Patterns of Digital Development in European Union Countries: Cluster Analysis Approach

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Abstract

This study focuses on the digital development of European Union Member States. The analysis was conducted using 2022 Digital Economy and Society Index (DESI) data and covered three key areas: the basic digitalisation of business, the adoption of advanced online activities, and the availability of 5G network infrastructure. The results show that most Member States have achieved a high level of basic digitalisation. At the same time, the use of advanced solutions, such as cloud computing and e-commerce, remains relatively limited. Particularly noteworthy is that the indicators are less strongly associated than might be expected. For example, countries with well-developed 5G infrastructure do not necessarily make greater use of advanced technologies. Cluster analysis divided the countries into three groups distinguished by different combinations of infrastructure development and the adoption of digital tools. The findings suggest that digital transformation is not linear, but a complex mix of technological, organisational, and cultural factors. The study highlights the importance of coordinated policies that support not only investment in infrastructure but also the development of digital skills and innovative business models.

Keywords: digital maturity; k-means; DESI; e-business; 5G technology

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Introduction

The digital maturity of the business sector is one of the key drivers of the competitiveness and resilience of European Union economies. Over the past decade, the adoption of digital technologies has gradually reshaped how companies organise processes, develop products, and communicate with the market. However, despite the widespread availability of digital tools, considerable differences remain among Member States in adopting advanced solutions and developing digital infrastructure (Kraus et al., 2021; Vial, 2019).

The digital divide is a central issue in contemporary social and economic development. The term refers to differences in access to digital technologies, levels of digital skills, and opportunities to benefit from the digital society (Moraliyska, 2024). It is a complex phenomenon involving infrastructural, educational, and institutional factors, whose consequences are reflected in economic, social, and regional disparities within the European Union (Obelovska et al., 2025).

Previous research has demonstrated the multidimensional nature of the digital divide and the need for its systematic measurement. Pejić-Bach and Marić (2025) emphasise that the complexity of digital development requires careful consideration of different aspects of inclusion in the digital society. Through a statistical analysis of the dimensions of the digital economy and society, Bánhidi et al. (2020) identified patterns and groupings among Member States. Using cluster analysis, Sevgi (2021) further showed that European countries can be differentiated according to their level of digital performance. Moraliyska (2024) highlights pronounced inequalities among European Union countries in digital inclusion, while Obelovska et al. (2025) emphasise the importance of linking digital skills and technological infrastructure, with particular emphasis on developing 5G networks.

Digital maturity data at the level of European Union Member States, as measured by the Digital Economy and Society Index (DESI), indicate that most European enterprises have achieved a high level of basic digitalisation, such as using e-invoices and integrated management systems. At the same time, the adoption of more complex forms of digital business, including cloud computing and e-commerce, remains considerably lower (Fu & Li, 2023). The availability of 5G network infrastructure, a key prerequisite for new business models and innovation, also varies greatly among countries. Examples such as Belgium, where officially recorded 5G coverage was very low, or Hungary, which records relatively high adoption of advanced online activities despite limited infrastructure, confirm the complexity of digitalisation. Previous studies have shown that successful digital transformation depends not only on technological infrastructure but also on the development of digital competencies, institutional support, and business culture (Ferreira et al., 2019; Matt et al., 2015). It is therefore increasingly clear that the digital maturity of enterprises is a multi-stage process that develops at different speeds and intensities across European Union Member States.

Despite a substantial body of research, a gap remains regarding a comprehensive overview of different dimensions of digital maturity within a single framework. Most

previous studies have focused on individual aspects of digital development, while an integrated approach covering the continuum from e-business to advanced communication technologies remains insufficiently developed. This study aims to analyse the interrelationships among three key aspects of digital development: the basic digitalisation of business, the adoption of advanced online activities, and the availability of 5G network infrastructure. Descriptive statistical analysis, Pearson correlation analysis, and k-means cluster analysis are employed to determine whether recognisable patterns exist in the grouping of countries by their level of digital development. The results provide insight into the heterogeneity of digital transformation processes and indicate the potential need for a balanced approach that combines infrastructure investment, competence development, and incentives for the adoption of advanced technologies in business.

This paper therefore seeks to address the identified gap by systematically analysing the digital maturity of European Union Member States and identifying patterns that may inform the design of more effective development policies. The remainder of the paper is structured as follows. The literature review presents previous research, the methodology section describes the methods used, the results section reports the findings, and the final section summarises the main conclusions.

Literature Review

Digital maturity

The digital maturity of enterprises in the European Union has been studied extensively because of its significant impact on the competitiveness, innovativeness, and resilience of Member State economies. According to the European Commission (2022), the digitalisation of business processes, namely the adoption of basic digital tools and e-business solutions, is widespread in most countries. Nevertheless, differences persist, particularly among smaller enterprises and in traditional sectors. Ferreira et al. (2019) identify basic digitalisation as an important foundation for innovation capacity. However, integrating digital tools does not automatically transform business models or improve performance; additional investment in competencies and organisational change is also required.

Advanced online activities, including cloud computing, e-commerce, and social media, alongside the adoption of disruptive technologies, represent the next stage of digital development and have a decisive impact on enterprises' international competitiveness, according to the Organisation for Economic Co-operation and Development (OECD, 2021). The OECD identifies these advanced technologies as indicators of digital transformation maturity because they enable innovative business models, integration into value chains, and faster responses to market change. However, the adoption of advanced online activities varies across countries and sectors. Bzhalava et al. (2022) found that insufficient digital skills, financial constraints, and uncertainty about data protection are the main reasons for slower adoption of such solutions. Infrastructure, particularly the availability of broadband networks and 5G technology, is another

important element of the digital transition, as it enables the reliable, fast, and stable communication required for more complex digital services. Olokundun et al. (2022) emphasise that introducing 5G networks can accelerate enterprises' digital transformation and enable new business models based on automation and real-time processing of large volumes of data. Their research nevertheless indicates that infrastructure investment alone is insufficient for intensive adoption of disruptive technologies if enterprises lack the internal capacities and competencies required to integrate such solutions. Pejić-Bach and Marić (2025) analyse the digital divide in the context of advanced technology adoption and emphasise the role of digital literacy, trust, and perceived risk in explaining differences between sectors and user groups. Their work conceptually explains why infrastructural and technical readiness does not lead to uniform maturity without appropriate competencies and institutional support.

Digital Economy and Society Index (DESI)

The Digital Economy and Society Index (DESI) is the European Commission's standard instrument for monitoring Member States' progress in digital transformation across the dimensions of connectivity, human capital, Internet use, digital public services, and integration of digital technologies. Bánhidi et al. (2020) conduct a multivariate analysis of these dimensions and show that DESI can identify stable patterns and country groupings. They conclude that individual dimensions contribute differently to overall development and that targeted, dimension-specific policies are more effective than universal approaches. Sevgi (2021) applies cluster analysis to DESI indicators and classifies countries into several groups according to digital performance, emphasising the relationship between the results, institutional characteristics, and differences among public policy regimes. Moraliyska (2024) confirms a pronounced digital divide within the European Union and links it to socioeconomic outcomes, showing that differences in digital inclusion correlate with disparities in productivity and innovation capacity. Using the latest DESI data, Obelovska et al. (2025) focus on digital skills and infrastructure, with particular emphasis on 5G. They show that infrastructure development must be accompanied by human capital development and propose methodological improvements to the index for more precise monitoring of emerging technologies.

Previous research shows that DESI is a valuable tool for measuring and comparing the digital development of European Union Member States, while also identifying limitations in its use. An increasing number of authors therefore apply additional analytical methods to obtain a clearer understanding of patterns and differences among countries. Cluster analysis is particularly prominent among these methods because it provides deeper insight into the dynamics of the digital divide.

Cluster analysis in measuring the digital divide

Cluster analysis is frequently used in digital maturity research because it enables countries to be grouped according to similarities in digital development indicators. This methodological approach reveals patterns that are not apparent from simple comparative statistics and facilitates the distinction between countries leading the

digital transition and those lagging. Dyba and Di Maria (2024) apply cluster analysis to segment countries by business digitalisation and the use of advanced technologies during a period of accelerated digitalisation. They find pronounced heterogeneity and a clear separation between groups adopting complex solutions more rapidly and groups retaining basic patterns of digitalisation. Huňady et al. (2024) confirm the usefulness of cluster analysis in a similar setting and show that combining indicators of business practices and infrastructure availability produces a more robust segmentation than reliance on individual indicators. The results of Sevgi (2021) and Moraliyska (2024) further support the suitability of cluster analysis for measuring and comparatively monitoring the digital divide at the country level, particularly when applied to standardised indicator sets. Based on these findings, the present study uses cluster analysis to identify groups of Member States with similar digital maturity profiles and to deepen understanding of the relationships among basic digitalisation, advanced online activities, and infrastructural prerequisites.

In view of the above, digital transformation clearly extends beyond the introduction of individual technologies. It is a multidimensional process in which the integration of basic digital tools, the adoption of advanced online activities, and infrastructure development complement one another and create distinctive patterns of digital development across European Union Member States. To provide a comprehensive understanding of digital development patterns in European Union economies and the relationships among the observed indicators, the study includes descriptive analysis and k-means clustering with an assessment of cluster validity. These procedures are described in greater detail in the following methodology section.

Methodology

This study uses publicly available European Commission data from the 2022 DESI. The analysis includes all European Union Member States for which data were available for all three indicators, resulting in a sample of 26 countries. The analysis is based on three indicators that quantify different aspects of the digital transformation of European enterprises. The first indicator, desi_dps_biz, refers to the level of business digitalisation, defined as the percentage of enterprises that use digital tools and processes. The second indicator, desi_2a2, covers advanced online activities, including cloud computing, e-commerce, and social media. In contrast, the third indicator, desi_5gcov, measures the availability of 5G infrastructure as a prerequisite for developing disruptive technologies. Data were collected for all European Union Member States with available values for all three indicators to ensure consistency and full comparability of the results.

The methodological procedure comprised three stages: descriptive statistics, analysis of relationships among variables, and cluster-based segmentation of Member States (Pejić Bach et al., 2022). The first stage involved descriptive statistical analysis, including calculating the arithmetic mean, minimum and maximum values, and standard deviation for each indicator. This provided a preliminary understanding of the data

distribution and identified variability among countries. In the second stage, Pearson correlation analysis assessed linear relationships among the indicators, with correlation coefficients interpreted according to generally accepted thresholds for weak, moderate, and strong relationships (Nieminen, 2022). In the third stage, k-means cluster analysis was used to group Member States into relatively homogeneous sets based on similarities in their levels of digital transformation and infrastructure readiness. This method enabled the identification of digital development patterns and clearer differentiation among countries sharing similar characteristics in basic digitalisation, advanced online activities, and 5G infrastructure. Before applying the algorithm, all variables were standardised using z-transformation to remove the influence of different measurement scales and ensure that each indicator contributed equally to the distance calculation. The number of clusters was determined using the elbow method, which analyses changes in within-cluster variance as the number of clusters increases successively. Three clusters were selected as optimal because further increases produced only a minimal reduction in model variance (Ketchen & Shook, 1996). The t-distributed Stochastic Neighbour Embedding (t-SNE) algorithm was used to visualise the resulting clusters by projecting multidimensional data into a two-dimensional space, thereby facilitating graphical presentation and interpretation of the groupings (van der Maaten & Hinton, 2008). Additional measures, including the Silhouette coefficient and Calinski-Harabasz index, were calculated to assess the cluster model's validity by examining the internal cohesion and separation of the resulting groups. Missing observations were removed before standardisation and clustering, thereby preserving the homogeneity and methodological consistency of the sample (Rousseeuw, 1987). Statistical data analysis and cluster analysis were performed in the R programming environment and in JASP. The results are presented in detail in the following section.

Results

The descriptive statistical analysis conducted for all European Union Member States in 2022 revealed pronounced differences in the level of business digitalisation, the use of advanced online activities, and the availability of 5G network infrastructure, as shown in Table 1. The mean value of the business digitalisation indicator (desi_dps_biz) was 83.73%, indicating a relatively high level of adoption of basic digital tools and processes by enterprises. However, the standard deviation of 20.21% and the range from 5.56% to 99.56% indicate substantial variability among countries: in some Member States, digital business solutions are nearly universal, while in others they have been implemented only to a limited extent. Advanced online activities (desi_2a2), including cloud computing, e-commerce, and social media, averaged 7.73%, with a standard deviation of 10.19%. This confirms that more advanced forms of digital transformation lag behind basic digitalisation and remain only modestly integrated into business processes in many Member States. The 5G infrastructure availability indicator (desi_5gcov) averaged 20.39%, with a minimum of 13.77% and a maximum of 99.72%.

This range and the standard deviation of 22.37% confirm pronounced heterogeneity in infrastructure readiness for the adoption of disruptive technologies.

Table 1
Descriptive statistics for the selected indicators in 2022

Indicator	Mean	Standard deviation	Minimum	Maximum
Business digitalisation (desi_dps_biz)	83,73	20,21	5,56	99,56
Advanced online activities (desi_2a2)	7,73	10,19	0,03	97,39
Availability of 5G infrastructure (desi_5gcov)	20,39	22,37	13,77	99,72

Source: Author's work

Pearson correlation analysis examined relationships among the analysed indicators, as shown in Table 2. The results indicated a weak negative relationship between business digitalisation and the adoption of advanced online activities (r = −0.35). Thus, countries in which a large proportion of enterprises use basic digital tools, such as e-invoices and integrated management systems, are not necessarily the same countries that lead in the use of advanced solutions such as cloud computing, e-commerce, or social media for business. The correlation between business digitalisation and 5G network coverage was very weak and negative (r = −0.08), suggesting that infrastructure alone is not yet strongly related to the extent of digital processes in enterprises. By contrast, the relationship between advanced online activities and 5G coverage was positive but weak (r = 0.08). Measures of internal cohesion and cluster separation were calculated to assess clustering quality. The average Silhouette coefficient for the three-cluster model was 0.54, indicating a satisfactory structure and moderate differentiation among the groups. Cluster-specific values ranged from 0.49 to 0.60, confirming that most countries were clearly classified, with only a few borderline cases. The Calinski-Harabasz index was 85.2, further confirming good separation and relatively low within-cluster variability.

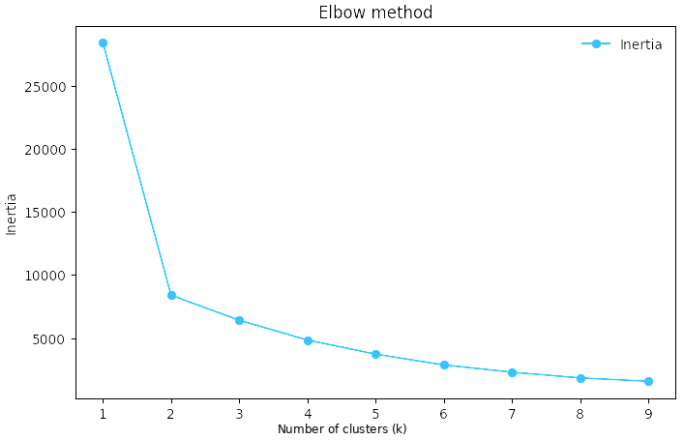
Table 2
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Indicators	Value
Correlation: business digitalisation – advanced online activities	−0.35
Correlation: business digitalisation – 5G coverage	−0.08
Correlation: advanced online activities – 5G coverage	0.08
Average Silhouette coefficient (k = 3)	0.54
Range of Silhouette coefficients by cluster	0.49–0.60
Calinski–Harabasz index	85.2

Source: Author's work

The elbow plot shows a sharp decrease in inertia up to the third cluster, after which further increases in the number of clusters yield only marginal improvements. This indicates that three is the optimal number of clusters because the curve becomes relatively flat after this point. Figure 1 presents the elbow method.

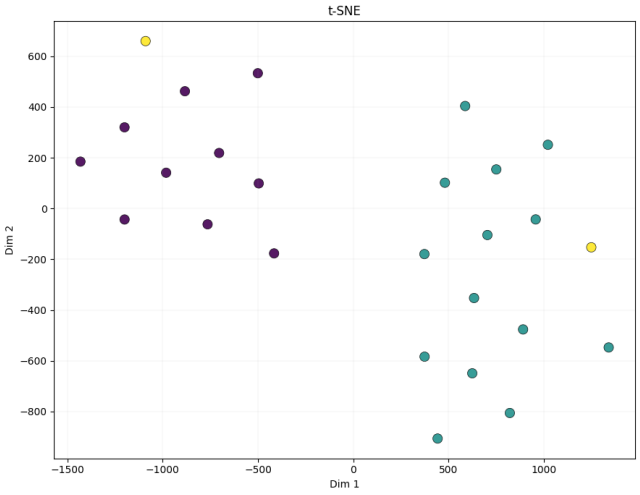
Figure 1
Elbow method



Source: Author's work

The t-SNE plot (Figure 2) reveals a three-part data structure, with the countries grouped into three clearly separated sets. This confirms that the selected number of clusters (three) is appropriate and that the two-dimensional visualisation effectively illustrates their differentiation.

Figure 2
t-SNE



Source: Author's work

Table 3 presents the mean values of each indicator by country, together with the cluster to which each country belongs. Cluster 1 includes countries with high business digitalisation and developed 5G infrastructure, but moderate adoption of advanced online activities. Cluster 2 comprises countries with average digitalisation, limited 5G availability, and a low level of complex digital business models. Cluster 3 stands out for a considerably higher proportion of advanced online activities compared with the other Member States. The cluster analysis thus indicates different dynamics of digital transformation and different priority areas for investment in digital capacity across European countries.

Table 3

Mean country values and corresponding clusters

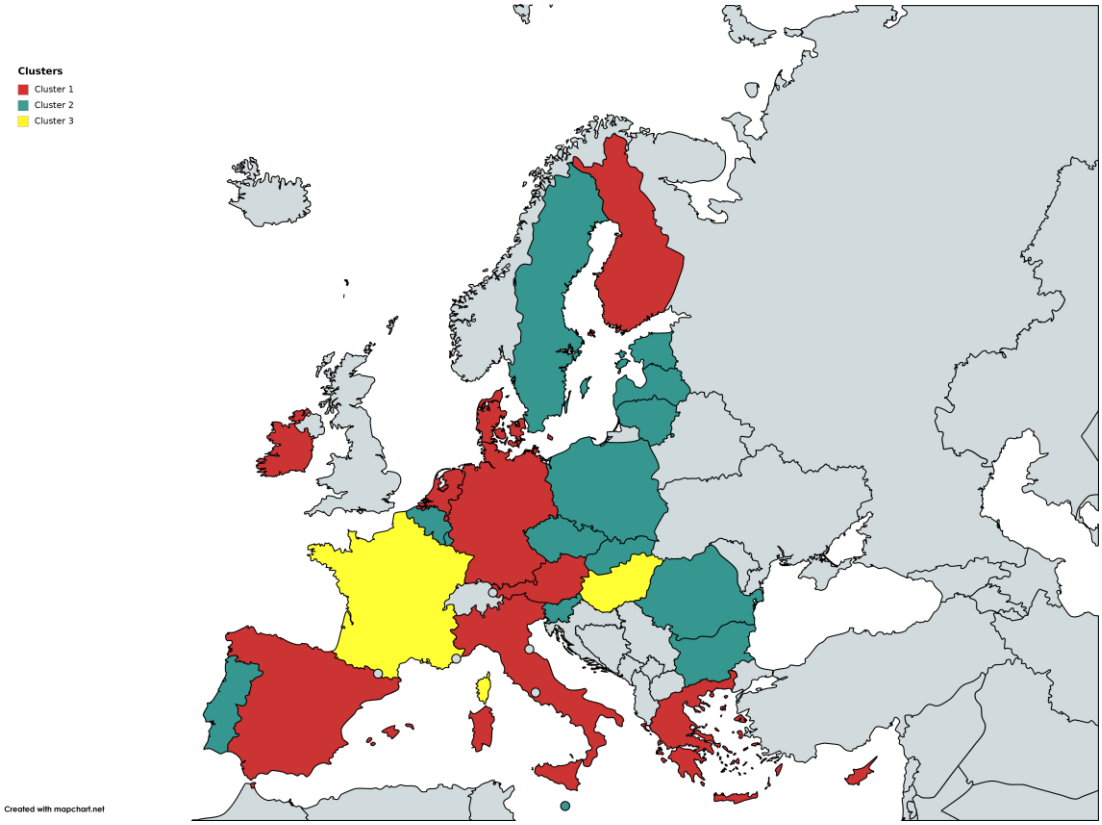
Country	Business digitalisation (%)	Advanced online activities (%)	5G coverage (%)	Cluster
Austria	86,37	18,00	76,80	**1**
Cyprus	87,94	0,27	74,96	**1**
Germany	83,17	1,98	86,51	**1**
Denmark	93,62	7,89	98,00	**1**
Greece	65,14	6,00	66,10	**1**
Spain	91,94	3,65	58,89	**1**
Finland	93,26	1,61	71,57	**1**
Netherlands	86,94	24,00	97,00	**1**
Ireland	99,56	3,88	72,10	**1**
Italy	82,59	6,18	99,72	**1**
Sweden	92,04	4,24	17,74	**2**
Romania	50,40	8,08	24,87	**2**
Portugal	85,75	2,22	25,20	**2**
Poland	73,75	1,77	34,25	**2**
Malta	96,81	3,31	20,00	**2**
Latvia	89,65	9,00	10,00	**2**
Slovakia	77,83	0,57	13,77	**2**
Lithuania	93,71	0,66	33,31	**2**
Slovenia	80,80	1,14	36,59	**2**
Estonia	97,39	0,03	18,32	**2**
Czechia	81,97	0,58	49,39	**2**
Bulgaria	87,42	0,43	40,09	**2**
Belgium	87,62	0,91	4,25	**2**
Luxembourg	94,93	3,23	12,69	**2**
France	83,36	33,35	74,41	**3**
Hungary	75,89	18,52	17,61	3

Source: Author's work

Figure 3 shows the distribution of European Union Member States across the three identified digital development clusters. Countries in Cluster 1 are shown in red and are characterised by a high level of basic digitalisation alongside limited adoption of advanced activities. Cluster 2 (green) comprises countries with lower 5G coverage and

average levels of digitalisation. Cluster 3 (yellow) includes countries that lead in the adoption of advanced digital tools, although they do not always possess the most developed infrastructure.

Figure 3
Clusters on geographical map



Source: Author's work

The findings confirm substantial differences in digital maturity among European Union countries, particularly in the relationship between basic digitalisation and the adoption of advanced solutions. The average level of business digitalisation is approximately 84%, whereas the use of advanced online activities is considerably lower, indicating an uneven digital development process. The findings partly align with Ferreira et al. (2019), who emphasise that adopting basic digital technologies improves operational efficiency but does not automatically ensure a transition to innovative business models. Dyba and Di Maria (2024) likewise note that many European countries continue to record modest results in adopting more complex solutions despite infrastructure investment, which is also reflected in the low average level of advanced activities found in this study. Huňady et al. (2024) show stable patterns in grouping countries with high levels of infrastructure and digital competencies alongside groups that lag; in the present cluster analysis, this distinction is most evident between Clusters 1 and 2. Bzhalava et al. (2022) also note that disruptive industries show more

dynamic growth in adopting advanced technologies. In contrast, traditional sectors adopt digital transformation more slowly, which may explain some of the heterogeneity observed in this study. The negative correlation between basic digitalisation and advanced activities ($r = -0.35$) is consistent with Olokundun et al. (2022), who concluded that even countries with developed 5G infrastructure require additional institutional support and stronger digital cultures to encourage the systematic use of new technologies.

Conclusion

The findings confirmed that the digital maturity of the business sector varies considerably across the European Union. Most countries have achieved a high level of basic business digitalisation (approximately 85% on average), while the adoption of advanced digital activities, cloud computing, and e-commerce remains limited, ranging from 0.03% to 33%. Furthermore, 5G coverage differs substantially, from complete availability to an almost complete absence of next-generation networks. Correlation analysis confirmed that high levels of basic digitalisation and developed infrastructure do not automatically lead to the broad adoption of advanced digital solutions. Cluster analysis identified three groups of countries: those with developed infrastructure and strong basic digitalisation but weaker adoption of advanced activities (e.g., Austria, Denmark, and Germany); those with average results and lower 5G availability (e.g., Belgium, Latvia, and Bulgaria); and countries such as France and Hungary that lead in the use of advanced digital tools despite more modest infrastructure.

This study contributes by integrating indicators of basic digitalisation, advanced online activities, and infrastructure availability into a single analytical framework. In this way, the paper builds on earlier studies that identified a digital divide among European Union Member States, while extending them through a cluster-based analysis of digital maturity patterns. The results are consistent with previous research emphasising barriers to the diffusion of advanced solutions, including insufficient digital skills and institutional constraints, and confirm the importance of advanced online activities for strengthening the international competitiveness of enterprises.

The practical implications primarily concern the design of public policies and support instruments for digital transformation. In countries with developed infrastructure but relatively limited use of advanced technologies, priority should be given to developing digital skills and strengthening confidence in the security of digital solutions. In countries that successfully develop advanced activities despite limited infrastructure, investment in network capacity should be intensified to ensure the sustainability and further development of the digital transition. The findings provide a clearer picture of the different development paths of Member States and the opportunities for targeted intervention, and may therefore inform more effective European and national policies. They also point to broader social benefits of digital transformation, including stronger competitiveness, greater innovation, and improved quality of life, thereby underlining the importance of a coordinated and inclusive approach to digital development.

The study's limitations stem from its focus on a single year and its use of aggregate data, which do not capture sectoral differences or trends over time. Future research should use longitudinal data as well as firm- and sector-level data, enabling more precise identification of the factors that drive the adoption of advanced digital technologies and providing more detailed insight into patterns of digital transition within the European Union.

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