

SMART SPECIALISATION STRATEGY (S3), BUSINESS BEHAVIOURS AND TERRITORIES: A STATISTICAL ANALYSIS OF ENVIRONMENTAL AND DIGITAL CHOICES BASED ON THE ISTAT PERMANENT CENSUS OF ENTERPRISES¹

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Abstract. The Smart Specialisation Strategy (S3) guides regional policies towards innovation-driven investments aligned with territorial strengths. Despite the widespread adoption of S3, empirical evidence on how the attitudes of firms influence investment choices within regional specialisation domains remains limited. This study addresses this gap by analysing non-linear relationships between firms' environmental awareness, technological modernisation, and investment behaviours. The analysis utilises data from the 2022 ISTAT Permanent Census of Enterprises, which developed a composite index to identify specialised firms by territorial and sectoral criteria.

To assess the relationships between environmental sensitivity and sustainable investments, as well as technological modernisation attitudes and digitalisation investments, Spearman's rank correlations were calculated to determine relationships at both the regional and specialisation-domain levels, as well as cluster analyses.

The findings highlight the potential of differentiated environmental and digital interventions tailored to sector-specific contexts. Future studies might investigate causal dynamics via longitudinal analyses to gain deeper insights into these relationships.

1. Introduction

In 2010, the European Commission urged national and regional governments to formulate Smart Specialisation Strategies (S3) for research and innovation (R&I), aiming to help European regions identify and leverage their competitive advantage (Foray et al., 2009). Since the 2014-2020 programming cycle, the European Commission has established Smart Specialisation as an *ex-ante conditionality* for accessing Structural Funds (European Parliament and the Council, 2013), reinforcing its role in guiding regional development strategies (REG. EU No 1303/2013). This approach was further reaffirmed in the 2021-2027 framework, where the effective governance of S3 was recognised as a *key enabling condition* for

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obtaining European Regional Development Fund (ERDF) resources dedicated to R&I and skills enhancement (EC, 2022).

It is a complex strategy, designed as part of the European Commission's reform of cohesion policy, whose objective is to identify strategic areas of intervention based both on an analysis of the strengths and potential of the economy and on an entrepreneurial discovery process (EDP) with broad involvement of the various institutional stakeholders insisting on the territories. The objective is to identify investment priorities in research, development and innovation that complement the existing tangible and intangible assets in the territories (Fratesi et al., 2021)

This paper moves within the theoretical framework of the Smart Specialisation Strategy. We utilised data from the Italian National Institute of Statistics (ISTAT), which introduced a novel enterprise classification encompassing all dimensions of smart specialisation (Foray et al., 2009). This dataset was used to identify potential S3 enterprises across Italian regions and to support the monitoring and evaluation of regional smart specialisation strategies.

The new S3 classification begins with a conceptualization process, which analyses the main lines of the S3 (five dimensions) and defines a general theoretical model, preserving the multidimensional approach that combines the fundamental dimensions: 1) innovative capacity, 2) R&D, 3) human capital, 4) driving ability to drive the development of the territory, 5) level of economic performance (e.g. added value).

After defining the latent dimensions and sub-dimensions of the S3, the variables that measure the S3 dimensions were researched. The elementary indicators were detected in the 2022 ISTAT Permanent Census of Enterprises, with a specific S3 section of the survey questionnaire.

Once the elementary indicators were selected, various aggregation methodologies were tested for the construction of a synthetic index of potential S3 enterprises. The most convincing methods proved to be the Wroclaw taxonomic method and the Mazziotta–Pareto index (MPI) for summarising a set of individual indicators that are assumed to be not fully substitutable.

The construction process of the synthetic indices (OECD, 2008) was followed: definition of the theoretical framework, selection and normalisation of the elementary indicators, and aggregation into a synthetic index for potential enterprises' S3.

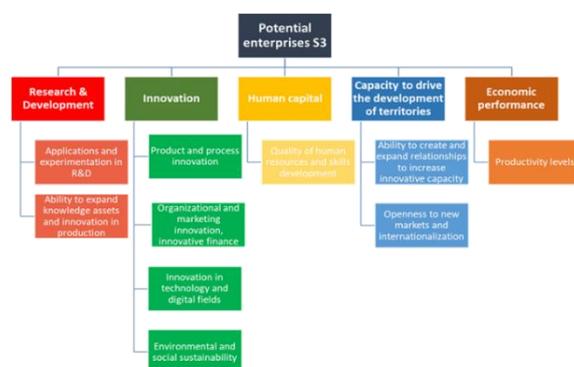
The classification enables the assessment of the specialisation areas selected by each Italian region, highlighting the dimensions in which a region demonstrates relative strengths or weaknesses. This analysis provides valuable guidance for prioritising investments and policy interventions (Iacobucci, 2014).

The data source used for the S3 classification is mainly the 2022 ISTAT Permanent Census of Enterprises, since it has a considerable wealth of information

that allows covering the different dimensions involved in S3. In addition, the classification incorporated data from the Frame-SBS register to account for variables related to productivity and performance, as well as from the ASIA Employment register to capture indicators pertaining to human capital. The five general dimensions, described above, have been decomposed into 11 indicators and more than 30 variables.

The output, obtained using the smart specialisation enterprise classification, consists of a set of statistical tables illustrating the indicators by area of specialisation at the national and regional level² (Figure 1).

Figure 1 – *S3 Dimensions and sub-dimensions.*



2. Correlation analysis

As an initial step in our analysis, we constructed a dataset aligned with our research objectives, drawing on data from the 2022 ISTAT Permanent Census of Enterprises. The objective was to test whether there are relationships between investment propensity and the corresponding sensitivity—both environmental and towards modernisation—and to determine whether these relationships are more pronounced at the territorial level (i.e., individual regions) or within specific territorial domains. One working hypothesis was that stronger relationships between investment propensity and sensitivity would be observed in certain S3 areas, such as a greater sensitivity toward environmental issues in Energy & Environment and Blue Economy specialisation areas. For each Italian region and specialisation area, we report the percentage of potential S3 enterprises with at least one investment for the digitalisation and those with at least one investment in environmental responsibility.

² <https://www.istat.it/it/archivio/273548>

Furthermore, as a proxy for the awareness toward modernisation, we consider the percentage of S3 enterprises undertaking technological modernisation within their area of activity. As a proxy for environmental accountability, we use the percentage of potential S3 enterprises that adopt standards for reporting on economic, social, and environmental sustainability aspects. In the table below, the descriptive statistics of the relevant variables of the analysis are presented (Table 1).

Table 1 – Summary statistics of quantitative variables.

Variable	Mean	Std. Dev.	Min	Max
Environmental Investments	67.7	17.1	16.6	94.5
Environmental Accountability (EA)	3.5	2.6	0.0	19.6
Digitalisation Investments	78.8	15.9	23.6	100.0
Technological Awareness (TA)	61.2	12.8	22.1	85.4

Source: Authors' elaboration on ISTAT data. N. observations = 252.

To empirically test these relationships, we employed Spearman's rank correlation coefficient, a non-parametric statistical measure assessing the monotonic association between two ranked variables. This method enables:

- cross-regional comparison of awareness-investment dynamics;
- sector-specific analysis within areas of technological specialisation.

Through this approach, we aim to determine whether heightened awareness effectively translates into increased investment propensity across different economic sectors and/or Italian regions.

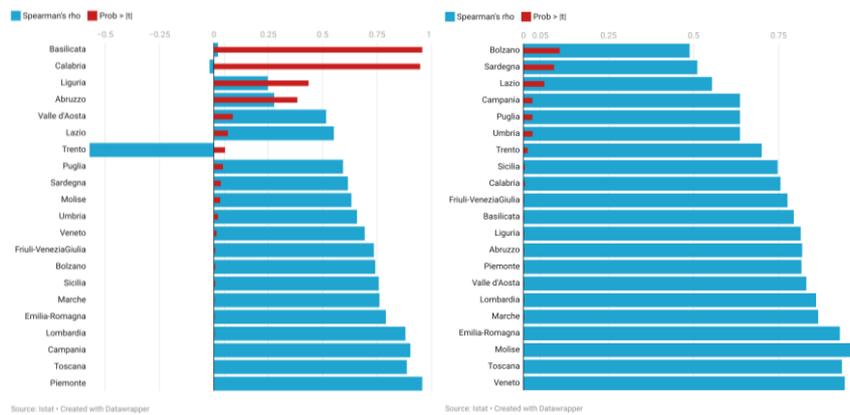
We first performed Spearman's rank coefficient for awareness and investment propensity in the environmental and technological domains across Regions (Figure 2).

In the environmental domain, most regions (14 out of 21) display statistically significant correlations, suggesting consistent patterns across territorial contexts ($p < 0.05$). Some of them have strong positive correlations ($\rho > 0.70$), such as Piemonte, Campania, Toscana, Lombardia, Emilia-Romagna, Marche, Sicilia, Bolzano, Friuli-Venezia Giulia, indicating strong evidence of association. Other regions (7) display high p-values ($p > 0.05$), implying weaker or non-significant correlations, meaning observed patterns may be due to randomness rather than systematic relationships.

In the modernisation domain, several regions show strong positive correlations, such as Molise (0.965), Veneto (0.9441), Toscana (0.9371), and Emilia-Romagna (0.9301), all with highly significant p-values ($p = 0$), suggesting a reliable relationship in these cases. On the other hand, some regions have weaker correlations or lack statistical significance, such as Bolzano (0.4895, $p = 0.1063$) and Sardegna (0.5105, $p = 0.0899$), where the p-values indicate that the correlation may not be meaningful. Interestingly, regions such as Campania, Puglia, Lazio, and Umbria

have moderate correlations with p-values slightly above or below the typical significance threshold of 0.05.

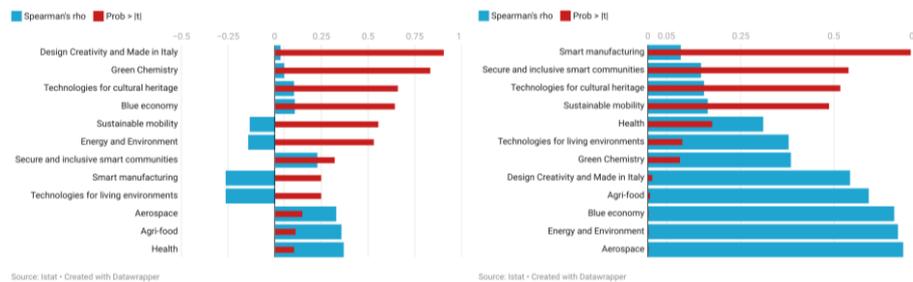
Figure 2 – Spearman’s rank coefficient for awareness and investment propensity in the environmental and technological domains across regions. Spearman’s correlation coefficient (ρ) and the corresponding p-value.



Source: Authors’ elaboration on ISTAT data. Left panel: environmental domain, right panel: modernisation domain.

The same analysis has been replicated across the 12 specialisation areas (Figure 3).

Figure 3 – Spearman’s rank coefficient for awareness and investment propensity in the environmental and technological domains across specialisation areas. Spearman’s correlation coefficient (ρ) and the corresponding p-value.



Source: Authors’ elaboration on ISTAT data. Left panel: environmental domain, right panel: modernisation domain.

Concerning businesses’ strategies in the environmental field, all the sectors have high p-values ($p > 0.05$), indicating weak or non-significant correlations, meaning observed trends may not be statistically robust. The closest to significance is Health

($p = 0.1009$), suggesting it may warrant further investigation for potential emerging trends.

Focusing instead on the behaviour of firms in the context of technological awareness, what emerges is that several specialisation areas exhibit statistically significant ($p < 0.05$), and positive correlations ($\rho > 0.5$), such as Aerospace, Energy & Environment, Blue Economy, Agri-food, and Design Creativity, supporting evidence of association.

In conclusion, the correlation analyses yield the following general findings: correlations at the regional level remain consistently strong across both transitions, underscoring the presence of structured investment behaviours. By contrast, sector-specific correlations appear less pronounced, with statistically significant relationships emerging solely within the domain of the digital transition. These findings underscore the need to address critical gaps through the implementation of targeted innovation policies.

3. Cluster analysis

This section presents the results of a cluster analysis aimed at classifying Italian regions and Smart Specialisation Strategy (S3) domains according to firms' behaviours in the same two strategic dimensions: Environmental Accountability (EA) and Technological Awareness (TA).

The analysis uses data from the 2022 ISTAT Permanent Census of Enterprises, including detailed information on environmental practices (e.g., certifications, energy efficiency, reporting) and digital adoption (e.g., cloud computing, e-commerce, ICT infrastructure).

To ensure comparability across variables, all indicators were standardised (z-scores). Outliers were removed using the interquartile range (IQR) method. Clustering was performed via the k-means algorithm (Lloyd, 1957; MacQueen, 1967), chosen for its scalability and interpretability despite its assumption of spherical and similarly sized clusters, which may not always perfectly capture heterogeneous group structures. The silhouette coefficient (Hennig, 2015; Rousseeuw, 1987) was used to evaluate clustering quality and determine the optimal number of clusters. Values around 0.4 indicate moderate separation, while values above 0.7 suggest well-defined clusters.

The cluster analysis based on the EA z-index ($K = 3$; silhouette = 0.426) yielded three regional profiles (Table 2).

Cluster 0 – *Moderate-Low environmental investment*: Groups Southern and peripheral regions (e.g., Sicilia, Lazio, Liguria, Sardegna, Molise). These areas show low engagement in formalised environmental practices (12% of firms report

sustainability) and limited environmental investments (18%). The mean EA index is 3.0, below the national average.

Cluster 1 – *High-Invest*: Comprises more industrialised and innovation-driven regions (e.g., Lombardia, Emilia-Romagna, Veneto). Around 40% of firms adopt environmental reporting, and 45% invest in environmental practices. The mean index is 3.6, reflecting a more integrated approach.

Cluster 2 – *Benchmark Performer*: Includes only the Autonomous Province of Trento, with 68% of firms engaging in disclosure and an EA index of 8.1, more than twice the national mean, driven by strong governance and innovation ecosystems. Since this cluster contains a single case, it should be interpreted as a peculiar outlier profile rather than a stable cluster.

Table 2 – Regional clusters by Environmental Accountability (EA): composition and average index.

Cluster	Profile	Size	Regions
0	Moderate–Low environmental investment	10	Bolzano, Friuli-Venezia Giulia, Lazio, Liguria, Marche, Molise, Sardegna, Sicilia, Toscana, Valle d'Aosta
1	High environmental investment	10	Abruzzo, Basilicata, Calabria, Campania, Emilia-Romagna, Lombardia, Piemonte, Puglia, Umbria, Veneto
2	Very high environmental investment	1	Auton. Province of Trento

The cluster analysis based on the TA z-index ($K = 2$; silhouette = 0.453) identified two regional profiles (Table 3).

Cluster 0 – *Mixed-Advanced Adoption* includes a heterogeneous group of regions, some of which show relatively strong digital infrastructures and widespread use of enabling technologies—such as Lombardia, Emilia-Romagna, Trentino-Alto Adige (Trento, Bolzano) and Friuli-Venezia Giulia. In these areas, over 50% of firms report adoption of cloud services, data analytics, and e-commerce platforms, supported by broadband coverage exceeding 85%. However, the same cluster also comprises regions with less mature digital ecosystems, such as Molise or Sicilia, highlighting intra-cluster heterogeneity.

Cluster 1 – *Lagging Digital Integration* comprises regions like Lazio, Campania, Abruzzo, and Sardegna, where fewer than 20% of firms implement advanced digital tools and broadband penetration is below 60%. Structural weaknesses—such as insufficient infrastructure and skills shortages—continue to hinder their digital transformation.

Table 3 – Regional clusters by Technological Awareness (TA): composition.

Cluster	Profile	Size	Regions
0	Mixed-advanced digital adoption	11	Basilicata; Bolzano; Calabria; Emilia-Romagna; Friuli-VG; Lombardia; Marche; Molise; Sicilia; Trento; Veneto
1	Lagging digital integration	9	Abruzzo; Campania; Lazio; Piemonte; Puglia; Sardegna; Toscana; Umbria; Valle d'Aosta

The cluster analysis based on the EA z-index applied to the 12 Smart Specialisation Strategy (S3) domains ($K=3$; silhouette=0.551) identified three distinct sectoral profiles (Table 4).

Table 4 – Sectoral clusters by Environmental Accountability (EA): composition.

Cluster	Profile	Size	S3 Specialisation Domains
0	Environmental Front-Runners	2	Design Creativity and Made in Italy; Health
1	Transitioning Domains	9	Aerospace; Blue Economy; Energy & Environment; Green Chemistry; Smart Manufacturing; Sustainable Mobility; Technologies for Cultural Heritage; Technologies for Living Environments; Secure and Inclusive Smart Communities
2	Environmental Laggard	1	Agri-food

Cluster 0 – *Environmental Front-Runners* includes the *Design Creativity and Made in Italy*, and *Health* domains. Over 55% of firms in these sectors adopt environmental certifications or implement energy efficiency solutions. The positive performance reflects a mix of consumer demand for transparency, regulatory alignment, and, in the case of Health, compliance with strict environmental and safety standards. These labels are intended as analytical descriptions of statistical profiles, not normative judgements. In these domains, environmental accountability is perceived not only as a compliance requirement but also as a reputational and competitive lever.

Cluster 1 – *Transitioning Domains* brings together sectors such as *Blue Economy*, *Green Chemistry*, *Smart Manufacturing*, and *Sustainable Mobility*. In this group, around 28% of firms report structured environmental practices. While these domains show engagement with sustainability principles, the level of diffusion is uneven, and performance is highly dependent on the maturity of local ecosystems, access to innovation resources, and sector-specific incentives.

Cluster 2 – *Environmental Laggard* consists solely of the *Agri-food* domain, which records the lowest levels of environmental commitment among all specialisations. Only 10% of firms adopt formal sustainability practices. Despite

significant potential for green innovation, e.g., through precision farming or regenerative practice, sectoral fragmentation, low capitalisation, and regulatory complexity continue to limit systemic progress.

The cluster analysis based on the TA z-index ($K = 2$; silhouette = 0.729) applied to the 12 S3 domains revealed two distinct digital maturity profiles, presented in Table 5.

Cluster 0 – *Digitally Progressive Domains* comprises eight domains, including *Aerospace*, *Smart Manufacturing*, *Sustainable Mobility*, and *Green Chemistr*, where over 52% of firms have adopted at least one advanced digital technology (e.g., cloud platforms, data analytics and automation systems). These sectors benefit from dynamic innovation ecosystems, integration into digital value chains, and public–private partnerships that support technological diffusion. Their maturity reflects both internal capabilities and favourable contextual factors, such as infrastructure, R&D networks, and access to skills.

Cluster 1 – *Digitally Lagging Domains* includes *Design Creativity and Made in Italy*, *Energy & Environment*, and *Health*. In these domains, fewer than 20% of firms report the use of enabling technologies. Despite their strategic relevance, their innovation models remain anchored to traditional processes, and digital integration is hindered by limited internal resources, infrastructure deficits, and low exposure to digital ecosystems. These findings indicate that sectoral digital gaps are structural and require targeted interventions, not only firm-level incentives. These weaknesses restrict their participation in Industry 4.0 trajectories and reduce their competitiveness in high-tech markets.

Table 5 – Sectoral clusters by Technological Awareness (TA): composition.

Cluster	Profile	Size	S3 Specialisation Domains
0	Digitally Progressive Domains	8	Aerospace; Blue Economy; Green Chemistry; Smart Manufacturing; Secure and Inclusive Smart Communities; Sustainable Mobility; Technologies for Cultural Heritage; Technologies for Living Environments
1	Digitally Lagging Domains	3	Design Creativity and Made in Italy; Energy & Environment; Health

4. Discussion of results and policy implications

The analysis reveals a marked territorial divide: Southern regions lag significantly in both environmental accountability and digital adoption, while North-Central areas exhibit a stronger strategic orientation, as reflected in higher EA and TA scores (Barca, McCann & Rodríguez-Pose, 2012; ISTAT, 2022). The Autonomous Province of Trento emerges as a benchmark case, benefiting from

proactive policies—co-financing, incentives, and public–private partnerships—that have fostered the widespread adoption of sustainable and digital practices (Foray, David & Hall, 2009).

At the sectoral level, domains such as “Design and Health” and others characterised by green-digital synergies stand out for their integration of technologies, supported by favourable regulatory environments and collaborative innovation networks (Pisano & Shih, 2012; OECD, 2021). Conversely, domains such as Agri-food show limited penetration of both sustainability and digital solutions, with below 20% of firms using e-commerce or cloud services—signalling the need for targeted capacity-building and incentive schemes (European Commission, 2021).

These findings point to the urgency of place-based policies: fiscal incentives for certifications (e.g., ISO 14001), broadband infrastructure expansion, and digital training programmes—leveraging NextGenerationEU and 2021–2027 EU Cohesion Policy resources (European Commission, 2020). Equally crucial are sectoral interventions for traditional industries—such as agri-food or construction—to stimulate digital uptake and green transitions (Barca et al., 2012).

The robustness of the cluster analysis—ensured through z-score standardisation, IQR-based outlier removal, and silhouette validation—offers a solid empirical foundation to inform Smart Specialisation Strategies and monitor behavioural change across territories and sectors (Rousseeuw, 1987). In addition, the correlation analyses yield two overarching insights: regional-level correlations remain consistently strong across both transitions, suggesting the presence of structured investment behaviours and territorially embedded innovation dynamics. By contrast, sector-specific correlations are comparatively weaker, with statistically significant relationships emerging only in the context of the digital transition. These findings underscore the need to address critical gaps through the implementation of targeted innovation policies, particularly in sectors where green and digital adoption remains limited.

5. Conclusions and future research directions

This study confirms the existence of well-differentiated territorial and sectoral profiles in green and digital investment, enabled by a rigorous correlation and clustering methodology. The North–South divide remains pronounced, with southern regions trailing in both strategic dimensions (ISTAT, 2022), while Trento exemplifies how institutional quality can accelerate convergence. These results strengthen the evidence that regional innovation ecosystems play a decisive role in shaping firms’ environmental accountability and technological awareness (Foray et al., 2009; OECD, 2021). Southern regions demonstrate structural weaknesses related to limited digital infrastructure and reduced access to innovation networks, while

North-Central regions benefit from stronger public–private partnerships and targeted Smart Specialisation policies (European Commission, 2021).

Sectoral insights highlight both frontrunners (e.g., Health, Design) and laggards (e.g., Agri-food), underscoring the need for tailored policies—ranging from ICT grants to sustainability incentives—to close structural gaps and foster ecosystem maturity (Foray et al., 2009; OECD, 2021).

At the policy level, our findings call for place-based strategies tailored to regional strengths and weaknesses. Priority actions should include fiscal incentives for adopting environmental certifications, investments in broadband infrastructure, and capacity-building programmes to strengthen SMEs’ integration within innovation ecosystems (European Commission, 2020; Foray et al., 2009).

A promising avenue for future research is longitudinal monitoring of cluster transitions using forthcoming business census waves. This would enable assessment of policy effectiveness and the identification of upward trajectories in green and digital maturity. Integrating predictive modelling techniques with the ISTAT datasets could allow policymakers to identify regions and sectors with the highest potential for transition and optimise the allocation of European funds under the Smart Specialisation Strategy framework (OECD, 2021; ISTAT, 2023).

From a methodological perspective, alternative clustering techniques, such as hierarchical models or latent class analysis, offer the potential to uncover latent subgroup structures that may be overlooked by standard k-means algorithms (Hennig, 2015; Kaufman & Rousseeuw, 1990). Moreover, incorporating explanatory variables such as governance quality, educational attainment, and sector-specific employment dynamics could significantly enrich the analysis by shedding light on the underlying enabling factors.

Finally, the integration of predictive models using machine learning may support forward-looking policymaking, identifying regions or sectors with the highest potential for transition. This would help optimise resource allocation and strengthen the strategic relevance of the Smart Specialisation framework, and support European tools and policies, such as the Multiannual Financial Framework – MFF 2028-2034 currently being defined, to design a balanced relationship between territorial equity and economic competitiveness.

References

- BARCA F.; MCCANN P.; RODRÍGUEZ-POSE A. 2012. The case for regional development intervention: Place-based versus place-neutral approaches. *Journal of Regional Science*, Vol. 52, No. 1, pp. 134–152.
- EUROPEAN COMMISSION 2020. *Digital Economy and Society Index (DESI) 2020: Italy*. Commission Staff Working Document.

- EUROPEAN COMMISSION 2021. *European Innovation Scoreboard 2021*.
- EUROPEAN COMMISSION 2022. *A New European Innovation Agenda (COM (2022) 332 final)*. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0332>
- EUROPEAN PARLIAMENT AND THE COUNCIL 2013. *Regulation (EU) No 1303/2013 of 17 December 2013*.
- FRATESI U.; GIANELLE C.; GUZZO F. 2021. *Assessing smart specialisation: policy implementation measures*. European Commission, Joint Research Centre. <https://data.europa.eu/doi/10.2760/71769>
- FORAY D.; DAVID P. A.; HALL B. 2009. *Smart Specialisation – The Concept*. Knowledge Economists Policy Brief No. 9, University of Bergen.
- HENNIG C. 2015. fpc: Flexible Procedures for Clustering. *Journal of Statistical Software*, Vol. 67, No. 1, pp. 1–38.
- IACOBUCCI D. 2014. Designing and implementing a smart specialisation strategy at regional level: Some open questions. *Scienze Regionali. Italian Journal of Regional Science*, Vol. 13, No. 1, pp. 107–126.
- ISTAT 2022. *Rapporto sul Censimento Permanente delle Imprese 2022*. Istituto Nazionale di Statistica.
- ISTAT 2023. *Rapporto Annuale 2023 – La situazione del Paese*. Istituto Nazionale di Statistica.
- ISTAT 2024. *Le aree di specializzazione intelligente italiane: imprese e territori*. Istituto Nazionale di Statistica.
- ISTAT 2024. *Censimento Permanente delle Imprese: Report di aggiornamento 2024*. Istituto Nazionale di Statistica.
- KAUFMAN L.; ROUSSEEUW P. J. 1990. *Finding Groups in Data: An Introduction to Cluster Analysis*. Wiley.
- OECD 2008. *Handbook on Constructing Composite Indicators: Methodology and user guide*. OECD Publishing.
- OECD 2021. *OECD Digital Economy Outlook 2021*. OECD Publishing.
- OECD 2022. *Green Growth Indicators 2022*. OECD Publishing.
- PISANO G.; SHIH W. 2012. *Producing Prosperity: Why America Needs a Manufacturing Renaissance*. Harvard Business Review Press.
- ROUSSEEUW P. J. 1987. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics*, Vol. 20, pp. 53–65.

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