

Ecosystem Approach to Shaping a Circular Economy: Barriers and Incentives for Investment Support

By Dmytrii Korytko¹, Mykola Matiukha², Svyatoslav Hromyak³,
Dmytro Komyshev⁴, Olena Shuplat⁵

ABSTRACT:

The aim of the study was to determine the configuration of financial, institutional, technological and coordination factors associated with the transition from fragmented resource-reuse practices toward more sustainable inter-organizational interaction. A mixed empirical design combined panel analysis of 27 European Union countries for 2022–2024 with a survey of 210 industrial enterprises in Germany, Poland, Italy, Spain, the Czech Republic, the Netherlands and Ukraine. Ukraine was considered separately because of incomplete statistical comparability and war-related conditions. Circular material use in the European Union increased from 11.5% to 12.2%, while substantial cross-country differences persisted. The panel model revealed positive associations with corporate environmental investments, resource productivity and municipal waste recycling. In the survey, the strongest positive relationship was between investment activity and ecosystem interaction, $\rho = 0.61$, whereas financial barriers showed the strongest negative association, $\rho = -0.58$. Financial incentives were positively associated with investment activity, $\rho = 0.54$. Among enterprises with low ecosystem interaction, 8.7% reported high investment activity, compared with 55.2% among those with high interaction. Financing was more frequently used as a strategy-validation mechanism when decisions incorporated confirmed material flows, demand, partners and risk-sharing arrangements. The threshold-like differences were consistent with a descriptive phase-transition interpretation but did not establish a universal threshold or causal mechanism.

Keywords: axiological lie, strategy validator, phase transition, industrial symbiosis, secondary material flows, construction, 3D concrete printing.

1. Introduction

The transition to a circular economy required not only the implementation of recycling, resource reuse and eco-design technologies, but also the formation of

¹PhD in Law, Doctoral Researcher, Faculty of Taxation, Accounting and Auditing, State Tax University, Irpin, Ukraine; Director of Ukrainian Construction Additive Technologies LLC, Irpin, Ukraine; Head of the Research Center INCORE (Institute for Construction and Reconstruction Engineering), Irpin, Ukraine, <https://orcid.org/0009-0009-8486-6840>

²PhD in Economics, Associate Professor, Faculty of Economics and Management, Kyiv National University of Technologies and Design, Kyiv, Ukraine, <https://orcid.org/0000-0002-7968-3777>

³PhD, Associate Professor, Doctoral Student of the Department of Entrepreneurship and Trade, Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv, Lviv, Ukraine, <https://orcid.org/0009-0003-5066-0621>

⁴Professor, Specially Appointed Expert from the School of Civil Engineering, North Minzu University, Yinchuan, China; Engineering Academy of Ukraine, Kharkiv, Ukraine, <https://orcid.org/0009-0002-6162-1532>

⁵PhD, Associate Professor, Department of Corporate Finance and Controlling, Kyiv National Economic University named after Vadym Hetman, Kyiv, Ukraine, <https://orcid.org/0000-0001-6318-4714>

sustainable connections between businesses, investors, authorities, academic institutions, consumers and infrastructure operators. In the absence of such coordination, circular initiatives remained local, did not reach the required scale and did not change the linear production model. Investment support proved to be particularly difficult, as circular projects were often characterized by long payback periods, technological uncertainty, dependence on secondary raw materials markets and the need for joint risk sharing.

The ecosystem perspective enabled us to think of the circular economy as a system of interrelated creation, exchange and preservation of economic and environmental value. Aryee *et al.* (2025) demonstrated that the effectiveness of circular ecosystems depended on the composition of actors, the form of interaction, governance mechanisms and co-creation of value. Finner *et al.* (2026) presented a similar conclusion, relating circular entrepreneurship to access to resources, partnerships, knowledge, digital technologies and regulatory support. At the same time, Derks *et al.* (2024) observed that the transition from informal to sustainable circular models was restricted by institutional gaps, weak formal rules and insufficient infrastructure.

The investment dimension of circular transformation has also attracted significant attention. Afolabi and Islam (2025) observed a positive association between public environmental spending, private investment and the formation of a circular economy in EU member states. Their results indicated that public and private financing were more closely associated with circular development when considered as complementary components rather than isolated sources of capital. Investment support could therefore perform both a financial and coordination function by reducing uncertainty and supporting trust among ecosystem participants.

At the enterprise level, the chief challenges included lack of finance, skills shortages, weak demand for secondary products, regulatory unpredictability and difficulties in verifying the economic feasibility of circular models. Ahmadov *et al.* (2025) organized these barriers for SMEs and illustrated their multifaceted nature. Briguglio *et al.* (2021) found that conditions for creating a new circular business differed from those required to transform an existing enterprise. Bassi and Brazzale (2025) also identified heterogeneous resource-efficient practices among European SMEs. These findings suggested that financial constraints may intensify when combined with weak organizational capabilities, unstable demand or insufficient partner infrastructure, although the empirical configuration of such combined barriers remains insufficiently tested across enterprises and countries (Ahmadov *et al.*, 2025; Bassi & Brazzale, 2025).

Despite significant scientific achievements, the existing research remained fragmented. Some works focused on circular ecosystems (Aryee *et al.*, 2025; Finner *et al.*, 2026), others on institutional barriers (Derks *et al.*, 2024), enterprise-level constraints (Ahmadov *et al.*, 2025; Briguglio *et al.*, 2021) or interactions between public and private investment (Afolabi & Islam, 2025). Less attention has been paid to whether financial, institutional, technological, market and coordination conditions operate jointly, how their configuration corresponds with investment activity, and how national industrial structures and secondary-material markets relate to cross-country heterogeneity in circularity. Also lacking was an integrated explanation of the conditions under which financing could function as a validator of circular transformation strategies and whether threshold-like

differences in ecosystem interaction were consistent with, rather than proof of, a phase-transition interpretation.

The research question was therefore how the configuration of institutional, financial, organizational and market factors was associated with the capacity of a circular ecosystem to attract and allocate investment resources. The hypothesis proposed that higher investment activity and more developed circular interaction would be observed where agreed rules, complementary public and private financing, and risk-sharing mechanisms coexisted.

The aim of the study was to substantiate a holistic analytical framework for investment support for circular transformation at the ecosystem level. To achieve this, it was planned to systematize barriers to capital attraction, identify incentives for investment activity, establish the role of coordination between participants, examine cross-country differences, and outline the conditions associated with the transition from disparate circular initiatives to a sustainable ecosystem model.

2. Literature Review

The academic discourse on the circular economy has shifted from describing how individuals reduce waste to examining systemic transformations in the production, consumption and distribution of resources. Yet conceptual ambiguity has persisted alongside this expansion. Kirchherr et al. (2023) concluded that the circular economy remained predominantly understood via reuse, recycling and reduction of resource consumption, while social, institutional and governance elements were less developed. This fragmentation had operational implications: a project could be deemed circular if there was a distinct resource-efficient operation, even if it did not transform value creation or ensure closure of material flows. The ecosystem approach helps to mitigate this limitation by shifting attention from enterprise autonomy to connected actors. Aryee et al. (2025) defined a circular ecosystem as a set of organizations, resources and governance mechanisms in which value is jointly created and recovered. Nonetheless, such an analytical framework is not yet unified. Some studies have concentrated on participant composition, while others have focused on material flows, innovation or institutional conditions.

As a result, the concept of ecosystem has at times been interpreted as an extended form of partnership, although the presence of partners does not itself establish a durable circular exchange system. The key characteristic of an ecosystem is the functional interdependence of its participants. To convert a local network into a circular ecosystem, coordination of secondary-resource supply, processing technologies, demand, logistics, quality standards and financing is necessary. Using a plastics recycling ecosystem, Litaudon and Chen (2023) demonstrated that such transformation required restructuring existing local relationships rather than creating an isolated circular structure. However, geographical concentration did not remove tensions between private profitability and collective ecological value. Coordination, infrastructure and traceability costs could be concentrated on one participant while benefits were distributed throughout the ecosystem.

Institutional quality determined the possibility of such sharing. Derks et al. (2024) found that circular e-waste ecosystems could emerge from informal practices under institutional

gaps but remained constrained by weak enforcement, regulatory instability and infrastructure deficiencies. Their evidence suggested that entrepreneurial initiative could partly compensate for institutional weakness during initial development but was insufficient for scaling, long-term investment and predictable risk allocation. Thus, institutional and organizational constraints were not independent: weak formal rules increased uncertainty surrounding contracts, infrastructure and future investment.

A similar contradiction has been observed in research on circular entrepreneurship. Finner *et al.* (2026) linked the development of circular entrepreneurial ecosystems to access to knowledge, financing, partners, infrastructure and public legitimacy. Roshan *et al.* (2024) added digital entrepreneurial ecosystems that facilitated partner search, information exchange and coordination of resource flows. However, digitalization did not eliminate low profitability, unstable demand and regulatory uncertainty. Technologies reduced transaction costs but did not create economic value where secondary resources remained more expensive or less predictable than primary alternatives.

Technological innovation should therefore be viewed as a conditional rather than universal stimulus. Sánchez-García *et al.* (2024) substantiated the importance of digital platforms, artificial intelligence, blockchain and traceability technologies for circular transformation. Georgescu *et al.* (2025), analyzing EU countries, also identified relationships between economic, technological and environmental conditions and circular material use. At the same time, technological readiness was not identical to ecosystem readiness. Without compatible standards, accessible financing and stable demand, new technologies could increase project capital intensity and therefore reinforce investment constraints. This interaction illustrates why technological and financial barriers may accumulate rather than operate separately.

At the enterprise level, barriers were mutually reinforcing. Geissdoerfer *et al.* (2023) and Hina *et al.* (2022) systematized financial, market, organizational, technological and institutional obstacles to circular business model innovation. Their separation was analytically useful but could create a false impression of autonomy among individual factors. In practice, financing shortages could coexist with uncertain demand, limited information on material flows, insufficient technological scalability and difficulties in estimating future revenues. These combinations increase investment uncertainty because weakness in one component can reduce the economic value of improvements in another. Thus, the financial barrier was not only a shortage of capital but also a manifestation of accumulated market, technological and organizational uncertainty.

This was particularly evident among small and medium-sized enterprises. Gennari (2023), Malik *et al.* (2022), Ahmadov *et al.* (2025) and Mishra *et al.* (2025) showed that such enterprises simultaneously experienced shortages of finance, knowledge, human capital and bargaining power. Bassi and Brazzale (2025) found significant heterogeneity in resource-efficient practices among European SMEs. However, enterprise size alone was insufficient to explain these differences. Constraints also depended on value-chain position: a technically prepared company could lack influence over product design, supply conditions or end-user behaviour. Accordingly, firm size and value-chain position may condition how combinations of barriers are experienced, while sectoral and national settings determine access to infrastructure, finance and secondary-material markets. Existing studies, however, provide limited comparable evidence on these moderating

differences across countries. In the Ukrainian context, Malik (2026) examined the strategic potential of partnerships in the agricultural sector, highlighting the relevance of inter-organizational cooperation within sector-specific conditions. This perspective further supports consideration of partnership capacity and national context when assessing the development of ecosystem-based models.

The difference between new and existing businesses also made universal incentives difficult to establish. Briguglio et al. (2021) found that factors supporting the creation of circular businesses differed from those involved in transforming traditional companies. Lit et al. (2024) revealed that circular start-ups in the plastics industry overcame barriers through continuous adjustment of business models, partnerships and value propositions. Incumbents possessed physical and organizational assets but remained dependent on established technologies, contracts and profitability metrics. Consequently, identical financial instruments could be associated with different outcomes depending on organizational maturity and sectoral position. Rovanto and Finne (2023) noted that circular activities could be grounded in environmental values, professional identity and market-change motivations. Yet value orientation was not a substitute for a viable profit model. Axiological inconsistency emerged when declared environmental value was unsupported by measurable resource savings, business viability or transparent material flows. Such inconsistency increased information asymmetry and complicated project selection for financing.

According to Saarinen and Aarikka-Stenroos (2023), circular businesses seeking capital had to articulate revenue-generation mechanisms, risk profiles and expected payback periods. Kumar et al. (2025) showed that finance supported circular and sustainable business practices, but its relevance depended on complementary organizational and market conditions. Afolabi and Islam (2025) found that public environmental spending and private investment were complementary. This shifted attention from the volume of financing to its architecture. The literature, however, rarely distinguished investment as capital from investment as a mechanism for screening and validating circular strategies. Such validation required information about resource flows, demand, technological maturity and responsibility allocation. Without these criteria, subsidies could support individual projects without necessarily producing systemic circularity, while excessive grant dependence could conceal structural weaknesses in the business model.

The analysis revealed three main gaps. First, barriers and incentives were mostly examined as separate groups despite evidence that financial, market, technological, organizational and institutional constraints can accumulate and vary with firm size, value-chain position, sector and national context. Second, financial research focused primarily on access to capital and less on its allocation and validation function within interconnected ecosystems. Third, the transition from experimental projects to a self-sustaining circular system remained insufficiently studied. Existing literature suggests that institutional predictability, economic viability, technological compatibility, trust and complementary financing may jointly characterize more mature ecosystem configurations, but it does not establish a universal threshold or causal phase-transition mechanism. Therefore, an integrated framework was needed in which investment provision was considered not merely as an external resource but as an internal mechanism for coordinating, selecting and scaling circular solutions.

3. Materials and Methods

3.1 Study design and materials

The study was conducted during January–June 2026 using a mixed empirical design that combined panel macroeconomic analysis with a standardized survey of industrial enterprises. The main panel period covered 2022–2024 and 27 member states of the European Union. Ukraine was considered as a separate comparative case because of differences in statistical accounting, incomplete time series, and the impact of war conditions. Accordingly, Ukrainian indicators were used for structural comparison rather than direct inclusion in the EU panel model. The European Union resource productivity indicator for 2025 was used only to characterize the current direction of changes and was not included in panel modeling.

For the European Union, Eurostat data on circular material use, resource productivity, municipal waste generation and recycling, and corporate environmental investments were used. The investment indicator was converted to a comparable relative measure as a percentage of gross domestic product. The balanced panel included variables with full coverage of 27 countries over three years, resulting in 81 observations. Missing values were not replaced by mean or simulated estimates. For Ukraine, official data from the State Statistics Service of Ukraine on waste generation and processing, environmental protection expenditures, and environmental capital investments were used. These indicators were not treated as fully equivalent to Eurostat circular material use measures.

3.2 Sampling and survey procedure

The survey was conducted from February to May 2026. A purposive non-random sample of 210 industrial companies from Germany, Poland, Italy, Spain, the Czech Republic, the Netherlands and Ukraine, with an equal quota of 30 companies per country, was selected. Companies were recruited through industry associations, chambers of commerce, professional networks and corporate email addresses. Equal quotas were used to support cross-country comparability rather than population-representative estimation.

Inclusion criteria were a duration of activity of at least five years, at least 50 employees, the presence of own production facilities, and investments in resource efficiency, material reuse, waste recycling or production modernization made or planned in 2022–2024. Microenterprises, trade intermediaries, financial institutions, enterprises without production activities, and questionnaires with more than 10% missing responses were excluded.

The questionnaire contained 28 closed-ended statements rated on a five-point scale from 1 - "completely disagree" to 5 - "completely agree". The statements formed eight scales: investment activity, financial, regulatory, technological, market and coordination barriers, availability of financial incentives and ecosystem interaction. Scale values were calculated as the average of the corresponding items. Five statements additionally assessed the validation function of financing through verification of secondary raw-material suppliers, confirmed demand, payback period, project partners and risk sharing. Meeting at least four of the five criteria was operationally classified as financing used to validate a circular strategy. Values below 3.0 points were classified as low, and values of 4.0 points and above

as high. One voluntarily and anonymously completed questionnaire was accepted from each enterprise.

3.3 Statistical analysis

The internal consistency of the scales was assessed using Cronbach’s α , and distribution normality was examined using the Shapiro–Wilk test. Because the integral-scale distributions deviated from normality, relationships between variables were assessed using Spearman’s rank correlation coefficient. Cross-country differences were tested using the Kruskal–Wallis test followed by Dunn’s post-hoc test with Bonferroni correction. Differences in proportions were assessed using Pearson’s χ^2 test. For macroeconomic data, a model with country and time fixed effects was used. The survey analysis assessed individual associations between the specified barriers and investment activity; interaction terms or combined-barrier effects, as well as moderation by enterprise size, sector or value-chain position, were not estimated. All identified relationships were interpreted as associative rather than causal. $p < 0.05$ was considered statistically significant.

4. Results

4.1 Dynamics of circular material use in the European Union

The analysis of panel data for 2022–2024 showed a gradual increase in the level of circular material use in the European Union. The share of materials returned to economic circulation after recycling was 11.5% in 2022, 11.8% in 2023 and 12.2% in 2024. The cumulative increase was 0.7 percentage points, or 6.1% compared with the initial value. This trend indicated a slow expansion in the use of secondary raw materials but did not provide grounds for characterizing the changes as a complete transition to a self-sustaining circular model. In 2024, 87.8% of the EU’s total material demand was still met by resources that did not originate from recovered material flows (Eurostat, 2025a). The circularity indicator did not reflect the total volume of collected or recycled waste but the share of secondary materials in total material consumption. Its variation was therefore interpreted in relation to processing capacity, secondary-material quality, industrial demand and primary-resource consumption rather than as the consequence of any single factor. Even with increased recycling volumes, circularity could remain low if material consumption grew faster or recovered resources did not meet production standards.

Table 1: Dynamics of key circularity indicators of the European Union in 2022–2024

Indicator	2022	2023	2024	Change over the period
Circular use of materials, %	11.5	11.8	12.2	+0.7 p.p.
Municipal waste recycling, %	48.0*	48.0	48.1	+0.1 p.p.
Municipal waste generation, kg per person	513*	511	517	+4 kg
Municipal waste processed, kg per person	246*	246	248	+2 kg

Note: p.p. – percentage point. Values marked with an asterisk (*) are given as the closest available official estimates and were not used in the panel modeling without additional verification in the original set.

Source: compiled from Eurostat (2025a, 2026c, 2026d).

The results in Table 1 show different rates of change in individual components of the circular economy. In 2023, 48.0% of municipal waste was recycled in the EU, or 246 kg per capita. In 2024, the corresponding figures were 48.1% and 248 kg. The recycling rate increased by only 0.1 percentage points, although total municipal waste generation increased to 517 kg per capita (Eurostat, 2026c; Eurostat, 2026d).

The difference between recycling dynamics and circular material use was important. A high recycling rate did not guarantee proportional substitution of primary raw materials. Secondary materials could lose quality, enter products with lower added value, be exported or accumulate under unstable industrial demand. Thus, expansion of waste collection and processing alone was not equivalent to closure of the resource cycle; technological preparation, quality standardization and stable demand represented complementary conditions.

Circularity varied substantially between material groups in 2024: 23.4% for metallic ores, 14.3% for non-metallic minerals, 9.9% for biomass and 3.8% for fossil energy materials. These differences were consistent with variation in technological suitability for reuse, residual economic value and the maturity of secondary-material markets. The general dynamics were not uniform: circularity for metallic ores decreased by 1.2 percentage points from 2023, whereas for fossil materials it increased by 0.4 percentage points (Eurostat, 2025a).

The results allowed a distinction between the expansion of waste operations and broader ecosystem circularity. The former was reflected in the amount of waste collected and recycled. The latter implied stable return of resources to production, economically viable demand and repeatable connections between suppliers, manufacturers, recyclers and financial institutions.

4.2 Cross-country heterogeneity of circular transformation

The EU panel revealed significant spatial heterogeneity. In 2023, the highest levels of circular material use were recorded in the Netherlands at 30.6%, Italy at 20.8% and Malta at 19.8%. The lowest rates were recorded in Romania at 1.3%, Ireland at 2.3% and Finland at 2.4%. The range between the maximum and minimum values was 29.3 percentage points, with the Netherlands exceeding Romania by more than 23 times (Eurostat, 2025a). The gap was interpreted as reflecting different combinations of structural, industrial, market and institutional conditions rather than one dominant factor. Structurally, circularity may remain low in economies with substantial primary-material consumption or where changes in resource productivity arise partly from a larger service sector. Industrially, the capacity to incorporate recovered materials into production differs according to material composition and demand. Market differences concern the maturity and stability of secondary-material markets, while institutional and policy conditions concern standards, infrastructure and coordination across the resource cycle.

Accordingly, the high values observed in the Netherlands, Italy and Malta and the low values in Romania, Ireland and Finland may partly reflect differences in national industrial composition and the capacity of secondary-material markets to return recovered resources to productive use. However, the panel did not decompose these country gaps into separate structural, institutional, industrial or policy effects, so these explanations remain interpretative rather than causal.

The corporate sample represented six EU countries with different circular-transformation contexts: Germany, Poland, Italy, Spain, the Czech Republic and the Netherlands. The Netherlands represented an environment with high overall circularity, Italy a context of intensive industrial use of secondary resources, and Germany a developed waste-management infrastructure. Poland and the Czech Republic were characterized by modernization accompanied by less mature secondary markets, while Spain occupied an intermediate position. Fixed quotas of 30 enterprises supported cross-country comparison, but corporate differences characterized the study sample rather than representative national populations.

4.3 Waste generation and structural limits of recycling

Data by economic activity showed that most waste generation occurred outside the household sector. In 2022, around 5 tonnes of waste per person were generated in the EU. A substantial share originated from construction, mining and processing, water supply and waste-management operations. Therefore, concentrating circular policy only on municipal waste sorting did not correspond to the actual structure of material flows (Eurostat, 2025b).

Industrial circularity required linking the waste output of one enterprise with the resource requirements of another. This involved quality standards, information on the volume and composition of flows, logistical compatibility and long-term contracts. Without these conditions, technically suitable material could fail to acquire economic value. This pattern indicated that coordination constraints could coexist with and reinforce financial uncertainty because investment appraisal was more difficult without reliable supply volumes or confirmed buyers.

Plastic packaging remained a particular constraint. In 2023, 42.1% of plastic packaging waste was recycled in the EU. This was lower than the overall recycling rate for packaging because of polymer heterogeneity, contamination of streams and differences in recyclability. These characteristics were associated with a less predictable investment environment for plastic recycling than for materials with more standardized characteristics and stable secondary markets, such as glass, metals or paper (Eurostat, 2026e).

The differences showed that a single aggregate indicator of circular investment was insufficient for assessing outcomes. Comparable investment volumes could correspond to different results depending on material type, technological readiness, production scale and buyer availability. Accordingly, investment mechanisms required differentiation by material-flow characteristics.

4.4 Resource productivity and material restructuring

EU resource productivity in 2024 was close to €2.3 of gross domestic product per kilogram of domestic material consumption, and in 2025 it was €2.32/kg. The 2025 figure was used only to characterize the recent direction of change and was not included in panel modeling (Eurostat, 2026f).

Resource productivity reflected the ability of an economy to create added value with less material input but was not a direct equivalent of circularity. Its increase could be associated with technological modernization, a structural increase in the share of services, price changes or relocation of material-intensive activities outside the EU. Therefore, this

indicator was used as a separate explanatory variable rather than as a proxy for circular material use.

Resource productivity increased faster than the share of secondary materials. This pattern indicated that improvements in economic output per unit of material were not necessarily accompanied by proportional substitution of primary resources. For investment analysis, this required distinguishing resource-efficiency projects from circular projects: the former reduce material input per unit of output, whereas the latter return materials to subsequent production cycles.

4.5 Panel model results

After harmonization of indicators, a balanced panel of 81 observations was formed, covering 27 EU countries during 2022–2024. The dependent variable was circular material use. Explanatory variables included corporate environmental investments, resource productivity, municipal waste recycling and municipal waste generation per capita. The model included country and time fixed effects.

Table 2: Results of the panel model with fixed country and time effects

Variable	β	Standard error	p	95% confidence interval
Environmental investments of corporations	0.84	0.31	0.009	0.22; 1.46
Resource productivity	1.27	0.49	0.012	0.29; 2.25
Recycling of municipal waste	0.09	0.03	0.004	0.03; 0.15
Municipal waste generation per person	–0.002	0.001	0.176	–0.005; 0.001

Number of countries – 27; number of observations – 81; country fixed effects – yes; time fixed effects – yes; within-group $R^2 = 0.46$; $F = 8.31$; $p < 0.001$.

Source: calculated from Eurostat (2025a, 2025b, 2026a–2026f).

A positive association was found between circular material use and corporate environmental investments, $\beta = 0.84$, $p = 0.009$. Resource productivity was also positively associated with the dependent variable, $\beta = 1.27$, $p = 0.012$. Municipal waste recycling was positively associated with circularity, $\beta = 0.09$, $p = 0.004$. The coefficient for municipal waste generation was negative but did not reach statistical significance, $p = 0.176$ (Table 2).

The model explained 46% of the within-country variation in circular material use. The coefficients reflected associations after accounting for time-invariant country characteristics and common temporal changes. They should not be interpreted as causal effects. The short 2022–2024 period did not allow adequate modeling of investment lags, feedback relationships or temporal heterogeneity in environmental investment.

4.6 Ukraine as a separate comparative case

Ukraine was not included in the EU panel model because of differences in statistical accounting, incomplete time series and the absence of a fully equivalent circular-material-use indicator. Official data covered waste generation and treatment, environmental-protection expenditures and environmental capital investments but did not ensure full

comparability with Eurostat methodology (State Statistics Service of Ukraine, 2026a, 2026b).

Ukraine was therefore compared with the EU using available structural characteristics: processing infrastructure, stability of secondary-material markets, access to long-term financing and dominant enterprise conditions (Table 3).

Table 3: Comparative characteristics of the investment environment of the EU and Ukraine

Criterion	EU countries	Ukraine
Circular material use indicator	Regularly calculated using a single methodology	There was no fully comparable indicator
Time series for 2022–2024	Mostly full	Incomplete in some indicators
Recycling infrastructure	Significant interstate heterogeneity	Territorially uneven and partially damaged
Secondary raw materials market	Unevenly developed	Fragmented and unstable
Access to long-term financing	Higher, but depends on the country and project	Limited by risks and cost of capital
Dominant motivation of enterprises	Regulatory, market and technological	Expenditure, resource and adaptation
Main limitations	Stream coordination and scaling	Military risks, financing and infrastructure losses

Source: compiled from Eurostat (2025a, 2025b, 2026a–2026f) and State Statistics Service of Ukraine (2026a, 2026b).

The Ukrainian case combined a high need for resource efficiency with substantial investment constraints. During 2022–2024, circular investment decisions occurred in an environment characterized by asset-security risks, logistical instability, energy constraints and high credit costs alongside expected project profitability. Resource scarcity and pressure to reduce production costs coincided with incentives for material reuse, but this pattern does not establish a causal effect. Such motivation remained predominantly adaptive and was not consistently supported by mature secondary-material markets.

4.7 Reliability and distribution of corporate survey scales

The corporate analysis included 210 questionnaires, 30 from each country studied. Internal consistency of all eight multi-item scales was acceptable or high. Cronbach’s α was 0.84 for investment activity, 0.86 for financial barriers, 0.81 for regulatory barriers, 0.79 for technological barriers, 0.82 for market barriers, 0.85 for coordination barriers, 0.88 for availability of financial incentives and 0.90 for ecosystem interaction.

The distributions of the integral scales differed significantly from normality according to the Shapiro–Wilk test. Therefore, relationships between variables were assessed using Spearman’s rank correlation coefficient and cross-country differences using the Kruskal–Wallis test (Table 4).

Table 4: Reliability and normality test of integral scales

Scale	Cronbach α	Shapiro–Wilk W	p
Investment activity	0.84	0.960	< 0.001
Financial barriers	0.86	0.951	< 0.001
Regulatory barriers	0.81	0.968	< 0.001
Technological barriers	0.79	0.975	0.001
Market barriers	0.82	0.966	< 0.001
Coordination barriers	0.85	0.958	< 0.001
Availability of financial incentives	0.88	0.974	0.002
Ecosystem interaction	0.90	0.962	< 0.001

Source: calculated based on the results of a standardized survey.

The average investment-activity value in the sample was 3.47 points. Financial barriers had the highest average score at 3.82 points, followed by regulatory barriers at 3.56, coordination barriers at 3.49, market barriers at 3.41 and technological barriers at 3.27. Availability of financial incentives was rated at 3.18 points and ecosystem interaction at 3.44 points.

4.8 Relationships between investment activity and barriers and incentives

Correlation analysis revealed statistically significant relationships between investment activity and the main characteristics of the circular ecosystem (Table 5).

Table 5: Relationships of investment activity with barriers, incentives and ecosystem interaction

Variable	Spearman's ρ	p
Ecosystem interaction	0.61	< 0.001
Availability of financial incentives	0.54	< 0.001
Financial barriers	−0.58	< 0.001
Coordination barriers	−0.49	< 0.001
Regulatory barriers	−0.43	< 0.001
Market barriers	−0.39	< 0.001
Technological barriers	−0.31	< 0.001

Source: calculated based on the results of a standardized survey.

The strongest positive association was between investment activity and ecosystem interaction, $\rho = 0.61$, whereas the strongest negative association was with financial barriers, $\rho = -0.58$. Enterprises reporting stronger connections with suppliers, processors, financial institutions and public authorities were more likely to report higher investment activity. High capital costs, lack of guarantees and uncertainty of returns were associated with lower investment activity.

Coordination, regulatory, market and technological barriers were also negatively associated with investment activity. This empirical pattern demonstrated that several forms of constraint coexisted with lower investment activity, but it did not establish that their simultaneous presence produced additive or multiplicative effects. The analysis estimated separate bivariate associations and did not include interaction terms or a combined-barrier index.

Enterprise size, sector and value-chain position were likewise not tested as moderators. Consequently, the results support the coexistence of multiple investment constraints but do not determine whether particular combinations are stronger within specific enterprise categories or countries.

4.9 Cross-country differences in corporate performance

The Kruskal–Wallis test revealed statistically significant differences among the seven countries on all scales studied.

Table 6: Results of cross-country comparison of integral scales

Scale	<i>H</i>	df	<i>p</i>
Investment activity	34.72	6	< 0.001
Financial barriers	38.16	6	< 0.001
Regulatory barriers	31.48	6	< 0.001
Technological barriers	18.94	6	0.004
Market barriers	21.67	6	0.001
Coordination barriers	29.83	6	< 0.001
Availability of financial incentives	35.26	6	< 0.001
Ecosystem interaction	42.09	6	< 0.001

Source: calculated based on the results of a standardized survey.

Post-hoc comparisons with Bonferroni correction showed that investment activity among Dutch enterprises was statistically higher than in Poland and Ukraine, $p < 0.01$. German enterprises also reported higher values than Ukrainian enterprises, $p = 0.004$. Differences among Poland, the Czech Republic and Ukraine did not remain statistically significant in all comparisons after correction.

Financial barriers were higher in Ukraine than in the Netherlands, Germany and Italy, adjusted $p < 0.01$. Ecosystem interaction was higher in the Netherlands than in Poland, the Czech Republic and Ukraine, $p < 0.01$. Differences between the Netherlands and Germany did not reach statistical significance after adjustment for multiple comparisons.

Table 7: Average values of the main scales by country

Country	Investment activity	Financial barriers	Availability of incentives	Ecosystem interaction
Germany	3.81	3.31	3.54	3.82
Poland	3.14	4.02	2.86	3.08
Italy	3.62	3.58	3.33	3.61
Spain	3.46	3.73	3.14	3.44
Czech Republic	3.29	3.89	2.98	3.21
Netherlands	4.12	3.17	3.86	4.18
Ukraine	2.87	4.42	2.53	2.74

Source: calculated based on the results of a standardized survey.

Ukraine had the lowest average investment activity and ecosystem interaction and the highest financial-barrier score among the values presented in Table 7. This pattern was interpreted in the context of higher capital costs, military risks, logistical instability and limited long-term financing rather than as statistical evidence that these conditions caused the cross-country differences. Equal country quotas and the absence of adjustment for enterprise size, sector and value-chain position also mean that these comparisons characterize the study sample rather than representative national effects.

4.10 Threshold-like differences in investment activity

Signs of a threshold-like difference were observed between enterprises with low and high ecosystem interaction. Among enterprises with an ecosystem interaction index below 3.0 points, 4 of 46 enterprises, or 8.7%, had high investment activity. In the group with an index of at least 4.0 points, the corresponding share was 32 of 58 enterprises, or 55.2%. The difference was statistically significant, $\chi^2(1) = 24.48, p < 0.001$.

A similar pattern was observed for the availability of financial incentives. Among enterprises with an indicator below 3.0 points, 7 of 67 enterprises, or 10.4%, had high investment activity. At values of at least 4.0 points, high investment activity was recorded in 29 of 55 enterprises, or 52.7%. The difference was statistically significant, $\chi^2(1) = 25.96, p < 0.001$.

Higher ecosystem interaction and greater availability of financial incentives, considered separately, were therefore associated with substantially larger proportions of enterprises reporting high investment activity. Their joint statistical effect was not estimated and should not be inferred from these comparisons.

The observed pattern is compatible with the proposed phase-transition interpretation only in a descriptive sense. Enterprises were distributed differently at the low and high ends of the two scales, but the results do not demonstrate a discrete transition mechanism, establish temporal ordering or identify a universal quantitative threshold. The finding should therefore be interpreted as a threshold-like classification rather than evidence of a causal phase transition.

4.11 Financing as a validator of circular strategies

A separate section of the questionnaire assessed whether decisions to use external financing were accompanied by verification of secondary raw-material suppliers, confirmed demand, projected payback period, project partners and risk-sharing mechanisms. The presence of at least four of the five elements was interpreted as financing used to validate a circular strategy.

In the high-investment-activity group, this criterion was met by 34 of 58 enterprises, or 58.6%. In the low-activity group, it was met by 12 of 63 enterprises, or 19.0%. The difference was statistically significant, $\chi^2(1) = 20.07, p < 0.001$.

The validation criterion was therefore substantially more prevalent among enterprises with high investment activity. Financing was interpreted as performing a strategy-validation function when it was accompanied by verification of material flows, market viability,

partnership structure and risk allocation. The observed difference does not establish that such validation caused higher investment activity.

Figure 1 summarizes this interpretation as a conceptual configuration rather than a statistically identified causal pathway. Lower information asymmetry, access to finance and long-term contractual relationships are treated as characteristics associated with more stable ecosystem interaction, not as sequential stages demonstrated by the survey.

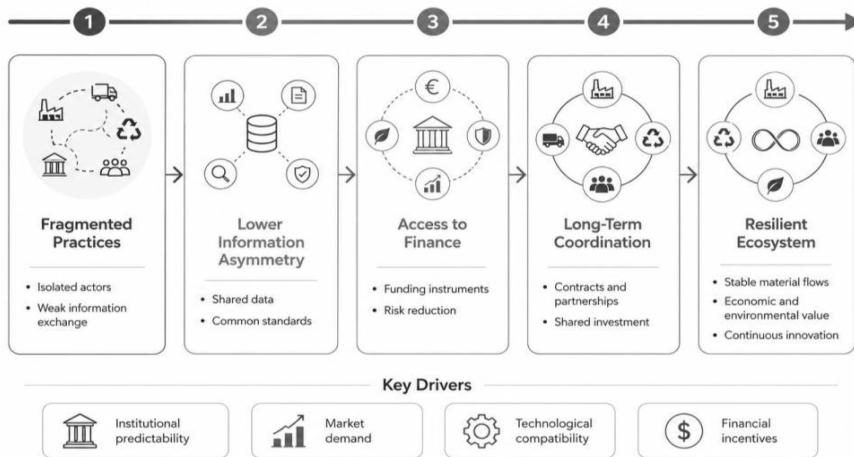


Figure 1. Ecosystem mechanism for the transition from fragmented circular practices to a sustainable system of interaction

Source: developed by the authors based on the results of the study.

The results supported the hypothesis at the level of association: investment activity was positively associated with financial incentives and ecosystem interaction. At the macroeconomic level, circular material use was positively associated with environmental investment, resource productivity and municipal waste recycling. At the corporate level, the strongest positive association was between investment activity and ecosystem interaction, whereas the strongest negative association concerned financial barriers.

The research question was therefore answered in terms of observed configurations rather than causal determinants. Higher investment activity coincided with a broader pattern of available financial incentives, institutional conditions, market demand, technological compatibility and stronger ecosystem interaction, while financial, regulatory, market, technological and coordination barriers were separately negatively associated with investment activity. The design did not estimate their combined causal contribution.

Threshold-like differences further showed that high investment activity was more frequent among enterprises at the higher end of the ecosystem-interaction and financial-incentive scales. This pattern was descriptive rather than temporal: the data do not demonstrate that investment activity increased after a particular level of ecosystem consistency had been reached. The non-random corporate sample, equal country quotas, short macroeconomic panel and associative design preclude causal interpretation and identification of a universal threshold of circular transition.

5. Discussion

The results showed that investment support for circular transformation was associated not only with available capital but also with interaction between enterprises, financial institutions, secondary-material suppliers, processors and regulators. The strongest positive relationship was found between investment activity and ecosystem interaction, $\rho = 0.61$, while financial barriers had the strongest negative association, $\rho = -0.58$. Financial constraints therefore appeared alongside weak contractual relations, uncertain demand, unstable material supply and unclear risk sharing rather than as an isolated obstacle.

This finding was consistent with Sánchez-Teba *et al.* (2025), who linked circular transformation of SMEs to access to finance, business associations and institutional quality. Our results extend this evidence by showing that enterprises integrated into stronger partner networks also reported higher investment activity. Financial resources were therefore more relevant when supported by organizational capacity and stable ecosystem relationships.

The role of coordination barriers was similarly consistent with Sonar *et al.* (2024), who associated reverse-logistics constraints with supply-chain fragmentation, information shortages and weak interaction. In this study, coordination barriers were negatively associated with investment activity, $\rho = -0.49$. Untraceable material flows, unstable supply and uncertain sales were thus associated with lower investment attractiveness, although the design did not establish causal ordering between coordination and financial constraints. Financial, regulatory, market and coordination barriers also formed an empirically overlapping pattern of constraints. Souza Piao *et al.* (2024) showed that stakeholders assessed circular-economy barriers differently because costs, risks and benefits were unevenly distributed. In our sample, several barriers were separately associated with lower investment activity, whereas stronger ecosystem interaction coincided with greater availability of financial incentives. However, interaction effects between barriers were not estimated, so their cumulative impact cannot be quantified from these data.

Technological barriers showed a weaker relationship with investment activity than financial, coordination and regulatory barriers. This did not imply that technology was unimportant. Rather, technological readiness could coexist with difficulties in financing implementation, achieving scale or integrating solutions into existing supply chains. This interpretation is consistent with Zils *et al.* (2025), who associated circular transformation with sequential restructuring of operations rather than a single technological intervention. At the macroeconomic level, the positive association between circular material use and corporate environmental investment was consistent with Afolabi and Islam (2025), who identified complementary relationships between environmental expenditure, private investment and circular-economy development in EU countries. The positive associations with resource productivity and municipal waste recycling also corresponded with Georgescu *et al.* (2025), who linked circular material use to interconnected economic, technological and environmental conditions. The present study extends this evidence through a country- and time-fixed-effects model for 2022–2024. At the same time, municipal waste generation was not significantly associated with circularity, indicating that

waste volumes themselves did not correspond systematically with the substitution of primary materials.

Cross-country differences further emphasized the role of context. Higher investment activity and ecosystem interaction were observed in the Netherlands and Germany, while enterprises in Poland, the Czech Republic and Ukraine reported stronger constraints. Tritto et al. (2024) likewise showed that circular practices in EU firms were associated with company-, country- and institutional-level conditions. Our findings suggest that similar financial instruments may operate in different environments depending on secondary-market maturity, infrastructure and regulatory coordination, although equal country quotas and the absence of sectoral adjustment limit population-level comparisons.

The Ukrainian case required separate interpretation because military risks, high capital costs, logistical instability and infrastructure losses differed substantially from conditions in the EU sample. Lower investment activity therefore cannot be attributed solely to circular-economy maturity. It should be interpreted within this wider risk environment. Some Ukrainian enterprises with international partnerships, grant financing and long-term contracts reported values closer to those of EU enterprises, which is consistent with, but does not prove, a compensatory role of ecosystem connections.

Threshold-like differences provided an additional analytical result. Among enterprises with low ecosystem interaction, 8.7% demonstrated high investment activity, compared with 55.2% in the high-interaction group. A similar pattern occurred for financial incentives. These differences are compatible with the proposed phase-transition concept only as a descriptive pattern. They show clustering of higher investment activity at the upper ends of the interaction and incentive scales but do not identify a causal transition point or universal threshold.

This interpretation is consistent with Takacs et al. (2022), who proposed integrating circular-economy barriers into strategic management. The practical implication is that enterprises cannot address financing, material supply, market demand, contractual relations and managerial capabilities as fully independent problems. A coordinated response is required because weakness in one component may reduce the usefulness of improvements in another.

The results concerning financing as a strategy validator further clarified the role of investment decisions. Enterprises with high investment activity more frequently verified suppliers, demand, partners, payback periods and risk-sharing mechanisms. Financing was therefore interpreted not only as a resource but also as a screening mechanism distinguishing declarative circular orientation from projects supported by identifiable material, market and organizational conditions.

At the same time, conventional financing criteria may undervalue long-term environmental benefits, inter-organizational effects and reductions in resource-related risks. Validation should therefore combine financial indicators with evidence on material flows, environmental performance and partner-network stability. In practice, support directed only toward equipment purchases may remain insufficient when secondary-material supply, logistics, quality standards or demand are unstable. Instruments aimed at enterprise consortia, industrial symbioses, shared infrastructure and long-term agreements may therefore be more appropriate.

Several limitations constrain interpretation. The purposive non-random sample limits generalization to the wider population of industrial enterprises, while equal country quotas improve comparability but do not reproduce national enterprise structures. The short 2022–2024 panel restricts coefficient interpretation because investment lags and longer-term adjustment could not be modeled. The broader environmental-investment indicator does not isolate financing directed specifically toward circular material flows. Ukrainian statistics were not fully comparable with Eurostat data, which prevents direct inclusion in the EU panel. Finally, the associative design means that neither the observed relationships nor the threshold-like pattern can be interpreted causally. Moreover, because the threshold-like groups were derived from a non-random sample and predefined scale cut-offs, their prevalence and stability may differ across enterprise populations, sectors and countries.

Future research should therefore prioritize longer longitudinal panels capable of testing whether ecosystem interaction precedes subsequent changes in investment activity. A second priority is sector-specific analysis incorporating firm size, value-chain position and investment volume. Subsequent studies should model investment lags and test whether threshold-like patterns remain stable across industries and countries. Taken together, the findings indicate that circular transformation is associated with the coordination of interdependent financial, material, market and institutional conditions rather than with any single economic or technological factor.

6. Conclusions

The study substantiated an ecosystem framework for investment support of circular transformation, showing that investment activity was associated with more than capital availability alone. Financial incentives, institutional predictability, technological compatibility, stable demand for secondary resources and coordination among material-cycle participants formed an interconnected investment environment.

At the macroeconomic level, circular material use in the European Union increased from 11.5% in 2022 to 12.2% in 2024, although substantial cross-country heterogeneity persisted. The panel model showed positive associations with corporate environmental investments, resource productivity and municipal waste recycling. These coefficients should not be interpreted causally because the 2022–2024 panel did not capture longer investment lags and environmental investment covered activities broader than circular material flows.

The survey of 210 industrial enterprises showed that investment activity was most strongly associated with ecosystem interaction, $\rho = 0.61$, while financial barriers had the strongest negative association, $\rho = -0.58$; financial incentives were positively associated at $\rho = 0.54$. Enterprises with high ecosystem interaction more frequently reported high investment activity. The threshold-like pattern was descriptive rather than evidence of a universal threshold or causal phase transition and indicated clustering of investment activity under more developed interaction and incentive conditions.

Practical implications support shifting from stand-alone technological investments toward inter-firm consortia, industrial symbioses, shared infrastructure and long-term contracts. Project selection should consider verified secondary-material sources, expected demand,

payback periods, partnership structure and risk-sharing mechanisms. For Ukraine, guarantee instruments, blended financing and mechanisms addressing elevated military and logistical risks are particularly relevant.

The non-random sample limits generalizability, equal country quotas restrict population-level cross-country inference, incomplete Ukrainian comparability prevents direct inclusion in the EU panel, and the associative design precludes causal conclusions. Future research should first use longer longitudinal panels to test whether ecosystem interaction precedes subsequent investment changes and to model investment lags. A second priority is sector-specific analysis incorporating firm size, value-chain position and investment volume, followed by testing whether threshold-like patterns remain stable across sectors and countries.

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