

SUSTAINABLE ENTREPRENEURSHIP AS A DETERMINANT OF THE DEVELOPMENT OF SUSTAINABLE LOGISTICS: IN ITALY AND POLAND

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Purpose: The purpose of this paper is to empirically examine whether sustainable entrepreneurship influences sustainable logistics development in Italy and Poland across economic, social, and environmental dimensions.

Design/methodology/approach: The study uses annual data for Italy and Poland from 2008 to 2023, obtained from the Eurostat database. The empirical analysis applies OLS and SUR models with lagged variables to capture dynamic interdependencies between the analysed dimensions.

Findings: The results confirm that sustainable entrepreneurship significantly influences the development of sustainable logistics, although the strength and dynamics of this relationship differ between Italy and Poland. In Italy, the impact of sustainable entrepreneurship on sustainable logistics is stronger and more immediate, while in Poland the effects are more delayed and temporally dispersed. The findings also indicate significant interdependencies among the pillars of sustainable logistics, particularly in Poland, which justifies the use of SUR models. Furthermore, the study confirms the importance of ESG-oriented investments, green innovation diffusion, and institutional pressures as mechanisms supporting the transformation of logistics systems supporting sustainable logistics transformation.

Research limitations/implications: The main limitations of the study are the relatively small sample size and the inclusion of only two countries. However, the study offers a methodological framework for future comparative analyses involving a wider range of economies and longer time horizons.

Practical implications: The findings may support policymakers and enterprises in designing sustainability-oriented logistics and economic strategies.

Social implications: The shift towards sustainable logistics may help reduce environmental pressure, improve resource efficiency, and support sustainable development objectives.

Originality/value: The originality of the study lies in integrating sustainable entrepreneurship and sustainable logistics within a dynamic empirical framework that incorporates time lags and

systemic interdependencies. The study contributes to the literature through a comparative analysis of Italy and Poland using synthetic indicators and SUR modelling.

Keywords: ESG, green logistics, supply-chain transformation, institutional pressures, SUR modelling, comparative analysis.

Category of the paper: Research paper.

1. Introduction

Modern economies face growing pressure to implement sustainable development principles, which is reflected in both public policies and corporate strategies. The logistics sector, in particular, as a key element of economic systems, plays a significant role in shaping the impact of economic activity on the natural environment and society (Koray et al., 2025; Bartosiewicz et al., 2025). The intensity of transport processes, the high emissions, and the growing demand for efficient supply chains make the transformation of logistics into sustainability one of the main challenges of the modern economy (Sun et al., 2025; Bugarčić et al., 2023).

At the same time, the concept of sustainable entrepreneurship, which involves the integration of economic, social, and environmental goals in the operations of businesses, is undergoing dynamic development (Odeyemi et al., 2024). Companies are increasingly implementing strategies based on ESG principles and taking steps to reduce their negative impact on the environment while seeking new sources of competitive advantage (Rosário et al., 2022). In this context, a crucial question arises about the role of sustainable entrepreneurship as a potential driver of transformation for entire sectors of the economy, including the logistics sector.

Research to date has focused primarily on analysing individual aspects of the phenomena discussed. On the one hand, studies on sustainable logistics are being developed that include, among others, green supply chains, emissions reduction, and transport efficiency, while on the other hand, sustainable entrepreneurship is being analysed in the context of innovation, social responsibility, and institutional regulations. However, attempts to comprehensively address the relationships between these two areas, especially at the macroeconomic and sectoral levels, are much less common.

The existing literature points to potential links between the implementation of sustainable practices in enterprises and changes in the functioning of supply chains, but empirical studies that would clearly determine the strength, direction, and dynamics of these relationships are still lacking. A particularly noticeable research gap is in quantitative analyses that simultaneously consider the multidimensional nature of sustainable development, the time lags in the impact of the analysed phenomena, and the structural differences between countries with different economic models.

The interdependencies between the individual pillars of sustainable logistics and their response to changes in the level of sustainable entrepreneurship also remain insufficiently understood. Previous research rarely considers the systemic nature of these relationships, which limits the ability to fully understand transformation mechanisms in the logistics sector (Tutar et al., 2026; Shabbir, 2023).

In response to identified research gaps, this article attempts to empirically verify the impact of sustainable entrepreneurship on the development of sustainable logistics in a comparative approach for two European countries, Italy and Poland. The research approach, based on dynamic analysis and the use of econometric models that account for time lags and interdependencies between variables, allows for an in-depth identification of the mechanisms of influence and structural differences between the analysed economies.

This article is empirical in nature and is based on the analysis of annual data for Poland and Italy from 2008 to 2023, sourced from the Eurostat database. The study uses proprietary synthetic indicators: the Sustainable Entrepreneurship Index (SE) and the Sustainable Logistics Index (SL), constructed based on diagnostic variables assigned to the three pillars of sustainable development: economic, social, and environmental. The research procedure includes trend analysis and descriptive statistics, correlation analysis, and econometric modelling.

In particular, linear regression models estimated by ordinary least squares (OLS) were used to identify the impact of current and lagged SE values on SL, thus capturing the dynamic nature of the relationships analysed. Furthermore, SUR (seemingly unrelated regressions) models were used, which enable the simultaneous analysis of individual pillars of sustainable logistics and account for their interconnections.

This research approach allows for a comprehensive analysis of the relationship between sustainable entrepreneurship and sustainable logistics, from both a static and a dynamic and systemic perspective. This article contributes to the literature by providing quantitative empirical evidence and developing a methodological approach that accounts for time lags and interdependencies between the analysed phenomena.

2. Literature Review

Sustainable entrepreneurship and sustainable logistics are part of a broader stream of research on sustainable development, the theoretical foundations of which stem from the concept of three pillars (economic, social, and environmental), known as the triple bottom line (Koray et al., 2025). The literature emphasises that sustainable economic development requires the simultaneous consideration of economic efficiency, social responsibility, and the reduction of negative environmental impact (Mezentseva et al., 2024; Andersson et al., 2022; Jindal, 2025).

Sustainable entrepreneurship is most often defined as business activities that integrate economic goals with social and environmental objectives, creating value for both owners and broader stakeholders (Rosário, Figueiredo, 2024; Yasir et al., 2023). Theoretically, this concept develops at the intersection of entrepreneurship theory, stakeholder theory, and the resource-based view (RBV) (Haryanto et al., 2026; Agrawal et al., 2025). According to this approach, companies that effectively implement sustainable strategies build competitive advantages through the development of unique resources and competencies, such as ecological innovation and the ability to manage social relationships (Rosário et al., 2022; Kucharski et al., 2025).

An important complement to this is institutional theory, which indicates that companies' sustainability efforts are largely determined by the regulatory environment, social norms, and stakeholder pressure. In this context, implementing ESG (Environmental, Social, Governance) practices can be both a result of regulatory pressure and an element of a strategy for building reputation and social legitimacy (Kim, Kim, 2025; Chipimo et al., 2025; Haryanto et al., 2026).

Sustainable logistics, in turn, expands on classic supply chain management concepts and focusses on minimising the negative impact of logistics processes on the environment while maintaining operational efficiency and service quality (Ferraro et al., 2026). The literature indicates that logistics plays a key role in achieving sustainable development goals, as it accounts for a significant portion of greenhouse gas emissions and resource consumption (Grechan et al., 2022). In this context, concepts such as green logistics, reverse logistics, and circular supply chains are being developed, including transportation optimisation, waste reduction, and resource reuse (Waqar et al., 2025; Bugarčić et al., 2023; Ferraro et al., 2026).

The relationship between sustainable entrepreneurship and sustainable logistics is relatively less quantitatively analysed, but existing research indicates that companies that implement sustainable strategies are more likely to invest in environmentally friendly logistics solutions and introduce process innovations that reduce environmental impact (Boonnual et al., 2025; Jayarathna et al., 2024). The literature also emphasises the importance of delayed effects: Transformation of business models and supply chains takes time, meaning that the impact of companies' actions on the logistics sector may only become apparent in the medium or long term (Palkina, 2022; Sreenivasan, Suresh, 2023; Jayarathna et al., 2024).

An important theoretical strand justifying the use of dynamic models in this study is the evolutionary approach and path dependence theory. According to this approach, economic processes are cumulative and depend on previous decisions, which means that the current level of logistics development is largely determined by previous investments and strategies of companies (Rakytá et al., 2022; Sonar et al., 2024; Duzgun, Atay, 2026).

Furthermore, the literature indicates the existence of interdependence between the individual pillars of sustainable development, which is reflected in system concepts and a holistic approach (Tutar et al., 2026; Shabbir, 2023). According to this approach, changes in one area (e.g., economic) can have consequences in others (social and environmental),

justifying the use of methods such as SUR models, which allow for the analysis of interdependent equations.

The literature discussed above suggests that sustainable entrepreneurship may influence sustainable logistics through several interconnected mechanisms. Recent studies indicate that ESG-oriented investments increasingly stimulate the adoption of green supply chain practices, low-emission transport systems, and environmentally efficient logistics infrastructure (Saeed et al., 2018; Xu et al., 2023). Institutional pressures and stakeholder expectations have also been identified as important drivers of green innovation diffusion and sustainable supply chain integration (Ning et al., 2021; Zhang et al., 2025). Previous studies have also emphasised the importance of institutional and financial mechanisms in supporting sustainability-oriented transformation processes and ESG implementation dynamics in European and transition economies (Olgić Draženović et al., 2023).

As these transformation processes are cumulative and time-dependent, the effects of sustainable entrepreneurship on sustainable logistics may emerge with significant time lags and vary across countries depending on institutional and structural conditions. Analysing the relationship between sustainable entrepreneurship and sustainable logistics therefore requires a dynamic, systemic research approach.

3. Research Methodology

3.1. Main idea and research problem

The main idea of this article is to analyse the extent to which sustainable entrepreneurship at the national level influences the development of sustainable logistics, both in a synthetic perspective and through its three fundamental dimensions: economic, social, and environmental. The study is grounded in the assumption that enterprises increasingly play a crucial role in shaping sustainable development processes, not only through their direct business activities but also through their influence on supply chains, resource utilisation, innovation, and stakeholder relations. As a result, the diffusion of sustainable entrepreneurial practices may constitute an important driver of transformation within the logistics sector.

The central research question this study addresses is: Can the development of enterprises operating in accordance with the principles of sustainable entrepreneurship contribute to advancing sustainable logistics at the national level? In addition, the study seeks to determine whether this impact is immediate or delayed, and whether it affects the individual dimensions of sustainable logistics differently.

Previous literature has extensively examined the determinants of logistics development, the role of sustainability in supply chains, and the growing importance of sustainable entrepreneurship and ESG-oriented business models. Numerous studies have analysed the influence of innovation, institutional conditions, environmental regulations, and economic development on logistics performance and sustainability outcomes. At the same time, research on sustainable entrepreneurship has primarily focused on firm-level behaviour, organisational capabilities, innovation processes, and the creation of social and environmental value.

Despite the growing body of literature, relatively little attention has been devoted to analysing the direct relationship between sustainable entrepreneurship and sustainable logistics at the macroeconomic level. Existing studies typically examine these phenomena separately or focus on selected aspects of sustainability without investigating their mutual interactions. Moreover, empirical evidence concerning the dynamic nature of this relationship remains limited. In particular, there is a noticeable lack of studies employing synthetic sustainability indicators and econometric approaches capable of capturing both contemporaneous and lagged effects between sustainable entrepreneurship and logistics development.

This study attempts to address this research gap by developing synthetic measures of sustainable entrepreneurship and sustainable logistics and by examining their interrelationships in two European countries characterised by different development trajectories. The empirical analysis combines descriptive statistics, correlation analysis, Ordinary Least Squares (OLS) estimation, and Seemingly Unrelated Regression (SUR) models, enabling the identification of both direct and delayed effects of sustainable entrepreneurship on logistics sustainability.

The contribution of this study is threefold. First, it provides empirical evidence on the relationship between sustainable entrepreneurship and sustainable logistics at the national level. Second, it captures the multidimensional character of sustainable logistics by separately analysing its economic, social, and environmental pillars. Third, it identifies the temporal structure of these relationships, showing whether sustainability-oriented entrepreneurial activities generate immediate outcomes or require time before their effects become visible in the logistics sector. The findings may contribute to the development of sustainability research and offer practical implications for policymakers, business leaders, and stakeholders responsible for designing strategies to support sustainable economic transformation.

3.2. Purpose of the article and research hypotheses

This study aims to empirically verify the impact of the overall sustainability index of sustainable entrepreneurship on the level of the sustainable logistics index in Italy and Poland.

This analysis aims to determine whether sustainable entrepreneurship is a factor that determines the transformation of the logistics sector and to examine the nature of this impact on the individual pillars of sustainable logistics: economic, social, and environmental.

The specific objectives of the article include:

- examine the impact of sustainable entrepreneurship (SE) on the overall sustainable logistics index (SL),
- determining whether the strength and direction of this impact differ between the pillars of sustainable logistics,
- verifying whether the relationships among the analysed variables are systemic and interdependent and justifying the use of SUR models, which allow consideration of interconnections among the pillars.

Based on the literature review and the adopted in the research, the following research hypotheses were formulated:

- Main hypothesis:
H0: Sustainable entrepreneurship has a statistically significant impact on the level of sustainable logistics.
- Specific hypotheses:
H1: An increase in the level of sustainable entrepreneurship has a positive impact on the overall level of sustainable logistics.
H2: Sustainable entrepreneurship influences the economic, social, and environmental pillars of sustainable logistics in different ways, with the direction and strength of these effects varying across countries and time periods.
H3: There is structural interdependence between the pillars of sustainable logistics, which justifies the use of SUR models.

The objective and hypotheses, formulated in this way, allow a systematic examination of the impact of sustainable entrepreneurship on the logistics sector and drawing practical conclusions for economic policy and corporate strategies in the area of sustainable development.

3.3. Data and scope of the study

The study employs annual data for Italy and Poland from 2008 to 2023, a period marked by both economic stability and significant disruptions, including the aftermath of the global financial crisis, the COVID-19 pandemic, and the expansion of sustainability-focused EU regulations. This timeframe enables the observation of long-term trends and structural changes resulting from the growing focus on sustainability, providing a basis to assess sustainable entrepreneurship and logistics across varying economic and institutional conditions.

Country selection focused on contrasting economic and developmental profiles. Italy represents a mature European economy with an established logistics infrastructure, sustainability policies, and a relatively stable economic trajectory. In contrast, Poland is experiencing rapid economic growth and evolving sustainability approaches. Comparing these two countries thus reveals differences in how sustainable entrepreneurship contributes to

sustainable logistics development. Their shared EU regulatory context supports comparability while maintaining meaningful structural contrasts.

All data are annual and come from Eurostat. We chose Eurostat because it provides harmonised, consistent statistics for European countries, ensuring reliable comparison over time and between countries. Using a single source reduces the risks of measurement inconsistency and makes the analysis more reliable. Eurostat also covers many economic, social, environmental, and sectoral indicators, making it ideal for building synthetic measures of sustainable entrepreneurship and logistics.

3.4. Level of analysis, variable construction, and synthetic indicator procedure

The analysis was carried out at two complementary research levels, capturing both the broad macroeconomic context and the sectoral specificity of the phenomenon under study. The first level adopts a macroeconomic (national) approach and addresses the category of sustainable entrepreneurship, while the second level adopts a sectoral approach, focussing on Section H (transport and storage), which is relevant for the analysis of sustainable logistics. This allows the simultaneous examination of the relationship between the overall level of economic development and its sectoral implications, thereby making a significant contribution to causal analysis.

In the study, two synthetic indicators were used: the Sustainable Entrepreneurship Index (SE) and the Sustainable Logistics Index (SL). Both indicators are based on analogous partial variables assigned to the three pillars of sustainable development: environmental (ENVE or ENVL), economic (ECOE or ECOL), and social (SOCE or SOCL). However, they differ in their level of aggregation and analytical function. The SE is macroeconomic in nature and was constructed on a per capita basis. It enables comparability between countries with different economic scales. SL, on the other hand, directly addresses the transport and warehousing sector, reflecting its specific structural and operational conditions.

Despite the use of similar partial indicators, the analysed constructs are not identical; they serve different analytical functions. In particular, SE and SL are treated as explanatory variables, allowing identification of the impact of the overall level of sustainable entrepreneurship on the development of sustainable logistics in the sector studied. This distinction is of crucial methodological significance and strengthens the interpretative coherence of the research model.

The construction of synthetic indicators is based on three pillars, each with specific diagnostic variables assigned to it.

The environmental pillar includes, in tons: carbon dioxide, methane, nitrous oxide, sulphur oxides (SO₂ equivalent), carbon monoxide, nitrogen oxides, and ammonia.

The economic pillar includes: enterprises – number, turnover or gross premiums written – million euros, personnel costs in total purchases of goods and services – percentage, production value – million euros, value added at factor cost – million euros, gross operating surplus –

million euros, total purchases of goods and services – million euros, gross investment in tangible goods – million euros, share of personnel costs in production – percentage, average personnel costs (personnel costs per employee) – thousand euros, gross operating rate – percentage, and share of gross operating surplus in value added – percentage.

The social pillar includes: wages and salaries – one million euros, social security costs – one million euros, employees – number, turnover per person employed – one thousand euros, apparent labour productivity (gross value added per person employed) – one thousand euros, wage adjusted labour productivity (apparent labour productivity by average personnel costs) – percentage, gross value added per employee – one thousand euros, growth rate of employment – percentage, persons employed per enterprise – number, share of personnel costs in total purchases of goods and services – percentage, and investment per person employed – thousands of euros.

During the construction of synthetic indicators, variables were classified as stimulants or destimulants.

Destimulants included all environmental variables and selected economic and social variables of a cost nature, that is, share of personnel costs in production – percentage, average personnel costs (personnel costs per employee) - 1000 euros, share of personnel costs in total purchases of goods and services – percentage. The remaining variables were classified as stimulants.

In the next step, a variable normalisation procedure was applied.

The following formula was used for stimulants:

$$z_{ijt} = \frac{x_{ijt}}{\max(x_{jt})},$$

and for destimulants:

$$z_{ijt} = \frac{\min(x_{jt})}{x_{ijt}},$$

where:

x_{ijt} - value of the j th diagnostic variable for the i th country in period t ,

z_{ijt} - normalised value of the j th diagnostic variable for the i -th country in period t ,

$\max_{jt}$ - maximum value of the j th variable in the set of all countries and periods covered by the analysis,

$\min_{jt}$ - minimum value of the j th variable in the set of all countries and periods covered by the analysis,

i - country index ($i = 1, 2$; Italy, Poland),

j - index of the diagnostic variable,

t - time index (year).

This normalisation ensures the comparability of variables with different units of measurement and eliminates scale effects, while accounting for their direction of impact.

In the next step, partial-pillar indices were constructed as arithmetic means of the normalised variables.

$$ECO_{it} = \frac{1}{n_{ECO}} \sum z_{ijt}, SOC_{it} = \frac{1}{n_{SOC}} \sum z_{ijt}, ENV_{it} = \frac{1}{n_{ENV}} \sum z_{ijt},$$

where:

$n_{ECO}, n_{SOC}, n_{ENV}$ – the number of diagnostic variables assigned to the economic, social, and environmental pillars, respectively,

ECO_{it} – the value of the synthetic indicator of the economic pillar for the i th country in period t ,

SOC_{it} – the value of the synthetic indicator of the social pillar for the i th country in period t ,

ENV_{it} – the value of the synthetic indicator of the environmental pillar for the i th country in period t .

Finally, the synthetic indicators of sustainable entrepreneurship and sustainable logistics were determined as the average of the three pillars.

$$SE_{it} = \frac{ECO_{it} + SOC_{it} + ENV_{it}}{3},$$

$$SL_{it} = \frac{ECO_{it} + SOC_{it} + ENV_{it}}{3}.$$

The use of equal weights in constructing the synthetic indicators was adopted to ensure methodological transparency and comparability across countries, periods, and dimensions (OECD, 2008). This approach avoids subjective prioritisation of individual pillars and allows the economic, social, and environmental dimensions to contribute equally to the overall sustainability measure. However, it should be acknowledged that equal weighting may affect the sensitivity of the results, as different weighting schemes could produce slightly different values for the composite indicators. Therefore, the adopted indices should be interpreted as synthetic approximations of sustainable entrepreneurship and sustainable logistics, rather than as exhaustive measures of these phenomena.

Indicators were constructed to maintain methodological consistency between the levels analysed. The adopted procedure for constructing synthetic indicators aligns with the multidimensional comparative analysis approach and enables a comprehensive assessment of complex phenomena such as sustainable entrepreneurship and sustainable logistics.

3.5. Research Methods, Econometric Modelling, and Model Validation

Empirical analysis used a set of complementary research methods that allowed the description and identification of relationships between the variables studied. The first stage involved trend analysis and basic descriptive statistics (maximum and minimum values, mean, standard deviation, and median), which allowed a preliminary characterisation of variable distributions, identification of their dynamics over time, and detection of potential outliers. The correlation analysis was then performed using Pearson, Spearman, Kendall, and Gamma coefficients, enabling the identification of linear, nonlinear, and monotonic relationships among

the indicators. Interpretation of the strength of the relationship was based on standard ranges of correlation coefficient values, where values close to 0 indicate no relationship, the range 0.0-0.3 indicates a weak relationship, 0.3-0.5 moderate, 0.5-0.7 good, 0.7-0.9 strong, and values above 0.9 indicate a very strong relationship. Similar ranges were adopted for negative values.

In the remainder of the study, linear regression models estimated by ordinary least squares (OLS) were used, serving as the primary tool to identify the impact of sustainable entrepreneurship on sustainable logistics. The coefficient of determination R^2 was used as a measure of model fit, with values interpreted as follows: below 0.3 – poor model fit, 0.3-0.6 – moderate fit, 0.6-0.8 – good fit, and above 0.8 – very good fit. Furthermore, the adjusted coefficient of determination was analysed, which allowed the inclusion of the number of explanatory variables and reduced the risk of overestimating the model quality.

In the first stage of modelling, a classic OLS linear regression model was used, in the following form:

$$SL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + \varepsilon_{it},$$

where:

SL_{it} - the Sustainable Logistics Index in country i and year t ,

SE_{it} - the Sustainable Entrepreneurship Index in country i and year t ,

ε_{it} - the error term.

This model was extended to include lagged values of the SE variable, enabling analysis of short- and medium-term effects and enhancing the model's ability to represent real-world economic processes. The introduction of lagged values for the SE variable stems from the dynamic nature of the analysed processes. The impact of sustainable entrepreneurship on the logistics sector is not immediate; It unfolds over time due to investment processes, organisational changes, and the gradual diffusion of sustainable development practices. The choice of lag lengths was empirical – various lag structures were tested, and only those that proved statistically significant were included in the final model specification.

To ensure the validity of the inferences, a wide range of verification procedures were conducted that covered key assumptions of the classical linear regression model. The following were verified:

- linearity in parameters,
- no perfect multicollinearity,
- zero expected value of the random term,
- homoscedasticity (White's test),
- no first-order autocorrelation (Durbin-Watson test),
- There is no higher-order autocorrelation, including second-order autocorrelation.

Furthermore, tests were conducted for the normality of the residual distribution, which is particularly important for the accuracy of statistical inference in small samples.

In the second stage of modelling, the SUR model was used, in which the dependent variable is the individual pillars of sustainable logistics.

$$ECOL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + SCOL_{it} + ENVL_{it} + \varepsilon_{it}$$

$$SOCL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + ECOL_{it} + ENVL_{it} + \varepsilon_{it}$$

$$ENVL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + ECOL_{it} + SOCL_{it} + \varepsilon_{it}$$

This method allows for interdependencies between model components by correlating random terms across equations (this leads to more efficient estimators than estimating separate equations using OLS). Furthermore, this approach allows for a more in-depth analysis of differences in the impact of the SE variable on the individual pillars of sustainable logistics.

The main limitations of this study include a small sample size ($T = 16$) due to the limited availability of comparable statistical data and the inclusion of only two economies in the analysis.

Although the empirical procedure includes a broad set of model validation tests, the results should nevertheless be interpreted with methodological caution. The use of synthetic indicators, while useful for capturing multidimensional phenomena, may be sensitive to the selection of diagnostic variables, the normalisation procedure, and the equal-weighting scheme adopted in the study. In addition, the relationships analysed may be influenced by omitted variables such as infrastructure quality, public investment, regulatory changes, energy prices, digitalisation processes, and sector-specific technological development.

Another important limitation concerns the potential endogeneity of the relationship between sustainable entrepreneurship and sustainable logistics, as more developed logistics systems may simultaneously facilitate the diffusion of sustainable entrepreneurial practices. Therefore, the results should primarily be interpreted as evidence of statistically observed relationships rather than definitive causal effects. Instead, the findings support evolutionary and path-dependence approaches, which suggest that sustainability-oriented transformation processes are cumulative, institutionally conditioned, and characterised by delayed adjustment mechanisms. The study also confirms the importance of analysing sustainable development dimensions simultaneously, as significant interdependencies and trade-offs may arise between economic, social and environmental objectives. Future studies could strengthen the robustness of the analysis by extending the sample to a larger group of countries, applying alternative weighting procedures, introducing additional control variables, and using more advanced dynamic panel methods.

However, it allows for the development of conclusions that will serve as a basis for researching this issue in other countries. In the longer term, the analysis is planned to be expanded to a broader set of economies. It, combined with the adopted methodology, which allows for the identification of the directions and nature of relationships between variables and the capture of their dynamics over time, will enable the verification of relationships across more diverse contexts and the formulation of conclusions with greater validity.

4. Research Results

Graph 1 presents the values of the Sustainable Logistics Index and its components from 2008 to 2023, along with trend lines, for the analysed countries, Italy and Poland. The data presented demonstrate the variability and direction of change in the three components of Sustainable Logistics (SL). Economic (ECOL), Social (SOCL), and Environmental (ENVL), as well as their synthetic representation in SL.

ECOL indicates various development paths. In Italy, this indicator remained relatively stable for a long time (a significant increase occurred only after 2020). The positive coefficient for the time variable indicates an upward trend, while the moderate R^2 suggests some time variability. In Poland, on the other hand, a clear and systematic upward trend is observed, as confirmed by the positive and relatively high coefficient for the time variable, and the high R^2 (0.9239) indicates a very good fit of the model to the data.

Taking into account the SOCL values, the level of development in the countries varies, and the dynamics of change differs. In the case of Italy, the trend equation indicates a practically zero, slightly decreasing trend. The very low coefficient of determination ($R^2 = 0.0011$) confirms the poor fit of the linear model. On the other hand, the positive slope and high R^2 (0.8953) indicate systematic improvement and a good fit of the model to the data.

The greatest differences between the countries analysed are visible in ENVL. In Italy, a positive coefficient for the time variable indicates a gradual improvement in pro-environmental activities, although a moderate R^2 suggests some fluctuations. In Poland, however, the slope is negative, indicating a downward trend, and the relatively low R^2 (0.4412) indicates a limited model fit and greater data variability.

SL in both countries shows an upward trend, but the nature of the trend differs. In Italy, a positive coefficient for the time variable and a moderate R^2 indicate relatively stable growth. In Poland, a positive trend is also observed, but its slope is smaller, and the lower R^2 (0.4074) reflects greater fluctuations in the indicator over time.

In summary, both countries are seeing improvements in sustainable logistics, although the underlying conditions differ. In Italy, development is more even and stable, while in Poland, strong economic and social growth is partially constrained by negative environmental trends.

The negative trends observed for the environmental pillar may indicate the presence of green transition trade-offs, particularly in economies undergoing intensive structural transformation. In the short and medium term, expansion of the logistics sector may increase transport intensity, energy consumption, and emissions more rapidly than environmental innovations can offset. This may also reflect delayed technological adoption and insufficient environmental infrastructure (Sonar et al., 2024; Ferraro et al., 2026).

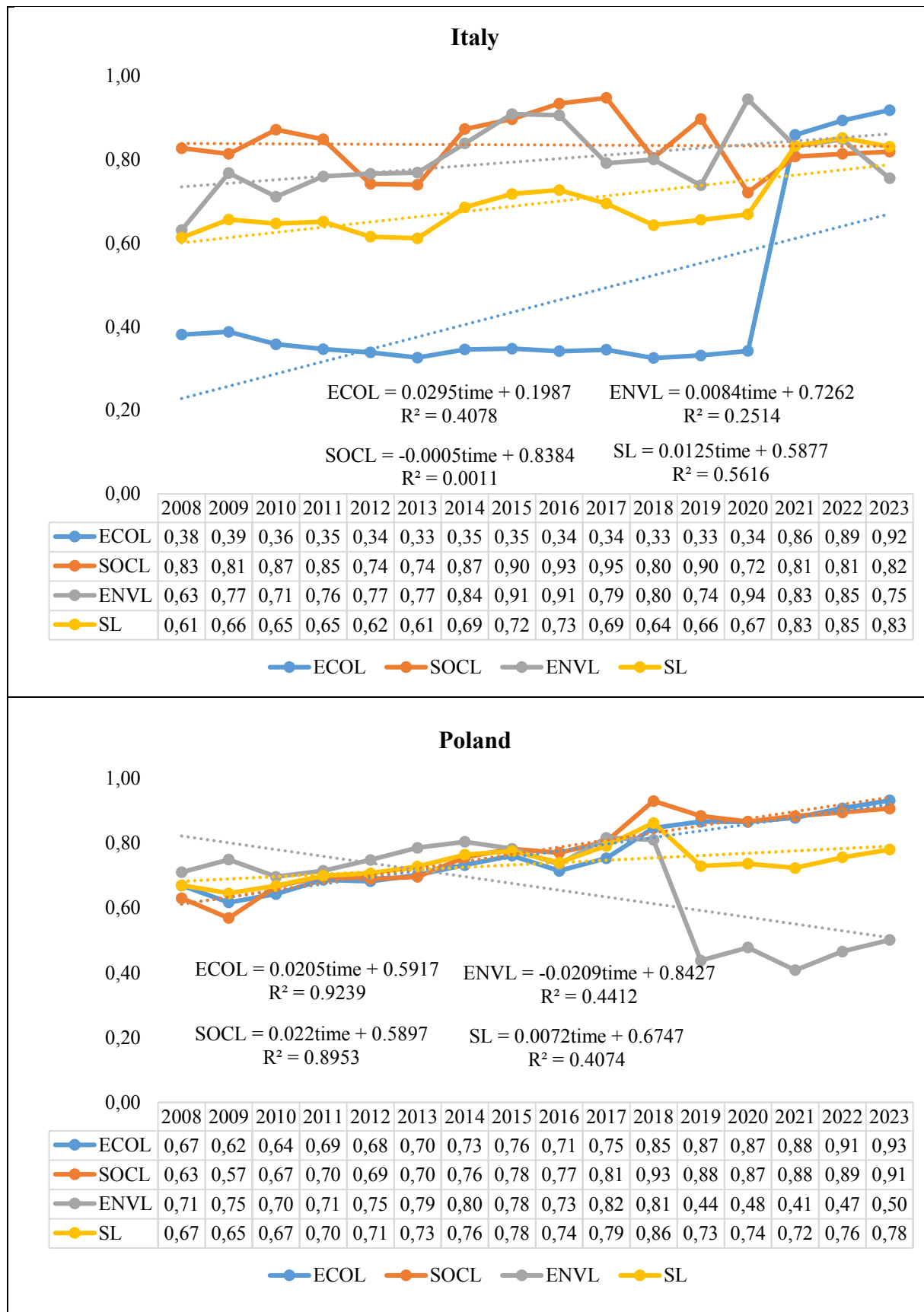


Figure 1. Sustainable Logistics Index in Italy and Poland, 2008-2023.

Source: Authors' elaboration based on Eurostat data.

Graph 2 presents the values of the Sustainable Entrepreneurship Index and its components from 2008 to 2023 for the countries – Italy and Poland – along with trend lines. The data presented demonstrate the variability and direction of change in the three key dimensions of sustainable entrepreneurship (SE): economic (ECOE), social (SOCE), and environmental (ENVE), as well as their synthetic representation in the SE.

ECOE indicates different development pathways between the countries analysed. In Italy, this indicator shows a relatively stable course with minor fluctuations and a weak upward trend, as confirmed by the low coefficient value for the time variable and the very low R^2 (0.1044), indicating a poor fit of the linear model. However, in Poland, a clear upward trend is observed: index values increase from 0.74 in 2008 to 0.93 in 2023, and positive slope and high R^2 (0.7776) indicate systematic improvement and good model fit.

With respect to SOCE, improvements are visible in both countries, though with varying intensity. In Italy, a moderate upward trend is observed and an average model fit ($R^2 = 0.438$), indicating a gradual but less stable improvement. In Poland, on the other hand, this component shows a strong and stable upward trend – values increase from 0.63 to 0.89 – and the high R^2 (0.9063) confirms a very good model fit and consistent development over time.

ENVE in both countries shows a clear upward trend (although the pace and final level differ). In Italy, the slope (0.0196) and the high R^2 (0.9019) indicate rapid and systematic improvement in environmental entrepreneurship. In Poland, the trend is also positive, with a slightly lower growth rate (0.0144) and high model fit ($R^2 = 0.8713$), while the index values reach a higher final level in 2023 (0.98), which may indicate an intensification of pro-environmental activities in recent years.

SE in both countries shows a clear upward trend. In Italy, growth is stable, with a moderately high model fit ($R^2 = 0.8605$), indicating a systematic improvement in the level of sustainable entrepreneurship, starting from a higher initial level (0.7425). In Poland, the growth rate is even more pronounced (slope = 0.0158), and the very high $R^2 = 0.9373$ indicates an excellent fit of the model and consistent growth across all dimensions analysed, despite the lower initial level (0.6424).

In summary, both countries are seeing significant improvements in sustainable entrepreneurship. In Italy, growth is mainly driven by the environmental component, with the economic component relatively stable. Poland, on the other hand, is characterised by more even and dynamic growth in all areas analysed, resulting in a stronger and more consistent increase in the SE.

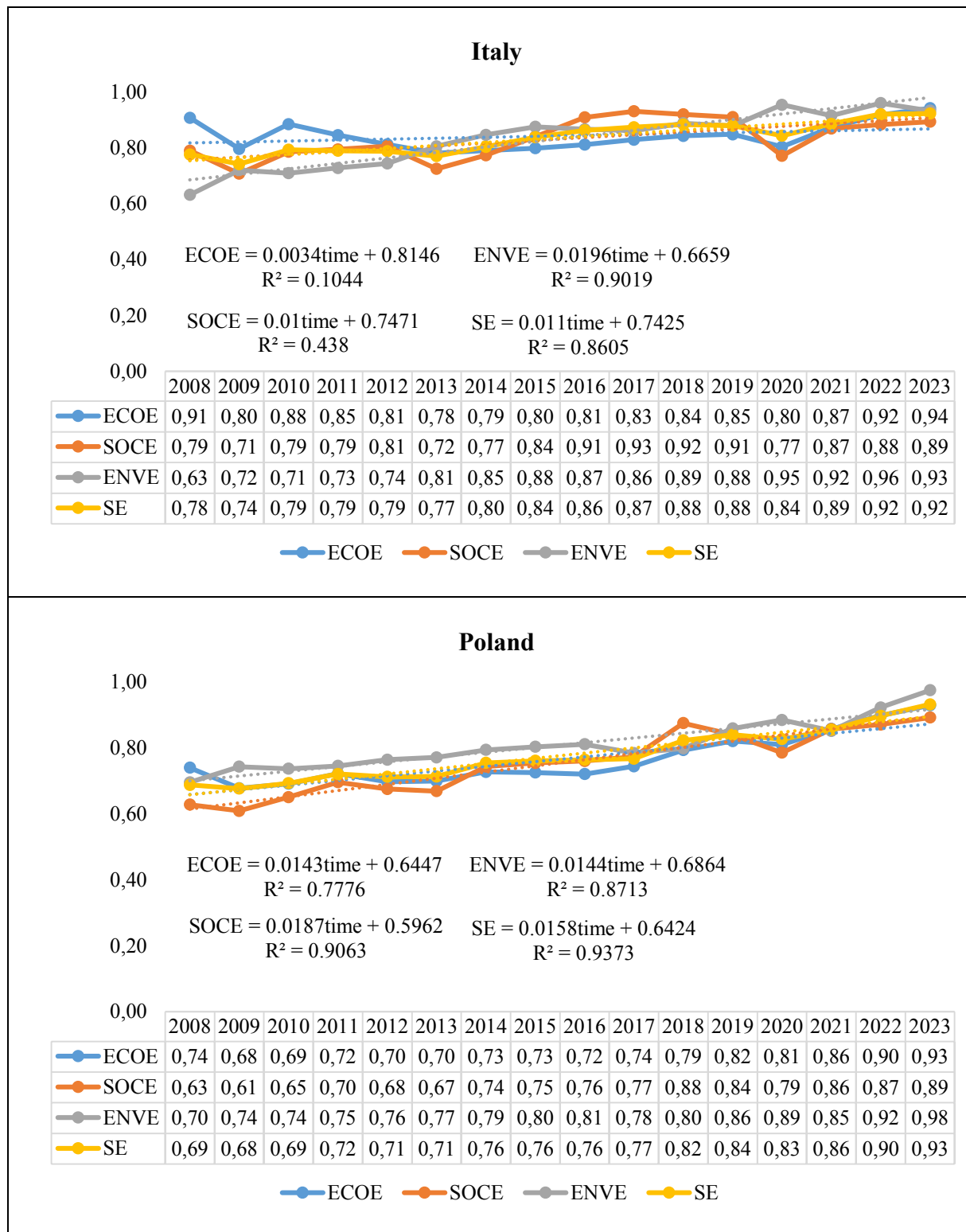


Figure 2. Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023

Source: Authors' elaboration based on Eurostat data.

Table 1 presents basic descriptive statistics for SL and SE in Italy and Poland from 2008 to 2023. The presented measures allow for assessing the levels, variations, and distributions of the analysed indicators in both countries.

For SL, higher mean values were recorded in Poland (0.74) than in Italy (0.69), indicating a generally higher level of this indicator during the period studied. Poland also has a higher minimum value (0.65) than 0.61. The maximum values are similar (0.86 in Poland and 0.85 in Italy). The lower standard deviation in Poland (0.05) compared to Italy (0.08) indicates a lower variability of the data, confirming greater stability. The median is also higher in Poland (0.73) than in Italy (0.66), reinforcing the conclusion that sustainable logistics is higher and more evenly distributed in Poland.

The situation is different for SE. A higher mean value was recorded in Italy (0.84) than in Poland (0.78), indicating a higher overall level of this indicator in that country. The maximum values are similar (0.93 in Poland and 0.92 in Italy). Italy has a lower minimum value (0.74 vs. 0.68), suggesting a more stable level of the indicator over time. The standard deviation is lower in Italy (0.05) than in Poland (0.08), indicating less variability and greater predictability of SE values. The median for Italy (0.84) is also higher than that for Poland (0.76), confirming the indicator's higher central tendency.

In summary, Poland achieves better results in sustainable logistics, characterised by higher mean values and lower variability. Italy, on the other hand, stands out for its higher level of sustainable entrepreneurship and, at the same time, has a more stable indicator over the analysed period. These results indicate different development profiles of the two countries in the areas of sustainable development.

Table 1.

Sustainable Logistics Index and Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023 - Basic descriptive statistics

Indicator		SL		SE	
Country		Italy	Poland	Italy	Poland
Basic descriptive statistics	Max	0.85	0.86	0.92	0.93
	Min	0.61	0.65	0.74	0.68
	Mean	0.69	0.74	0.84	0.78
	SD	0.08	0.05	0.05	0.08
	Median	0.66	0.73	0.84	0.76

Source: Authors' elaboration based on Eurostat data.

Table 2 shows the results of the correlation analysis between SL and SE in Italy and Poland from 2008 to 2023. The use of several correlation measures (Pearson, Spearman, Gamma, and Kendall) provides a more comprehensive assessment in terms of the strength and nature of the relationships between the variables analysed.

In Italy, all the coefficients indicate a relatively strong positive relationship between SL and SE. The Pearson linear correlation coefficient is 0.76, indicating a strong positive relationship: an increase in the level of sustainable logistics is accompanied by an increase in the level of sustainable entrepreneurship. Similar conclusions follow from nonparametric measures: Spearman's coefficient (0.71) also indicates a strong monotonic relationship, while the values of the Gamma (0.55) and Kendall (0.55) coefficients suggest moderate but clear rank

agreement. Indicates that the indicators relationship between the analysed in Italy is stable and relatively strong, regardless of the measurement method adopted.

In Poland, a positive correlation between SL and SE is also observed, but its strength is significantly lower than in Italy. The Pearson coefficient is 0.59, indicating a moderate linear correlation. The Spearman coefficient (0.66) suggests a moderately strong monotonic relationship, while the Gamma coefficient (0.50) and Kendall coefficient (0.50) indicate moderate rank agreement. These results indicate that, while an increase in sustainable entrepreneurial activity accompanies the growth of sustainable logistics in Poland, this relationship is less pronounced and more diverse than in Italy.

In summary, a positive correlation between sustainable logistics and sustainable entrepreneurship is observed in both countries (it is stronger in Italy than in Poland). In Italy, the development of these two areas is more interconnected and complementary, whereas in Poland, this relationship is weaker and may be influenced by additional external factors.

Table 2.

Sustainable Logistics Index and Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023 - Correlation

Correlation, 2008-2023		
Correlation coefficient	Italy	Poland
	SL/SE	SL/SE
Pearson's R	0.76	0.59
Spearman's Rho	0.71	0.66
Gamma	0.55	0.50
Kendall rank	0.55	0.50

Source: Authors' elaboration based on Eurostat data.

Table 3 presents the OLS estimation results for Italy and Poland, where SL is the dependent variable and current and lagged SE values are the explanatory variables.

In the case of Italy, the resulting model shows a very high degree of fit ($R^2 = 0.823$), indicating that more than 82% of the variability in the dependent variable is explained by the adopted set of regressors. Parameter analysis indicates that the current SE value has a positive and statistically significant effect on SL ($p = 0.0090$). A one-period delay in SE has the opposite effect ($p = 0.0205$). The SE variable, lagged by 4 periods, again shows a positive effect ($p = 0.0459$). The results obtained suggest a dynamic and time-varying mechanism of the impact of SE on SL. The effect is positive in the short term and then reverses, only to become positive again in the long term. The occurrence of negative lagged coefficients may reflect short-term adjustment costs associated with sustainability-oriented transformation processes. Implementing sustainable business practices often requires organizational restructuring, technological adaptation, compliance with environmental regulations, and substantial investment, which may temporarily reduce operational efficiency in the logistics sector before long-term benefits become apparent (Palkina, 2022; Jayarathna et al., 2024). Therefore, the coexistence of negative short-term and positive long-term effects supports the assumption

that the relationship between sustainable entrepreneurship and sustainable logistics is dynamic, cumulative and non-linear.

In the case of Poland, the model has a significantly lower fit ($R^2 = 0.389$), indicating that the included variables explain only a portion of the variability of SL. Unlike in Italy, the current SE value is not statistically significant, whereas its lags are. In particular, a one-period delay shows a negative effect that approaches statistical significance ($p = 0.0512$), while a four-period delay shows a positive and significant effect ($p = 0.040$). The constant is statistically significant, suggesting the presence of other unaccounted for factors influencing SL. The results suggest that in Poland the relationship between the analysed variables is more time-distributed, with effects manifesting primarily with lag.

Verification of the assumptions of the classical least-squares method confirms the validity of both models. In none of the cases were we able to detect heteroscedasticity (White's test), autocorrelation of the random component (LM tests and the Durbin-Watson statistic), or deviations from the normality of the residual distribution. Furthermore, the models are correctly specified, and multicollinearity is absent.

A comparison of the results for both countries reveals significant differences, including differences in the relationships between the variables. Italy is characterised by a stronger and more immediate response of the SL to changes in the SE, while in Poland, this relationship is weaker and more lagged. It may reflect structural differences between the economies and different transmission mechanisms of the analysed phenomena.

Table 3.

The OLS estimation, dependent variable: SL, explanatory variables: SE, SE(t-1), SE(t-2), SE(t-3), SE(t-4)

Italy				
Model 1: OLS, using observations 2008-2023 (T = 16)				
Dependent variable: SL				
Variable	Coefficient	Std. error	P-value	R-squared
const	−0.378	0.237	0.1488	0.823
SE	1.976	0.576	0.0090	
SE(t-1)	−1.620	0.562	0.0205	
SE(t-4)	0.939	0.398	0.0459	
Assumptions of OLS				
Assumption	Test / Indicator	Result / Statistic	p-value	Assessment of fulfillment
1. Linearity in parameters	Model specification	Linear model (const + SE + SE(t-1) + SE(t-4))	-	Fulfilled
2. There is no perfect multicollinearity	Estimation possible	All std. error finite, model stable	-	Fulfilled
3. Expected value of error = 0	Constant term in the model	Constant present	-	Fulfilled
4. Homoscedasticity	White’s test	LM = 11.798; df = 9	0.225	Fulfilled
5. No autocorrelation of residuals (1st order)	LM test; DW	LMF = 0.479; DW = 1.445	0.511	Fulfilled
6. No autocorrelation of residuals (2nd order)	LM test	LMF = 0.339	0.726	Fulfilled
7. Normality of residuals	Test Chi²	χ²(2) = 0.774	0.679	Fulfilled

Poland				
Model 1: OLS, using observations 2008-2023 (T = 16)				
Dependent variable: SL				
Variable	Coefficient	Std. error	P-value	R-squared
Const	0.563	0.160	0.0064	0.389
SE(t-1)	-1.406	0.625	0.0512	
SE(t-4)	1.750	0.733	0.040	
Assumptions of OLS				
Assumption	Test / Indicator	Result / Statistic	p-value	Assessment of fulfillment
1. Linearity in parameters	Model specification	Linear model (const + SE_1 + SE_4)	–	Fulfilled
2. There is no perfect multicollinearity	Estimation possible	All std. error finite, model stable	–	Fulfilled
3. Expected value of error = 0	Constant term in the model	Constant present	–	Fulfilled
4. Homoscedasticity	White’s test	LM = 5.996; df = 5	0.307	Fulfilled
5. No autocorrelation (1st order)	LM test; DW	LMF = 0.799; DW = 1.209	0.397	Fulfilled
6. No autocorrelation (2nd order)	LM test	LMF = 0.384	0.695	Fulfilled
7. Normality of residuals	Test Chi²	χ²(2) = 0.684	0.710	Fulfilled

Source: Authors' elaboration based on Eurostat data.

Table 4 presents the estimation results for the SUR models for Italy and Poland, which simultaneously estimate three equations with different dependent variables: ECOL, SOCL, and ENVL. The models include both current and lagged values of the SE variable, as well as interrelationships among the analysed areas (depending on the equation). Using the SUR method allows for potential correlation between random terms across equations, thereby increasing estimation efficiency.

To verify the validity of the SUR model, a Breusch–Pagan test was performed on the random term covariance matrix (which assesses whether the random terms across the individual equations are correlated, a key assumption that justifies the use of systemic estimation rather than separate OLS models).

In the case of Italy, no statistically significant correlation was found between the random terms was found ($p > 0.05$), indicating that there was no basis for rejecting the hypothesis of their independence. It may suggest weaker structural connections between the analysed pillars in this economy.

In the case of Poland, the results ($p < 0.01$) indicate a statistically significant correlation between the random terms in the equations, which confirms the existence of interdependencies between the pillars of sustainable logistics and the validity of the SUR model.

The results obtained indicate the varied nature of the interdependencies between the pillars of sustainable logistics in the countries studied.

In Italy, the results indicate varying levels of fit across the individual equations. The best fit was obtained for the SOCL equation ($R^2 = 0.677$), moderate for ECOL ($R^2 = 0.448$), and the poorest for ENVL ($R^2 = 0.181$). In the equation for ECOL, the positive effect of the current SE value is statistically significant ($p = 0.0110$), indicating that an increase

in SE directly increases the level of ECOL. In the SOCL equation, a strong positive effect of current SE ($p = 0.0010$) is also observed, while its one-period delay has a negative effect ($p = 0.0060$). Furthermore, the ECOL variable negatively affects SOCL ($p = 0.0046$), suggesting some substitutability between these two areas. The negative relationship between the economic and social pillars in Italy may indicate the presence of sustainability trade-offs within mature logistics systems. Improvements in economic efficiency may partly result from automation, process optimisation, labour rationalisation, and cost-reduction strategies, which can temporarily weaken certain social dimensions, such as employment dynamics or labour indicators.

In the ENVL equation, only the SE values are significant: a delay has a negative effect ($p = 0.0422$), while a delay has a positive effect ($p = 0.0367$), which confirms the presence of lagged effects.

In the case of Poland, the models show a very high fit for the ECOL equations ($R^2 = 0.976$) and SOCL ($R^2 = 0.922$) and a relatively high fit for ENVL ($R^2 = 0.724$). In the ECOL equation, the SE variable lagged by four periods plays a key role ($p = 0.0057$), and the relationships with the other variables are also significant. SOCL has a positive effect ($p < 0.001$), while ENVL has a negative effect ($p = 0.0124$). In the SOCL equation, the SE(t-4) lagged effect is also significant, but its effect is negative ($p = 0.0289$). At the same time, ECOL has a strong positive effect ($p < 0.001$), and ENVL has a positive effect ($p = 0.0159$), indicating the complementarity of these areas. In the ENVL equation, the only significant explanatory variable is SE lagged by 1 period, with a significantly negative impact ($p = 0.0002$).

Comparison of the results of the SUR model for both countries reveals significant differences in the structure of relationships between the areas analysed. In Italy, the current value of the SE variable dominates, and the interrelationships among ECOL, SOCL, and ENVL are relatively weak and time-limited. However, in Poland, lagged SE effects play a key role, as do clear and positive relationships between the dimensions studied, indicating their significant integration and complementary nature.

Table 4.

The SUR estimation, dependent variables: ECOL, SOCL, ENVL, explanatory variables: SE, SE(t-1), SE(t-2), SE(t-3), SE(t-4) and ECOL, SOCL, ENVL (depending on the model)

Italy				
Model 2: SUR, using observations 2008-2023 (T = 16)				
Equation 1				
Dependent variable: ECOL				
	Coefficient	Std. error	P-value	R-squared
const	-2.338	0.905	0.0272	0.448
SE	3.287	1.055	0.0110	

Cont. table 4.

Equation 2				
Dependent variable:SOCL				
	Coefficient	Std. error	P-value	R-squared
const	0.021	0.270	0.9389	0.677
SE	3.140	0.627	0.0010	
SE(t-1)	-2.071	0.559	0.0060	
ECOL	-0.266	0.068	0.0046	
Equation 3				
Dependent variable: ENVL				
	Coefficient	Std. error	P-value	R-squared
const	0.933	0.327	0.0190	0.181
SE(t-2)	-1.358	0.574	0.0422	
SE(t-4)	1.255	0.512	0.0367	
Cross-equation VCV for residuals				
	0.0316	(0.033)	(-0.501)	
	0.0002	0.0017	(-0.232)	
	-0.0053	-0.0006	0.0035	
Tests				
Breusch-Pagan test for diagonal covariance matrix				
Chi-square(3) = 3.67133 [0.2992]				
log determinant = -15.8171				
Poland				
Model 2: SUR, using observations 2008-2023 (T = 16)				
Equation 1				
Dependent variable: ECOL				
	Coefficient	Std. error	P-value	R-squared
const	-0.011	0.102	0.9174	0.976
SE(t-4)	0.558	0.149	0.0057	
SOCL	0.571845	0.069	3.22e-05	
ENVL	-0.109	0.034	0.0124	
Equation 2				
Dependent variable:SOCL				
	Coefficient	Std. error	P-value	R-squared
const	0.005	0.176	0.9759	0.922
SE(t-4)	-0.902	0.339	0.0289	
ECOL	1.699	0.204	3.22e-05	
ENVL	0.187	0.062	0.0159	
Equation 3				
Dependent variable: ENVL				
	Coefficient	Std. error	P-value	R-squared
const	2.529	0.336	2.00e-05	0.724
SE(t-1)	-2.392	0.426	0.0002	
Cross-equation VCV for residuals				
	0.0002	(-0.999)	(-0.088)	
	-0.0003	0.0005	(0.077)	
	-9.7808e-05	0.0001	0.0074	
Tests				
Breusch-Pagan test for diagonal covariance matrix				
Chi-square(3) = 12.1334 [0.0069]				
log determinant = -27.2246				

Source: Authors' elaboration based on Eurostat data.

In both countries studied, sustainable logistics and entrepreneurship are developing, but their nature differs. In Italy, the interdependencies between these areas are stronger and more stable, whereas in Poland they are more dynamic, less predictable, and often delayed.

5. Discussion of the Results

Empirical results confirm the existence of significant relationships between the level of sustainable entrepreneurship (SE) and the development of sustainable logistics (SL), but their nature and strength vary significantly between the countries analysed.

In the case of Italy, we observe stronger and more direct links between the studied phenomena. The high correlation coefficients and the very good fit of the regression models indicate that the development of sustainable entrepreneurship is translated relatively quickly into changes in the logistics sector. At the same time, the results of the OLS and SUR models reveal the nonlinear and dynamic nature of these relationships: the impact of SE changes over time, assuming both positive and negative values at various lag periods.

The presence of negative coefficients in some model specifications should not be interpreted as evidence that sustainable entrepreneurship directly reduces sustainable logistics development. Instead, these coefficients may indicate short-term adjustment costs, transition frictions, and delayed absorption of sustainability-oriented investments (Palkina, 2022; Jayarathna et al., 2024). Implementing sustainable business practices often requires restructuring logistics processes, investing in new technologies, adapting to regulatory requirements, and making organisational changes. These actions may temporarily weaken certain aspects of logistics performance before positive effects emerge in the longer term. Thus, the coexistence of negative short-term and positive long-term effects confirms the dynamic and non-linear nature of the relationship between sustainable entrepreneurship and sustainable logistics.

In Poland, negative lagged effects may also reflect the transitional nature of the economy, greater dependence on external financing mechanisms, and slower diffusion of sustainable technologies within the logistics sector (Rakytá et al., 2022; Sonar et al., 2024).

In Poland, these relationships are more dispersed and lagged. The lower values of the determination coefficients and the lack of significance of the current SE values in the models indicate that the impact of sustainable entrepreneurship on logistics is revealed primarily with delay. This may be due to the economic transformation phase and the greater role of external factors, such as public policy, EU funds, or structural changes in the transport sector.

Another important element of the difference in analysis is the dependencies in the structure between the pillars of sustainable logistics. In Poland, strong interdependencies between the pillars were confirmed (Breusch-Pagan test results), indicating their complementary nature. This means that changes in one area (e.g., economic) influence others (social and environmental). On the contrary, in Italy, the lack of significant correlations between the equations suggests greater autonomy between the individual pillars.

Different directions of change in the environmental pillar are also notable, particularly in Poland, where a downward trend is observed in environmental logistics despite the growth of sustainable entrepreneurship (Bartosiewicz et al., 2025). This may indicate insufficient effectiveness in implementing environmental solutions in the transport sector or the dominance of cost factors over environmental ones.

6. Conclusions and Practical Implications

The results of the study clearly confirm that sustainable entrepreneurship is a significant factor in the development of sustainable logistics, although the nature of this impact varies depending on the economic and structural conditions of the countries analysed. In particular, these relationships are dynamic and often manifest with delay, which means that the effects of implementing sustainable development practices are not immediate, but rather extended over time.

In Italy, a more direct and stable mechanism of sustainable entrepreneurship's impact on the logistics sector is observed, likely due to a higher level of institutional maturity and greater systemic cohesion. In Poland, however, these relationships are more complex and diffuse and their effects are revealed primarily in the longer term, indicating the significant role of intermediary factors such as public policy, infrastructure investments, and the absorption of EU funds. At the same time, the results indicate significant differences in the functioning of the individual pillars of sustainable logistics – the relative weakness of the environmental pillar is particularly noticeable, especially in Poland, where it has not seen consistent improvement despite the overall increase in sustainable entrepreneurship.

The identified relationships have significant practical implications. First, they point to the need for long-term and consistent policies supporting the development of sustainable entrepreneurship, as only within this time frame can lasting effects be achieved in the logistics sector (Ma et al. 2025). This means that economic policy instruments should be designed taking into account delays in the transmission of these effects and the need for stable support for structural transformation. Of particular importance here is the development of tools supporting the green transformation of logistics, including investments in low-emission technologies, the development of transport infrastructure, and regulations limiting the sector's negative environmental impact (Kucharski et al., 2025; Ferraro et al., 2026).

From the perspective of businesses, the results of the study emphasise the importance of considering sustainable development activities as part of a long-term strategy, not just a short-term response to regulatory or social pressure. Integrating economic, social, and environmental dimensions can generate synergistic effects, especially under conditions of strong systemic interconnections between these areas. At the same time, it is necessary to consider that the

implementation of sustainable solutions may involve temporary costs and a decrease in efficiency in the short term, which, however, leads to improved results in the long term.

The findings of the study also indicate the need to increase the effectiveness of environmental initiatives in the logistics sector, particularly in developing economies, where a lack of coherence is observed between the growth of sustainable entrepreneurship and the improvement of environmental indicators. From a practical perspective, the findings suggest that sustainable entrepreneurship can serve as an important catalyst for the transition towards more sustainable logistics systems. The results indicate that investments in ESG practices, green innovation, and sustainability-oriented business models may generate benefits not only at the firm level but also across logistics networks and supply chains. At the same time, the identified time-lagged effects imply that the benefits of sustainability initiatives may not be visible immediately and therefore require a long-term strategic perspective from both managers and policymakers. The differences observed between Italy and Poland further suggest that sustainability policies and support mechanisms should be adapted to national institutional and economic conditions rather than implemented through a uniform approach. These findings may support decision-makers in designing more effective strategies for sustainable economic and logistics development.

In summary, the conducted indicate that an effective transformation of the logistics sector toward sustainable development requires coordinated actions at the macroeconomic and microeconomic levels, taking into account both national specificities and the long-term nature of the processes being analysed. From a theoretical perspective, the study contributes to the literature by demonstrating that the relationship between sustainable entrepreneurship and sustainable logistics should not be interpreted as linear or instantaneous. Instead, the findings support evolutionary and path-dependence approaches, according to which sustainability-oriented transformation processes are cumulative, institutionally conditioned, and characterised by delayed adjustment mechanisms. The study also confirms the importance of analysing sustainable development dimensions simultaneously, as significant interdependencies and trade-offs may arise between economic, social and environmental objectives.

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