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ENVIRONMENTALLY ORIENTED MODELLING FOR SUPPORTING DECISION-MAKING IN BUSINESS ECOSYSTEM

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Abstract. The study focuses on models of environmentally oriented development to support decision-making in business ecosystems (BE). The goal is to show the relationship between technical greening measures and BE performance results. The study's stages include the characteristics of BE; evaluation of greening measures and their impact on functioning; construction of factor-analysis models of technical greening and BE efficiency; determination of validation criteria based on elasticity indicators; and justification of the feasibility of the proposed methodology for decision support in BE. The methodology is based on the conceptualisation of BE, the construction of "input-output" models, the calculation of the integral indices I_{TGI} and I_{BEEEI}, factor/regression analysis, and elasticity assessment (point and arc). For an energy company, the most significant I_{TGI} parameters are the share of new equipment with reduced noise and lower water discharge. The results of BE greening depend significantly on environmental costs and payments to support the ecobalance. The average annual growth rate of I_{TGI} exceeds that of I_{BEEEI}, indicating a lag between implementation and results; the nonlinear nature of the relationship is confirmed. The arc elasticity index indicates a moderate average sensitivity of I_{BEEEI} to changes in I_{TGI}, while the point elasticities reflect greater volatility in response to shocks. The study confirmed the presence of a measurable, but lagging and nonlinear relationship between technical greening and the results of greening the business ecosystem. This makes the constructed models an effective tool for supporting management decisions in sustainable development. The practical value lies in the proposed methodology for assessing internal drivers of business ecosystem efficiency in alignment with external challenges, enabling the systematic evaluation of environmental initiatives, their effectiveness, and their integration into digital decision-support systems for monitoring sustainable transformations.

Keywords*:* model, business ecosystem, ecologization, technical measures, efficiency, platform, energy company.

JEL Classification: O3, Q57, C3

1. INTRODUCTION

The urgency of climate change and resource scarcity intensifies the need for environmentally sustainable development models. The transition to sustainable development within business ecosystems, which requires collective action by interconnected participants, is becoming increasingly important. However, due to the complexity and dynamism of business and ecosystem development, planning and assessing efforts toward the "green" transition remain challenging. Traditional decision-making methods often fail to ensure real-time adaptation based on unified indicators.

To address these challenges, this study proposes a "green" development model to evaluate and optimize the greening of business ecosystems (BEs). Such models can dynamically collect and analyze data, provide predictive insights, identify inefficiencies, and support adaptive strategies for sustainable development. The concept of BEs fosters the creation of intelligent, flexible ecosystems in which sustainability becomes a measurable, continuously optimized process.

A recent study (Sasongko et al., 2024) analyzed the history and evolution of the BE concept over the past 30 years, demonstrating its growing relevance in management and innovation. The authors of that publication emphasize the Asian region's leading role, particularly China's, in funding BE research. Europe ranks second in this regard, with significant support provided by the European Commission and national research councils. At the same time, it is stressed that further studies should focus on BE platforms, which remain relatively underexplored in academic literature. Therefore, conducting an empirical investigation based on the functioning of a domestic company's BE will provide deeper insights into the creation of such platforms and complement existing results with new findings. Hence, the research topic is both relevant and timely.

2. THEORETICAL BACKGROUND

The concept of BE functioning is based on a study (Moore, 1996) that views companies as elements of broader networks of interdependent participants, in which performance is understood as an emergent property of interaction rather than the sum of individual firms' isolated actions. However, the question of how the principles of ecosystem vitality and self-regulation affect participant interactions within BEs remains unresolved.

This issue was further developed in a study (Gawer & Cusumano, 2014), which examined the role of platforms associated with the "network effect." Its authors highlighted the main characteristics of the platform as the strategic role of the leader, the network effect, openness to innovation, and the orchestration of interactions, and emphasized that the more users are engaged with a platform, the more valuable it becomes to the network due to"…an increasing set of complementary innovations." In this interpretation, the notion of an owner emerges, linked to the leader or "orchestrator" of the BE. Stańczyk (2018) noted that the leader coordinates the micro-design of BE creation and disseminates values at the firm level through BE architecture. However, that publication did not explore how participants influence BE outcomes.

Subsequent studies characterised BEs in terms of emergence, self-organisation, evolution, and adaptation (Peltoniemi & Vuori, 2008). Nevertheless, these characteristics were largely descriptive, and the authors pointed to the need for further research. This conclusion makes it reasonable to link the BE concept to findings from the study of the "iconic" innovative business model presented in Mikhalkina & Cabantous (2015). The authors attempted to generalize the process of forming a universal business model: the emergence of a core business idea, its recognition of uniqueness by stakeholders through analogy, and subsequent imitation as a template. This process closely resembles the mechanisms of BE formation and functioning. However, questions remain unresolved in BE research: how to create a template and what the behavior of BE participants and their coordinated interaction with the "orchestrator" should be. Contributing factors include the challenge of identifying the BE as a business model within a specific company or enterprise, and the need to examine the links between activities and BE performance outcomes.

It should be noted that "templates" of business models have already been developed (Osterwalder & Pigneur, 2010). However, further research must be oriented toward sustainable development. The study (Boons & Baldassarre, 2019). finds that business models should be consciously designed to align with the SDGs, with attention to structural clarity, boundary definition, and outcome uncertainty. This approach enables the systematic design of sustainable business models, the assessment of side effects, the reduction of dependence on less sustainable models, and the strengthening of institutional conditions for more sustainable solutions. The study of Kovtun (2020) shows that the main task of ecologization (greening) business models is to reduce the eco-destructive impact of human economic activity. The study of Correia & Lopes (2023) highlights the importance of biodiversity preservation. In identifying concrete solutions that underpin "greened" actions at the BE level, the study by Graça & Camarinha-Matos (2021) deserves attention. Within the BE design framework, a simulation model is proposed with an evaluation and impact mechanism. That, through adjustments to performance indicator weights, enables measurement and deliberate influence over organisational behaviour within a joint IT ecosystem, thereby enhancing the sustainability of cooperation. The study (Polyanska et al., 2022) emphasized the need to form ecosystem thinking capable of accounting for the negative impact of economic activity in decision-making. The study (Zapukhliak et al., 2019) highlighted the importance of shifting readiness to achieve growth and resilience. The study (Polyanska et al., 2024) noted that ecologically oriented BE models should be grounded in strategic planning results. Digitalization was identified as a key factor in decision-making within BEs (Psyuk & Polyanska, 2024). Yet the question remains unresolved about how to combine and account for these requirements and criteria when making decisions in BE management.

One way to overcome these difficulties is to enhance enterprise innovation and the development of BE. Such an approach was applied in a study (Han et al., 2022), where the authors proposed a metatheoretical framework of aggregated conceptual boundaries of ecosystems, summarized across three dimensions: roles (self-organization, nonlinearity, shared vision), structures (complementarity, modularity, connectedness), and processes (emergence, coopetition, coevolution). In this way, the theory of orchestration is highly relevant to the transformation of business ecosystems, as it explains how a focal firm assumes the role of orchestrator and drives ecosystem-wide change through three key phases – initiating, opening, and integrating – by strategically coordinating, mobilizing, and aligning interdependent actors and resources (Mann et al., 2022). This concept is valuable when considering participants in the business ecosystem and finding a leader who would be a role model.

The ecosystem perspective is crucial for studying the firm's internal environment and decision-making processes, as it highlights that strategic choices, performance metrics, and resource configurations must be understood not only within the firm's boundaries but also in relation to ecosystem dynamics, external stakeholders, and broader institutional conditions that shape value creation and resilience (Cobben et al., 2022). The study of Acuña (2024) highlights that technological innovations play a critical role within business ecosystems, as their integration into management practices not only advances environmental and social sustainability but also strengthens ecosystem competitiveness, reputation, and long-term value creation aligned with the Sustainable Development Goals. Empirical evidence shows that within ecosystems, sustainable technologies play a significant role: the "Technology-Organization-Environment" factors explain 59.10% of the variance in sustainable technology adoption, yet research remains fragmented and requires further validation across industries and ecosystem contexts (Hoque et al., 2025). Thus, although literature examines various aspects of BE, insufficient attention has been paid to how activities within BE influence its productivity and its ability to respond effectively to external challenges, such as those related to sustainable development. All of this supports the argument for an urgent need for systematic analytical and evaluative methods to develop effective tools that move from passive monitoring to purposeful, adaptive BE management (Zheng, 2022). One way to address this need, as proposed in the article, is to develop and study ecologically oriented models that enable exploration of the relationship between environmental measures and BE platform performance outcomes, and to identify the nature of interactions and their significance for decision-making.

3. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The aim of the study is to construct models of environmentally oriented development to support decision-making in business ecosystems (BEs) and to investigate the systemic relationship between sustainable transformation and technical "greening" measures. This will enable identification of patterns and the cumulative impact of technical "greening" decisions on the performance of a dynamic BE. To achieve this aim, the following objectives were set:

– to develop the concept of the BE by examining the BE platform of an energy company and identifying the factors based on the principles of ecologization that determine its outcomes;

– to examine technological innovations that contribute to ecological outcomes, as well as the results of such activities within the BE using the example of an energy company, and on this basis to calculate integral indicators of BE efficiency – I_{TGI} and I_{BEEEI};

– to develop models of environmentally oriented development based on the defined integral indicators of sustainable transformation and to identify the factors influencing the results of TG and BEEE;

– to assess the impact of "greening" activities on the outcomes of BE ecological transformation using point and arc elasticity indicators.

The research is conducted on the example of a gas production enterprise coordinated within the Naftogaz Group – Ukraine's leading state-owned joint-stock energy company (Naftogaz Group, 2025). The article presents an example of an energy business ecosystem, highlighting a key extraction company whose operational data served as the basis for the study. The analysis is based on data characterizing a specific framework of the business ecosystem's functioning, represented by JSC "Ukrgasvydobuvannya." On the one hand, the enterprise, as a structural unit of the energy company, operates independently, managing its interactions with BE participants – suppliers, consumers, and stakeholders. On the other hand, it maintains a close connection with the parent company, aligning its actions with the parent company's strategy and corporate development priorities. This dual interaction reflects the logic of a BE platform, and the case itself can serve as an illustrative example of its specific features.

For the research, materials were selected that characterize the use of technologies with reduced negative environmental impact. This approach allows the combination of business interests with efforts to improve the ecological situation, which is consistent with the idea of a BE. Table 1 presents data on technical greening measures in the hydrocarbon extraction process.

Tab. 1

Data on technical greening measures of the energy company

Indicator	2018	2019	2020	2021	2022	2023	2024
Xtgi1	80.30%	82.10%	84.70%	85.70%	88.40%	90.10%	91.10%
Xtgi2	69.50%	83.00%	85.60%	88.10%	90.00%	91.40%	92.30%
Xtgi3	83.50%	83.50%	88.90%	90.10%	90.10%	93.20%	93.9%
Xtgi4	87.40%	96.30%	100%	100%	100%	100%	100%
Xtgi5	85%	90%	92%	94%	94%	96%	97%
Xtgi6	60%	85%	86.40%	87.10%	87.10%	88.50%	89.50%

Source: enterprise data

Accordingly, Table 2 presents the selected data on BE greening results, determined by the indicators provided therein. These results reflect both the outcomes of greening the technical component and the enterprise's overall environmental policy. They include expenditures on environmental protection, waste management, and decarbonization measures.

The assessment methodology uses an integral indicator based on a systems approach, comprising variables that reflect the BE's functioning, and it guides the selection of these variables. The method includes several structured stages.

Tab. 2

Data on the environmental efficiency of the BE of the energy company

Indicator	2018	2019	2020	2021	2022	2023	2024
Xbeeei1	0.0015	0.002	0.002	0.0025	0.003	0.0034	0.004
Xbeeei2	2.326	2.,006	2.001	3.02	2.98	3.01	3.04
Xbeeei3	42.32	41.93	40.23	39.12	40.11	42.36	42.9
Xbeeei4	366.5	775.3	589.4	563	580	602	611
Xbeeei5	2.54	4.52	5.86	6.52	7.25	6.98	7.19
Xbeeei6	1.02	1.52	1.98	2.01	2.04	1.98	2.08

Source: enterprise data

The starting point is the calculation of the integral indicator (I), based on the stady of Lepetyukha and Rudska (2016), which we apply to compute the Technical Greening Index (I_{TGI}) that is used to study the impact of technical modernization on the enterprise, while the impact of greening measures on the efficiency of the BE model is represented by the Business Ecosystem Environmental Efficiency Index (I_{BEEEI}). Table 3 lists the variable factors used for these calculations.

Tab. 3

Indicators for the calculation of I_{TGI} and I_{BEEEI}

Indicators for the calculation of I_{TGI}	Indicators for the calculation of I_{BEEEI}
X_{tgi1} – Share of new equipment with lower noise impact	X_{beeei1} – Waste used for own needs, million m^3
X_{tgi2} – Share of new equipment with lower CO_2 or other gas emissions	X_{beeei2} – Utilization and disposal of industrial waste, thousand tons
X_{tgi3} – Share of new equipment with lower discharges of pollutants into water	X_{beeei3} – Greenhouse gas emissions into the atmosphere, thousand tons
X_{tgi4} – Share of environmentally friendly lubricants and fuels (materials meeting eco-standards)	X_{beeei4} – of which CO_2, tons
X_{tgi5} – Degree of water purification	X_{beeei5} – Environmental taxes, million UAH
X_{tgi6} – Share of equipment and machinery meeting eco-standards	X_{beeei6} – Environmental protection expenditures, million UAH

Source: enterprise data

The integral efficiency indicator I is calculated using formulas (1) and (2), respectively:

$$I_{TGI} = 1 - \frac{x_{\text{tgi},io}}{x_{\text{tgi},o}}, \quad (1)$$

$$I_{BEEEI} = 1 - \frac{x_{\text{beeei j0}}}{x_{\text{beeeio}}}, \quad (2)$$

where $x_{tgi,i0}$, $x_{beeei,j0}$ – distance to the reference point in the space of normalized variables;

$x_{tgi,0}$, $x_{beeei,0}$ – reference distance for both integral indicators, respectively;

i – index of the technical greening indicator (I_{TGI}); j – index of the BE efficiency indicator (I_{BEEEI}).

The closer the value of indicator I is to 1, the higher the level of the evaluated parameter.

Additionally, regression analysis was used to investigate how variable factors influence I_{TGI} and I_{BEEEI}. This analysis identifies the key driving forces and supports modeling for the future transformation of the business ecosystem based on the multiple linear regression formula:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon, \quad (3)$$

where $x_1, x_2, \ldots, x_n$ – independent variables;

$\beta_1, \beta_2, \ldots, \beta_n$ – corresponding coefficients.

To verify the relationship between the calculated integral indicators, the elasticity of technical greening efficiency and BE ecologization efficiency was examined as follows:

$$E_{TGI,\,BEEEI} = \frac{\%\Delta I_{BEEEI}}{\%\,\Delta I_{TGI}}, \tag{4}$$

where $\%\Delta I_{BEEEI}$ – change in the integral indicator of BE ecologization efficiency, measuring the extent to which the BE improved (or worsened) due to environmental technologies;

$\%\Delta I_{TGI}$ – change in the efficiency of technological greening solutions or nature-oriented (eco) measures.

For validation of the obtained results, the arc elasticity indicator was applied, calculated according to Formula 5:

$$E_{mid}^{arc} = \frac{\frac{I_{BEEEI_1} - I_{BEEEI_0}}{(I_{BEEEI_1} + I_{BEEEI0})\cdot\frac{1}{2}}}{\frac{I_{TGI_1} - I_{TGI_0}}{(I_{TGI_1} + I_{TGI_0})\cdot\frac{1}{2}}} \tag{5}$$

Thus, the proposed methodology aims to confirm the main hypothesis – the existence of a measurable relationship between the application of technical greening practices and the efficiency of BE ecologization.

4. RESULTS AND DISCUSSION

Modern organizations employ diverse business models to support sustainable development. The BE model transforms business goals beyond profit into sustainable outcomes – particularly ecological ones (CO_2 reduction, resource efficiency) – and translates them into joint initiatives among participants, centered on a leader. Accordingly, BE greening begins with integrating ecological principles at the strategic level, including the incorporation of environmental considerations into mission, vision, investment, and innovation planning. For example, the leader of the energy company JSC Ukrgasvydobuvannya directs its "green" efforts toward emission reduction (Methane Partnership in the oil and gas sector, leak detection and repair, minimization of venting/flaring), technological modernization (equipment renewal), strengthened waste and water management (reinjection), implementation of ISO 14001 and RES for internal needs, as well as compensation eco-initiatives aimed at achieving net-zero operations by 2040. Tactical and operational implementation covers green logistics (eco-friendly transport, route optimisation), energy efficiency (low-energy technologies), waste management (recycling, circular economy), eco-friendly product design, and sustainable office practices, all of which are extended to BE participants. Ecological innovations enhance competitiveness, while compliance with green standards opens access to new markets. The technical maturity of the BE model affects its ability to implement greening measures. The BE approach encourages stakeholder involvement in ecological initiatives, especially in resource-intensive sectors, where results depend on partners' environmental readiness. Table 4 presents a comparative characterization of the elements of a BE platform.

The data in Table 4 indicate that the Naftogaz BE platform reflects most of the characteristics described by Gawer & Cusumano (2014): the strategic role of the leader, network effects, openness to innovation, and the orchestration of interactions. At the same time, in the case of Naftogaz, the emphasis has shifted significantly toward greening and sustainable development. In contrast, the analyzed study places greater focus on technological and market innovations. Thus, a systemic, technology-driven approach oriented towards green principles is key to addressing environmental challenges, where each technical element contributes to the overall productivity and growth of the BE.

Based on the data in Tables 1 and 2, using the integral efficiency indicator formulas (1) and (2), the variables were standardized, and the integral indicators I_{TGI} and I_{BEEEI} were calculated. The results are presented in Tables 4 and 5.

Tab. 4

Comparison of business ecosystem platform characteristics

Platform characteristic (Gawer & Cusumano, 2014)	Platform characteristic of Naftogaz Group
Platform as the core of the ecosystem – creates the foundation for interaction and innovation	JSC Ukrgazvydobuvannya, as the core of the energy BE: unites extraction, supply, regulators, consumers, and communities
Orchestrating role of the leader – sets rules, standards, and balances interests	The leader sets strategic priorities (net-zero by 2040, ISO 14001, RES), coordinates the activities of suppliers and partners
Network effect – the more participants, the greater the platform's value	Expansion of the effect through partnerships (international climate initiatives, community engagement, partnership with Methane Oil & Gas)
Open and modular architecture – enables the integration of innovations from external participants	Implementation of ecological and technological innovations: new equipment, green logistics, RES, eco-office practices
Innovation dynamics – ecosystem innovations that cumulatively strengthen the platform	Environmental innovations (emission reduction, waste management, water reinjection) enhance competitiveness and open access to new markets
Balance of competition and cooperation (coopetition)	A combination of collaboration with suppliers, consumers, and regulators, alongside internal competition for innovation and efficiency
Strategic importance – platforms set industry rules and create entry barriers	Naftogaz, as a state-owned company, establishes "greening" standards for the market, shapes sectoral policy, and sets sustainable development trends

Tab. 5

Calculation of I_{TGI} based on Table 1 data

Calculated indicators	2018	2019	2020	2021	2022	2023	2024
Suma	41.42505	14.88222	4.939476	2.487843	1.143465	1.112307	0
Cio	6.436229	3.857749	2.222493	1.57729	1.069329	1.032241	0
$\overline{C_o}$	2.534102						
S0	2.104567						
C0	6.733192						
I_{TGI}	0.044251	0.427206	0.670007	0.765806	0.841227	0.901231	1

As seen in Table 5, the ITGI values increase, indicating greater attention to implementing technical greening measures over the study period.

Tab. 6

Calculation of I_{BEEEI} based on Table 2 data

Calculated indicators	2018	2019	2020	2021	2022	2023	2024
Suma	19.76057	26.00297	16.25259	12.13552	12.3148	14.12729	15.31272
Cio	4.445286	5.,099311	4.03145	3.483607	3.509244	3.758628	3.85612
$\overline{C_o}$	4.025346						
S0	0.581012						
C0	5.213464						
I_{BEEEI}	0.144547	0.018686	0.224186	0.329613	0.324679	0.276688	0.289011

Thus, the calculated integral indicators allowed us to consider the factors affecting the results of technical greening (I_{TGI}) and the effectiveness of business ecosystem greening (I_{BEEEI}) (Table 7). For the specified table, all descriptive statistics were calculated, and a correlation matrix was constructed (Fig. 1).

	X_{tgi1}	X_{tgi2}	X_{tgi3}	X_{tgi4}	X_{tgi5}	X_{tgi6}
X_{tgi1}	1					
X_{tgi2}	0.885391	1				
X_{tgi3}	0.948624	0.830428	1			
X_{tgi4}	0.784985	0.969883	0.774466	1		
X_{tgi5}	0.931555	0.982695	0.909653	0.935993	1	
X_{tgi6}	0.722182	0.958165	0.668208	0.975368	0.902618	1

Fig. 1. Correlation matrix of technical environmental measures

In particular, the matrix of pairwise correlation coefficients shows that x_5 is closely related to the other parameters, so it is rejected (it serves as an indicator of the degree of water purification). Next, we check all the remaining variables for multicollinearity using the Farrar-Glauber algorithm. The results are presented in Table 8.

Tab. 7

Revised input data for building the I_{TGI} model

Year	X_{tgi1}	X_{tgi2}	X_{tgi3}	X_{tgi4}	X_{tgi5}	X_{tgi6}	I_{TGI}
2018	80.30%	69.50%	83.50%	87.40%	85%	60%	0.044251
2019	82.10%	83.00%	83.50%	96.30%	90%	85%	0.427206
2020	84.70%	85.60%	88.90%	100%	92%	86.40%	0.670007
2021	85.70%	88.10%	90.10%	100%	94%	87.10%	0.765806
2022	88.40%	90.00%	90.10%	100%	94%	87.10%	0.841227
2023	90.10%	91.40%	93.20%	100%	96%	88.50%	0.901231
2024	91.10%	92.30%	93.9%	100%	97%	89.50%	1

After consistent application of this algorithm, it was finally established that the following factors have the greatest influence on the I_{TGI}:

– x_1 – the share of new equipment with reduced noise impact, with the following results: coefficient of determination $R^2(x_1) = 0.919887$, correlation coefficient $R(x_1, y) = 0.931347$;

– x_3 – the share of new equipment with reduced discharge of pollutants into water, with the following results: coefficient of determination $R^2(x_3) = 0.920741$, correlation coefficient $R(x_3,y) = 0.931501$.

The constructed multivariate linear regression has the following form and gives the following results:

$$y = 5.45 \cdot x_{tgi1} + 2.12 \cdot x_{tgi3} - 6.04.$$

The coefficient of determination for this model is $R^2(y) = 0.9341$. Based on the data in Table 7, a multivariate linear regression was constructed. It is worth noting that this model does not include data on the number of repairs that meet environmental standards, as these indicators do not show dynamics and are 100% each year (x_4). As a result, the following dependence was obtained:

$$y = -9.73\ x_{tgi1} + 9.076 x_{tgi2} + 3.835\ x_{tgi3} + 2.278\ x_{tgi5} - 5.314\ x_{tgi6}.$$

The application of this model yields results with high accuracy, as indicated by a coefficient of determination (R^2) of 0.981. This model (excluding lubricants that meet environmental standards) is more accurate in predicting values than the previous one, which was calculated using this indicator. Thus, in the considered case, the most significant parameters of I_{TGI} are the share of new equipment with lower noise levels and lower pollutant discharge into water.

The initial data for studying the impact of greening measures on BE operational results are presented in Table 8, based on the data in Table. 2.

Tab. 8

Inputs for building the model

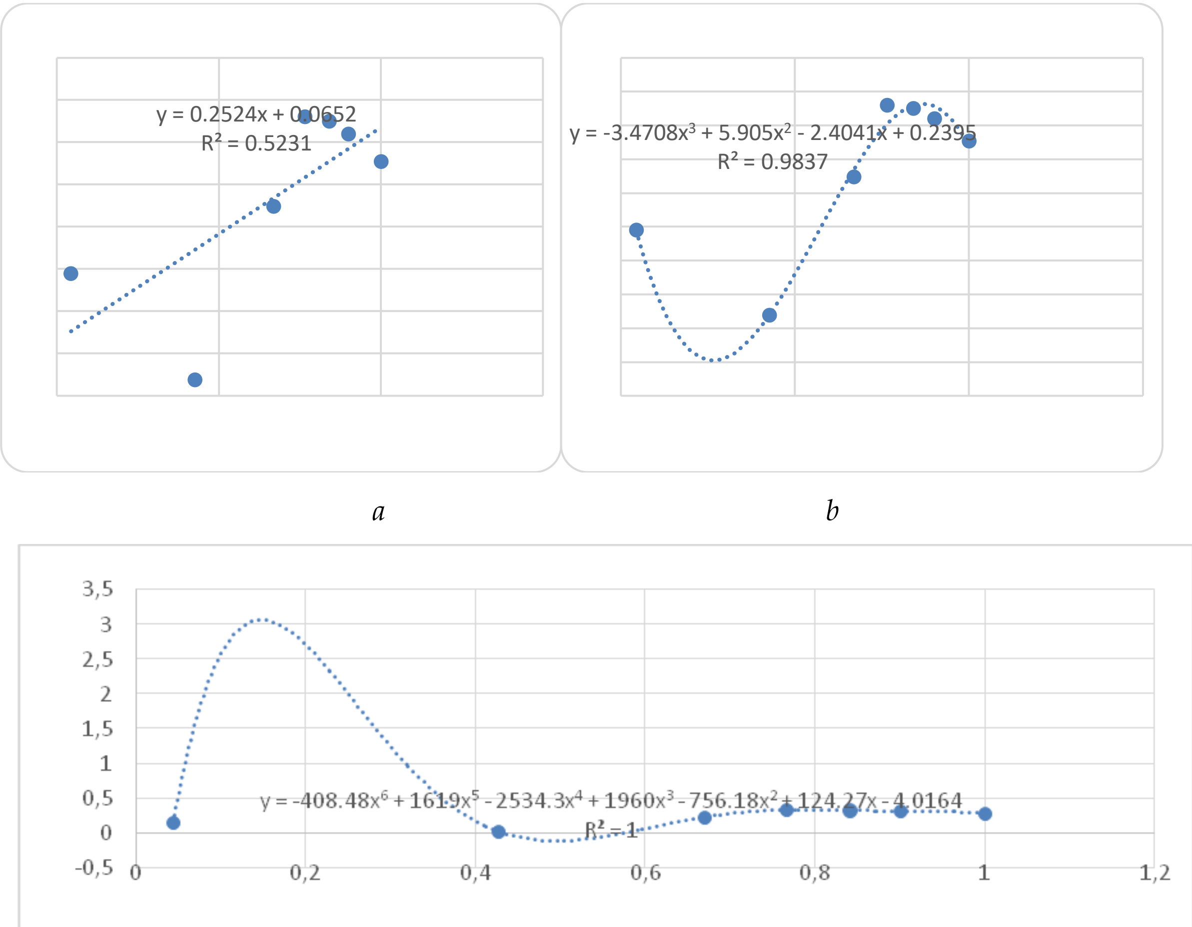
Рік	X_{beeei1}	X_{beeei2}	X_{beeei3}	X_{beeei4}	X_{beeei5}	X_{beeei6}	I_{BEEEI}
2018	0.0015	2.326	42.32	366.5	2.54	1.02	0.0444
2019	0.002	2.006	41.93	775.3	4.52	1.52	0.4272
2020	0.002	2.001	40.23	589.4	5.86	1.98	0.6700
2021	0.0025	1.993	39.94	423.5	7.12	2.35	0.7658
2022	0.003	1.989	39.21	476.8	8.56	2.88	0.8412
2023	0.0034	1.98	39.02	443.4	9.72	3.12	0.901231
2024	0.004	3.04	42.9	611	7.19	2.08	1

Thus, the following mathematical relationship is obtained, with R2 = 0.9998.

У(I_BEEEI)=7.526 - 0.578X_("beeei" 2) - 0.143X_("beeei" 3) + 0.000005" " "X" _("beeei" 4) + +0.273X_("beeei" 5) - 0.802" " "X" _("beeei" 6).

Based on the modelling results, we can conclude that the extent of greening largely depends on the enterprise's costs, the costs of implementing the environmental policy, and payments to support the enterprise's ecological balance.

The relationship among these integral performance indicators was investigated using regression analysis (Fig. 2).



a *b*

c

Fig. 2. Graphical representation of the relationship between integral performance indicators using the regression analysis method: a – linear dependence; b – nonlinear dependence (trinomial of the third degree). c – nonlinear dependence (sixth degree polynomial)

Source: formed by authors

The study using linear dependence has a coefficient of determination (R^2) of 0.5231, whereas the study using power regression has $R^2 = 0.9837$. As we can see, the largest coefficient of determination R^2 is for nonlinear regression (Fig. 2. b).

Note that linear regression and the coefficient of determination are given purely for illustrative purposes. Calculations show that for a second-degree polynomial, the coefficient of determination will be 0.5912. A high coefficient of determination is observed for a cubic parabola. It is equal to 0.9837. At the same time. a further increase in the degree to 4 and 5 causes an insignificant improvement in the coefficient of determination to 0.9847 and 0.9982, respectively. At the sixth degree, the coefficient equals 1 because we have data for 6 years, but the corresponding graph shows strong fluctuations at intermediate points (see Fig. c).

Using the elasticity index (Formula 4), the sensitivity of one parameter to changes in the other is determined (Table 9). In the context of the relationship between I_{BEEEI} and I_{TGI}, elasticity helps explain how changes in the technical landscape affect BE performance.

Tab. 9

Determination of the annual point elasticity of the BE model functioning

Year	I_{TGI}	I_{BEEEI}	% of changes in I_{TGI}	% of changes in I_{BEEEI}	Point elasticity
2018	0.044	0.145	N/A	N/A	N/A
2019	0.427	0.019	870.45%	-86.90%	-0.10
2020	0.670	0.224	56.95%	1078.95%	18.94
2021	0.766	0.330	14.32%	47.32%	3.30
2022	0.841	0.325	9.79%	-1.52%	-0.15
2023	0.901	0.310	7.13%	-14.77%	-0.64
2024	1.000	0.277	10.98%	-10.64%	-0.96

The conclusion regarding point elasticity is that the relationship is nonlinear and unstable at the point level. I_{BEEEI} may respond either sharply positively (after a delay) or sharply negatively (in response to years of shocks), especially when previous elasticity values are very low. Year-to-year point elasticity indicators demonstrate a nonlinear and unstable short-term relationship: in 2019, a ninefold increase in I_{TGI} coincided with an 86.9% decrease in I_{BEEEI}, resulting in negative elasticity (-0.10), which reflects adaptation barriers and initial costs; in 2020, moderate I_{TGI} growth of 56.95% was accompanied by an approximately elevenfold increase in I_{BEEEI}, producing very high elasticity (~18.94), which reflects both a delayed response and the effect of low elasticity values from 2019; in 2021, elasticity remained elevated (~3.30), whereas in 2022-2024 it became negative (-0.15; -0.96) despite continued I_{TGI} growth, likely due to external shocks.

To complement these unstable point signals, arc elasticity for the period 2018-2024 was calculated using Formula 5 and the data in Table 9. Arc elasticity was ≈0.342, indicating a moderate average sensitivity of outcomes to technical greening across the 2018-2024 period, including peaks, declines, and delays. Overall, the available data confirm a positive but delayed and nonlinear relationship between environmental measures (ITGI) and ecosystem outcomes (IBEEEI): technical greening leads to improved outcomes, but the effect manifests with a lag and remains sensitive to shocks.

The case of a gas extraction enterprise (with a 71% share of hydrocarbon extraction) is used as a lens to study a dominant case (a leader) rather than as a general system evaluator. It enables the capture of coordination interfaces (supplier-operator-regulator-user) through which technical greening measures (I_{TGI}) spread to ecosystem outcomes (I_{BEEEI}). The calculations reveal a statistically significant, delayed, and nonlinear relationship between I_{TGI} and I_{BEEEI}, consistent with adaptation costs and the impact of external shocks. Generalization to the studied BE is possible if structural interactions, governance, and market conditions are similar. Applying this approach beyond the investigated case is advisable only when another ecosystem exhibits comparable participant interactions, governance rules, and market conditions. When scaling the analysis, it is necessary to consider each participant's share, include conclusions with at least one subsequent partner in the chain and a horizontal partner, and perform basic reliability checks using factor models and elasticity analysis. Under such conditions, the method can be reliably transferred to assess how technical decisions affect sustainable development outcomes of other BE participants and to support managerial decision-making.

The study of the constructed models of ecologically oriented development in the BE confirms the main hypothesis of a measurable relationship between technical greening practices and the effectiveness of BE greening. The case of the energy company demonstrates technical modernisation, aligned with sustainable development policy, that enhances not only the productivity of an individual enterprise but also the overall sustainability of BE.

The analysis of a BE case in this article goes beyond theoretical comparisons with natural systems, emphasising the relevance of the case study method. This approach enabled empirical analysis grounded in conceptual justification and generated applied knowledge to address current challenges at the intersection of business and ecosystems, using company data. The constructed ecologically oriented BE models expand the management knowledge base from a "profit-first" approach to a balanced approach to BE development. Their analysis exemplifies the creation of systematic analytical and evaluative methods suitable for flexible response to challenges and for use in decision-support systems within the BE.

Unlike approaches that consider BE factors and results without clear input–output differentiation, the proposed framing of I_{TGI} (inputs) and I_{BEEEI} (outputs) enables the examination of patterns, identification of time lags, and assessment of BE sensitivity through elasticity. Another advantage of this approach is its focus on the ecosystem level (as illustrated by the energy company, where interrelated business units jointly determine the success of policies, including environmental ones). This logic makes lags visible in "normal" years, I_{TGI} growth precedes improvements in I_{BEEEI}, while in crisis periods, part of the effort temporarily does not translate into results (Table 12).

A key strength of the study lies in the application of point and arc elasticities ("relative to I_{TGI}") with sensitivity checks. Point elasticity indicates that I_{BEEEI} reacts to adaptation costs and external shocks; on average across the period, the response is positive, moderate, and lagged, underscoring the time needed for effects to accumulate. Arc elasticity reduces the influence of "extreme" years and provides a statistically more reliable conclusion about the presence, direction, and strength of the impact. The findings lead to a practical conclusion: technical investments should be made on time and be accompanied by measures to increase BE's absorptive capacity (governance, financing, networks, and operational readiness) to reduce the lag between I_{TGI} and I_{BEEEI} and stabilize outcome responses. The proposed BE platform framework enables integration of I_{TGI}/I_{BEEEI} streams into digital decision-support systems, automatic calculation of elasticities, and rapid policy adjustments.

At the same time, studying has limitations and drawbacks. The relationships examined are valid within a specific environment and given institutional and market conditions; beyond these, estimates may shift. Another limitation is that the analysis primarily focuses on environmental factors. It is advisable to expand the study to include the relationships among environmental outcomes, levels of technical development, financial and economic conditions, and investment–innovation prospects.

Given these caveats, future research directions include examining broader interactions among BE variables and outcomes, as well as considering the governance rules and market conditions of the BE platform, better to estimate the time lag between ITGI and IBEEEI.

5. CONCLUSIONS

The study develops and tests a methodological framework for modelling environmentally oriented development in business ecosystems (BEs) and for identifying the systemic relationship between technical greening measures and the ecological transformation of the ecosystem. The empirical analysis, conducted on the example of a gas production enterprise operating within the Naftogaz Group, confirms the existence of a measurable, statistically interpretable relationship between technological modernisation aimed at reducing environmental impact and the overall environmental efficiency of the business ecosystem.

The constructed integral indicators – the Technical Greening Index (I_{TGI}) and the Business Ecosystem Environmental Efficiency Index (I_{BEEEI}) – enabled the synthesis of multidimensional environmental and technological data into generalized quantitative parameters that reflect systemic transformation processes. The dynamics of these indices demonstrate a consistent improvement in the environmental orientation of the enterprise's technological base and confirm that technical modernization acts as a key driver of ecosystem-level ecological outcomes. Regression modelling revealed significant factor dependencies between individual greening measures and integral ecosystem performance indicators, substantiating the hypothesis of cumulative and systemic effects of technical environmental decisions within a dynamic BE. The elasticity analysis, including both point and arc elasticity calculations, confirmed the sensitivity of ecosystem environmental efficiency to changes in technical greening intensity, thereby validating a cause-and-effect relationship rather than a coincidental correlation.

At the methodological level, the study's main contribution is the development of a universal algorithm for assessing environmentally oriented development in business ecosystems. The proposed approach is based on a systems-distance method for constructing integral indicators, thereby ensuring invariance with respect to the sectoral specifics of the analysed object. The model's computational logic remains unchanged across industries, scales, and territorial contexts, as it relies on normalized variables, reference-point comparisons, and regression-based identification of factor influence. The substitutability of variable indicators enables the model to be adapted to other industries (energy, manufacturing, transport, utilities), other types of ecosystems (corporate groups, industrial clusters, regional systems), and different environmental priorities (carbon reduction, waste minimization, water efficiency, biodiversity impact). Thus, the methodology should be regarded not only as a case-specific analytical tool but also as a transferable framework for modelling sustainable transformation processes in complex socio-economic systems.

Furthermore, due to its formalized structure, reliance on measurable variables, and compatibility with statistical modelling techniques, the proposed approach can serve as a computational module within digital decision-support systems. The integral indices and elasticity metrics may serve as analytical blocks in digital twin architectures for business ecosystems, enabling the simulation of future technical greening scenarios and the evaluation of their projected systemic effects. In this context, the methodology supports not only retrospective assessment but also forward-looking strategic modelling of environmentally oriented development trajectories.

Overall, the results confirm the study's main hypothesis: technical greening measures generate a measurable cumulative effect on the ecological efficiency of a business ecosystem. The research expands the theoretical understanding of the interaction between technological modernisation and ecosystem transformation. It provides a structured, scalable, and algorithmically defined instrument to support environmentally oriented managerial decision-making in dynamic business ecosystems.

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Полянська Алла, Бандура Андрій, Сала Даріуш, Мартинець Володимир, Микитюк Олег. Побудова та дослідження моделі екологічно орієнтованого розвитку для підтримки ухвалення рішень у бізнес-

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Об'єктом дослідження є моделі екологічно орієнтованого розвитку для підтримки ухвалення рішень у бізнес-екосистемах (БЕ). Метою є показ взаємозв'язку між технічними заходами озеленення та результатами діяльності БЕ. Етапи дослідження включають характеристики БЕ; оцінку заходів озеленення та їх вплив на функціонування; побудову моделей факторного аналізу технічного озеленення та ефективності БЕ; визначення критеріїв валідації на основі показників еластичності; та обґрунтування доцільності запропонованої методології підтримки рішень в рамках БЕ. Методологія базується на концептуалізації БЕ, побудові моделей «вхід–вихід», розрахунку інтегральних індексів ITGI та IBEEEI, факторно-регресійному аналізі та оцінці еластичності (точковій і дуговій). Для енергетичної компанії найважливішими параметрами ITGI є частка нового обладнання зі зниженим шумом і меншим скидом у воду. Результати озеленення БЕ суттєво залежать від екологічних витрат і платежів для підтримки екобалансу. Середньорічні темпи зростання ITGI перевищують темпи зростання IBEEEI, що свідчить про відставання між впровадженням і результатами; нелінійний характер зв'язку підтверджено. Індекс дугової еластичності вказує на помірну середню чутливість IBEEEI до змін ITGI, тоді як точкові еластичності відображають більшу волатильність у відповідь на шоки. Дослідження підтвердило наявність вимірюваного, але запізнювального та нелінійного зв'язку між технічним озелененням і результатами озеленення бізнес-екосистеми. Це робить побудовані моделі ефективним інструментом для підтримки управлінських рішень у сфері сталого розвитку. Практична цінність полягає в запропонованій методології оцінки внутрішніх рушійних сил ефективності бізнес-екосистеми відповідно до зовнішніх викликів, що дозволяє систематично оцінювати екологічні ініціативи, їх ефективність та інтегрувати їх у цифрові системи підтримки рішень для моніторингу сталих трансформацій.

Ключові слова: модель, бізнес-екосистема, екологізація, технічні заходи, ефективність, платформа, енергетична компанія.