Territorial Typologies of Innovation-to-Sustainability Transformation: Evidence for EU Member States

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Extended Abstract

Aim

This paper aims to bring light into the process of transforming the strategic innovation capacity into sustainable development outcomes in the case of the European Union (EU) Member States, with the aim of identifying territorial typologies relevant for the design of EU Cohesion Policy post-2027. In a context marked by geopolitical uncertainty, green and digital transitions, and increasing pressure on public budgets, understanding the efficiency of this transformation process becomes crucial for shaping more targeted and performance-oriented policy interventions.

Methodology

Using Eurostat data, two composite dimensions are constructed, namely an input dimension measuring the strategic innovation capacity of the member states, and an output dimension related to sustainable development outcomes. Considering that the extracted data are either benefit-type or cost-type variables, a normalization or an inverse normalization step was performed prior to using the indicators for the analysis. For the normalization, the following formula has been used (Han et al. 2012):

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

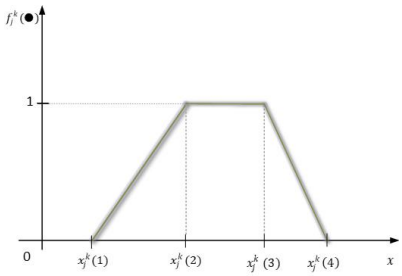
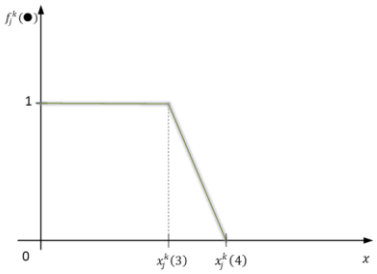
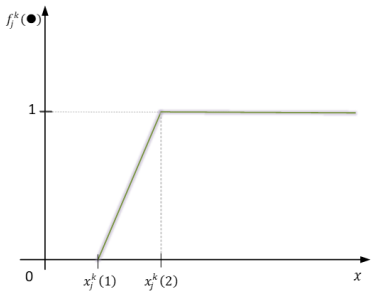
The number of clusters has been determined as suggested in the scientific literature by considering the values obtained for the Silhouette score (Rousseeuw 1987), Davies-Bouldin index (Davies and Bouldin 1979), Calinski-Harabasz score (Calinski and Harabasz 1974), and dendrogram (Murtagh 1985; Wilkinson and Friendly 2009). As a result, three clusters have been used.

Grey systems theory, through the grey clustering method, offers a distinct tool for complex and uncertain situations, characterized by limited data. Over years, it has been proven that grey systems theory has proved its applicability in a wide range of domains, which have made it the primarily option for the researchers in the field when dealing with incomplete data. In

particular, the grey clustering analysis has been used in research papers from various research directions, such as, but not limited to (Dumitrescu et al. 2025): economics (e.g. Wiecek-Janka et al. (2020), Li et al. (2014), Delcea et al. (2025), Tilica et al. (2024)), risk and security (e.g. Wu et al. (2019), Qi et al. (2021), Chen et al. (2023), Hu et al. (2020), Liu et al. (2015), Kumar (2021), Hossain et al. (2022)), project and sustainability evaluation (e.g. Chen et al. (2024), Tan et al. (2020), Huo et al. (2023), Wang et al. (2022), Zhang et al. (2022)), environment evaluation (e.g. Liu (2021) , Yu et al. (2019), Delgado et al. (2020), Delgado et al. (2021)), industry and materials (e.g. Tan et al. (2024), Guo et al. (2021), Li et al. (2020), Tian (2016), Yue et al. (2018), Zhao et al. (2024)).

Three classical forms of the grey clustering functions have been used as suggested in the dedicated scientific literature (Crisan et al. 2025; Ioanas et al. 2026; Liu et al. 2016, 2012; Marin et al. 2025; Panait, et al. 2026; Delcea et al. 2021; Xie et al. 2019), which are briefly depicted in Table 1. Based on the data, the turning points of these functions have been established for each indicators considered in the analysis.

Table 1. Forms of grey clustering functions

Type	Graphical representation	Equation
1		$f_j^k(x) = \begin{cases} 0, & x \notin [x_j^k(1), x_j^k(4)] \\ \dfrac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)}, & x \in [x_j^k(1), x_j^k(2)] \\ 1, & x \in [x_j^k(2), x_j^k(3)] \\ \dfrac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)} & x \in [x_j^k(3), x_j^k(4)] \end{cases}$
2		$f_j^k(x) = \begin{cases} 0, & x \notin [0, x_j^k(4)] \\ 1, & x \in [0, x_j^k(3)] \\ \dfrac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)} & x \in [x_j^k(3), x_j^k(4)] \end{cases}$
3		$f_j^k(x) = \begin{cases} 0, & x < x_j^k(1) \\ \dfrac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)}, & x \in [x_j^k(1), x_j^k(2)] \\ 1, & x \geq x_j^k(2) \end{cases}$

To capture the complexity of the innovation-to-sustainability nexus, multiple weighting scenarios are developed, ranging from full emphasis on innovation capacity to full emphasis on sustainable outcomes. Additionally, a four-year dynamic perspective is incorporated using a grey clustering approach, allowing the observation of countries' movements across clusters. Overall, the scenarios presented in Figure 1 have been considered.

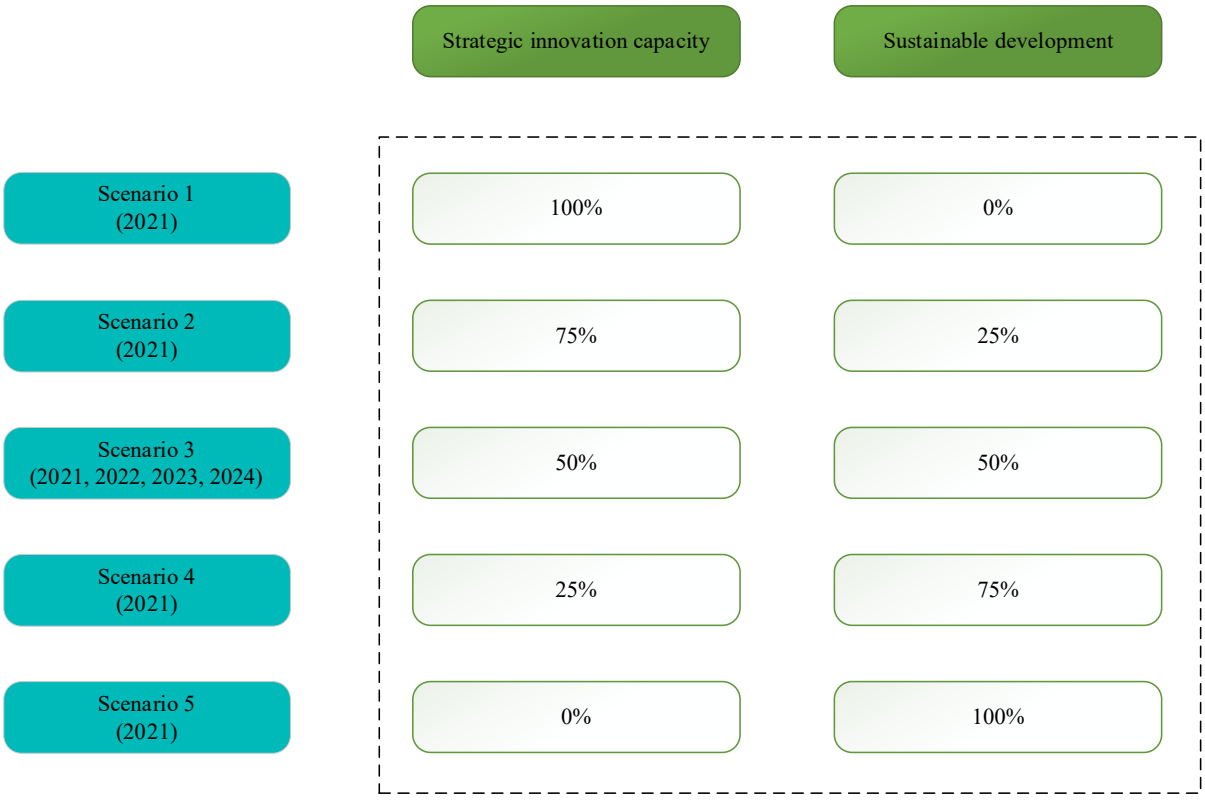


Figure 1. The scenarios considered in the analysis

Additionally, robustness is ensured through 100,000 simulations with slightly varying coefficients, enabling an assessment of cluster stability.

Results

The results reveal distinct territorial typologies. "Systematic leaders" demonstrate a consistent ability to translate innovation inputs into sustainable outcomes. Other groups include countries with strong innovation capacity but limited sustainability performance, as well as states achieving relatively good outcomes despite weaker innovation inputs. These asymmetric patterns suggest that innovation capacity alone does not automatically guarantee sustainable transformation.

The findings provide evidence for a more nuanced, place-based approach to EU Cohesion Policy post-2027. Rather than uniform support mechanisms, differentiated strategies are needed to address structural inefficiencies in the innovation-to-sustainability conversion process and to foster upward convergence across Member States.

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