SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 230

INNOVATIONS AS AN ELEMENT OF STIMULATING SUSTAINABLE ENTREPRENEURSHIP IN POLAND

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Purpose: The aim of the study was to analyse the impact of innovation on sustainable entrepreneurship in Poland in the years 2008-2023. The article also attempts to assess how investments in innovation affect the sustainable development of enterprises.
Design/methodology/approach: The study was conducted between April and July 2025. Taking into account the aim of the study, a main hypothesis (H0) and three auxiliary hypotheses (H1, H2, H3) were formulated. Eurostat statistical data and the following methods were used for the analysis: ordinary least squares (OLS) and seemingly unrelated regression (SUR).
Findings: The results of the study confirmed a strong relationship between the level of innovation and sustainable entrepreneurship in Poland in the years 2008-2023. The analysis showed that the impact of innovation (in SUR models) varies depending on three key dimensions of sustainable entrepreneurship (economic, social, environmental) and develops at different intervals. Innovation has the most visible impact on the environmental area and, to a lesser extent, on economic performance.
Research limitations/implications: The limitations of the study include factors such as sustainable entrepreneurship and innovation indicators, which were constructed on the basis of secondary information and synthetic aggregation of various indicators, lack of distinction between types of innovation, the time frame of the data, and the sample size. Another potential limitation of the study is that it was conducted for a single country, which may imply that the results cannot be generalised to other countries.
Originality/value: The analysis indicates that innovation is crucial for sustainable entrepreneurship in Poland, should be supported in the long term, and its implementation should take into account social and environmental objectives. In the authors' opinion, the article may inspire other researchers and people interested in innovation and sustainable entrepreneurship.
Keywords: entrepreneurship, innovations, sustainable development, sustainable entrepreneurship.
Category of the paper: research paper.

1. Introduction

The modern economy is increasingly facing challenges related to the need to reconcile economic growth with care for the natural environment and social well-being. Interest in sustainable development is constantly growing among both the general public and economic operators (Kozar, Oleksiak, 2025; Misztal, Kowalska, 2020). We are also seeing a shift in consumption and production patterns towards more sustainable development (Tepliuk et al., 2023; Wodnicka, 2023; Xi, 2024). In this context, sustainable entrepreneurship is becoming not only desirable but also a necessary model of business activity (Alfaiza et al., 2025; Kowalska, Misztal, 2023). Some researchers even point to green entrepreneurship (Mondal, Singh, 2023; Sobko et al., 2024) or green self-employment (Kozar, 2024; Kozar, Wodnicka, 2024a). A key factor enabling the development of sustainable entrepreneurship is technological, organisational and social innovation, which allows enterprises not only to increase their competitiveness but also to reduce their negative impact on the environment.

In Poland, as in other developing countries, innovation is playing an increasingly important role in building a solid foundation for an economy focused on economic, social and environmental development (Ferlito, Faraci, 2022; Sagar, 2023). Initiatives supporting the development of innovative solutions, both from the state and the private sector, are essential to accelerate the transition towards sustainable development (Hoang et al., 2021) and a key factor in the development of modern enterprises that strive to achieve a sustainable competitive advantage in line with environmental protection and social expectations (Azmat et al., 2023). The essence, therefore, is whether and how innovation stimulates sustainable entrepreneurship and what challenges and opportunities are associated with this process. In this regard, this article attempts to examine the relationship between innovation and sustainable entrepreneurship in Poland in the years 2008-2023. To achieve this objective, existing data from the Eurostat database was used. The statistical data obtained was analysed using the OLS (ordinary least squares) and SUR (seemingly unrelated regression) methods.

The article consists of six parts: introduction, literature review, research methodology, research results, discussion, and conclusion. The introduction justifies the choice of topic and presents the research objectives and methods. Next, based on a review of the literature, the issue of innovation and its role in sustainable entrepreneurship is presented. The third part describes the research methods (statistical and econometric) used in the study, justifying their selection, as well as the research hypotheses helpful in achieving the objective of this article. The next part presents the results obtained and analyses them. Based on these results, a discussion is presented in the fifth section. The article concludes with conclusions.

2. Innovations and their role in sustainable entrepreneurship – literature review

Nowadays, sustainable development is a key topic in scientific discourse. It is analysed at many levels as a systemic approach that requires a balance between economic growth, environmental protection and social integration. As the literature review shows, research is increasingly focusing on the problems and challenges of sustainable development and on specific solutions implemented by various market players in this area (Kozar, Wodnicka, 2024b). In this context, much attention is also paid to the issue of sustainable entrepreneurship (Cantele et al., 2020; Pricopoaia et al., 2024). Interest in this phenomenon is growing today because knowledge about the factors shaping sustainable entrepreneurship and the phenomenon itself is still limited (La Rocca, Dal Molin, 2024).

The growing importance of environmental issues and sustainable development has a significant impact on shaping contemporary economic trends and determines the directions of development and management of modern organisations (Misztal, Kowalska, 2023). This has also resulted in sustainable entrepreneurship. It has emerged as an area of economic activity that combines social, environmental and economic goals. Researchers are increasingly recognising that entrepreneurs can play an important role in achieving sustainable development goals, even though they often face ethical dilemmas related to pursuing economic interests while taking social and environmental interests into account (La Rocca, Dal Molin, 2024; Niemann et al., 2020).

The literature on the subject offers a variety of definitions and approaches to the nature, objectives and challenges of sustainable entrepreneurship (Bajdor et al., 2021; Chakuzira et al., 2024; Rosário et al., 2022; Terán-Yépez et al., 2020). A key factor in the development of sustainable entrepreneurship is a change in the way we think about natural resources, the growing importance of entrepreneurs in creating added value, and technological progress enabling the implementation of eco-innovations. Sustainable entrepreneurship is a business model which, in addition to the pursuit of profit, emphasises activities that support social development and environmental protection (Kimuli et al., 2025; Kowalska, Misztal, 2023).

As indicated by the analysis of literature by many authors and researchers, innovation plays a key role in achieving sustainable development goals (Alarcon Ferrari et al., 2021; Imaz, Eizagirre, 2020; Nogueira et al., 2024). Although the role of innovation in accelerating progress towards sustainable development is widely recognised, discussions continue about the nature of the relationship between innovation and sustainable development (Fatma, Haleem, 2023; Nenni et al., 2024). Some studies examine the relationship between sustainable development goals and, for example, social innovation (Mueller, 2021), frugal innovation (Albert, 2022), technological innovation (Thavorn et al., 2021), and eco-innovation (Fatma, Haleem, 2023).

Innovations in organisational processes, production technologies and economic models play a key role in the development of sustainable entrepreneurship, as they enable the efficient use of resources, reduce negative environmental impacts and create social and economic value in the long term (Pricopoaia et al., 2024). Innovation refers to actions taken by individuals or organisations to create new ideas, including products, workplace processes or improvements to existing services and products. Innovation is also understood as the process of developing or implementing better solutions that are necessary in response to the latest requirements or emerging business circumstances (Hoang et al., 2021). Innovation can contribute to the development of a company, support its competitiveness in the face of changing market trends and increase profitability.

Matt Ridley argues that innovation is one of the least understood concepts in the world (Mueller, 2021). At the same time, innovation has become one of the most important drivers of economic growth and success (Tran, Vu, 2024). By implementing innovation, companies and national economies strive to improve their development and growth, with a view to progressing towards a future in which economic prosperity harmoniously coexists with social justice and environmental protection (Ayandibu, Ayandibu, 2024).

3. Research methodology

3.1. Research objective, scope and justification

This study aims to analyse the impact of innovation on sustainable entrepreneurship in Poland in the years 2008-2023.

The analysis covered the impact of economic crises (the financial crisis - 2008, the COVID-19 pandemic), on the variability of the studied indicators.

Studying the relationship between innovation and sustainable entrepreneurship in Poland in 2008-2023 is crucial for a modern, competitive and responsible economy. Challenges such as climate change, digitalisation and global competition require companies to innovate and conduct business with respect for the environment and society. Poland has made significant progress but still faces challenges regarding the broad implementation of innovations and their linkage to sustainable development goals. National strategies emphasise combining innovation with social responsibility and environmental protection. Studying this relationship helps assess how investments in innovation affect the sustainable development of enterprises and guides policymakers and companies on how to support sustainable development in a knowledge-based economy effectively.

3.2. Research hypotheses

In the face of growing economic, social and environmental challenges, it is important to understand how innovation development affects enterprises' sustainable and responsible development. Based on available literature and analysis of current trends, the following research hypotheses were formulated, allowing us to verify both the impact of innovation on sustainable entrepreneurship and the nature of this relationship over time and in economic, social and environmental dimensions.

Based on the aim of the study, the following main hypothesis (H0) and three auxiliary hypotheses (H1, H2, H3) were formulated:

H0: Innovation significantly impacted sustainable entrepreneurship in Poland from 2008-2023.

Justification: Innovation is a key factor in developing modern enterprises that strive to achieve a sustainable competitive advantage. In sustainable entrepreneurship, innovations can lead to more efficient use of resources, introducing ecological technologies and improving social conditions in the workplace. In Poland, as an economically developing country in the years 2008–2023, it can be expected that the increase in innovation contributed to the development of sustainable practices, which justifies the study of this impact.

H1: Poland's innovation and sustainable entrepreneurship indicators in 2008-2023 are characterized by a positive trend.

Justification: Over the last few decades, there has been a growing awareness of the role of innovation and sustainable development. In Poland, innovation and sustainable entrepreneurship are systematically promoted with the accession to the EU and the inflow of structural funds. Therefore, both indicators are growing, reflecting a long-term positive trend resulting from public policies, education and the growing demand for socially and ecologically responsible solutions.

H2: A strong, positive correlation exists between innovation and sustainable entrepreneurship in Poland in 2008-2023.

Justification: Innovation and sustainable entrepreneurship are closely related concepts – innovations often enable implementing sustainable practices, such as environmentally friendly technologies or business models that limit negative impacts on nature and society. A positive correlation would indicate that as companies become more innovative, their commitment and effectiveness in sustainable development also increase.

H3: Innovation has a time-differentiated impact on the three dimensions of sustainable entrepreneurship (economic, social and environmental).

Justification: Sustainable entrepreneurship includes three complementary dimensions that may respond to innovation differently and at different times. For example:

- Economic effects of innovation may appear relatively quickly through increased efficiency and revenues.
- Social changes, such as improving working conditions or engaging communities, may require more time to implement and evaluate.
- Environmental changes, e.g. emission reduction or energy efficiency, are often the result of long-term investments and policies.

Differentiation of impacts over time requires considering the dynamics of processes and the specificity of individual dimensions of sustainable development.

3.3. Data sources and construction of indicators

The main source of statistical data was the Eurostat database. To ensure comparability of data in the time and country cross-section, all variables were normalized and transformed into indices with values within the range [0,1].

The dependent variable is the synthetic index of sustainable entrepreneurship in Poland (SusEnt), defined by the pattern:

$$SusEnt = \frac{\mathrm{E+S+Env}}{3} \tag{1}$$

$$SusEnt = \frac{1}{3}\left(\frac{1}{n_E}\sum_{i=1}^{n_E} E_i + \frac{1}{n_S}\sum_{j=1}^{n_S} S_j + \frac{1}{n_{Env}}\sum_{k=1}^{n_{Env}} Env_k\right) \tag{2}$$

where:

- SusEnt – the synthetic index of sustainable entrepreneurship in Poland;
- E, S, Env – the components of the synthetic index of sustainable entrepreneurship in Poland (synthetic economic, social and environmental index);
- $E = \frac{1}{n_E}\Sigma_{i=1}^{n_E} E_i$ – an average of n_E economic variables (number of businesses, revenue or written premiums, total production value, value-added (factor cost), gross operating profit, total purchases, investment in fixed assets, operating profitability rate, operating profit share in value added, investment ratio, labour cost share in production, average labour cost);
- $S = \frac{1}{n_S}\Sigma_{j=1}^{n_S} S_j$ – an average of n_S social variables (employee compensation, social insurance expenses, workforce size, revenue per employee, gross value added per worker, labour productivity adjusted for wages, value added per staff member, employment growth rate, average staff per business, investment per employee, staff-related expenses, proportion of personnel costs in overall goods and services expenditure);
- $Env = \frac{1}{n_{Env}}\Sigma_{k=1}^{n_{Env}} Env_k$ – an average of n_{Env} environmental variables (emission of carbon dioxide, methane, nitrous oxide, sulphur oxides, carbon monoxide, nitrogen oxides, ammonia).

The independent variable is the synthetic index of the innovation in Poland (I), given by the formulas:

$$I = \frac{\text{RD+PAT+DIGI+ICTA+RDP}}{5} \tag{3}$$

$$I = \frac{1}{n}\sum_{i=1}^{n} I_i \tag{4}$$

where:

- I – the synthetic index of the innovation in Poland;
- RD – total R&D (research and development) expenditure in Poland;
- PAT – number of patents granted in Poland;
- DIGI – number of enterprises in Poland with high levels of digital intensity;
- ICTS – number of enterprises in Poland employing ICT specialists and offering ICT-related training to staff;
- RDP – number of R&D personnel employed by enterprises in Poland;
- n – number of index components (5);
- I_i – normalized value of the analytical indicator belonging to the innovation index.

The analytical indicators used to construct the dependent variable and the independent variable were normalized (in order to unify the measurement scale) using the following formulas:

$$St_{ij} = \frac{Var_{ij}}{\max\limits_{i}\{Var_{ij}\}}, St_{ij} \in [0;1] \tag{5}$$

$$Dt_{ij} = \frac{\min\limits_{i}\{Var_{ij}\}}{Var_{ij}}, Dt_{ij} \in [0;1] \tag{6}$$

where:

- St_{ij} – the normalized value of the j-th variable in the i-th year (stimulant);
- Dt_{ij} – the normalized value of the j-th variable in the i-th year (destimulant);
- Var_{ij} – the value of the j-th variable in the i-th year;
- $\max\limits_{i}\{Var_{ij}\}$ – the lowest value of the j-th variable in the i-th year;
- $\min\limits_{i}\{Var_{ij}\}$ – the highest value of the j-th variable in the i-th year.

3.4. Statistical and econometric methods used in the study

In the first stage of the study, synthetic indicators of innovation and sustainable entrepreneurship for Poland in the years 2008-2023 were developed. The construction of the indicators was based on a set of analytical indicators that were normalized and aggregated to obtain synthetic measures. These indicators were presented in tabular and graph form, enabling clear comparisons between years. Then, their statistical analysis was carried out, in which basic measures of central tendency and variability were calculated: mean, median, standard deviation, minimum and maximum values. Such analysis allowed us to identify general innovation and sustainable entrepreneurship trends and capture periods of particular fluctuations.

Then, the intensity and direction of relationships between variables were assessed using correlation analysis. For this purpose, various correlation coefficients were used: Pearson's linear correlation coefficient, nonparametric Spearman's rank coefficient and Kendall's Gamma and tau coefficients. This approach allowed us to consider both linear and ordinal and non-linear dependencies, which increased the credibility of the results. Correlation analysis allowed us to identify significant links between the level of innovation and individual aspects of sustainable entrepreneurship, indicating potential interaction mechanisms.

Next, an econometric model describing the linear relationship between the synthetic indicator of innovation and the synthetic indicator of sustainable entrepreneurship was estimated using the ordinary least squares (OLS) method. The effects of time delays (lags) were taken into account, which allowed us to capture possible delayed effects - phenomena in which the impact of innovation on sustainable entrepreneurship is not immediate but extends into subsequent years. The model was checked in terms of the assumptions regarding OLS (they were met), and it took the form:

$$SusEnt = \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \varepsilon_i \quad (7)$$

The Seemingly Unrelated Regressions (SUR) method was also used to extend the analysis. SUR allows for the simultaneous estimation of several regression equations where the explanatory variables differ, but the random components may be related. The advantage of this method is that it takes into account potential interdependencies between different dimensions of sustainable entrepreneurship – economic (E), social (S) and environmental (Env). Such estimation allowed for a more precise estimation of parameters and a comprehensive approach to the studied phenomena. The estimated equations of the SUR model took the following form:

$$\begin{aligned} E &= \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot S + \propto_8 \cdot Env + \varepsilon_i \\ S &= \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot E + \propto_8 \cdot Env + \varepsilon_i \\ Env &= \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot E + \propto_8 \cdot S + \varepsilon_i \end{aligned} \quad (8)$$

Applying the SUR model made it possible to assess the direct impact of innovation on each dimension of sustainable entrepreneurship and capture the relationships between these dimensions. It provided a more nuanced picture of the interdependencies within the innovation-entrepreneurship system, which allows for formulating more accurate recommendations for economic policy and strategies to support innovation in sustainable development.

4. Research results

Table 1 presents the values of Poland's sustainable entrepreneurship index in 2008-2023. It measures the degree of integration of sustainable development principles in the activities of enterprises, taking into account three main pillars: economic, environmental and social aspects.

The columns compare the year of measurement and the corresponding values of the index. Starting from the value of 0,747 in 2008, the index shows a clear upward trend, reaching the highest value of 0,947 in 2019. Then, slight decreases are noted, stabilizing around 0,93 in 2020-2023.

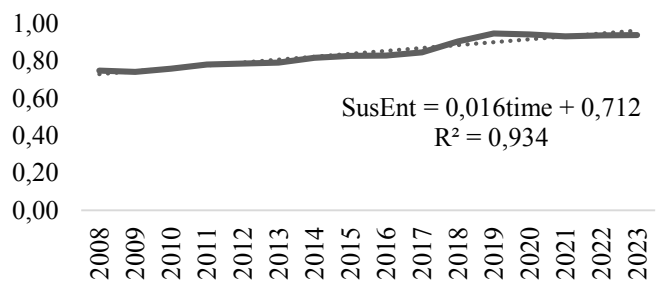
The table also includes basic descriptive statistics for the analyzed period:

- Mean: 0,844 – indicates the average level of the SusEnt index in Poland in the analyzed period.
- Standard deviation: 0,074 – shows how much the indicator values differ from the average; a low value suggests stable growth.
- Median: 0,828 – half of the observations are below this value, indicating later development.
- Maximum value: 0,947 – the highest level of sustainable entrepreneurship recorded in 2019 (strong economic conditions, increased regulatory and social pressure, development of technology and innovation, experience of companies and market maturity).
- Minimum value: 0,740 – the lowest value of the indicator from 2009 (global financial crisis of 2008-2009, low level of maturity of companies in terms of ESG (Environmental, Social, Governance), lack of strong regulations and incentives).

Based on the presented data and the graph presenting the given indicator and its trend line, it can be seen that Poland has systematically increased the level of sustainable entrepreneurship over the 16 years analyzed, which may indicate growing ecological awareness, technological progress and social responsibility of companies.

Table 1.
The index of sustainable entrepreneurship in Poland (2008-2023)

Country	Time	Indicator (SusEnt)	Basic descriptive statistics				
Poland	2008	0,747	**Mean**	**Standard deviation**	**Median**	**Max**	**Min**
	2009	0,740	0,844	0,074	0,828	0,947	0,740
	2010	0,757	**Trendline**				
	2011	0,780					
	2012	0,785					
	2013	0,790					
	2014	0,816					
	2015	0,827					
	2016	0,829					
	2017	0,845					
	2018	0,903					
	2019	0,947					
	2020	0,941					
	2021	0,931					
	2022	0,935					
	2023	0,938					



Source: own study on the basis of Eurostat, (https://Ec.Europ a.Eu/Eurostat), 30.05.2025.

Table 2 presents the values of the innovation index for Poland in the years 2008-2023. It measures the level of innovation in the economy, considering various factors influencing the ability to create and implement innovations.

In subsequent years, the index shows a clear upward trend - from the value of 0,454 in 2008, through a systematic increase, to the highest value of 0,961 recorded in 2023. It means a significant development of innovation in Poland during the analyzed period.

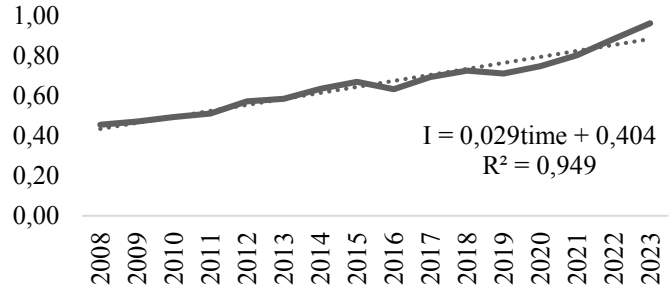
Basic descriptive statistics for the analyzed period are:

- Mean: 0,658 – indicates the average level of the innovation index in Poland in 2008-2023.
- Standard deviation: 0,141 – informs about the variability of the index about the average; a moderately high value indicates dynamic changes and significant growth in individual years.
- Median: 0,650 – half of the observations are below this value, which confirms innovation development, especially in the second half of the analyzed period.
- Maximum value: 0,961 – the highest level of innovation achieved in 2023 (strong R&D development, institutional support, increased awareness).
- Minimum value: 0,454 – the lowest indicator recorded in 2008 (early stage of innovation development, low investment and awareness).

Based on the presented data, it can be stated that Poland has been systematically improving its position in terms of innovation over the last 16 years, which may indicate increased investment in research and development, a growing number of modern technologies and the growing competitiveness of the economy on the global market.

Table 2.
The index of the innovation in Poland (2008-2023)

Country	Time	Indicator (I)	Basic descriptive statistics				
			Mean	**Standard deviation**	**Median**	**Max**	**Min**
	2008	0,454	0,658	0,141	0,650	0,961	0,454
	2009	0,470					
	2010	0,492	**Trendline**				
	2011	0,510					
	2012	0,570					
	2013	0,583					
	2014	0,633					
	2015	0,668					
Poland	2016	0,631					
	2017	0,692					
	2018	0,723					
	2019	0,710					
	2020	0,746					
	2021	0,801					
	2022	0,882					
	2023	0,961					



Source: own study on the basis of Eurostat (https ://Ec.Europ a.Eu/Eurostat), 30.05.2025.

Table 3 presents four different correlation coefficients measuring the direction and strength of the relationship between sustainable entrepreneurship and innovation.

1. Pearson's R = 0,911 – a high value indicates a strong, positive linear correlation between sustainable entrepreneurship and innovation. It means that the increase in innovation is strongly associated with the increase in sustainable entrepreneurship in Poland.
2. Spearman's Rho = 0,926 – Spearman measures the rank correlation, so this value also indicates a very strong, positive relationship, but it considers monotonic (not necessarily linear) relationships. The higher positions in innovation correspond to higher positions in sustainable entrepreneurship.
3. Gamma = 0,817 – the Gamma coefficient indicates a strong, positive correlation between the ordinal variables. It confirms the consistency of trends in the rankings of both variables.
4. Kendall's Tau = 0,817 – the Kendall tau value also indicates a significant and positive ordinal correlation, i.e. consistency between the ordinal data sets on sustainable entrepreneurship and innovation.

All four coefficients indicate a very strong and positive correlation between sustainable entrepreneurship and innovation in Poland. Countries or regions with a higher level of innovation also show a higher level of sustainable entrepreneurship, suggesting that innovation may be a key factor supporting sustainable entrepreneurship development.

Table 3.
The Pearson's R, Spearman-s Rho, Gamma and Kendall rank correlation coefficients (correlation between SusEnt and I; Poland; 2008-2023, $p < 0,05$)

Correlation coefficients (SusEnt/I – Poland)			
Pearson's R	**Spearman-s Rho**	**Gamma**	**tau Kendall**
0,911	0,926	0,817	0,817

Source: own study on the basis of Eurostat (https://Ec.Europ a.Eu/Eurostat), 30.05.2025.

Table 4 presents a linear model estimated using the least squares method (OLS) on annual data from 2008-2023 (T=16). The dependent variable is the level of sustainable entrepreneurship (SusEnt), and the explanatory variable is innovation (I) in a given year and with delays up to 5 years back ($_{t-1}$ to $_{t-5}$). Only a delay of 5 years was included in the model because it is the only statistically significant coefficient. Interpreting:

- The constant (const) = 0,526 ($p < 0,0001$) — denotes the average level of sustainable entrepreneurship when innovation is equal to zero;
- The coefficient for $I_{(t-5)}$ = 0,610 ($p < 0,0001$) — indicates that an increase in innovation five years ago by one unit causes an average increase in sustainable entrepreneurship by 0,61 units currently.

The model explains as much as 88,6% of the variance of the dependent variable ($R^2 = 0,886$), which indicates a very good fit for the model.

The model meets the standard assumptions of linear regression:

- Linearity – the relationship between variables is linear.
- No autocorrelation of residuals – the LM test showed that the residuals are independent (p = 0,488).
- No heteroscedasticity – the White test confirmed the constant variance of the residuals (p = 0,196).
- Normality of the error distribution – the normality test of the residuals confirmed a distribution close to normal (p = 0,963).
- No collinearity – the model has only one explanatory variable, so this assumption is automatically met.

The model indicates that innovation significantly impacts the level of sustainable entrepreneurship in Poland, but this effect is revealed only after about five years. It means that investments and the development of innovations need time to translate into specific results in the field of sustainable development of enterprises. A high R^2 value indicates that innovation is a very strong predictor of sustainable entrepreneurship.

Table 4.

The linear regression model, Ordinary Least Squares (Poland, 2008-2023)

$$SusEnt = \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \varepsilon_i$$

Model 1: OLS, using observations 2008-2023 (T = 16)				
Dependent variable: SusEnt				
	Coefficient	Std. error	P-value	R-squared
const.	0,526	0,043	<0,0001	0,886
$I_{(t-5)}$	0,610	0,073	<0,0001	
Assumptions of OLS				
Linearity				✓
No autocorrelation and independence of errors				✓
LM test for autocorrelation up to order 1				
Null hypothesis: no autocorrelation				
Test statistic: LMF = 0,529				
with p-value = P(F(1, 8) > 0,529) = 0,488				
No heteroscedasticity				✓
White's test				
Null hypothesis: heteroskedasticity not present				
Test statistic: LM = 3,256				
with p-value = P(Chi-square(2) > 3,256) = 0,196				
Normality of errors				✓
Test for normality of residual -				
Null hypothesis: error is normally distributed				
Test statistic: Chi-square(2) = 0,076				
with p-value = 0,963				
Lack of collinearity				✓
There is only one independent variable in the model, this assumption is automatically met				

Source: own study on the basis of Eurostat (https ://Ec.Europ a.Eu/Eurostat), 30.05.2025.

Table 5 presents the model of interdependent equations estimated using the Seemingly Unrelated Regression (SUR) method, using annual data from 2008-2023 (T = 16). The model consists of three related equations, in which the dependent variables are, respectively: the economic (E), social (S) and environmental (Env) dimensions of sustainable entrepreneurship.

Each equation includes as an explanatory variable innovativeness (I) in the current year and with lags up to five years back ($_{t, t–1, ..., t–5}$), as well as dependent variables from the remaining equations in order to take into account the mutual relations between the dimensions of sustainable development. Additionally, each equation contains a constant (const).

- Equation 1 - economic dimension (E) - dependent variable: E; $R^2 = 0,961$ - the model fits the data very well.

Significant coefficients:

- $I_{(t–5)} = -0,513$, $p = 0,001$ - innovation from five years ago negatively affects the current level of the economic dimension;
- $S = 1,468$, $p < 0,0001$ - a higher level of the social dimension significantly increases the value of the economic dimension.

Interpretation: a positive and strong impact of the social dimension on the economic dimension suggests that pro-social activities contribute to the growth of the economic aspect of sustainable entrepreneurship. On the other hand, a negative impact of innovation with a delay may indicate initial costs or a shift in the effects of innovative investments in time.

- Equation 2 - social dimension (S) - dependent variable: S; $R^2 = 0,985$ - a model very well fitted to the data.

Significant coefficients:

- $I_{(t–5)} = 0,366$, $p < 0,0001$ - a positive impact of innovation from five years ago;
- $E = 0,655$, $p < 0,0001$ - the economic dimension positively impacts social development.

Interpretation: the effects of innovation in the social dimension are also delayed but positive. It indicates that innovative investments contribute to social development but with a delay of several years. In turn, economic development positively impacts the social dimension of sustainable entrepreneurship.

- Equation 3 - environmental dimension (Env) - dependent variable: Env; $R^2 = 0,809$ - moderately good model fit.

Significant coefficient:

- $I_{(t–2)} = 0,415$, $p < 0,0001$ - the positive impact of innovation from two years ago.

Interpretation: in the case of the environmental dimension, the effect of innovation appears earlier than in the other dimensions - after two years. It indicates that innovative activities can quickly impact the environmental aspects of enterprises' activities.

Model 2 confirms the existence of significant relationships between the dimensions of sustainable development and innovation and between the dimensions themselves (E, S, Env). The effects of innovation are temporally differentiated: they affect the environment faster

(after 2 years), while they affect social and economic aspects with a five-year delay. In addition, the relationships between dimensions indicate mutual reinforcement of these aspects of sustainable development. These results have important implications for public policy and business strategies promoting innovation to achieve sustainable development.

Table 5.
The Seemingly Unrelated Regressions method (Poland, 2008-2023)

$$E = \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot S + \propto_8 \cdot Env + \varepsilon_i$$

$$S = \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot E + \propto_8 \cdot Env + \varepsilon_i$$

$$Env = \propto_0 + \propto_1 \cdot I + \propto_2 \cdot I_{(t-1)} + \propto_3 \cdot I_{(t-2)} + \propto_4 \cdot I_{(t-3)} + \propto_5 \cdot I_{(t-4)} + \propto_6 \cdot I_{(t-5)} + \propto_7 \cdot E + \propto_8 \cdot S + \varepsilon_i$$

Model 2: SUR, using observations 2008-2023 (T = 16)				
Equation 1				
Dependent variable: E				
	Coefficient	Std. error	P-value	R-squared
const	-0,044	0,05	0,402	0,961
$I_{(t-5)}$	-0,513	0,103	0,001	
S	1,468	0,117	1,48E-06	
Equation 2				
Dependent variable: S				
	Coefficient	Std. error	P-value	R-squared
const	0,044	0,031	0,191	0,985
$I_{(t-5)}$	0,366	0,046	4,35E-05	
E	0,655	0,051	1,26E-06	
Equation 3				
Dependent variable: Env				
	Coefficient	Std. error	P-value	R-squared
const	0,654	0,041	4,91E-08	0,809
$I_{(t-2)}$	0,415	0,059	6.,49e-05	
Cross-equation VCV for residuals				
	0,000177	(-0,996)	(-0,519)	
	-0,00012	8,06E-05	-0,552	
	-0,00011	8,12E-05	0,000269	
Tests				
Breusch-Pagan test for diagonal covariance matrix				
Chi-square(3) = 17,213 [0,0006]				
log determinant = -31,564				
Hansen-Sargan over-identification test				
Chi-square(1) = 0,462 [0,497]				

Source: own study on the basis of Eurostat (https ://Ec.Europ a.Eu/Eurostat), 30.05.2025.

Data analysis from 2008-2023 indicates a systematic increase in the level of sustainable entrepreneurship and innovation in Poland. Both indicators show a clear upward trend, especially after 2010, which indicates the growing maturity of companies, technological progress and the strengthening of social and environmental responsibility. A very strong positive correlation between these phenomena confirms that innovation supports sustainable entrepreneurship development. Importantly, innovation's impact is delayed–innovative activities' effects are visible in sustainable development only after several years, with the environmental dimension after two years and the social and economic dimension after five years. Moreover, the individual dimensions of sustainable development reinforce each other –

social development supports economic development, and economic development contributes to improving social aspects. These results have practical significance: they confirm the need for a long-term, integrated approach in public policies and business strategies that treat innovation as a key factor driving the sustainable development of enterprises.

5. Discussion

The research results confirmed a strong relationship between the innovation level and sustainable entrepreneurship development in Poland from 2008 to 2023. Pearson's R reached 0,911, and rank-based correlations exceeded 0.8.

Among the most important findings of the analysis is the impact of the five-year lag in the innovation index ($I_{(t-5)}$) on the current level of sustainable entrepreneurship. The estimated coefficient of 0,610, accompanied by a highly significant p-value, suggests that innovation effects become visible only after several years. It aligns with the arguments of Dangelico and Vocalelli (2017) and Bocken et al. (2014). They emphasized the long-term environmental and social impacts. The analysis supports the rationale for strengthening innovation support mechanisms in policy with a perspective of extending short-term incomes.

The effect of innovation in SUR models varies across the three key dimensions of sustainable entrepreneurship and unfolds at different time intervals. A relatively rapid and significant impact was found on the environmental dimension (Env), with a two-year lag and a coefficient of 0,415 ($p < 0,001$). In contrast, the economic dimension (E) showed a negative relationship after five years ($\beta = -0,513$; $p = 0,001$). These results show that innovation-related costs may outweigh short-term economic gains. This result contrasts Smith et al. (2013), who argued that financial benefits typically materialize first. Meanwhile, the social dimension (S) demonstrates links to both innovation ($\beta = 0,366$) and the economic component ($\beta = 0,655$), pointing toward positive synergistic effects among the three pillars of sustainable development.

Our study allows us to identify several theoretical and empirical implications:

- long-term support for innovation proves essential, as effects tend to appear only after several years. Programs such as subsidies, tax reliefs, or EU-funded initiatives should be designed with an extended time horizon;
- investments in green innovation yield faster returns and are a suitable vehicle for driving the green transition in the economy;
- innovation strategies should also foster social development.

There are a few limitations to be considered when interpreting the findings. The study is limited to Poland and is performed from 2008 to 2023, which may restrict the generalizability of the findings to other nations, especially those with alternative economic systems or institutional structures. The sustainable entrepreneurship and innovation performance indexes

were constructed from secondary information and a synthetic aggregation of distinct indicators; thus, other performance measurement options might influence the results. In addition, the study fails to differentiate between innovation kinds; technological, organizational, and social innovations might have different effects on sustainable entrepreneurship performance, which the current structure cannot capture. Finally, the yearly data limits sample size to as few as 16 observations, reducing degrees of freedom and the possible robustness and accuracy of time-lagged regression estimates.

6. Conclusions

The paper shows that innovations are crucial for sustainable entrepreneurship in Poland. The high correlation between the indices proves that the increase in innovation is conducive to the subsidence of changes towards more sustainable business activity. The phenomena from five years ago had the most significant impact on innovations, which means that their effects are associated with a time delay. The results of the SUR model show that innovations have the most visible effect on the environmental area and, to a lesser extent - and with a greater delay - on economic results.

These conclusions have practical significance. Innovations should be supported long-term, and their implementation should consider social and environmental goals. Programs are needed that will allow companies to allocate time at the beginning to achieve positive results.

The limitations of the analysis, such as the short period, focus on one country, and the lack of division into types of innovation, show the need for further research, also from an international perspective.

In the future, it is worth extending the research to other countries, especially in Central and Eastern Europe, to compare the conditions and effects of innovation. It is also recommended to consider different types of innovation – technological, organizational and social – because they can affect sustainable development in various ways.

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