%AF.pdf; Bourguignon F., Platteau J.-P. Institutional Challenges at the Early Stages of Development Lessons from a Multi-Country Study. Cambridge University Press, 2023. 351 p.

[11] Гасанов С., Петруха С. Теоретична сутність державної підтримки сільського господарства в системі державного регулювання аграрного сектору. *Економіст*. 2014. № 7. С. 16–17.; Забловський А., Петруха С., Назукова Н. Єдина комплексна стратегія розвитку сільського господарства та сільських територій на 2015–2020 роки: оцінка дороговказів податкового реформування. *Економіст*. 2015. № 7. С. 6–12.; Петруха С. В., Палійчук Т. В., Петруха Н. М. Місцеві фінанси в умовах коронакризи: нова бюджетна архітектоніка та фінансова спроможність регуляції секторальних і соціально-економічних процесів. *Фінанси України*. 2020. № 12. С. 83–105. DOI: https://doi.org/10.33763/finukr2020.12.083

whether it will remain at the level of a declarative concept. In this regard, in the future, emphasis should be placed on institutionalising these determinants in the form of a managed, multi-level management system, which facilitates the transition to understanding the organisational and economic mechanisms of bioeconomic recovery.

Thus, the systemic nature of bioeconomic recovery involves studying determinants not as isolated variables, but as interconnected subsystems that are in a state of constant dynamic equilibrium between economic feasibility, social justice and environmental sustainability. To adequately reflect these processes, a multi-level analytical approach is necessary, synthesising macroeconomic, meso-institutional and micro-organisational information. Each level reflects a separate contour of managerial influence. Still, their effectiveness is achieved only under the condition of inter-level coherence, that is, the system's ability to respond in a coordinated manner to both external and internal disturbances.

At the macro level, the analysis focuses on the formation of the regulatory environment, state policy for green (circular) transformation, national decarbonisation strategies, the financial architecture of recovery (including the public finance system), and the role of the state as an institutional moderator of intersectoral processes.

At the meso level, the interaction of subjects within bioeconomic clusters and regional ecoregions is studied, with a key issue being network integration and the distribution of competencies among government, business, science, and rural territorial communities.

At the micro level, the focus shifts to management decisions within enterprises, innovation platforms and production systems, forming the practical basis for circularity, digital transformation and technological adaptability.

Such multi-level relationships can be described as a dynamic objective function of bioeconomic recovery, reflecting the interaction of six key groups of determinants: economic, social, institutional and managerial, environmental, cognitive and technological, and behavioural and motivational. Formally, it can be presented as follows:

$$R_{bio} = \max_{\pi \epsilon \Omega}\left\{\sum_{i=1}^{n} \int \left(a_j E_i, \beta_j S_i, \gamma_j I_i, \delta_j Ec_i, \epsilon_j K_i, \zeta_j B_i\right)\right\} \tag{1}$$

Where E_i – economic determinants (capital structure, access to "green" finance, investment attractiveness);

S_i – social (quality of life, social capital, human potential);

I_i – institutional and managerial (regulatory and normative certainty and stability of legislation, quality of regulation, degree of managerial coordination);

Ec_i – environmental (level of resource efficiency, biodiversity, climate neutrality);

K_i – cognitive and technological (digitisation, R&D, innovation culture);

B_i – behavioural and motivational (propensity for cooperation, trust, innovation openness);

coefficients $a_j, \beta_j, \gamma_j, \delta_j, \epsilon_j, \zeta_j$ reflect the elasticity of the influence of each group of determinants in the objective function;

π – is a set of management policies and mechanisms that optimise the result $\mathcal{R}_{bio}$ in the set of possible solutions Ω.

The formula demonstrates that the effectiveness of bioeconomic recovery is a function of the coherence between these groups of determinants, and not just the result of their combined action. In practical terms[12], this means that even a significant increase in economic or technological capacity does not guarantee a sustainable effect in the absence of social capital or institutional stability.

Therefore, multi-level analysis should be accompanied by feedback modelling, verification of impact coefficients, and calibration of the indicator system, which enables adaptive management of recovery processes in real-time.

In this context, the interdisciplinary integration of methods, comprising econometric models with fixed effects (for assessing stable determinants), structural equation models (SEM) for latent factors, and cognitive modelling, which enables the assessment of nonlinear interdependencies within the system, becomes particularly important. This approach opens up the possibility of moving from a static description to the architectonics of guided evolution, when the bioeconomic system is considered not as an object of forecasting, but as an intellectual subject of self-regulation.

Thanks to this methodological toolkit, an analytical basis is established for the next stage: the institutionalisation of the identified determinants within the framework of the organisational and economic mechanisms, which will be further detailed. At this stage, the multi-level typology of determinants is transformed into a system of specific management functions, principles, tools, and cluster solutions that ensure the integrity of the bioeconomic recovery architecture.

Within the framework of a multi-level system of bioeconomic recovery, identifying the vectors of action of determinants, their origin, direction of influence, and functional role in the management process is of particular importance. Such a formulation of the task allows not only to describe the factors that shape economic dynamics, but also to distinguish those of them that enhance or, conversely, inhibit recovery processes.

For this purpose, it is advisable to use a four-dimensional analytical matrix that reflects the structural logic of the interaction of endogenous (internal) and exogenous (external) determinants, classified according to their stimulating or inhibiting effect on the system.

Endogenous stimulating determinants are internal drivers of development that provide positive dynamics through organisational innovations, the implementation of eco-design principles, energy-saving technologies, the development of cluster cooperation, and the creation of internal control and knowledge management systems. They provide self-supporting mechanisms for the regeneration of the economic system and create internal synergistic effects.

Endogenous inhibiting determinants are associated with the inertia of management practices, personnel shortages, resistance to innovation, a low level of

[12] Research Institute (IFPRI) I. F. P. Intertemporal trends in agricultural productivity. Washington, DC : International Food Policy Research Institute, 2016. DOI: https://doi.org/10.2499/9780896298811_02; Research Institute (IFPRI) I. F. P. Typology of agricultural productivity zones. Washington, DC : International Food Policy Research Institute, 2016. DOI: https://doi.org/10.2499/9780896298811_04; Aldona Zawojska, Nadiia Stoliarchuk, Tomasz Siudek, Volodymyr Mamchur. Restoration of the Agricultural Sector in Ukraine. Innovation and Investment for Food Security and Sustainable Development. Warszawa, CeDeWu. 2025. 196 p.

the organisation's digital maturity, fragmentation of information flows, and ineffective communication between subsystems. Their effect is manifested in the form of reduced adaptability, loss of competitiveness and slowing down the pace of transition to bio-oriented models.

Exogenous stimulating determinants are external institutional and political factors that form a favourable environment for recovery. These include regulatory circularity standards, a system of energy supply guarantees, a European taxonomy framework for green finance, and preferential financial instruments that stimulate decarbonisation, energy efficiency, and investment in bio-based production.

Exogenous inhibiting determinants manifest themselves in the form of price and climate shocks, institutional instability, regulatory uncertainty, imperfections in eco-service markets, and infrastructure constraints. Their negative impact is particularly noticeable in transition economies, where the flexibility of adaptation mechanisms has not yet reached a critical level.
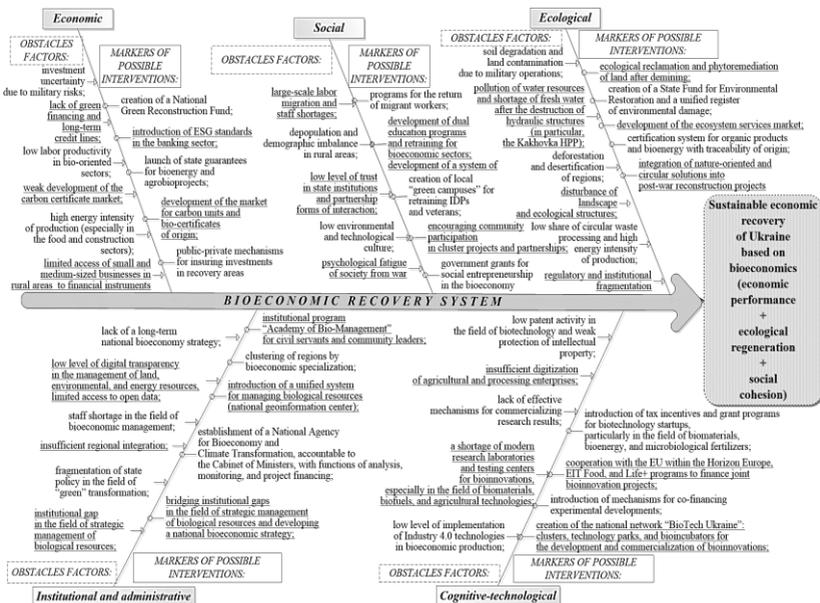
This approach allows not only the vertical structuring of factors but also the identification of feedback loops between them. Thus, exogenous incentives can activate relevant processes. In particular, state support for clusters accelerates the development of sectoral (industry) innovations. At the same time, internal inhibiting factors can neutralise positive external impulses, as is the case with a low management culture or stakeholders' distrust of the state regulator.

In a visual dimension, it is advisable to present these relationships in the form of a cause-and-effect diagram, adapted to Kaoru Ishikawa's "fishbone" principles[13], which demonstrates how different groups of determinants form a system of obstacles and opportunities in the process of shaping bioeconomic recovery. This approach provides a holistic view of the configuration of risks and points of managed intervention that can be used to optimise sustainable development policies, filling them with the spirit of the bioeconomic paradigm.

Thus, the typology of socio-economic determinants is not an end in itself of theoretical generalisation, but acts as an algorithmic basis for building effective management mechanisms in the bioeconomic environment. Its practical significance lies in creating a manageable matrix of relationships between knowledge and policy instruments, within which each group of determinants correlates with the corresponding forms of influence, efficiency indicators and levels of implementation. This approach transforms the analytical typology into a system of management guidelines, allowing for the modelling of the interaction between strategies, institutions, and economic agents based on scientifically grounded coherence.

[13] Ishikawa K. The Preparation and Use of Control Charts. Introduction to Quality Control. *Dordrecht*, 1989. P. 147–200. DOI: https://doi.org/10.1007/978-94-011-7688-0_3; Петруха С. В., Стахов Б. В. Імперативи та детермінанти сталого розвитку аграрного сектору економіки в умовах модернізації системи управління державними фінансами. Причорноморські економічні студії. 2020. № 52. С. 13–20. DOI: https://doi.org/10.32843/bses.52-40

Economic | Social | Ecological

Economic

OBSTACLES FACTORS:
- investment uncertainty due to military risks;
- lack of green financing and long-term credit lines;
- low labor productivity in bio-oriented sectors;
- weak development of the carbon certificate market;
- high energy intensity of production (especially in the food and construction sectors);
- limited access of small and medium-sized businesses in rural areas to financial instruments

MARKERS OF POSSIBLE INTERVENTIONS:
- creation of a National Green Reconstruction Fund;
- introduction of ESG standards in the banking sector;
- launch of state guarantees for bioenergy and agrobioprojects;
- development of the market for carbon units and bio-certificates of origin;
- public-private mechanisms for insuring investments in recovery areas

Social

OBSTACLES FACTORS:
- large-scale labor migration and staff shortages;
- depopulation and demographic imbalance in rural areas;
- low level of trust in state institutions and partnership forms of interaction;
- low environmental and technological culture;
- psychological fatigue of society from war

MARKERS OF POSSIBLE INTERVENTIONS:
- programs for the return of migrant workers;
- development of dual education programs and retraining for bioeconomic sectors;
- development of a system of creation of local "green campuses" for retraining IDPs and veterans;
- encouraging community participation in cluster projects and partnerships;
- government grants for social entrepreneurship in the bioeconomy

Ecological

OBSTACLES FACTORS:
- soil degradation and land contamination due to military operations;
- pollution of water resources and shortage of fresh water after the destruction of hydraulic structures (in particular, the Kakhovka HPP);
- deforestation and desertification of regions;
- disturbance of landscape and ecological structures;
- low share of circular waste processing and high energy intensity of production;
- regulatory and institutional fragmentation

MARKERS OF POSSIBLE INTERVENTIONS:
- ecological reclamation and phytoremediation of land after demining;
- creation of a State Fund for Environmental Restoration and a unified register of environmental damage;
- development of the ecosystem services market;
- certification system for organic products and bioenergy with traceability of origin;
- integration of nature-oriented and circular solutions into post-war reconstruction projects

BIOECONOMIC RECOVERY SYSTEM

Sustainable economic recovery of Ukraine based on bioeconomics (economic performance + ecological regeneration + social cohesion)

Institutional and administrative

OBSTACLES FACTORS:
- lack of a long-term national bioeconomy strategy;
- low level of digital transparency in the management of land, environmental, and energy resources, limited access to open data;
- staff shortage in the field of bioeconomic management;
- insufficient regional integration;
- fragmentation of state policy in the field of "green" transformation;
- institutional gap in the field of strategic management of biological resources;

MARKERS OF POSSIBLE INTERVENTIONS:
- institutional program "Academy of Bio-Management" for civil servants and community leaders;
- clustering of regions by bioeconomic specialization;
- introduction of a unified system for managing biological resources (national geoinformation center);
- establishment of a National Agency for Bioeconomy and Climate Transformation, accountable to the Cabinet of Ministers, with functions of analysis, monitoring, and project financing;
- bridging institutional gaps in the field of strategic management of biological resources and developing a national bioeconomic strategy;

Cognitive-technological

OBSTACLES FACTORS:
- low patent activity in the field of biotechnology and weak protection of intellectual property;
- insufficient digitization of agricultural and processing enterprises;
- lack of effective mechanisms for commercializing research results;
- a shortage of modern research laboratories and testing centers for bioinnovations, especially in the field of biomaterials, biofuels, and agricultural technologies;
- low level of implementation of Industry 4.0 technologies in bioeconomic production;

MARKERS OF POSSIBLE INTERVENTIONS:
- introduction of tax incentives and grant programs for biotechnology startups, particularly in the field of biomaterials, bioenergy, and microbiological fertilizers;
- cooperation with the EU within the Horizon Europe, EIT Food, and Life+ programs to finance joint bioinnovation projects;
- introduction of mechanisms for co-financing experimental developments;
- creation of the national network "BioTech Ukraine": clusters, technology parks, and bioincubators for the development and commercialization of bioinnovations;

Fig. 2. Issues of formation, architecting and ontogenesis of the bioeconomic recovery system

Source: compiled by the authors based on[14].

The application of this approach requires multi-contour management thinking based on four key principles[15]:

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[14] Шубалий О. М., Петруха С. В., Косінський П. М., Петруха Н. М. Формування системи інформаційно-аналітичного забезпечення розвитку біопаливних виробництв на базі підприємств агросектору. *Наукові праці НДФІ*. 2023. № 3. С. 133–147. DOI: https://doi.org/10.33763/npndfi2023.03.133; Шубалий О. М., Петруха С. В., Косінський П. М., Петруха Н. М. Фінансово-економічне стимулювання розвитку переробної промисловості на основі природно-ресурсного потенціалу регіонів у повоєнний період. *Фінанси України*. 2023. № 3. С. 55–74. DOI: https://doi.org/10.33763/finukr2023.03.055 URL: https://finukr.org.ua/docs/FU_23_03_055_uk.pdf; Костєв В. М., Пугачов В. М. Економічні пріоритети хвильових зрушень. Київ: ННЦ «ІАЕ», 2024. 196 с.; Klymenko K., Petrukha N., Petrukha S. "Green" Marshall Plan For Ukraine: Financial, Economic and Regulatory Context. *RFI Scientific Papers*. 2024. № 1 (106). С. 20–49. DOI: https://doi.org/10.33763/npndfi2024.01.020

[15] Arıcıoğlu M. A., Yiğitol B. Paradigm Change in Strategic Management. *Advances in Business Strategy and Competitive Advantage*. 2019. P. 179–195. DOI: https://doi.org/10.4018/978-1-5225-7180-3.ch010; Klikauer T. Managerialism. London : Palgrave Macmillan UK, 2013. 362 p. DOI: https://doi.org/10.1057/9781137334275; Жук В. М. Неформальні інститути селянства у моделюванні реформ та аграрні політики: теорія і практика. *Економіка АПК*. 2017. Т. 24. № 7. С. 5–18.; Kropyvko M. Positives and negatives of the agrarian system of Ukraine. *Ekonomika APK*. 2020. Vol. 309. № 7. P. 6–19. DOI: https://doi.org/10.32317/2221-1055.202007006

First, linking determinants to tools (policy-tool mapping), i.e. determining which norms, incentives, or organisational decisions are relevant for a specific type of factors;

Second, focus on key performance indicators (KPIs), which allow correlating the impact of determinants with measurable goals of economic, environmental and social efficiency;

Third, implementation of feedback mechanisms, under which monitoring results are not recorded passively, but directly adjust the weight parameters of the model and management decisions;

Fourth, coordination between levels of the management system, i.e. ensuring the transition from macroeconomic strategies to micro-organisational practices, which guarantees the unity of goals and synchronisation of policies in the space of bioeconomic development (recovery).

The generalisation of the results of the conducted epistemological and typological analysis gives grounds to assert the following:

The determinants of bioeconomic recovery constitute a network system of interacting subsystems – economic, social, institutional, ecological and cognitive-technological, within which there is a constant circulation of resources, information and decisions;

Socio-economic factors are of dominant importance, because they ensure institutional predictability, cooperative ability and innovative adaptability of bio-oriented systems;

The developed classification architecture (levels of influence, origin, content groups) creates an analytical platform for transforming theoretical knowledge into practical management, with the possibility of linking to specific policies, indicators and implementation mechanisms;

Visualisation in the form of a structural-functional model and a diagram of cause-and-effect relationships serves as a tool for integrating analytics and management, reducing the risk of decision fragmentation and increasing the transparency of the system.

As a result, the analysis performed enables us to transition from theoretical knowledge of determinants to the practice of their institutionalisation, where the epistemological understanding gained is transformed into specific organisational and economic mechanisms, management tools, and cluster solutions. This evolution – from abstract typology to an architecture of action – ensures the formation of a bioeconomic management system capable not only of responding to the challenges of the post-crisis economy but also of actively shaping a new model of regenerative development, based on a balance between efficiency, social trust, and regenerative sustainability.

2. The formation of organisational and economic mechanism and institutional features for implementing the bioeconomy paradigm in economic recovery processes

The formation of an effective system of economic recovery management, taking into account the provisions of the bioeconomic paradigm, assumes the presence of an organisational and economic mechanism that combines institutional stability, social interaction and technological dynamics. In the current conditions of the war economy

and early post-war reconstruction, this mechanism assumes the role of an integrator between the state, scientific, business, and public sectors, which collectively form the architecture of a regenerative economy based on the principles of circularity, regenerativity, and social justice.

Unlike classical regulatory models focused on a linear vertical of power[16], the bioeconomic mechanism forms a decentralised network management system, in which the key coordinators are partnership institutes[17] in the form of bioclusters, innovation networks, regional development agencies (including agrarian chambers), energy cooperatives, and green financing platforms. These institutional forms ensure a transition from fragmented projects to comprehensive recovery programs that initially integrate local initiatives into the national and, in the future, the European context, which is a priori permeated with the spirit of the bioeconomic paradigm.

From the standpoint of management epistemology[18], the organisational and economic mechanism is considered a holistic system of connections that transforms the laws governing the functioning of the bioeconomy into practical algorithms of action. Its place in the structure of economic recovery is determined by the fact that it combines analytical rationality (knowledge, models, and methods) with institutional reality (norms, organisations, behavioural practices). Thus, the organisational and economic mechanism plays the role of a translator between the theoretical level of determinants and the practical level of management decisions, ensuring the controllability, coherence, and adaptability of recovery processes.

This mechanism forms a structured field of interaction between economic agents, within which rights, resources, responsibilities and incentives are distributed to achieve common development goals. Its content is not reduced to a set of tools or functions; it appears as an institutional and organisational environment in which economic processes acquire systemic coherence, and the conflict of interests is

[16] Klikauer T. Managerialism. London : Palgrave Macmillan UK, 2013. DOI: https://doi.org/10.1057/9781137334275; Classical Political Economy and Modern Theory: Essays in Honour of Heinz Kurz / I. Steedman et al. Taylor & Francis Group, 2013. 384 p.; Удосконалення інформаційно-правового забезпечення сфери АПК та захисту прав суб'єктів агробізнесу: колективна монографія / Я. П. Аргат, І. В. Ковальчук, І. Ю. Ломакіна, О. І. Настіна, А. О. Пахомова. Біла Церква : Білоцерківський національний аграрний університет, 2023. 201 с.

[17] Петруха Н. М., Петруха С. В. Державне регулювання інтегрованих корпоративних об'єднань в умовах структурно-інституціональної та функціональної трансформації сільської економіки: проблеми методології, теорії, соціально-економічної та секторальної політики : монографія. Київ : ТОВ «Видавничий дім «Професіонал», 2020. 496 с. + 1 електрон. опт. диск.; Petrukha S., Petrukha N., Alekseienko N., Mazur A., Maltsev M. The post-war potential and regulatory capacity of rural territorial communities in the clustering and integrating agri-food chains of local added value creation. Modern foundations of economics, management and tourism. Boston : International Science Group. Primedia eLaunch, 2022. P. 96–126. DOI: https://doi.org/10.46299/ISG.2022.MONO.ECON.4.3.1; Гуторов А. О. Корпоратизація в аграрному секторі економіки. Монографія. Київ: ННЦ «ІАЕ», 2024. 256 с.

[18] Від кризи до зростання: уроки ЄС для промислового відновлення України: колективна монографія / за ред. д.е.н., проф. В. А. Омельяненка. НАН України, Ін-т економіки пром-сті. Київ, 2024. 198 с.; Мельникова М., Бойченко М., Кочешкова І. Управління розвитком промислових територій: циркулярність, публічність, екологічність : монографія / НАН України, Ін-т економіки пром-сті, 2023. 174 с.

transformed into a coordinated process of cooperation. If in classical economics[19] the mechanism mainly performs the function of correcting market distortions, then in bioeconomy[20] it is focused on creating conditions for long-term regeneration of resources, environmentally-oriented innovation and social cohesion. Therefore, the organisational and economic mechanism of bioeconomic recovery should be interpreted as a five-component system in which the following blocks interact[21]:

Target block formulates strategic and operational goals of recovery (economic, environmental, social, and technological). It sets normative and value guidelines, coordinates state policy goals with the interests of local communities and business structures;

Functional block ensures the implementation of key management functions (potential diagnostics, planning, coordination, stimulation, control, monitoring, and performance assessment);

Instrumental block covers the means of achieving goals (financial and credit, tax, innovation, information, analytical and legal instruments);

Institutional block represented by a set of subjects and forms of interaction (state, business, science, territorial communities, public organisations, international partners);

Performance block reflects integrated indicators of recovery effectiveness (GDP growth rates in bioeconomy sectors, energy efficiency, carbon emissions reduction, growth in the share of "green" employment, trust and social cohesion index).

Each block is in a state of interdependence with the others, forming a closed management outline. This closedness, the presence of feedback and the possibility of adaptive adjustment of decisions distinguish the bioeconomic mechanism from conventional administrative structures built on a rigid hierarchy and command-and-control logic. This approach allows us to identify the basic principles of the organisational and economic mechanism of bioeconomic recovery, which are[22]:

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[19] Eltis W. The Classical theory of economic growth. London : Macmillan, 1984. 372 p.; Саблук П. Т. Аграрним реформам – усвідомлений розвиток. *Економіка АПК*. 2012. № 6 (212). С. 3–5.

[20] Збарський В. К. Біоекономіка у розвитку АПК України. *Економіка АПК*. 2017. № 8 (274). С. 94–97.; Kucher O. Bioeconomy as the modern paradigm of economic development. *Bioeconomics and Agrarian Business*. 2021. Vol. 12, № . 2. DOI: https://doi.org/10.31548/bioeconomy2021.02.002

[21] Петруха Н. Повоєнне відновлення аграрного сектору економіки на засадах біоекономіки. *Економічний аналіз*. 2023. Том 33. № 4. С. 49–58. DOI: https://doi.org/10.35774/econa2023.04.049; Лупенко Ю. О., Андрос С. В. Погляд на агропромисловий комплекс україни крізь призму аналізу статистичних даних. *Економічний вісник Національного технічного університету України «Київський політехнічний інститут»*. 2020. Т. 1, № 17. DOI: https://doi.org/10.20535/2307-5651.17.2020.216336; Гадзало Я. М., Саблук П. Т., Лупенко Ю. О. Аграрна реформа в Україні, її наукове забезпечення, результативність. *Економіка АПК*. 2021. № 7. С. 6–15. DOI: https://doi.org/10.32317/2221-1055.202107006

[22] Козак М. Організаційно-економічний механізм розвитку сільських територій. Вісник Хмельницького національного університету. Серія «Економічні науки». 2021. Т. 298. № 5(2). С. 291–296. DOI: https://doi.org/10.31891/2307-5740-2021-298-5(2)-49; Степаненко Т., Виноgraденко С. Організаційно-економічні засади екологізації землекористування. *Наукові інновації та передові технології*. 2022. № 9(11). DOI: https://doi.org/10.52058/2786-5274-2022-9(11)-359-372; Ivanov K. Economic mechanism in Bulgarian foreign trade. Sofia : Bulgarian Chamber of Commerce and Industry, 1985. 45 p.

Synergy of resources and competencies, which ensures the integration of the potential of different sectors of the bioeconomy and actors into common coordinates of development;

Adaptability, which allows the system to respond promptly to changes in the external environment, expressed in market, technological, environmental or social factors;

Ecological rationality, which provides for the priority of regenerative and circular approaches to the use of natural capital;

Inclusiveness, which guarantees the participation of all stakeholders, in particular territorial communities, in the formation and implementation of recovery policies;

Openness and transparency, which create conditions for public control and increase trust in institutions;

Decentralisation of management, which forms a polycentric model, within which local clusters receive space for self-regulation;

The system's innovativeness and learning capacity are the key to the permanent modernisation of management structures and knowledge renewal.

These principles form the axiological core of the mechanism, setting not only the rules of operation but also the moral and value code of bioeconomic management, in which efficiency is inseparable from the ethics of responsibility to nature and society.

The organisational and economic mechanism of bioeconomic recovery implements its action through a system of interconnected functions, which are[23]:

Analytics, identification of socio-economic determinants, assessment of resource potential, identification of growth points and risks;

Coordination to synchronise actions between state, regional and corporate levels of management;

Innovations that stimulate the implementation of bioinnovations, activate investments in R&D, biotechnology, and energy-efficient production;

Control that provides systematic monitoring of effectiveness, transparency of the project and policy effectiveness assessment;

Communications that contribute to the development of horizontal connections, partnerships and open data platforms, enhancing network interaction.

The tools for implementing these functions include[24]:

[23] Pysarenko V., Pronko L., Pidvalna O., Lozhachevska O., Fastovets N., Ribeiro R. Marketing management of the bioeconomic potential of enterprises and the quality of their innovative products in the post-war recovery strategy. *Financial and Credit Activity Problems of Theory and Practice*. 2024. № 6 (59). P. 648–664. DOI: https://doi.org/10.55643/fcaptp.6.59.2024.4637; Nykyforov V., Maliovanyi M., Kasych A. Scientific fundamentals of the biorefiner project – dominants of the bioeconomic cluster in the region. *Transactions of Kremenchuk Mykhailo Ostrohradskyi National University*. 2020. Vol. 5–6. P. 47–53. DOI: https://doi.org/10.30929/1995-0519.2020.5-6.47-53

[24] Klymenko K., Petrukha N., Petrukha S. "Green" Marshall Plan For Ukraine: Financial, Economic and Regulatory Context. *RFI Scientific Papers*. 2024. № 1 (106). С. 20–49. DOI: https://doi.org/10.33763/npndfi2024.01.020; Шубалий О. М., Петруха С. В., Косінський П. М., Петруха Н. М. Фінансово-економічне стимулювання розвитку переробної промисловості на основі природно-ресурсного потенціалу регіонів у повоєнний період. *Фінанси України*. 2023. № 3. С. 55–74. DOI: https://doi.org/10.33763/finukr2023.03.055; Baber H., Fanea-Ivanovic M. Alternative Finance : A Framework for Innovative and Sustainable Business Models. Taylor & Francis, 2024. 308 p.

Green financing mechanisms through guarantees of origin, green bonds, ESG investments;

Tax (fiscal) and credit incentives for bio-oriented enterprises;

Public-private partnership in creating cluster infrastructure;

State programs for training and retraining of personnel in the bioeconomy;

Digital analytical platforms for monitoring bioresources, emissions, and investment flows;

Cluster innovation hubs (biohubs), which serve as knowledge centres for technology transfer.

The integration of these tools creates a multiplier effect, in which management actions in one subsystem, in particular in the areas of state support, access to financial resources or public investment programs, activate processes in other areas – educational, social, and environmental, which strengthen the sustainability and institutional capacity of the entire recovery system.

The effectiveness of the organisational and economic mechanism of bioeconomic recovery is also determined by the sequence and coherence of its implementation stages, which form a closed management cycle[25]:

Diagnostics of potential – assessment of natural resource, social, financial and technological prerequisites for the formation of a bioeconomic system;

Cluster network design – identification of territorial development centres, creation of clusters as an institutional form of integration of participants;

Institutionalisation of interaction – development of regulatory acts, signing partnership agreements, formation of joint management structures;

Formation of infrastructure and knowledge management – creation of logistics, energy, digital and innovation platforms that ensure the circulation of resources and data;

Monitoring and evaluating performance – regular tracking of KPIs, adaptation of tools and policies based on analysis results.

The algorithm is iterative, meaning that after each cycle, the system undergoes an update phase, where feedback results compose new management decisions. This turns the mechanism into a self-learning structure capable of evolutionary adaptation in conditions of uncertainty and constant external shocks.

Among the various organisational forms, the biocluster most fully embodies the logic of the bioeconomic mechanism. It acts as an institutional shell that combines resources, knowledge, technologies and social ties to achieve complex recovery

[25] Малихіна О. М., Петруха С. В., Предун К. М., Кістіон Д. В., Хоменко О. М., Кучеренко О. І., Петренко Г. С., Рижакова Г. С., Веремєєва Т. І. Еколого-економічне моделювання предикторів інвестиційних програм сталого розвитку девелопменту в концепті стандартів біосферосумісного будівництва. *Шляхи підвищення ефективності будівництва в умовах формування ринкових відносин*. 2018. № 38. С. 45–54. URL: https://core.ac.uk/download/pdf/337304296.pdf; Петруха Н. М., Каращенко В. С. Управління розвитком аграрної галузі в контексті сучасних економічних тенденцій. *Академічні візії*. 2024. № 31. DOI: https://doi.org/10.5281/zenodo.11912968; Applications of Modern Production Theory: Efficiency and Productivity (Studies in Productivity Analysis) / ed. by A. D. (Editor), R. F. (Editor). Springer, 1988. 292 p.; Phillips P. W. B. Innovation in agri-food clusters: Theory and case studies. Cambridge, MA : CABI, 2013. 218 p.; Antle J. M., Capalbo S. M. Agricultural Productivity: Measurement and Explanation. Taylor & Francis Group, 2015. 422 p.

goals. Therefore, a biocluster is not just a concentration of enterprises in a specific industry, but a network system of cooperation that ensures the coordination of economic and climate goals, the reduction of transaction costs of interaction between participants, the joint use of resources (energy, data, bioraw materials), increasing the competitiveness of regions through ecological specialisation and the development of human capital by creating educational and innovative centres[26].

In the national context, a biocluster can become a key institutional unit of post-war recovery policy, since it combines the principles of regional decentralisation with the need for strategic coordination at the state level. The socio-economic determinants considered in the previous subsection are practically implemented in the biocluster through institutional forms of governance, financing mechanisms, social platforms and partnership models.

In modern economic architecture, it is appropriate to consider a biocluster not only as an institutional form of production organisation, but as a spatial-network system of bioresource management that integrates territorial, intellectual and financial flows. Its mission is to form a "mutual reinforcement economy", where the results of the activities of some participants automatically become resources for others, and the effect of interaction exceeds the sum of individual results.

In this sense, the biocluster serves as the foundation for polycentric management of the bioeconomy, within which regional development nodes operate autonomously but are integrated into a single national network through a system of information, financial, and regulatory connections. This logic corresponds to the European concept of S3 Smart Specialisation[27], in which clusters play the role of platforms for the "fusion" of science, business, education and public administration. In Ukrainian conditions, this means transitioning from a hierarchical management model to a flexible network configuration, in which economic dynamics are determined by the ability to self-organise and adapt at the local level. Table 1 presents the general content of the key systemic functions of the biocluster in the mechanism of bioeconomic recovery, demonstrating their structural interaction and instrumental implementation at different management levels.

A biocluster performs an integration function, i.e., uniting enterprises from different links of the biochain – from raw material producers to processing enterprises, logistics

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[26] Петруха С. В., Петруха Н. М., Демидьонок І. А., Тарасенко М. І. Децентралізація та сталий розвиток сільських територій: довоєнне координування систем прийняття кластерних рішень. Інноваційно-інвестиційний механізм забезпечення конкуренто-спроможності країни. Львів-Торунь : Ліга-Прес, 2022. С. 22–56. DOI: https://doi.org/10.36059/978-966-397-255-8-2; Онікієнко Н. В., Петруха Н. М., Рижакова Г. М. Науково-прикладні компоненти полікритеріальної системи оцінки інноваційного розвитку підприємств: імперативи взаємодії інтегрованих структур. *Шляхи підвищення ефектив-ності будівництва в умовах формування ринкових відносин*. 2023. № 52 (1). С. 261–273. URL: http://ways.knuba.edu.ua/article/view/314384/305292; Kowalski A. M. Clusters and Cluster Policy Models : Driving Competitiveness in the Global Economy. Edward Elgar Publishing Limited, 2025. 220 p.

[27] Analysis of key parameters of smart specialisation strategies (S3). URL: https://op.europa.eu/en/publication-detail/-/publication/3026007b-8be2-11ed-999b-01aa75ed71a1/language-en

structures and consumers – into a single system of interaction[28]. Its essence lies in the combination of vertical integration (supplier → producer → consumer) with horizontal (cooperation between enterprises of the same or related industries). This creates a synergistic effect, in which production, energy, technological and information flows become complementary. Thus, the integration function is manifested in the interaction of the agricultural sector with bioenergy and processing industries, where biomass residues or by-products of agricultural production are converted into resources for energy or the production of biomaterials[29].

The innovative function of the biocluster is aimed at accelerating technology transfer, developing joint laboratories, competence centers, bioincubators and technology parks. Within the framework of this function, clusters form an institutional infrastructure for research and development (R&D), stimulate small and medium-sized businesses to implement innovative solutions in the field of biowaste processing, the creation of new bioproducts and circular production technologies. Of particular importance is the digital transformation of cluster systems[30], which includes the implementation of IoT monitoring, geographic information systems (GIS), digital accounting of bioresources and modelling of bioenergy flow processes. This function contributes to the intellectualisation of production and increased technological flexibility, which is a determining condition for recovery in the face of military and climate challenges.

The financial-intermediary function ensures the accumulation and redistribution of financial resources between cluster participants, creating conditions for attracting "green" investments, grants, venture financing and public-private partnership instruments. It transforms the cluster into a kind of "financial connector" that integrates state programs, donor funds, and private capital into a unified system of support for bioeconomic initiatives. In post-war Ukraine, such a function will be of strategic importance; therefore, bioclusters should become the primary channels for attracting resources from the European Union, the World Bank, and international environmental funds for the implementation of regional recovery programs.

No less important is the regulatory-communication function of bioclusters, which forms a two-way connection between state structures, business and civil society. The cluster serves not only as a platform for discussion but also as a tool for coordinating state, regional, and local policies. The cluster adapts European environmental standards, harmonises local regulations, and creates common platforms for open data and information, as well as analytical systems for bioresource

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[28] Ryzhakova G., Petrukha S., Petrukha N., Krupelnytska O., Hudenko O. Agro-Food Value Added Chains: Methodology, Technique and Architecture. *Financial and Credit Activity: Problems of Theory and Practice*. 2022. Volume 4 (45). P. 385–395. DOI: https://doi.org/10.55643/fcaptp.4.45.2022.3809

[29] Vallier E. Innovation in Clusters: Science-Industry Relationships in the Face of Forced Advancement. Wiley & Sons, Incorporated, John, 2022. 256 p.

[30] Яцун А., Вдовенко Н. Фінансові інструменти сталого розвитку в аспекті моделювання аграрного сектору економіки України. *Acta Academiae Beregsasiensis. Economics*. 2024. № 5. С. 230–245. DOI: https://doi.org/10.58423/2786-6742/2024-5-230-245; Арзубов М. В., Батюк А. Є. Аналіз рішень та підходів кластеризації геопросторових даних для оптимізації продуктивності вебкарти та взаємодії користувача. *Український журнал інформаційних технологій*. 2023. Вип. 5. № 2. С. 88–96. DOI: https://doi.org/10.23939/ujit2023.02.088

management. This function enables the translation of state goals, such as the "green" transition, community restoration, and decarbonisation of production, to the level of specific enterprises, while providing feedback on real barriers and the results of policy implementation.

At the same time, the biocluster performs an evolutionary and personnel development function, which includes the formation of human capital, fostering social cohesion, and promoting a new ethical culture of production and public participation. Within its framework, the biocluster appears as an educational and innovative hub, where educational, scientific and social programs are combined. This involves creating a system of training personnel for bioeconomic enterprises, retraining workers, reintegrating veterans of the Russian-Ukrainian war into a peaceful economic environment[31], and developing "green" employment opportunities in rural communities. The evolutionary and personnel function ensures not only the continuous renewal of competencies, but also the formation of social trust, which is a key determinant of the stability of cluster systems.

Table 1

System functions of the biocluster in the mechanism of bioeconomic recovery

Biocluster function	Strategic role in post-war bioeconomic recovery	Key management tasks	Typical tools	Expected effects / Indicative KPIs
Integration function	Restoring broken production chains and forming new regional connections between the agricultural, energy and processing sectors	Reintegration of enterprises into common logistics networks; creation of cross-sectoral cooperation to replace lost capacities; support for business relocation	Cluster agreements on the sharing of infra-structure; logistics alliances between regions; digital maps of production capacities; supply-demand mapping platforms	Increase in the number of integrated production nodes; reduction of logistics losses; growth in the volume of interregional supplies of bio-raw materials
Innovative function	Transition from restoring the "infrastructure of the past" to creating an innovative, low-carbon production base	Reintegration of enterprises into common logistics networks; creation of cross-sectoral cooperation to replace lost capacities; support for business relocation	Bioincubators, technology parks, Green Recovery Labs; state vouchers for research; digital platforms for joint developments; EU and World Bank grants	Number of R&D projects implemented in affected regions; increase in the share of energy-saving technologies; reduction of carbon emissions in restored production

[31] Petrukha N. M., Petrukha S. V., Hudenko B. O., Hudenko O. D. The Policy of Heroes – A New Philosophy of Veteran Business. *Business Inform*. 2024. № 1. P. 392–404. DOI: https://doi.org/10.32983/2222-4459-2024-1-392-404; Тріпак М. М., Петруха С. В., Петруха Н. М., Коноваленко Д. В. Ветеранський бізнес: резильєнтність інклюзивної економіки та державних фінансів. *Інклюзивна економіка*. 2024. № 2 (04). С. 42–55. DOI: https://doi.org/10.32782/inclusive_economics.4-8

Table 1 (continuance)

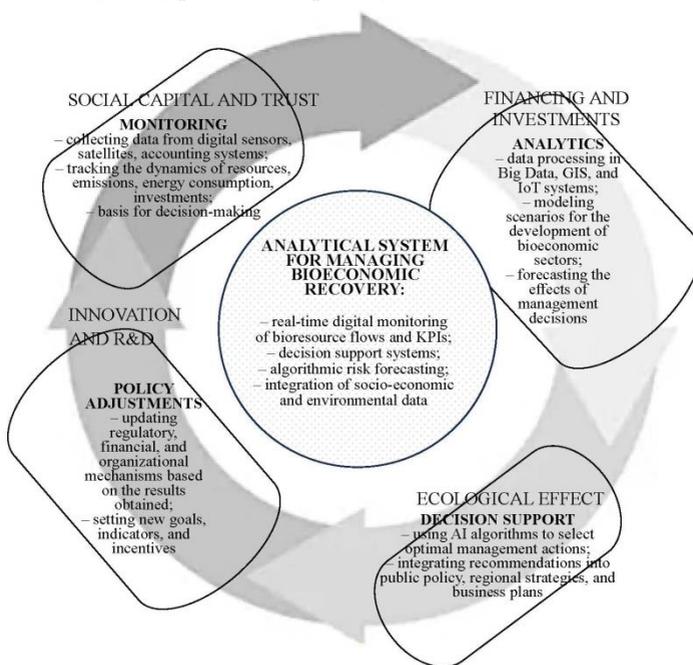| Financial-intermediary function	Accumulation of resources for the recovery of infrastructure, enterprises and communities through "green", social and reconstruction financing	Attraction of international grants and loans for the recovery of bio-oriented enterprises; formation of a system of regional recovery funds; coordination of donor programs	Public-private partnership; "green' bonds; rebuild bonds; G7 and EU trust funds; World Bank programs for the recovery of bioeconomic chains	The volume of funds attracted to biocluster projects; the number of enterprises that have resumed work; the share of financing directed to "green" investments
Regulatory-communication function	Coordination between the central government, communities, international partners and businesses in the field of bioeconomic recovery	Harmonisation of Ukrainian legislation with European Green Deal standards; development of regional recovery plans with a bioeconomic component; development of digital transparency systems	National Council for Bioeconomy; regional recovery coordination offices; BioData UA open data platforms; intergovernmental programs "Green Reconstruction Dialogues"	Level of regulatory harmonisation with the EU; number of regions that have integrated the bioeconomic approach into recovery plans; degree of participation of communities and businesses in the policy dialogue
Evolutionary and personnel development function	Post-war human capital formation: training, veteran reintegration, development o f "green" employment	Launch of cluster training centres; creation of retraining programs; support for young professionals in devastated regions; development of social innovations and cooperatives	Programs "Green Skills for Recovery", "BioFuture Academy"; partnerships with universities and communities; digital educational platforms; social startups in the bioeconomy	Number of people trained or retrained; growth in employment in bioeconomy sectors; index of trust and social cohesion in communities

Source: compiled by the authors based on[32].

The system functions of the biocluster, summarised in Table 1, demonstrate that its role in bioeconomic recovery goes far beyond sectoral coordination or a simple association of enterprises. The biocluster is transformed into an institutional and spatial form of development management that combines production, financial,

[32] Бунтов І. Ю. Перспективи розвитку біотехнологій в Україні [Текст] : монографія. Харків : Лібуркіна Л. М., 2019. 276 с.; Байдала В. В. Біоекономіка в Україні: формування, перспективи розвитку та макроекономічні впливи [Текст] : монографія. Суми : Наталуха А. С. [вид.], 2016. 375 с.; «Зелена» економіка як підґрунтя екологізації місцевого розвитку [Текст] : монографія / Бондар О. І., Галушкіна Т. П., Унгурян П. Я. ; за заг. ред. д-ра біол. наук, проф. О. І. Бондаря ; Держ. екол. акад. післядиплом. освіти та упр. Херсон : ОЛДІ-ПЛЮС, 2018. 237 с.; Петруха Н. Повоєнне відновлення аграрного сектору економіки на засадах біоекономіки. *Економічний аналіз*. 2023. Том 33. № 4. С. 49–58. DOI: https://doi.org/10.35774/econa2023.04.049

scientific, educational and social resources in a common recovery circuit. As a result of the Russian-Ukrainian war, this multi-level architecture enables the overcoming of economic space fragmentation by integrating local initiatives into the national recovery system. The functional directions of the clusters – from integrational to evolutionary and human resources – form a chain of recovery synergy, where production, innovation, financing, regulation, and personnel training act in concert. This creates the conditions for the transition from chaotic recovery to a managed reconfiguration of the economy, focused on sustainability, trust and innovation.

Further development of the biocluster mechanism in the context of digital transformation necessitates the formation of a SMART bioeconomic recovery control loop as a dynamic system that combines digital analytics (real-time monitoring of bioresource flows and KPIs), algorithmic decision support (scenario modelling, machine learning, risk forecasting), and automated feedback (dynamic adjustment of financial and regulatory parameters depending on the results).

Fig. 3. SMART bioeconomic recovery control loop

Source: compiled by the authors based on[33].

We position such a SMART bioeconomic recovery control loop as an innovative tool for state and regional policy, combining strategic focus with operational responses to environmental changes. Its implementation transforms the organisational and economic mechanism of bioeconomic recovery from adaptive to predictive, which increases the resilience of bioeconomic recovery to global shocks, climate risks and geopolitical instability.

Thus, the organisational and economic mechanism of bioeconomic recovery is a multi-level, self-learning system in which managerial, financial, technological and social components function in a single loop. Its effectiveness is determined not so much by the volume of resources involved as by the quality of institutional interaction, the speed of knowledge transfer and the ability to adapt. Acting as a transmission channel between the theory of determinants and the practice of recovery, this mechanism lays the groundwork for transitioning from disparate initiatives to a holistic management architecture, where economic efficiency is combined with environmental expediency and social justice.

At the same time, the institutional form of the biocluster ensures the practical implementation of the specified mechanism, transforming the systemic logic of management into specific models of interaction among enterprises, scientific centres, communities, and authorities. The biocluster serves not only as a space for innovative cooperation but also as a channel for approximating the bioeconomic paradigm with the industry level, where production, social and environmental priorities are coordinated.

Due to the interdependence between the mechanism and the institutional form of its implementation, the following analytical dimension of the study is revealed: the industry-cluster approximation of the bioeconomic model, within which bioeconomic principles are applied in production systems, technological chains, and processes of resource renewal.

3. The organisational, economic and institutional principles of approximation of the bioeconomic paradigm to the processes of economic recovery of bioeconomy industries

In the current conditions of the post-war transformation of the Ukrainian economy, bioeconomy appears not only as a theoretical model of sustainable development, but as a practical paradigm for the reconstruction of production systems focused on the regeneration of natural capital, innovative reproduction of resources and social cohesion. Its approximation at the sectoral level involves the transfer of systemic principles of bio-oriented management to specific sectors of the real economy, such as agricultural, forestry, bioenergy, food, pharmaceutical, biochemical, processing, and water management. At this level, the transformation of general economic patterns and determinants analysed in the previous subsection into practical production mechanisms that form the basis for sustainable economic recovery takes place.

Bioeconomy industries are sectors whose activities are related to the production, processing, and use of biological resources, utilising environmentally balanced technologies and principles of circularity. Their structure includes: firstly, primary industries – bioagricultural, forestry, fisheries, water management complexes; secondly, processing industries – food, biochemical, pharmaceutical industries; thirdly, the renewable energy sector – bioenergy, biogas, biomethane, second-generation biofuels;

fourthly, supporting industries – digital resource management technologies, bioengineering, bioproduct logistics. The interaction between these subsystems forms a single bioeconomic complex, in which material, energy, and information flows are in a state of constant recycling and reutilisation. At the same time, each industry functions as a production system – an organised set of processes and connections that ensure the transformation of bioresources into economic and social value.

In classical economics[34], a production system is defined as a set of interconnected elements – labour, means of production, technologies and management. In the bioeconomic context, this concept undergoes a qualitative expansion due to the positioning of the system as an open ecological and socio-technical network, in which performance is determined not only by the efficiency of resource use, but also by the degree of their recovery, reduction of the carbon footprint, adaptability to climate change and the ability to self-organise. Its key attributes include[35]: bioresource circularity, which ensures the closure of material cycles; energy efficiency and waste minimisation; intellectualisation of processes, which is carried out through the use of digital technologies, big data and IoT monitoring; social integration, which involves the inclusion of local communities in the processes of bioproduction and decision-making; organisational plasticity, which can ensure rapid restructuring of technological and managerial relations in response to shocks in demand, supply or resource constraints.

This understanding of production systems requires new organisational and economic management models capable of harmonising the goals of ecologically oriented development (recovery) with economic profitability. Therefore, the basic carrier of the approximation of the bioeconomic paradigm is the biocluster, which is the key institutional form through which the macro-level organisational and economic mechanism "descends" to the industry (meso-level) and micro-level. The biocluster integrates enterprises from different links of the production chain, research institutes, educational institutions, local governments, and financial institutions, creating an environment of convergence of knowledge, resources, and technologies, where circularity, digitalisation, and decentralised management become everyday business practices.

The general logic of the transition from the bioeconomic paradigm to the level of industry production systems is presented in the form of a multi-level model (Figure 4), which consistently reflects the value-conceptual framework of the bioeconomy, the organisational and economic mechanism for managing recovery, institutional forms of implementation (bioclusters, regional platforms, innovation hubs, partnerships "state – business – science – communities"), production systems

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[34] Productivity and Organizational Management / S. G. Broncano et al. ; ed. by C. Machado, J. P. Davim. De Gruyter, 2017. DOI: https://doi.org/10.1515/9783110355796; Dowse J., Woods I. ESG Unlocked : How successful companies and investors build our natural, social, human and financial capital. Walter de Gruyter GmbH, 2026. DOI: https://doi.org/ 10.1515/9783111428949

[35] Байдала В. Вплив біоекономіки на продовольчу безпеку України. *Agricultural and Resource Economics: International Scientific E-Journal*. 2016. Т. 2, № 3. С. 48–59. DOI: https://doi.org/10.51599/are.2016.02.03.05; Талавиря М., Газуда Л., Газуда М. Перспективи розвитку біоекономіки замкнутого циклу в Україні. *Геополітика України: історія і сучасність*. 2021. № 2(27). С. 128–138. DOI: https://doi.org/10.24144/2078-1431.2021.2(27).128-138

of bioeconomy industries, and the results of bioeconomic recovery with their feedback on the mechanism and paradigm.
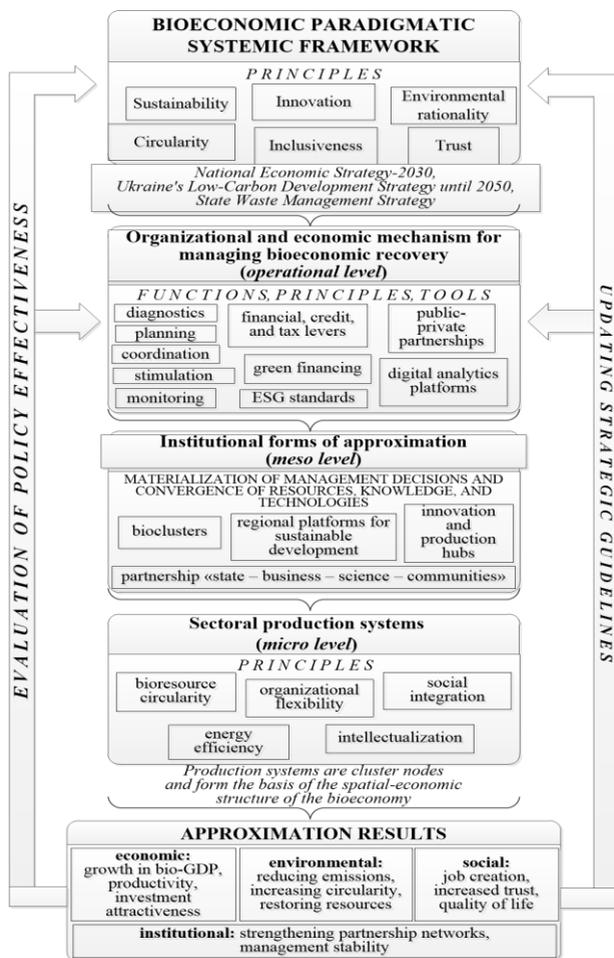
Fig. 4. Model of approximation of the bioeconomic paradigm into industry production systems

Source: compiled by the authors based on[36].

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[36] Фатенок-Ткачук А. О. Парадигма проявів «нової» еконеоміки. *Актуальні проблеми економіки*. 2012. № 12 (138). С. 53–60.; Павлов О. Парадигма сільського розвитку. *Економіка України*. 2006. № 7. С. 41–48.; Nagothu U. S. Bioeconomy Approach: Constraints and Opportunities for Sustainable Development. Taylor & Francis Group, 2020. 268 p.

Within the biocluster, the production systems of bioeconomy industries function as nodes of a network economy, connected by common infrastructure, logistics, technological standards, and monitoring systems for emissions, energy consumption, and resource quality. This positioning of production systems within the biocluster structure provides economies of scale, reduces transaction costs, accelerates the diffusion of innovations, and also creates the prerequisites for harmonising the economic, environmental, and social goals of recovery.

A combination of endogenous and exogenous factors determines the effectiveness of bioeconomy production systems. Endogenous factors include[37] the quality of human capital and managerial competencies, the level of environmental awareness of personnel, technological flexibility and ability to innovate, the cost structure and the level of energy intensity of production, the internal organisational culture that sets cooperative behaviour and attitude to risk, the effectiveness of digital infrastructure, quality control systems, logistics and resource accounting.

Exogenous factors include[38] the legal field, environmental regulation and certification standards, financial and credit policy, access to "green" investments and tax preferences, the state of the region's natural resource potential, the level of development of the innovation ecosystem and partner networks, social trust and the stability of solvent demand for bioproducts. The interaction of these factors forms the bioeconomic elasticity of the production system, i.e. its ability to maintain stability and restore functionality under conditions of external shocks or structural constraints.

Within bioeconomic production systems, it is advisable to evaluate the effectiveness of organisational, technical, and economic measures through a system of integrated performance indicators that reflect the economic, energy, and environmental effects of implementing innovations. The basic concept is the absolute effect of an organisational and technical measure[39]:

$$E_i = \Delta P_i - C_i \tag{2}$$

Where E_i – absolute effect obtained from the implementation of the i-th project (measure);

ΔP_i – profit increase obtained as a result of the implementation of the project (measure);

C_i – total costs for the implementation of the project (measure).

[37] Яремова М., Тарасович Л., Кільніцька О. Детермінанти розвитку циркулярної біоекономіки: методологічно-прикладний аспект. *Сталий розвиток економіки*. 2025. № 4 (55). С. 641–650. DOI: https://doi.org/10.32782/2308-1988/2025-55-87; Гонта Д., Кирилюк Є., Прощаликіна А., Риженко Н. Формування складників національної біоекономіки України в умовах прискорення науково-технічного прогресу : монографія. Черкаси: ЧНУ ім. Б. Хмельницького, 2020. 233 с.

[38] Вострякова В., Зайцева-Чіпак Н., Фау Є. Інноваційний розвиток біоекономічного потенціалу України. Вінниця. 2024. 52 с.; Зелена трансформація та стала біоекономіка: моногр.; за наук. ред. А. А. Олешко, О. Ю. Будякової. Київ: КНУТД, 2024. 496 с.

[39] Петренко Г. С., Петруха Н. М., Рижакова Г. С., Марчук Т. С., Малихіна О. М., Приходько Д. О. Вибір імперативів бюджетування інвестиційно-будівельного проєкту як напрям удосконалення системи фінансового менеджменту підприємства. *Управління розвитком складних систем*. Київ. 2021. № 46. С. 108–117. DOI: https://doi.org/10.32347/2412-9933.2021.46.108-117

This formula is universal for assessing the economic benefits of energy-saving technologies, biowaste processing systems, and digital solutions for monitoring energy or raw material consumption.

Accordingly, the relative effect (return on investment period or cost-effectiveness) is calculated as[40]:

$$К_i = \frac{C_i}{\Delta P_i} \tag{3}$$

Where $К_i$ – characterises the speed of return on investment, i.e. the time for which additional profit compensates for the invested resources.

In the bioeconomic context, this indicator allows the comparison of returns on investment, for example, for secondary raw material utilisation systems, photovoltaic and bioenergy plants, or circular water supply projects.

The comparative assessment of the results of several alternative solutions is based on the effect–cost principle, which is generally reflected by the equation[41]:

$$E = \frac{\sum_{i=1}^{n} \Delta P_i}{\sum_{i=1}^{n} C_i} \tag{4}$$

Where E – the integral efficiency coefficient of the project (measure) complex.

For bioeconomic enterprises, this indicator is advisable to use when analysing targeted programs for modernising production, particularly when determining the optimal combination of energy, technological, and managerial innovations.

If the object of assessment is a single innovation process, it is advisable to define the effect as the relative change in the result "before" and "after" the project (measure)[42]:

$$E_r = \frac{R_1 - R_0}{R_0} \tag{5}$$

Where R_0 і R_1 – are, respectively, the base and new (project) levels of the indicator (e.g., profit, energy consumption, raw material yield).

Formula (5) represents the increase in efficiency resulting from the introduction of an innovation, such as technologies for the deep processing of organic raw materials or digital emission control.

The generalised effect, taking into account indirect factors, can be presented as follows[43]:

[40] Григоренко В. В., Малихін М. О., Петренко Г. С., Петруха Н. М., Рижакова Г. С. Прикладні підсистеми аналітичного супроводу інституційних учасників при реалізації проєктів ДПП у будівництві. *Управління розвитком складних систем*. Київ. 2021. № 45. С. 141–149. DOI: https://doi.org/10.32347/2412-9933.2020.45.141-149

[41] Безтелесна Л., Буткевич В. Інноваційний розвиток підприємств харчової промисловості. *Bulletin National University of Water and Environmental Engineering*. 2023. Т. 4. № 104. С. 75–86. DOI: https://doi.org/10.31713/ve420236

[42] Шпаков А. В., Жалдак Р. Ю., Кушнір І. І., Петруха Н. М., Ніколаєв Г. В., Рогов-ченко В. С. Інноваційно-прикладна основа структурно-функціональної регламентації операційної системи управління провідних стейкхолдерів будівельного проєкту. *Управління розвитком складних систем*. Київ. 2021. № 47. С. 151–161. DOI: https://doi.org/10.32347/2412-9933.2021.47.151-161

[43] Вороніна В. Л., Нечитайло Ю. А. Інвестиції: фактори та ризики. *Управління змінами та інновації*. 2022. № 4. С. 5–8. DOI: https://doi.org/10.32782/cmi/2022-4-1

$$\text{E}_{\text{заг}} = \text{E}_r + \sum_{j=1}^{m} aj \times \Delta S_j \tag{6}$$

Where aj – weighting factor of the j-th indirect result (social, environmental, institutional);

ΔS_j – change in the corresponding indicator (e.g., employment level, emission reduction, increased trust in the bioproducer).

This approach allows integrating "non-price" effects into the overall assessment of the effectiveness of bioeconomic interventions.

Each industry of the bioeconomy has its own configuration of endogenous and exogenous determinants, but is subject to a common systemic logic of functioning. The seasonality of bioproduction necessitates flexible planning, optimisation of the production cycle duration, and a combination of capital investments in processing capacity and raw material storage infrastructure. Seasonality in traditional processing industries (canning, fruit and vegetable, sugar, wine, etc.) is a key factor in uneven capacity utilisation, slow turnover of funds and increased fixed costs. The quality of the input bio-raw materials directly affects the yield of nutrients, production cost, return on assets, and labour productivity. Thus, a 1% change in the dry matter content of tomatoes or the sugar content of beets can be equivalent to an 18–20% increase in the volume of raw materials or an additional tens of kilograms of product per ton of raw materials[44].

Technological adaptability creates the possibility of switching to alternative types of raw materials (for example, sugar beet/raw cane sugar, and potatoes/cereals in starch and alcohol production[45]), which alters the structure of costs and profitability, and therefore directly affects the trajectories of economic growth of bio-enterprises. Resource integration and complex waste processing (as traditionally implemented in sugar, alcohol, canning, winemaking and meat-processing enterprises) provide additional production of bio-products based on side streams. They are a direct prototype of circular bio-production models.

In this context, organisational and economic determinants shape the practical manageability of production systems. Bioeconomic approximation requires their targeted development[46]:cluster integration as a tool for coordinating the interests of

[44] Щербич М., Поян О., Сиротюк І. Інноваційні енерготехнології переробки харчової сировини. *Scientific Works*. 2022. Т. 86, № 1. С. 133–142. DOI: https://doi.org/10.15673/swonaft.v86i1.2415

[45] Каличева Н. Є., Куценко Н. М., Годунов Ф. А. Управління якістю продукції харчової промисловості. *Вісник економіки транспорту і промисловості*. 2023. № 84. С. 175–182. DOI: https://doi.org/10.18664/btie.84.301467

[46] Шубалий О. М., Петруха С. В., Косінський П. М. Фінансово-економічне стимулювання сталого розвитку переробних підприємств у воєнних та повоєнних умовах. *Фінанси України*. 2022. № 12. С. 73–87. DOI: https://doi.org/10.33763/finukr2022.12.074; Belova I., Yaroshchuk O., Brych V., Borysiak O., Brych B., Petrukha N. Factor-Oriented Digital Model for Optimizing Biomass Supply Chains in the Circular Bioeconomy. 2025 15th International Conference on Advanced Computer Information Technologies (ACIT), (Sibenik, Croatia, 17–19 September 2025). 2025. P. 293–297. DOI: https://doi.org/10.1109/ACIT65614.2025.11185662; Petrukha S., Petrukha N., Stoliarenko O., Ortina G., Stuzhuk R., Plakhotnii D. Natural Resources and Financial Security: The Synergy of Sustainable Development Economics and Artificial Intelligence. *Grassroots Journal of Natural Resources*. 2025. 2025. Vol. 8. № 2 (August 2025). P. 775–795. DOI: https://doi.org/10.33002/nr2581.6853.080236

participants; institutionalisation of partnerships between business, the state, communities and scientific institutions; financial inclusion through the creation of conditions for access to "green" lending; deployment of innovation infrastructure (bioincubators, laboratories, technology parks); digital process management based on ERP systems, IoT solutions, blockchain platforms for transparent tracking of resource flows. These elements create a practical basis for the recovery of industries, as they not only stabilise production dynamics but also outline a long-term trajectory for transitioning to climate-neutral development.

The institutional dimension of approximating the bioeconomy to industry production systems involves the formation of a system of rules, norms, and incentives that supports the circular logic of management. We refer to the development of national and regional bioeconomy strategies and harmonising them with the principles of the European Green Deal. This should be facilitated by developing mechanisms for public-private partnerships in creating joint investment platforms, developing institutes for certifying ecological products and the origin of bioenergy, and further institutionalising a system of educational and scientific support capable of providing training for bioeconomy industries and effective technology transfer. These elements create a normative and value framework within which bioeconomy production systems not only meet global sustainability requirements, but also receive clear signals regarding the desired development trajectories (recovery).

Organisational and economic determinants in this context perform a synergistic function, combining microeconomic incentives with macroeconomic policy. Their influence is manifested in at least three key areas: first, in increasing labour productivity through the introduction of innovative methods of organising production, automation and optimal layout of fixed assets, which is especially critical for seasonal and continuous output; second, in increasing energy efficiency through digital control systems, optimisation of technological modes and rational use of thermal and cold processes; third, in minimising raw material losses through complex processing and application of the principles of "zero waste", when by-products and waste become the basis for new technological chains and types of products. Taken together, this forms a mechanism of circular self-reinforcement, in which each technological or organisational update creates additional opportunities for further environmental, energy and economic optimisation of the system.

Thus, the approximation of the bioeconomic paradigm to the processes of economic recovery in industries is a key stage in transforming the management model, from an abstractly constructed organisational and economic mechanism to a real institutional practice embodied in production and cluster solutions. At the industry level, this approximation is manifested through production systems that act as carriers of bioeconomic principles, and through bioclusters that ensure their integration into spatial and organisational configurations. As a result, a new type of economic growth is formed, called renewable-biooriented, in which efficiency is measured not only by GDP growth, but also by the volume of restored resources, preserved ecosystems, improved quality of life and the level of trust in society. Such an approximation closes the methodological cycle, from knowledge of determinants and the construction of a management mechanism to their materialisation in

production and cluster structures, which ensures the practical implementation of the bioeconomic model of economic recovery.

CONCLUSIONS

During the study of the organisational, economic and institutional principles of approximation of the bioeconomic paradigm to the processes of economic recovery of bioeconomy industries, it was proven that the modern bioeconomy model is being formed as a new type of economic rationality, based on the principles of regeneration of natural capital, intellectualisation of production processes and social cohesion. In the context of the post-war transformation of the Ukrainian economy, bioeconomy ceases to be an abstract theoretical construct. It acquires practical significance, becoming a framework for reconstruction that combines the requirements of energy security, climate neutrality, and social sustainability. Its implementation provides the possibility of transitioning to a model of restorative growth, where efficiency is measured not only by GDP growth but also by the system's ability to reproduce resources, reduce anthropogenic load, and improve the quality of life of the population.

In the epistemological dimension, we clarified the content of the economic category "determinants" in the bioeconomic context. The results of the study show that determinants are not a static set of factors, but rather the embodiment of a network of interconnected economic, social, institutional, managerial, environmental, cognitive, and technological variables. The study proposes a multi-level typology of determinants, categorised by level of influence (macro-, meso-, and micro-level), origin (endogenous and exogenous), and content (economic, social, institutional, environmental, cognitive, and technological). This approach offers a comprehensive understanding of the mutual influences and interdependencies that shape the processes of bioeconomic recovery. It forms a methodological basis for further operationalisation of the bioeconomic paradigm.

Based on the analysis, we formed a four-dimensional matrix of endogenous and exogenous, stimulating and inhibiting determinants, visualised in the form of a "fishbone" diagram. This approach not only systematised the factors that stimulate or inhibit the development of bioeconomic recovery, but also identified possible management interventions. The group of inhibiting determinants includes investment risks, personnel shortages, regulatory fragmentation, resource degradation and digital inequality. At the same time, management interventions should be based on expanding the green financial framework, increasing policy coordination, developing R&D infrastructure, stimulating environmental innovations, and digitalising management.

We paid particular attention to the dominant role of socio-economic determinants that determine the implementation potential of the bioeconomic paradigm. Determinants such as social capital, trust, quality of human capital, institutional capacity, and behavioural and motivational attitudes shape the environment within which the transformation of bioeconomy ideas into practical management decisions takes place. For Ukraine, this factor is of particular importance in the post-war context, as it provides a link between technological modernisation, social consolidation, and economic stability.

In structural and functional terms, we substantiated the organisational and economic mechanism of bioeconomic recovery as a five-component self-learning system, comprising target, functional, instrumental, institutional, and performance blocks. The interaction between these components forms a closed loop with developed feedback mechanisms, which ensures the system's self-adaptation to external shocks and internal constraints. The results of the study showed that the consistency between the structural blocks of the mechanism, rather than the amount of resources involved, determines the ability of the economic system to recover and achieve a synergistic effect among economic, social, and environmental outcomes.

Our study proposes the concept of a "SMART bioeconomic recovery control loop" as an innovative tool for state and regional policy. Such a control loop combines digital analytics of bioresource flows and key performance indicators in real-time, algorithmic decision support, and a feedback system that automatically adjusts the parameters of financial, tax, and regulatory instruments. This enables the transition from adaptive to predictive management mode, ensuring the system's increased resilience to climate, energy, and geopolitical challenges.

The key institutional form of implementing the organisational and economic mechanism is defined as a biocluster, which acts as a space for integrating entities at different levels – the state, business, science, and communities. Within bioclusters, the interests of participants are coordinated, joint infrastructure and logistics solutions, quality standards, innovation hubs and educational and scientific platforms are formed. The cluster model helps reduce transaction costs, accelerate the diffusion of innovation, expand cooperation opportunities, and provide a multiplier effect for economic, environmental, and social recovery at the regional level.

The study developed a model for approximating the bioeconomic paradigm in industry production systems, which represents a multi-level structure for implementing bioeconomic principles. It consistently reflects the transition from the value-conceptual framework (bioeconomic paradigm) to the organisational and economic management mechanism, institutional forms (bioclusters, platforms, and innovation hubs), production systems of bioeconomy industries, and the results of their functioning, which, through feedback, ensure the evolutionary renewal of the mechanism and paradigm. Such a model creates a methodological basis for "descent" strategic guidelines to the level of specific technological, organisational and financial decisions.

We explored the concept of industry production systems in the bioeconomy as open socio-technical networks, the effectiveness of which is determined by the interaction of endogenous and exogenous factors. In this context, the "bioeconomic elasticity" of a production system is the ability to maintain stability and functionality under conditions of external shocks or structural constraints due to a combination of internal (human capital, innovation, energy efficiency, digitalisation) and external (regulatory and legal environment, access to green finance, the state of natural resource potential, the development of partnerships) factors.

A significant scientific and practical outcome of the study is the adaptation of the classical set of formulas for assessing the effectiveness of organisational, technical, and economic measures to the conditions of bioeconomic production. The method for determining the absolute effect, return on investment period, integral coefficient of "effect-costs", relative change in results and generalised

effect, taking into account social, environmental and institutional components, has been improved. This allows for the assessment not only of economic performance, but also the comprehensive sustainability of bioeconomic projects, including energy, environmental, and social results.

In conclusion, the research results showed that approximating the bioeconomic paradigm to the economic recovery processes of industries is a system-forming stage of transforming the management model, from theoretical and methodological understanding to practical implementation in production and cluster structures. The combination of a multi-level typology of determinants, an organisational and economic mechanism with a SMART control loop, the institutional form of a biocluster and industry production systems forms a holistic methodological framework for renewable and bio-oriented development. Such a framework can serve as a scientific and methodical basis for designing state policies, regional strategies, and cluster programs for the bioeconomic reconstruction of Ukraine in the post-war period.

ABSTRACT

This study focuses on a systematic analysis of the architecture of economic recovery management in the context of the emergence of a new bioeconomic reality. Today, the traditional, resource-intensive model of reconstructing (recovery) economic systems is methodologically and economically incapable of ensuring long-term sustainability, which necessitates a transition to a restorative, biologically oriented development paradigm. The study presents a clarified content of the category "determinants" and a multi-level typology of socio-economic, institutional-management, environmental and cognitive-technological factors developed by the authors that determine the dynamics of bioeconomic recovery. Socio-economic determinants play a leading role in shaping the implementation environment for bioeconomic strategies and determining the cooperative, innovative, and institutional potential of the system. Authors have formed a model of the organisational and economic mechanism of bioeconomic recovery as a holistic, self-learning structure, encompassing target, functional, instrumental, institutional, and performance blocks, united by a feedback system. The study proposes the concept of a SMART bioeconomic recovery control loop, which integrates digital analytics, algorithmic decision support, and automated adjustment of management parameters into a single SMART system. At the same time, the biocluster serves as a key institutional mechanism for integrating resources, knowledge, and innovations among entities in the bioeconomy sector. The researchers have developed a multi-level model that approximates the bioeconomic paradigm in production systems, demonstrating the transition from conceptual principles to the operational level of technological, financial, and management decisions. The analytical apparatus for assessing the effects of organisational, technical, and economic measures, adapted to the conditions of bioeconomic production, enables the quantification of the economic, energy, environmental, and social outcomes of innovations. The results of the study provide a conceptually complete methodology and applied basis for the development of state policies, regional strategies, and cluster programs aimed at the bioeconomic reconstruction of Ukraine in the post-war period.

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