



Circular Economy in Post-Crisis Recovery: Closed-Loop Models as a Tool for Regional Economic Sustainability

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Abstract: The shift of economic systems towards circularity is perceived as a priority in terms of recovery from the crisis and ever more macroeconomic instability. Closed loop models are seen less as a tool of environmental reconstruction, but rather, a structural mechanism to enable economic modernisation and sustainability at large. Conversely, the quantitative estimation of the effects of circularity on broader – macroeconomic – dynamics are still meagre, especially in terms of a more comparative cross-country dimension. Our purpose with this study is to focus on the development and testing an integrated Grid-locked technique to empirically estimate the impact of circularity on the economic sustainability of the European Union, in the crisis haven, “ad virum”. Recovery path. The balanced panel comprises the EU-27 for 2015–2024 (270 country-year observations). The countries in the sample are heterogeneous in significant ways: the gap in real GDP per capita exceeds three times; the share of industry in GDP ranges from about 15–30%; the level of urbanization ranges from about 55% to more than 80%; circularity indicators show more than twofold cross-country differentiation. Together, this warrants the use of a panel model with country and time fixed effects. Our methodology proceeds on the formation of composite indices of circularity and economic resilience based on minmax normalizing indicators across the whole panel of observations and then econometrically estimating them using a fixed effects model (Stata 17.95% confidence interval, clustered robust standard errors, Hausman test for specification selection). The circularity index combines resource productivity, recycled materials use, waste recycling, environmental expenditures and the share of renewable energy; the economic sustainability index combines real GDP per capita, employment stability and investment activity. The results show a statistically significant positive correlation between the integrated circularity index and the economic resilience index for the years 2021–2024 when controlling for structural characteristics of economies (industry structure, investment, urbanization) and for timeinvariant national characteristics. The growth of the integrated circularity index relates to an increase the aggregate index of economic sustainability in the post-crisis period. There is also a tendency to reduce the cross-country variability of economic resilience in recovery phase. The significance of the study in practice is showing the feasibility of integrating circular indicators into the system of macroeconomic monitoring and strategies for longterm structural stabilization within the European Union.

Keywords: agricultural business, circular economy, economic sustainability, green economy, post-crisis recovery, panel model, integral index, macroeconomic analysis, sustainable development, regions of the world.

Introduction

The aggravation of the crisis over the last few years has proven the limits of simplistic, linear models of regional economic recovery based on the ‘intensive’ use of resources and the reproduction of a pre-war or pre-crisis economic infrastructure. Despite the active application of the concept of circular economy there is no one point of reference at a regional level to assess how a closed-loop model could contribute to making the economy of a territory more resilient in the post-crisis period. Research activity is mostly centred on the level of enterprises, individual supply chains or strategic declarations creating a hiatus between a theoretical foundation for circular transformation and its quantifiable effects on the resilience of a regional economy.

At present, the idea of circular economy is taken into consideration as the basis of a post-Crisis recovery model, which guarantees the long-term economic sustainability of territories. Cetin and Kirchherr [8] introduced a model framework of build back circular, in which “recovery from crises is enhanced by a closed resource cycle that seeks to minimize losses and values the adaptivity of economic systems”. The regional aspect of this transformation is investigated by Bourdin and Jacquet [5], who demonstrated how territorial circularity strategies reinforce cities and regions’ institutional coherence and economic stability.

The mechanisms of influence of circular practices on the sustainability of production systems have been empirically confirmed by Le et al. [23], who found a positive statistically significant relationship between environmental innovations, closed-loop production models, and resilience indicators. The institutional prerequisites for the implementation of such models are systematized by Hartley et al. [19], who emphasized the role of policy instruments and multi-level governance in ensuring the effectiveness of circular transformation.

A methodological framework for the assessment of closed-loop models was proposed by Shabanpour et al. [32], in which they provided a toolkit for assessing the circularity of supply chains. These studies merge to form a complete outlook at the same time on the relation between the circular economy, regional strategies and the economic sustainability. An integrated regional model for assessing the consequences of closed-loop models on the assessment of economic resilience in the post-crisis context remains to develop.

Despite the fact that there are more and more studies in relation to the circular economy, our field continues to be characterized by many gaps. Firstly, there is not an articulated “family” of quantitative indicators that could allow a complete measurement of the influence that the circular economy models have had and will have on the economic sustainability of the territories in the post-crisis period. Secondly, most empirical studies have been carried out at the micro level of firms or single sectors, studying only in a disjointed way the meso level of the territorial economic system. Thirdly, there is rarely an integration between institutional-strategic studies that concern phases of adoption of circular practices and econometric models for assessing economic resilience, making it difficult to define a coherent analytical framework. It is therefore not possible to formulate an integrated regional approach capable of synthesising the strategic, structural and quantitative aspects of the circular transformation in the recovery post-crisis.

The purpose of the study is to develop and empirically test an integrated analytical model for assessing the impact of closed-loop models on the economic sustainability of the European Union in the post-crisis period and to determine their role as a tool for the long-term recovery of economic systems.

To achieve this goal, the following tasks were identified: to systematize theoretical approaches to the interpretation of the circular economy and economic resilience at the macro level; to operationalize the concepts of circularity and economic resilience through a system of quantitative indicators; to form integral indices of circularity and economic resilience; to conduct an econometric assessment of the impact of circularity on economic resilience indicators in the post-crisis period; to substantiate practical implications for recovery strategies.

Literature Review

Studies of the circular economy presented in recent works mark the movement from the theory of closed model to their inclusion in the regional sustainability agenda. Attuning the performance of circular business models was initially formed by Achillas and Bochtis [1] who proved that performance growth of the system is based on closed cycles of resources. Later authors shifted to financial and institutional aspects of supporting the conversion to a circular economy: Afolabi and Islam [2] demonstrated the circular economy power of public environmental spending plus private investment on the formation of circular economy in European Union.

The technological dimension of circular transformation is revealed by D. Altan et al. [3], who demonstrated that the introduction of digital technologies increases the transparency of supply chains and their adaptability to external shocks, while Borms et al. [4] empirically confirmed that enterprises with a higher level of circularity are characterized by greater organizational resilience in the post-pandemic period. The transition to the territorial level of analysis was made by Cader et al. [6], who proposed a system of indicators for measuring circularity in the regional context, laying the methodological foundations for quantifying the sustainability of spatial systems.

The mechanisms for implementing circular practices through industrial symbiosis are substantiated by Castellet-Viciano et al. [7], which is complemented by the territorial approach of Chembessi et al. [9], who proved the importance of spatial proximity for the formation of circular value added and local interaction ecosystems. In the post-crisis dimension, Cifuentes-Faura [10] considered the circular economy as the basis for economic recovery after COVID-19, and De Giovanni [11] demonstrated the potential for integrating closed supply chains with digital tools and incentive systems that enhance the effectiveness of closed-loop models.

The systematization of models for implementing the circular economy through open innovation mechanisms was carried out by Kalantzis et al. [22], while Massari et al. [24] and Mehrabi et al. [25] developed tools for modeling and optimizing sustainable closed networks under uncertainty. The cross-country and regional dimension of circularity assessment was analyzed by Pakuta et al. [29], who identified methodological limitations of existing indicative approaches, while Rabbi [30] proposed an interdisciplinary model of the transition to circularity at the level of regional socioeconomic systems. In the broader context of the interconnection of economic growth, social dynamics and environmental quality, the long-term aspects of the transformation of economic systems are considered by Muolo et al. [26].

In the European context, the structural manifestations of closed-loop models are formed as a combination of institutional strategies, territorial coordination and indicative monitoring. The European framework for strategic management of the circular transition, analyzed by Hartley et al. [19] shows that closed-loop models are integrated into policy through a combination of regulatory, financial, and information instruments. At the level of cities and regions, Bourdin and Jacquet [5] showed that spatial strategies of the circular economy contribute to the formation of local value chains and reduce resource dependence. Empirical assessments of the comparative performance of EU countries by Pakuta et al. [29] confirm the existence of significant interstate differentiation in the implementation of closed-loop models, which reflects different levels of institutional maturity and technological readiness.

Thus, in the European Union, closed-loop models are manifested structurally through increased resource productivity, development of secondary material flows, integration of industrial symbiosis, and institutionalization of circular strategies at the national and regional levels. The generalization of these studies shows that despite significant progress in the strategic, technological and indicative dimensions, an integrated quantitative model for assessing the impact of closed-loop models on the economic sustainability of regions in the post-crisis context remains insufficiently conceptualized, which determines the scientific feasibility of further empirical analysis.

Materials and Methods

The study was conducted in 2025 based on panel data for 2015–2024. The spatial boundaries covered all 27 member states of the European Union. The unit of analysis was “country-year”. The total number of observations was 270. The sample is purposive and non-random and covers the full composition of the integration association, which ensures the representativeness of the results at the EU level.

In the sample countries, there was significant heterogeneity in structural indicators (related to development level, sectoral specialization, or resource intensity). At the time of first analysis, there was more than three-fold variation in real GDP per capita across the countries at this time, evidencing the co-existence of rich Western and Northern European economies with Central and Eastern European countries undergoing structural convergence. The share of industry in GDP varied from about 15–30%, and the level of urbanization ranged from about 55% to over 80%. Circularity indicators also showed significant cross-country differentiation: the values of circular material use rate and renewable energy share differed by more than half between the lowest and highest performing countries. Such variability justifies the use of a fixed-effects panel approach to control for time-invariant national characteristics.

The sample included only countries with complete time series for all key variables for 2015–2024 and no changes in the methodology for calculating the indicators during the study period. Harmonization was checked by analyzing Eurostat methodological notes and relevant statistical metadata. Countries with fragmented or incompatible data would be subject to exclusion; no such cases were recorded in the study. Imputation of missing values was not applied.

The post-crisis period is defined as 2021–2024, which allowed us to reflect the recovery phase after the pandemic shock of 2020 and to take into account a possible structural break in the trajectories of economic dynamics.

The empirical base draws on official Eurostat, World Bank and OECD data [27, 28] and International Energy Agency data [20]. The full circularity index is made up of the following statistical indicators: resource productivity (GDP per domestic material consumption), circular material use rate (%), municipal waste recycling rate (%), gross domestic expenditure on environmental protection (% of GDP), and renewable energy share (% of final energy consumption). Gross macroeconomic indicators were converted into constant 2015 prices using the GDP deflator [21]. Relative indicators (per capita or as % GDP) were computed for cross-country comparability purposes. Real GDP per capita and type gross investment were log transformed in order to reduce distribution asymmetry.

The circularity index was formed after linear normalization of the indicators using the min-max method, with minimum and maximum values determined for the entire panel of observations for the period under study. The integral indicator was calculated as the average of the normalized components with equal weights.

The index of economic stability included three components: the annual growth rate of real GDP per capita; employment stability, measured by the coefficient of variation of the employment rate over the period; and investment dynamics, measured by the change in the share of gross fixed capital formation in GDP. After normalization of the components, the integral index was determined as their average value. The research procedure included the stages of data collection, checking their harmonization, deflation of nominal indicators, normalization of variables, formation of integral indices, and econometric evaluation of relationships.

A panel model with country and time fixed effects was used to assess the impact of circularity on economic sustainability:

$$RI_{it} = \alpha + \beta_1 CI_{it} + \beta_2 Post_t + \beta_3 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (1)$$

where RI_{it} is the economic stability index; CI_{it} – circularity index; $Post_t$ – post-crisis period indicator; X_{it} – control variables (share of industry in GDP, level of gross investment, level of urbanization); μ_i – fixed country effects; λ_t – time effects; ε_{it} – random error.

The stationarity of the panel series was checked by standard panel tests. The overall significance of the model was assessed by the F-test, and the significance of individual parameters was assessed by the Student's t-test. Clustered robust standard errors were used to correct for heteroscedasticity and autocorrelation. The choice between fixed and random effects was made on the basis of the Hausman test. The level of statistical significance was set at 0.05 with a confidence interval of 95%. The data were processed using Stata 17 software.

Results

Spatial and temporal dynamics of the circularity index in the EU countries (2015–2024)

The integrated circularity index (CI), formed on the basis of resource productivity, circular material use rate, municipal waste recycling, environmental protection costs, and the share of renewable energy, showed a steady upward trend during the study period. Primary statistics are obtained from the Eurostat database [14, 16, 17, 18], as part of the Circular Economy Monitoring Framework of the European Commission [12, 13].

In 2015–2019, there was a gradual increase in the average CI value for the panel. In 2020, there was a temporary decline in the integral indicator, which is consistent with the overall dynamics of economic activity. In 2021–2024, the average CI value exceeded the pre-crisis level, indicating a structural deepening of circular practices. Table 1 summarizes the descriptive statistics of the index.

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Table 1: Descriptive statistics of the circularity index (CI) in EU countries, 2015–2024

Indicator	Average	Standard deviation	Min	Max
CI (entire panel)	0.512	0.147	0.182	0.843
CI (2015–2019)	0.476	0.152	0.182	0.801
CI (2021–2024)	0.548	0.136	0.224	0.843

Source: calculated by the author based on Eurostat data [14, 16, 18] within the Circular Economy Monitoring Framework European Commission [12]

Note: CI values are normalized in the range of 0–1; post-crisis period – 2021–2024

As can be observed in Table 1, the average level of circularity in the post-crisis period is higher than the pre-crisis level by 0.072 points, while at the same time the cross-country variability of circular strategies is decreasing, showing an increasing similarity of the circular strategies taken. The economic sustainability index (RI) is formed from three components: the annual rate of growth of real GDP per capita; coefficient of variation in employment; the change in the share of gross fixed capital formation in GDP. Data from Eurostat [15, 17] & World Bank, for deflators. Table 2 displays the primary (unnormalized) values of the components used for formulating the RI.

Table 2: Primary components of the economic stability index (panel averages)

Component	2015–2019	2020	2021–2024
Real GDP growth rate per capita (%)	2.1	−4.5	2.8
Employment variation coefficient	0.034	0.067	0.029
Change in CF share in GDP (percentage points)	0.6	−2.1	1

Source: calculated by the author based on data from Eurostat [15, 17] and the World Bank [36]

Note: raw components before normalization are given; GFCF – gross fixed capital formation

In 2020, the RI declined due to a drop in economic growth and increased employment volatility. In 2021–2024, there was a resumption of positive investment dynamics and stabilization of employment, which contributed to the growth of the integral indicator. Estimating a panel model with country and time fixed effects confirmed a statistically significant positive relationship between CI and RI.

The coefficient on CI is positive and significant ($p < 0.01$) indicating a robust association between circularity levels and economic resilience. Post is laudable accounts of within sample updated structural particulars of postcrisis contagion period. Estimates align with intuitions that closed-loop on the whole engender a more concentrated economic recovery path within the EU.

Formation and structural characteristics of the economic sustainability index

The Economic Resilience Index (ERI) for the panel of EU-27 countries for the years 2015–2024 is constructed as an integral indicator which builds on three normalized components: (1) real GDP growth rate per capita; (2) stability, measured as the coefficient of variation of the employment rate; (3) investment dynamics, defined as the change in the share of gross fixed capital formation (GFCF) in GDP. After min-max normalisation of the components (the global

minima and maxima are defined for the entire 2015–2024 panel), the integral indicator is constructed as an arithmetic mean of the three components with equal weights. RI values lie in the interval $[0;1]$.

For the panel, the average RI value for 2015–2019 was 0.533. In 2020, the index fell to 0.312 (the minimum average value for the whole period), reflecting a general decline in all 3 components. In 2021–2024, RI recovered to 0.521, 0.209 points above the level for crisis multiyear period but, nevertheless, slightly below the average for the pre-crisis period (-0.012). The standard deviation of the integral index fell from 0.148 to 0.137 from the 2015–2019 to 2021–2024 periods (revealing slight convergence of the trajectories of recovery). The minimum RI value in the panel was 0.121, and the maximum value was 0.879, illustrating that even in the recovery phase some differentiation between countries still remains high.

The structural analysis shows that it was the component of economic growth that tended to have the highest amplitude of change. The average growth rate of real GDP per capita was 2.1% in 2015–2019, -4.5% in 2020 and 2.8% in 2021–2024. Thus, it was this component that settled the depth of decline of the integral R.I. during the crisis and its recovery. As for the component of employment stability, as a feature of stability in the labor market, the coefficient of variation tended to rise from 0.034 prior the crisis to 0.067 in 2020 (almost twice fingers), showing volatility of the labor market. In 2021–2024, the coefficient of variation tends to fall to 0.029, lower than the average before the crisis and indicating recovery in the stabilization function of employment.

The investment component itself exhibits a cyclical attribute: the average change in the GFCF share in GDP was $+0.6$ percentage points in 2015–2019, -2.1 percentage points in 2020, and $+1.3$ percentage points in 2021–2024. The recovery in investment activity (in GFCF growth) in the post-crisis phase (over the crisis) is stronger than the average pre-crisis growth, suggesting an increased weight of investment in the adaptation phase.

A brief comparative analysis of the periods shows: Change in factor of variation. While in 2015-2019 the main “source” of cross-country differentiation was the GDP growth component, in 2020 the employment variability indicator became dominant. Gaining strength of investment component. In 2021–2024 investment dynamics contributed more positively to the RI than in the pre-crisis period. Reduced cross-country asymmetry. The standard deviation of the integrated index decreased by 7.4% in the post-crisis period compared to the pre-crisis period. The distribution of the RI in 2020 had an increased leftward asymmetry, which signals a larger number of countries with sharply deteriorating macroeconomic indicators. In 2021–2024 we restore symmetry, which indicates that the recovery trajectories are leveling.

The coefficient of variation of the integral RI decreased from 0.278 in the period 2015–2019 to 0.263 in 2021–2024, which confirms the trend towards moderate convergence. The results indicate that the integrated index of economic stability is sensitive to systemic macroeconomic shocks; features the synchronous reaction of three key components; partially recovered to pre-crisis values in the post-crisis period; and experienced a decline in cross-country differentiation beyond 2020.

Thus, the formed RI not only captures the level of economic dynamics, but also reflects the structural ability of economic systems to stabilize and adapt. The obtained quantitative characteristics of the integral indicator create an empirical basis for further econometric assessment of the relationship between circularity and economic resilience in a panel model with fixed effects.

Econometric assessment of the impact of circularity on economic sustainability

The econometric estimation was performed according to the specification of a panel model with country (μ_i) and time (λ_t) fixed effects, as defined in the Materials and Methods section. The unit of analysis is “country-year”; the total number of observations is 270; the number of groups (countries) is 27. The dependent variable is the integral index of economic sustainability (RI), and the main explanatory variable is the integral circularity index (CI). The control vector X_{it} includes the share of industry in GDP (%), GFCF (% of GDP), and urbanization (%). Standard errors are clustered by country; significance level – 0.05; confidence interval – 95%.

The choice of a fixed-effects model is justified by the results of the Hausman test ($\chi^2 = 11.37$; $p = 0.021$), which indicates systematic differences between countries and the incorrectness of the assumption of randomness of individual effects. The overall significance of the model was confirmed by the F-test ($F = 18.94$; $p < 0.001$). The estimation was performed taking into account heteroscedasticity and within-group autocorrelation by using clustered robust standard errors. Table 3 shows the results of the baseline specification, which includes the CI, the post-crisis indicator ($Post_t = 1$ for 2021–2024), and control variables.

Table 3: Results of fixed-effects panel regression (dependent variable – RI)

Variable	Coefficient	Robust SE	t	p-value
CI	0.284	0.091	3.12	0.002
Post (2021–2024)	0.117	0.046	2.54	0.012
Share of industry in GDP (%)	0.063	0.028	2.21	0.028
CF (% of GDP)	0.148	0.052	2.84	0.005
Urbanization (%)	0.019	0.017	1.12	0.264

Source: calculated by the author in Stata 17

Note: standard errors are clustered by country; 95% confidence interval; N = 270; groups = 27; within R² = 0.41; F (model) p < 0.001; Hausman p = 0.021

Turning to the results at CI, we find a positive and significant coefficient ($\beta=0.284$; $p=0.002$). In other words, a smart increase of 0.1 points in the circularity index will boost RI with 0.028 points if everything else held constant. Given that the RI is normalised in the range of 0–1, this effect is of an economically meaningful size. For the Post indicator, we find a positive coefficient of 0.117, supporting the structural specificity of 2021–2024 figure after controlling for other variables ($p=0.012$). For the colinear GFCF (% of GDP), we again obtain a statistically significant value ($p=0.005$), supporting the role of stabilizing investment activity. The level of urbanization did not attain significance, $p=0.264$. To cement the results, we perform an alternative specification with a CI lag (CI t-1) which guard against the simultaneity bias.

Table 4: Extended model with lagged CI

Variable	Coefficient	Robust SE	t	p-value
CI (t-1)	0.251	0.097	2.59	0.010
Post (2021–2024)	0.109	0.049	2.22	0.027
Share of industry in GDP (%)	0.058	0.03	1.93	0.055
CF (% of GDP)	0.142	0.054	2.63	0.009
Urbanization (%)	0.017	0.018	0.94	0.348

Source: calculated by the author in Stata 17

Note: model with lagged CI; standard errors clustered by country; 95% confidence interval; N = 243; groups = 27; within R² = 0.38; F (model) p < 0.001

The lagged value of the CI variable is still statistically significant ($p = 0.010$), meaning that the positive association remains with a time delay. The drop from 0.284 to 0.251 of the coefficient does not change the direction of the

relationship confirming its robustness. The estimated coefficients indicate statistically significant positive correlations between the level of circularity and economic resilience among the EU-27 members for 2015–2024. Share of explained within-group variation (within $R^2 = 0.41$ in baseline) indicates moderate explanatory power of the specification.

The positive coefficient on CI, combined with the significance of the investment component, suggests that circular practices are associated with more stable macroeconomic trajectories in the post-crisis period. At the same time, the lack of significance of the urbanization variable indicates the secondary nature of this factor in explaining the variation of RI within the chosen specification. Thus, the results of the econometric estimation confirm the existence of a statistically significant positive relationship between the integrated circularity index and the integrated economic sustainability index, controlling for structural characteristics of the economy and time effects. The estimates are consistent with the chosen methodology and provide a quantitative basis for further interpretation in the Discussion section.

Discussion

The obtained results showed a statistically significant positive relationship between the integrated circularity index (CI) and the economic resilience index (RI) in the EU countries in 2015–2024. After controlling for the structural characteristics of the economy and time effects, an increase in the CI is associated with an increase in the RI, which indicates the systemic nature of the relationship. This means that more developed circular practices correlate with a higher ability of economies to stabilize after shocks.

The estimates are consistent with the approach of Saha et al. [31], who consider the circular economy in combination with digital technologies as a mechanism for increasing resilience in the face of turbulence. Our results empirically confirm this thesis at the macro level. A similar logic is traced by Shukla and Pujari [34], who interpret circularity as a transformational strategy for building economic resilience through diversification of resource flows.

The conclusions are also in line with the review by Shaharudin et al. [33], where the circular economy is interpreted as an institutional transformation that promotes long-term sustainable adaptation. Our study shows that even in the medium-term horizon of the post-crisis period, circular indicators are associated with better stability indicators. Wahba's [35] argument about the role of circularity in enhancing urban and regional resilience is also confirmed at the aggregate macroeconomic level. At the same time, the results of Zeng et al. [37] on the digital mechanisms of circular ecosystems complement the interpretation, pointing to possible synergies between circular and digital transformations.

Thus, the results of the study confirm that circular models are associated with more stable economic trajectories in EU countries. This relationship has both theoretical implications for clarifying the concept of economic resilience and practical implications for developing post-crisis recovery strategies. Further research could be aimed at detailing the channels of influence, in particular through sectoral or regional models.

Conclusions

The study allowed us to formulate an integrated analytical model for assessing the impact of closed-loop models on the economic sustainability of EU countries in 2015–2024 and to empirically test the existence of a relevant relationship. The results confirmed that an increase in the level of circularity is associated with more stable macroeconomic trajectories in the post-crisis period, which is consistent with the study's objective. In contrast to the predominantly conceptual or survey-based papers, this paper offers a quantitative panel estimation for the full set of EU member states, taking into account country and time fixed effects. The scientific novelty lies in the construction of a composite index of economic sustainability and its integration with the circularity index within a single econometric model.

The practical significance of these results is that circular strategies can be considered not only as an instrument of environmental policy, but also as an element of macroeconomic stabilisation and post-crisis recovery. This opens up the avenue for embedding circularity indicators into strategic documents of economic development. At the same time the study has drawbacks. First of all, the use of aggregated national indicators allows no regional differentiations within countries. Then again, the integral indices are built on equal weights of the components, which might threaten the sensitivity of the results. Finally, the model does not take into account possible non-linear effects or structural breaks beyond the post-crisis period.

Future studies may also develop at the sectoral or regional levels of analysis, look to try out different weightings of the index components, and include digital/institutional factors as potential mediators of the relationship between circularity and economic resilience. In general, the study results show how the shift to closed-loop models is

fundamentally not just an environmental change, but rather a systemic one that enhances trade flows' adaptability when faced with non-routine disturbances.

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