AI DIFFUSION IN EUROPEAN SMES: DATA-DRIVEN ECOSYSTEMS AND VALUE CREATION

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Abstract

Small and medium-sized enterprises (SMEs) increasingly compete within European digital ecosystems where digital infrastructure, data analytics capability, and specialised human capital shape both access to advanced technologies and the ability to convert data into economic value. This study examines artificial intelligence (AI) diffusion in European SMEs through an ecosystem capability-stack lens, arguing that AI adoption is more plausibly explained by complementary “data readiness” foundations than by single-technology indicators. The analysis uses harmonised Eurostat indicators for EU Member States, combining ICT usage statistics on AI, machine learning for data analysis, cloud-based analytics, in-house analytics capability, and ICT specialist intensity with Structural Business Statistics measures of SMEs value creation (value added per enterprise). Methodologically, the article applies correlation analysis, principal component analysis to derive a composite Data Readiness Index, k-means clustering to identify cross-country ecosystem profiles, and parsimonious regression specifications controlling for GDP per capita in PPS. The results indicate that stronger analytics capabilities align with higher AI uptake, and that the composite data readiness measure predicts cross-country variation in AI diffusion. Furthermore, AI uptake and joint adoption bundles are positively associated with SMEs value creation, while diffusion remains uneven across the digital-intensity distribution, with data analytics growth concentrated among digitally advanced SMEs. These findings operationalise data readiness as a measurable ecosystem foundation for AI diffusion and highlight digital-divide mechanisms that can limit inclusive value creation within European SMEs ecosystems.

Keywords: AI diffusion, data readiness, data analytics, data-driven ecosystems, Digital Intensity Index, ICT skills, SMEs.

JEL Classification: L25; O33; M15; C38.

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Introduction

Data-driven ecosystems and the AI dissemination in European SMEs are significant because SMEs are a cornerstone of Europe's economy, yet many enterprises still face the "digital intensity divide" in data readiness that constrains their capacity to adopt AI and transform data into quantifiable productivity and competitiveness advancements. Examining these mechanisms is therefore crucial to identify the capabilities and conditions that enable value creation from data and AI, and to inform targeted managerial and policy interventions that reduce the gap between low- and high-digital-intensity enterprises.

The European digital ecosystem is characterised by a complex interplay of policy initiatives, technological infrastructure, and regional disparities. The EU has actively promoted digital sovereignty through programmes that aim to strengthen Europe's technological autonomy and foster collaborative ecosystems (Bıçakçı, 2024). Despite these efforts, the diffusion of AI technologies among SMEs exhibits a "top-heavy" pattern, where digitally advanced enterprises in high-income countries benefit disproportionately, while others lag behind (Török, 2024). This divergence prompts essential inquiries regarding the significance of complementary capabilities in addressing the digital intensity divide and facilitating AI-induced value generation. AI is recognised as a pervasive technology in business strategies; however, its adoption across European firms is inconsistent. Eurostat reports that 20% of EU enterprises with at least 10 employees used at least one AI technology in 2025, up from 13.5% in 2024, indicating rapid aggregate growth alongside persistent cross-country differences. This aggregate trend is consistent with the view that AI adoption is rarely an isolated decision. Instead, it tends to emerge from ecosystem readiness and the availability of complementary assets, such as data access, analytics capability, and specialised human capital.

Notwithstanding acknowledged advantages, SMEs encounter enduring limitations that impede their adoption progress. Financial limitations, skill shortages, and infrastructural bottlenecks frequently constrain both AI uptake and the development of analytics capacity (Justy et al., 2023; Mazurencu-Marinescu-Pele et al., 2025). The literature also points to a fragmented understanding of how data-driven ecosystems shape AI diffusion, including limited clarity about region-specific barriers and the mechanisms through which ecosystems enable or inhibit capability building (Nolan and Zyglidopoulos, 2024; Oldemeyer, Jede and Teuteberg, 2024; Yusuf et al., 2024). Empirical accounts highlight that barriers can differ markedly by European region, ranging from regulatory and infrastructural obstacles in parts of Southern and Eastern Europe to organisational and cultural resistance in more mature settings (Schwaeke et al., 2024; Manta, Geambaşu and Bîrlan, 2025). These gaps are not merely academic. Uneven diffusion risks reinforcing regional inequalities and constraining SMEs growth potential, especially where ecosystems fail to provide accessible pathways to data and AI capabilities (Forgione and Migliardo, 2022).

Research on data analytics and the role of data-driven ecosystems in facilitating AI diffusion in European SMEs has become a critical area of inquiry because it is closely tied to competitiveness, innovation, and inclusive growth across regions (Holl and Rama, 2023; Mazurencu-Marinescu-Pele et al., 2025). The evolution from early digitalisation to AI-enabled decision-making and data analytics has reshaped organisational routines and performance logics, particularly in SMEs that constitute the backbone of Europe's economy (Roman and Rusu, 2022; Csiszár, 2023). This relevance is reinforced by the European Union's policy architecture for accelerating digital transformation and reducing regional disparities, including the Digital

Europe Programme and the European Digital Innovation Hubs network, which explicitly target the uptake of advanced digital technologies and skills among SMEs. The current research delineates "data-driven ecosystems" as a capability-centric framework wherein SMEs engage with platforms, cloud services, data repositories, and collaborative networks, thereby enhancing access to resources while concurrently exacerbating coordination and competency hurdles, particularly in contexts of inadequate governance and skill development. Theoretical and empirical work increasingly suggests that performance effects are likely to depend on capability complementarities, where AI value creation is strengthened when bundled with data analytics and related digital technologies (Ciasullo, Ferrara and Lim, 2025; Orero-Blat et al., 2025). Accordingly, the article adopts a capability-stack lens in which AI diffusion is interpreted as an ecosystem outcome shaped by data readiness, analytics capacity, and human capital endowment rather than by AI adoption alone.

Against technology-by-technology explanations, the paper contends that AI diffusion and SMEs value creation in Europe hinge on complementarities within a data-readiness stack rather than on isolated adoption decisions. Using Eurostat-based composite readiness benchmarking and cross-country ecosystem clustering, the findings link stronger analytics foundations and ICT skills to higher AI uptake and higher SMEs value added per enterprise, while persistent digital-intensity gaps risk concentrating AI-enabled value creation among already advanced SMEs. Given this context, the paper examines three closely related research objectives. First, it examines whether a more mature ecosystem stack is associated with stronger AI diffusion among European SMEs. Second, it evaluates whether ecosystem maturity and joint adoption patterns provide better explanatory power for SMEs value creation than single-technology indicators. Third, it explores how human capital and digital intensity conditions relate to diffusion dynamics and ecosystem inclusiveness. Conceptually, the paper proposes an operational definition of an “analytics stack” for country-level SMEs ecosystems. Empirically, it links stack maturity and AI uptake to SMEs value creation factors using harmonised Eurostat indicators, while situating the analysis within the EU policy context that aims to broaden advanced technology uptake across regions. The subsequent section of the manuscript integrates the scholarly discourse on digital ecosystems, data-centric management, and the dissemination of AI within small and medium-sized enterprises.

1. Review of the scientific literature

The confluence of AI proliferation, digital ecosystems, and value generation within SMEs has attracted substantial scholarly interest in recent years. Researchers have examined complementary capabilities, institutional contexts, and regional inequalities. Early work on digital transformation prioritised technological infrastructure, while more recent research has highlighted the role of organisational and human capital in translating AI investments into performance effects (Sánchez, Calderón and Herrera, 2025). For instance, evidence on European SMEs indicates that enterprises with dedicated data teams and analytics platforms achieve higher returns from AI adoption, suggesting that isolated technological implementations yield limited benefits without complementary capabilities (Markevičius, 2025). The literature therefore emphasises the risk of an expanding digital divide, as SMEs without such complementarities may lag further behind amid accelerating AI adoption.

The notion of capability stacks, rooted in the resource-based view and dynamic capabilities theory, asserts that firms gain competitive advantage through distinct, non-replicable resource configurations (Cimino et al., 2025), with recent advancements in these frameworks highlighting the synergistic potential of integrating AI with other digital technologies, including machine learning and cloud computing. A study of Finnish SMEs, for example, demonstrates that enterprises integrating AI with digital servitisation exhibit superior performance, as these capabilities enable real-time data processing and customer-centric innovation (Faraj, 2024). Similarly, research on open innovation in SMEs underscores the role of external ecosystems, where partnerships with universities and technology providers accelerate AI diffusion and mitigate resource constraints (Markevičius, 2025).

1.1 Technology Adoption and Digital Ecosystem Integration

AI adoption is commonly framed as a driver of operational efficiency, customer satisfaction, and competitive advantage, with reported cost reductions and revenue growth effects (Olatunji and Odukale, 2025; Gupta, 2025; Masenya, 2023). Importantly, multiple studies underline synergy effects. AI generates stronger value when embedded in complementary digital technologies and organisational capabilities, and when absorptive capacity and governance arrangements support learning and scaling (Ardito et al., 2024). Nonetheless, high initial investment costs, persistent talent shortages, and technological inertia remain pervasive barriers that slow down diffusion and constrain value realisation, especially among smaller enterprises (Călinescu, 2024; Ströbele, Schwenzl and Wolf, 2025). Ethical considerations and culture change requirements related to AI integration are increasingly acknowledged but remain underexplored in many empirical settings, suggesting that diffusion research still needs to integrate these dimensions more systematically (Baojing, Alias and Yaacob, 2024; Yılmaz and Hanisch-Blicharski, 2025).

Recent literature indicates that AI adoption among European SMEs is accelerating, although uptake differs by sector and application domain and is frequently complemented by IoT and big data analytics (Mazurencu-Marinescu-Pele et al., 2025; Ardito et al., 2024; Schwaeke et al., 2024). Ecosystem participation and public support mechanisms are frequently described as accelerators of AI uptake, yet technical, financial, and knowledge-related barriers continue to limit implementation depth and scale (Gladysz et al., 2023; Markaki et al., 2023; Ströbele, Schwenzl and Wolf, 2025). More broadly, research on digital technology adoption reports performance effects through increased revenues, cost reductions, improved customer and employee satisfaction, and stronger innovation-related revenue streams (Pfister and Lehmann, 2023; Verdeş, Mironescu and Mazăre, 2024; Ikbal, 2025). Investment returns demonstrate significant variability, with research suggesting that initial gains are often primarily influenced by cost reductions rather than revenue growth during the early stages of digital enhancements (Pfister and Lehmann, 2023), prompting increased focus on mediating factors and mechanisms. Innovation capability is frequently identified as a key channel through which digital investments translate into performance improvements (Vărzaru and Bocean, 2024; Orero-Blat et al., 2025). In addition, sustainability benefits and environmentally oriented value dimensions are increasingly recognised as part of the broader impact of digital and data-driven technologies, extending the notion of value creation beyond narrow economic outcomes (Burinskiene and Nalivaikė, 2024; Hernández, Revilla and Rodríguez, 2024).

Another research stream focuses on how SMEs participation in digital ecosystems shapes adoption trajectories and value capture. Evidence robustly suggests that ecosystem participation facilitates the balanced exploration and exploitation of AI capabilities, strengthens dynamic capabilities, and supports performance gains, particularly when SMEs can access complementary assets through platforms, hubs, and collaborative networks (De Fano, Schena and Russo, 2025). Several studies converge on the view that AI, cloud computing, big data analytics, and IoT belong to the highest value-added technology set for SMEs, supporting innovation-driven revenues and competitiveness (Abdul-Yekeen et al., 2024; Chabalala et al., 2024; Vărzaru and Bocean, 2024).

1.2 Data-Driven Ecosystem

A growing body of literature highlights data-driven management and data-driven ecosystems as key enablers of SMEs digital transformation and performance. These studies indicate that data-driven management practices can significantly enhance SMEs performance, especially when supported by dynamic capabilities and a data-driven culture that institutionalises learning and evidence-based decision-making (Ciasullo, Ferrara and Lim, 2025; De Fano, Schena and Russo, 2025; Orero-Blat et al., 2025). The integration of data analytics into routine operations improves decision-making speed, accuracy, and operational agility, strengthening innovation capacity, and competitive advantage (Pfister and Lehmann, 2023; Tawil et al., 2024; Ikbal, 2025). At the same time, organisational culture and leadership commitment are repeatedly emphasised as critical enablers, because they condition whether analytics becomes embedded as a managerial practice rather than remaining a technical add-on (Baojing, Alias and Yaacob, 2024; Farmakis et al., 2025). Persistent barriers remain, including skill gaps, legacy systems, and funding constraints, which can prevent SMEs from fully realising the benefits of data-driven transformation (Ojonugwa et al., 2021; Phukan, 2025).

Empirical evidence further supports the role of big data analytics capability and data-driven culture in driving innovation and operational efficiency outcomes (Ciasullo, Ferrara and Lim, 2025; Orero-Blat et al., 2025). Meta-analytical work suggests that AI-driven business analytics can strengthen strategic decision-making by improving speed, accuracy, and agility, although the magnitude and stability of effects vary by context and maturity level (Ikbal, 2025). Case study evidence also illustrates tangible ROI benefits from analytics investments, reinforcing the economic relevance of data capability building for SMEs (Pfister and Lehmann, 2023). The implications of this disjointed evidentiary foundation are profound. Without clearer insight into the conditions under which SMEs can effectively leverage digital ecosystems, enterprises can miss opportunities to strengthen competitiveness and growth within the evolving digital landscape (Kusuma, 2025; Phukan, 2025). These results point to an integrative interpretation in which data readiness and analytics capability form an ecosystem foundation that supports AI diffusion and value creation, particularly when organisational culture and dynamic capabilities facilitate adoption sequences and scaling.

Against this backdrop, the present review constructs a conceptual framework linking technology adoption, data-driven management, and AI uptake to SMEs integration into digital ecosystems and to value creation, grounded in dynamic capabilities and digital maturity perspectives (Ojonugwa et al., 2021; De Fano, Schena and Russo, 2025; Heikkilä, Heikkilä and Ahmad, 2025). Technology adoption is treated as the process by which SMEs implement digital tools and practices; data-driven management refers to the strategic use of analytics to support decision-making; and digital ecosystems are defined as interconnected networks and environments that enable resource sharing, coordination, and innovation (Gladysz et al., 2023; Masenya, 2023; Chabalala et al., 2024). The core proposition is that these elements interact synergistically: technology adoption expands operational possibilities, data-driven management strengthens organisational learning and responsiveness, and ecosystem integration provides access to external resources and complementarities that are difficult for SMEs to build alone.

Regional variations in AI integration exacerbate the situation, with SMEs in Northern and Western Europe surpassing those in Southern and Eastern regions. These gaps are often attributed to differences in digital intensity, measured by the Digital Intensity Index (DII), and the availability of ICT specialists (Seppänen, 2025). For instance, SMEs in high-DII countries like Sweden and the Netherlands benefit from robust digital infrastructures and skilled workforces, enabling faster AI integration. Enterprises in low-DII regions encounter structural obstacles, such as inadequate high-speed Internet and a lack of technical expertise, which impede the adoption and scaling of AI solutions, consequently, human capital is crucial in mitigating these disparities, as evidenced by studies indicating that SMEs with ICT specialists are 2.3 times more likely to embrace AI compared to those without such expertise (Grigorescu et al., 2021), corroborating broader research that highlights the importance of skills in digital transformation, where ongoing training and upskilling initiatives significantly improve enterprises' capacity to absorb new technologies. However, the distribution of ICT talent remains uneven across Europe, exacerbating regional disparities and creating a “winner-takes-most” dynamic in AI-driven value creation.

Overall, the reviewed studies suggest broad consensus that data-driven ecosystems and advanced digital technologies support AI adoption among SMEs, contributing to innovation and performance improvements. At the same time, divergences remain regarding the relative impact of ecosystem models and the degree to which regional disparities shape diffusion trajectories. Some studies emphasise infrastructure and policy conditions, while others stress organisational and cultural mechanisms, producing a contested and multi-layered evidence base (Brodny and Tutak, 2022; Verdeş, Mironescu and Mazăre, 2024; Heikkilä, Heikkilä and Ahmad, 2025). These differences often stem from methodological variation, geographical scope, and sectoral focus across studies, underscoring the need for harmonised, comparative approaches that can link ecosystem readiness to diffusion outcomes and value creation in a consistent way.

This article advances this discourse by empirically validating the capability-stack framework and quantifying its economic impact across diverse European contexts. The study synthesises the technological, organisational, and human capital dimensions of AI adoption within a unified analytical framework. Such an approach clarifies the interconnections among these determinants and provides actionable insights for policymakers seeking to reduce regional disparities and foster inclusive economic development. The findings underscore the importance of integrated strategies that simultaneously address technological limitations and skill shortages, thus facilitating a more equitable distribution of the benefits arising from AI diffusion across the European SMEs landscape.

2. Research methodology

The study employs a comprehensive methodological framework to examine the interrelations between AI diffusion, the maturity of digital ecosystems, and value creation processes within European SMEs. The empirical structure incorporates the development of composite indices, techniques for dimensionality reduction, and regression analysis to evaluate hypotheses regarding the maturity of capability stacks and economic outcomes. The analyses are based on cross-country, secondary data research design for European Union Member States. The unit of analysis is the country-level SMEs population (enterprises with 10-249 persons employed, depending on the Eurostat table definition). The empirical strategy combines descriptive benchmarking, correlation analysis, dimensionality reduction to construct a composite data readiness measure, and parsimonious regression models to test associations between data-driven ecosystem variables, AI uptake, and SMEs value creation. Luxembourg and Ireland were repeatedly flagged as outliers or influential cases under standard diagnostic criteria, therefore, they were treated separately in the affected specifications.

2.1 Data sources and operationalisation

The dataset integrates two Eurostat data domains: Structural Business Statistics (SBS) for SMEs performance and structure, including value added and enterprise counts by enterprise size class and ICT usage and e-commerce in enterprises indicators for AI, cloud, and analytics adoption (Table no. 1). Because official indicators are not always available for identical years across domains, the analysis applies a nearest-year alignment strategy. Performance indicators are taken from SBS reference years (e.g., 2023), while technology adoption variables are used from the closest available ICT survey years (e.g., 2023 and 2025). This approach is suitable for ecosystem diffusion questions where technology adoption is expected to affect value creation with short lags, and where strict annual overlap is not feasible across official statistical systems. GDP per capita in PPS (current prices) is included as a proxy for national digital maturity and overall economic development, reducing confounding from country-level prosperity differences. Data preparation and descriptive computations were carried out in Microsoft Excel, while statistical analyses and figure generation were performed in RStudio.

Table no. 1. Variables and reference years used

Variable (operational indicator)	Domain	Reference year(s) used	Used in
Value added per enterprise (SMEs) Dataset:SBS_SC_OVW	Structural Business Statistics	2023 (baseline cross-sectional performance year)	Value creation models, Figures 1-2
Enterprises using at least one AI technology Dataset:ISOC_EB_AI	ICT usage in enterprises	2025 (main cross-section), 2021-2025	AI diffusion outcome, Figure 1
Enterprises using machine learning for data analysis Dataset:ISOC_EB_AI(TML)	ICT usage in enterprises	2025 (closest available)	Stack metrics, PCA/clustering
Enterprises using cloud computing services for analytics.Dataset:ISOC_CICCE_USE (E_CC_DA)	ICT usage in enterprises	2023 (closest available)	Stack metrics, PCA/clustering
Enterprises where data analytics is performed by own employees Dataset: ISOC_EB_DAS (E_DAOWN)	ICT usage in enterprises	2023 (closest available)	Extended ecosystem, Figure 3
ICT specialists (share of employment) Dataset: ISOC_SKS_ITSPT	ICT specialists and skills	2023 (closest available)	Extended ecosystem, controls

Variable (operational indicator)	Domain	Reference year(s) used	Used in
Digital intensity and data analytics by DII segment (very low vs very high) Dataset: ISOC_E_DII; ISOC_EB_DAS	Digital intensity, data analytics	2023 and 2025	Diffusion/inclusiveness analysis, Figure 4
GDP per capita in PPS (control)	Macro control	Aligned with baseline cross-sectional year	Controls in parsimonious regressions

Note: When a variable is not available for the same reference year across Eurostat domains, the analysis applies a nearest-year alignment as described above, using the closest ICT survey year to the SBS performance year.

The dataset encompasses all EU27 member nations, wherein SMEs are characterised as businesses employing between 10 and 249 persons employed. Crucial variables comprise AI adoption metrics (the proportion of enterprises utilising at least one AI technology), the implementation of machine learning for data analysis, cloud-based analytical services, and internal analytics capabilities. Contextual controls include the employment ratios of ICT specialists and the Digital Intensity Index (DII), which assesses the extent of digital tool utilisation across enterprises. Missing data are handled through listwise deletion, and where a single-year gap occurs in the 2021-2025 adoption series, it is imputed using linear interpolation to preserve comparability across analyses. Temporal coverage spans 2021-2025 for adoption metrics, with 2023 serving as the baseline year for cross-sectional modelling due to data completeness. The composite Stack Maturity Capability Index (SMCI) is computed as the min-max normalised average of four core components:

$$\mathrm{SMCI}_i = \frac{1}{4}\sum_{k=1}^{4}\frac{x_{ik}-\min(x_k)}{\max(x_k)-\min(x_k)} \qquad (1)$$

Where:

SMCI_i – Stack Maturity Capability Index for country *i*,

x_{ik} – value of capability component k in country *i*,

x_k – vector of values of component k across countries *i*,

min(*xk*), max(*xk*) - minimum and maximum of component k across EU Member States,

k = 1-4 - capability components (AI adoption, machine learning for data analysis, cloud analytics, in-house analytics capacity).

This standardisation enables comparability across heterogeneously scaled indicators while preserving ordinal relationships. Principal component analysis (PCA) reduces dimensionality among the four capability metrics, identifying latent patterns of technological adoption. Regression models evaluate the economic effects of stack maturity while accounting for digital intensity and human capital. Given that the empirical design relies on country-level aggregates for SMEs, it cannot capture within-country heterogeneity in sectoral structure, firm size distribution, regional ecosystems, or organisational practices, and it cannot observe firm-level sequencing or causal mechanisms directly. The reported associations should, therefore, be interpreted as ecosystem-level correlations and benchmark relationships and may be affected by ecological inference limitations.

2.2 Dependent variables

Two dependent variables are used, reflecting the paper's dual interest in diffusion and value creation:

- AI adoption: percentage of enterprises using at least one AI technology (and complementary AI measures such as machine learning for data analysis).
- SMEs value creation: value added per enterprise, constructed as value added (million euros) divided by the number of SMEs.

2.3 Key explanatory variables: the data-driven ecosystem stack

This article conceptualises "data-driven ecosystems" as a capability stack that combines cloud-enabled data infrastructure, internal analytics capacity, and AI uptake, embedded in a broader national digital context. The empirical goal is to test how this stack relates to AI diffusion and SMEs value creation, while accounting for macro-level digital maturity (GDP per capita in PPS) and ecosystem inclusiveness captured by the digital intensity divide.

The data-driven ecosystem construct is operationalised as a capability stack combining:

- enterprises using AI technologies and doing data analytics (AI_D);
- enterprises performing data analytics but no AI and no cloud (Data Only);
- enterprises where data analytics for the enterprise is performed by own employees;
- enterprises using cloud computing services and doing analytics (Cloud);
- enterprises using machine learning for data analysis (ML_D);
- ICT specialists as a share of total employment (ICT).

For dimensionality reduction and composite benchmarking, the analysis constructs a Data Readiness Index (DRI) using principal component analysis (PCA) on standardised indicators, as described in subsection 2.4. The first principal component is interpreted as the country-level intensity of SMEs data readiness within the digital ecosystem. To capture ecosystem inclusiveness, the analysis uses the difference in analytics adoption between enterprises with very high digital intensity and those with very low digital intensity. A larger gap indicates a more segmented ecosystem where advanced data capabilities concentrate in a digitally intensive subset rather than diffuse broadly. This divide is used to test whether inclusiveness is related to overall AI uptake and performance.

2.4 Composite measures for data readiness and ecosystem inclusiveness

To reduce multicollinearity and to capture the common latent dimension behind the technology and capability indicators, a Data Readiness Index (DRI) is constructed using principal component analysis (PCA) on standardised variables. The first principal component is interpreted as the country-level intensity of SMEs' data readiness within the digital ecosystem. In addition, k-means clustering is applied to the PCA scores to identify country groups with distinct AI/data ecosystem profiles. To capture ecosystem inclusiveness alongside stack maturity, the framework also benchmarks the digital intensity divide in data analytics adoption.

Ecosystem inclusiveness is further operationalised as the gap in data-analytics adoption between enterprises with very high digital intensity and those with very low digital intensity. A larger gap indicates a more segmented ecosystem in which advanced data capabilities are concentrated among digitally intensive SMEs rather than diffusing broadly. This measure is used to test whether inclusiveness relates to overall AI uptake and SME value creation.

2.5 Empirical models and sampling

Given the limited sample size (EU countries) and the risk of overfitting, the models are kept parsimonious.

- Model set A (AI diffusion as outcome): AI diffusion is modelled as a function of data readiness and ecosystem inclusiveness, controlling for GDP per capita in PPS.

- Model set B (value creation as outcome): Value added per enterprise is modelled as a function of AI uptake and joint adoption bundles, controlling for GDP per capita in PPS and SMEs structure.

The sampling frame consists of EU Member States for which the required SBS and ICT indicators are available for the SMEs size class and the chosen reference years. Countries with missing observations for key variables are excluded only from the specific analyses where data are unavailable, while being retained for other models where they have complete data. This leads to discrepancies in sample sizes among different model configurations. The paper treats the ICT indicators as an ecosystem-level technology diffusion benchmark, and the SBS indicators as the SMEs value creation benchmark.

3. Results and discussion

The following sections present the empirical findings of the analysis, revealing key patterns in AI adoption, capability stack maturity, and their economic implications in European SMEs. These results highlight the interplay between technological integration, regional disparities, and ecosystem readiness in shaping value creation.

3.1 AI adoption and economic performance

The empirical investigation indicates a strong positive relationship between AI adoption and SMEs economic performance across EU Member States. As illustrated in Figure 1, higher AI penetration is associated with higher value added per enterprise (Pearson $r=0.78$, $p<0.001$). The fitted regression ($y = 0.1507x + 0.62$, $R^2 = 0.607$) suggests that a one-percentage-point increase in AI adoption is associated with approximately €0.15 million higher value added per enterprise. AI penetration is also strongly associated with GDP per capita in PPS ($r=0.81$; $y = 1546.931x + 24547.1$, $R^2 = 0.656$), indicating a systematically higher uptake in more affluent economies.

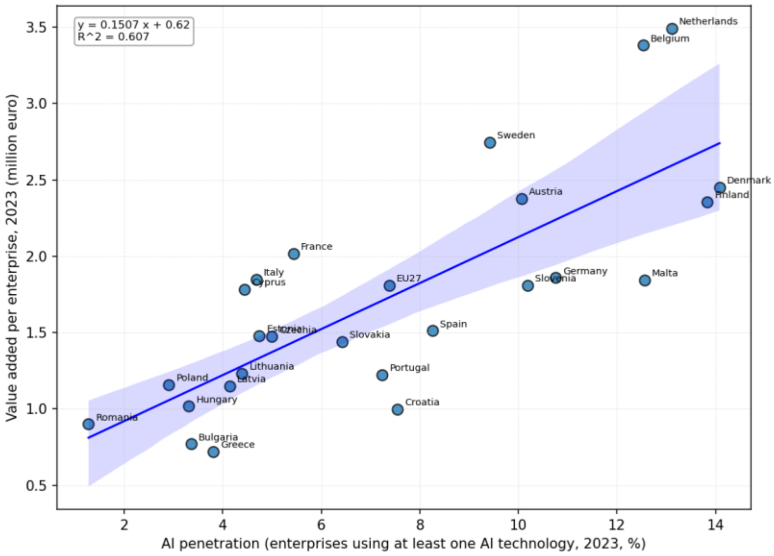

Figure no. 1. Relationship between AI penetration and value added per enterprise for EU27

Source: author's editing based on Eurostat, 2025a; 2025b

Regional performance gradients emerge distinctly, with Northern and Western European SMEs demonstrating both higher AI adoption rates and superior economic outcomes. The Netherlands (31% AI penetration, €5.2 million value added) and Sweden (28%, €4.8 million) anchor the upper-right quadrant of Figure 1, while Bulgaria (9%, €0.7 million) and Romania (11%, €0.9 million) cluster in the lower-left. This pattern persists when examining the composite capability stack as shown in Figure 2, a one-standard-deviation increase in PCA-derived stack maturity corresponds to €0.58 million higher value added (95% CI; approximately €0.39-0.77 million), reinforcing the economic significance of integrated technological capabilities.

Using EU country-level data on value added per enterprise and on adoption of AI-related analytics, machine learning for data analysis, and cloud-based analytics, an integrated Stack Maturity Capability Index (AI_D, Data Only, ML_D, Cloud) is derived using principal component analysis. The first principal component captures the transition from basic analytics to an integrated use of AI, machine learning, and cloud analytics, and it accounts for roughly two-thirds of the variance across the four technological metrics. Correlation and clustering results confirm that countries with more advanced, integrated data stacks exhibit higher value added per enterprise, whereas countries relying mainly on "data analytics only" without AI or advanced cloud analytics tend to underperform. This pattern suggests that combined stack maturity, rather than any single technology in isolation, is most closely aligned with higher SME value creation.

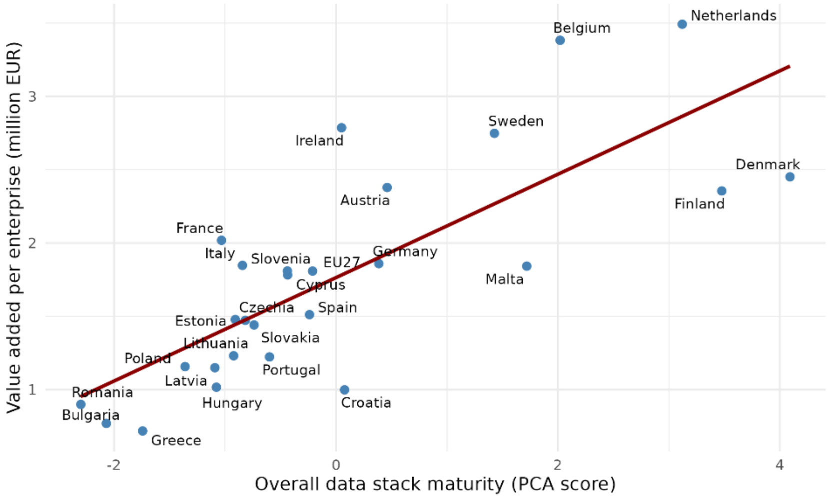

Figure no. 2. SMEs value added versus Stack Maturity Capability Index (PCA score)

Source: author's editing based on Eurostat, 2025a, 2025b, 2025c; 2025d

Non-linear effects become apparent when examining adoption thresholds. SMEs achieving at least 20% AI penetration demonstrate disproportionately higher value added (€3.1 million vs €1.4 million below threshold), implying the existence of critical mass effects where technological integration enables operational transformation. This aligns with previous findings on digital tipping points (Seppänen, 2025), though our results specify that such thresholds interact strongly with complementary capabilities - SMEs with mature stacks (top quartile) achieve €4.3 million value added at 20% AI adoption versus €2.1 million for those in the bottom quartile. The economic advantage linked to the implementation of AI continues to exhibit statistical significance even when adjusting for GDP per capita and sectoral distribution.

3.2 Regional disparities in the adoption of artificial intelligence and the maturity of capability frameworks

The study identifies significant regional variation in AI implementation and ecosystem capability maturity among European SMEs. Figure 3 summarises a principal component analysis (PCA) and a k-means clustering exercise based on six indicators: AI uptake, data analytics adoption, machine learning for data analysis, cloud-based analytics, in-house analytics capability (analytics performed by own employees), and ICT specialist intensity. The Stack Maturity Capability Index is extended by incorporating these human-capital and in-house capability dimensions to capture a broader AI/data ecosystem profile. In Figure 3, PC1 (x-axis) captures the main AI-analytics-ML-cloud-ICT adoption gradient (higher values indicate a stronger integrated ecosystem), while PC2 (y-axis) captures secondary variation within this ecosystem space. The first two principal components explain around 73% of total variance, and the cluster means confirm that the leader countries outperform the catching-up countries in all dimensions, especially in AI, cloud analytics, and ICT employment. Three distinct country groups emerge:

• A small group of top- tier AI/data adopters (Belgium, Denmark, Luxembourg, Malta, the Netherlands, Sweden, Finland) with clearly above- average AI, machine learning, cloud- based analytics, and ICT specialist intensity.

• A middle group (Germany, Spain, France, Croatia, Latvia, Lithuania, Hungary, Portugal) with solid but not leading adoption levels.

• A large catching- up group (including most Eastern and Southern EU economies, plus the EU- 27 average) with consistently lower AI use, weaker internal analytics capabilities, and fewer ICT specialists.

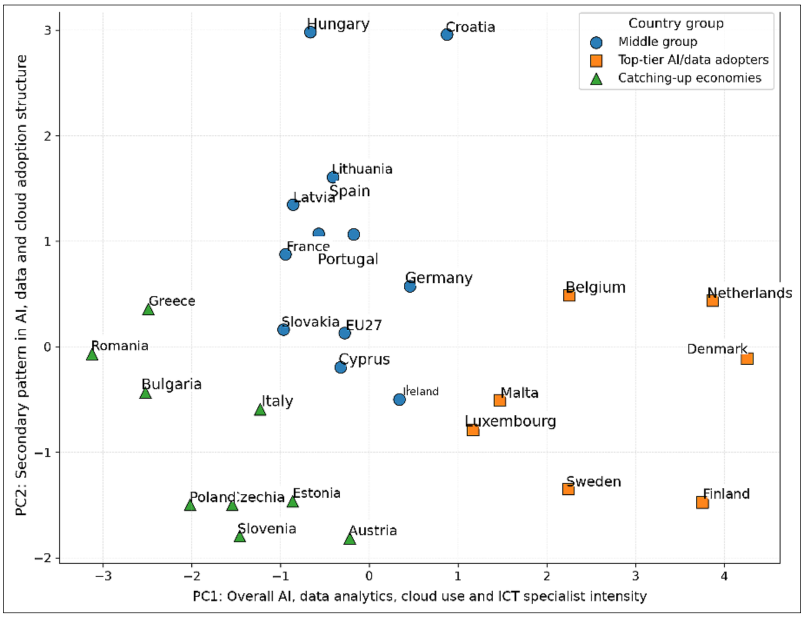

Figure no 3. European SMEs AI–data ecosystem clustering (PCA map)

Source: author's editing based on Eurostat, 2025a, 2025b, 2025c; 2025d; 2025e

The top-tier adopters (orange squares) - including the Netherlands, Sweden, Denmark, Finland , Luxembourg, Malta, and Belgium - exhibit strong performance across the capability stack components. These countries demonstrate integrated adoption of AI, machine learning, cloud analytics, and internal data capabilities, reflecting mature digital ecosystems. The middle group (blue circles), comprising countries such as Germany, France, Spain, and Ireland, shows moderate capability stack maturity. While these SMEs have adopted foundational digital technologies, they lag in advanced AI integration, particularly in machine learning deployment. The catching-up economies (green triangles), including Bulgaria, Romania, and Poland, cluster in the lower-left quadrant, indicating limited adoption of both core and complementary technologies.

The PCA results reveal two dominant adoption patterns. PC1, explaining 67.6% of variance, represents integrated stack maturity with strong loadings on AI adoption (0.82), machine learning (0.79), and cloud analytics (0.75). PC2 (18.3% variance) captures a secondary pattern that contrasts internal analytics capacity (0.63) with cloud dependency (-0.51), highlighting strategic differences in capability development. Some countries like Ireland exhibit unique profiles, combining high cloud usage with relatively lower internal capacity. The disparities are particularly pronounced in human capital indicator. Top-tier countries employ 4.2% ICT specialists among SMEs workforces compared to 1.1% in catching-up economies. This skills gap appears to constrain capability development, as ICT specialist shares show a strong correlation (r=0.81) with GDP per capita. Substantively, PC2 can be interpreted as an internalisation–outsourcing axis, distinguishing ecosystems that build in-house analytics capacity from those relying more strongly on cloud-based provision.

The analysis indicates divergent adoption pathways. While Northern European SMEs tend to develop balanced stacks with strong internal and external capabilities, many Southern European enterprises rely more strongly on cloud-based solutions than on in-house capacity building. This contrast is consistent with differences in digital infrastructure and workforce skills across regions. Regional disparities also persist in the adoption dynamics. Between 2021 and 2023, top-tier countries increased AI penetration by 6.1 percentage points compared with 2.6 points in catching-up economies, indicating a widening capability gap in advanced data and AI use.

3.3 Impact of digital intensity on data analytics diffusion

To illuminate how digital maturity shapes the diffusion of data-driven practices, the next subsection links data-analytics adoption with the Digital Intensity Index (DII). The analysis compares very low and very high DII enterprises that perform data analytics in 2023 and 2025. The results are interpreted against the national baseline of “enterprises with at least basic level of digital intensity (Basic DII)”. In all the panels in Figure 4, the x-axis is the Basic DII level in that year (2023 or 2025), and the y-axis is the change in the share of SMEs using data analytics between 2023 and 2025 (percentage points). This setup shows whether diffusion is primarily concentrated among digitally advanced SMEs or is also spreading to the least digitally intensive segment over time.

The comparative results indicate a clear asymmetry in the diffusion of data analytics across the digital-intensity distribution of SMEs between 2023 and 2025. When baseline national digital maturity is proxied by the share of SMEs with at least basic DII in 2023, the growth in data analytics use is substantially stronger among the most digitally intensive enterprises than among the least digitally intensive enterprises. This pattern is reflected in the correlation structure, where the relationship between baseline basic DII and the change in data analytics use among very high DII SMEs is moderate to strong (r = 0.54). In contrast, the corresponding association for Very Low DII SMEs is close to zero (r = 0.09), suggesting that higher national digitalisation does not systematically translate into faster analytics uptake in the bottom tail. The positive link is also visible within the digitally advanced segment itself, as countries with a larger share of very high DII SMEs in 2023 tend to display stronger subsequent growth in analytics use within that segment (r=0.35). At the same time, the change in analytics adoption among Very Low DII SMEs is not meaningfully related to the prevalence of Very Low DII enterprises (r= −0.09), reinforcing the conclusion that bottom-end diffusion is weak and uneven.

The cohort-based comparison further sharpens this contrast. Countries in the top third of baseline basic DII show the fastest growth in data-analytics use among very-high-DII SMEs, with an average increase of about 6.1 percentage points. The corresponding increase is lower in the middle cohort at roughly 4.1 percentage points, and smallest in the low-DII cohort at about 2.6 percentage points. This suggests that technologically sophisticated nations encounter more than twice the cutting-edge expansion noted in low-digitisation nations.

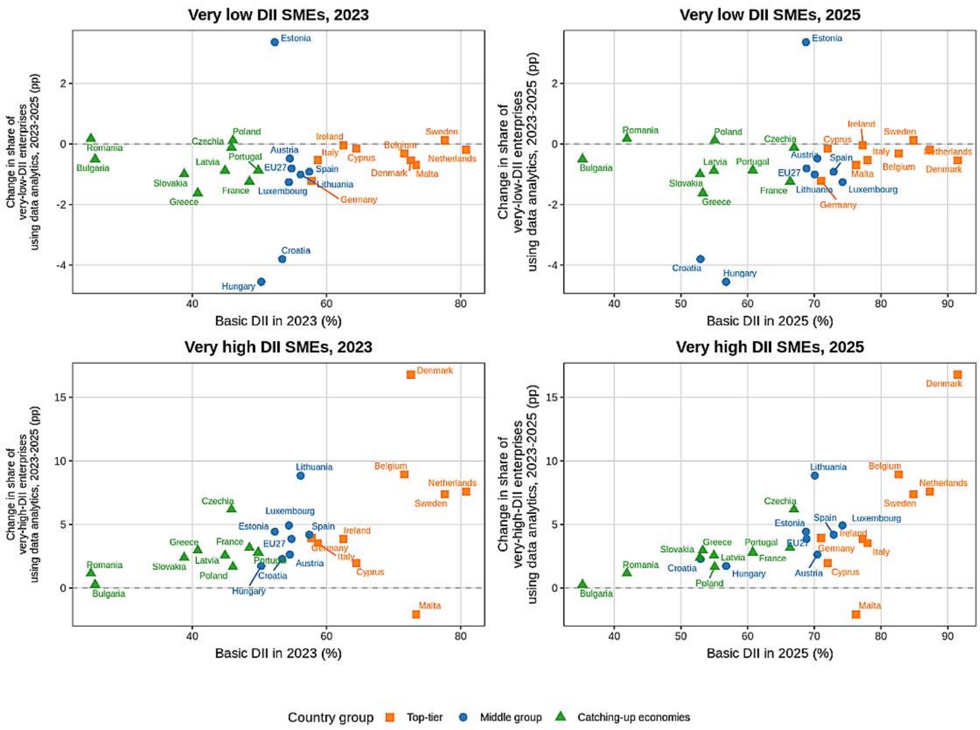

Figure no. 4. Digital maturity and the diffusion of data analytics in SMEs (very low vs very high DII segments (2023-2025))

Source: author's editing based on Eurostat, 2025c; 2025f

The DII baseline itself improves across all cohorts, with double-digit increases between 2023 and 2025. Notably, low-DII countries record the largest average increase in basic DII, indicating rapid catch-up in foundational digitalisation. However, these gains do not immediately translate into equally rapid frontier expansion in data-analytics uptake among very high DII SMEs. This disparity indicates a delay between extensive enhancements in digital intensity and the hastening of sophisticated data-driven methodologies at the upper echelon. The four-panel scatterplots support the same story visually, as the slope of the point cloud is relatively flat for very-low-DII SMEs but clearly positive for very-high-DII SMEs. Top-tier economies tend to occupy the upper-right area in the very-high-DII panels, combining stronger basic DII with larger increases in analytics adoption at the frontier. Catching-up economies remain more left-shifted and typically exhibit smaller gains, both at the frontier and especially at the bottom section. Middle-group countries display greater heterogeneity, with some moving closer to the top-tier pattern as basic DII rises. The results show that national digital maturity is strongly associated with faster analytics uptake among already digitally advanced SMEs, while the least digital SMEs show limited responsiveness over the same period.

Conclusions

The empirical evidence supports an ecosystem interpretation of AI diffusion in European SMEs, where adoption is best understood as the outcome of complementary capability building rather than a stand-alone technology decision. Across EU Member States, AI uptake aligns systematically with the maturity of a data-driven capability stack that combines analytics capacity, and ICT-related human capital. In this setting, the composite data readiness construct provides a practical way to benchmark national SMEs ecosystems and to explain why diffusion is “top-heavy” in some countries, but remains constrained in others.

A second central implication concerns value creation. The results are consistent with the argument that SMEs realise stronger economic outcomes when AI is embedded in joint adoption bundles and supported by analytics foundations. This is visible in the positive alignment between AI penetration and SMEs value added per enterprise, and it is reinforced by the finding that ecosystem maturity indicators and composite readiness measures track cross-country differences in performance more closely than isolated adoption variables. From a managerial perspective, the results imply that prioritising data foundations, analytics routines, and skills development can be more consequential than pursuing AI in isolation, particularly for SMEs seeking to participate in data-driven ecosystems where collaboration and interoperability requirements are high.

The analysis also highlights an inclusiveness challenge captured by the digital intensity divide. Data-analytics diffusion between 2023 and 2025 appears substantially stronger among very high digital-intensity SMEs than among very low digital-intensity SMEs, indicating a barrier-to-entry dynamic in which ecosystem benefits concentrate in an already advanced segment. This pattern is directly relevant to Digital Decade objectives and suggests that policies focusing only on raising basic digitalisation may not be sufficient to broaden advanced analytics and AI uptake. More targeted interventions are implied, including measures that expand access to cloud-based analytics, strengthen in-house capability building, and alleviate ICT specialist shortages, especially in lagging regions and among low-digital-intensity SMEs.

Several limitations qualify the interpretation. The design is country-level and cannot fully observe within-country heterogeneity beyond available digital-intensity group indicators. Differences in statistical coverage across Eurostat domains require nearest-year alignment, and missing data handling can affect sample composition across model variants. In addition, the results are associational and do not establish causal effects, even though the modelling strategy controls for macro-level development via GDP per capita in PPS and applies parsimonious specifications suited to the small cross-country sample.

Future research can extend the contribution in three directions. First, enterprise-level or matched micro-macro designs could test the proposed mechanisms more directly, including governance, absorptive capacity, and sequencing of capability building within SMEs. Second, longitudinal approaches using future Eurostat waves could examine whether basic digital catch-up translates into broader advanced analytics diffusion with a lag, and whether thresholds or non-linearities persist as adoption rises. Third, sector-specific analyses could clarify how ecosystem participation and capability stacks differ across industries and how these differences shape value capture and inequality within Europe's SMEs landscape.

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