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Digitalisation Strategies and Sustainable Well-being in Italian Provinces: A PoSet Approach

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Abstract

This study investigates the multidimensional relationship between digitalisation strategies and sustainable well-being across Italian provinces. Building upon the emerging concept of digitainability - the synergistic integration of digitalisation and sustainability - this research adopts an innovative methodological approach combining the Partially Ordered Set (PoSet) theory with cluster analysis. Drawing upon the Italian National Institute of Statistics (ISTAT) databases, the study constructs a comprehensive Digitalisation Index encompassing educational, infrastructural, and socio-economic indicators. The analysis reveals heterogeneous patterns of progress among provinces, highlighting territorial disparities and the need for context-specific policy interventions. Results show that while Northern and Central Italian provinces exhibit higher levels of digitainability, Southern and Island regions remain structurally disadvantaged. The PoSet and cluster-based framework provides a robust, non-compensatory method for ranking and comparing complex territorial phenomena, offering a replicable model for policymakers and researchers. The findings underscore the necessity of integrated strategies that promote digital education, inclusive innovation, and sustainable infrastructures as mutually reinforcing drivers of territorial well-being.

JEL Classification: *C10, O33, Q56, R11*

Keywords: *digitalisation; sustainability; digitainability; PoSet; cluster analysis; SDGs; Italian provinces*

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1. Introduction

In recent decades, digitalisation has emerged as one of the most powerful transformative forces shaping economies, societies, and institutions worldwide. Its potential to foster innovation, enhance productivity, and promote inclusive development has been widely acknowledged. At the same time, the global commitment to sustainable development—anchored in the United Nations' 2030 Agenda and its 17 Sustainable Development Goals (SDGs)—has called for a profound rethinking of how technological advancement can support environmental and social progress. The intersection of these two megatrends—digitalisation and sustainability—has given rise to the concept of digitainability, a term coined to describe the degree to which digital transformation and sustainable development mutually reinforce each other (Lichtenthaler, 2021; Gupta & Rhyner, 2022).

In Italy, the digital and ecological transitions have become central to national and regional policies, particularly through the *Piano Nazionale di Ripresa e Resilienza* (PNRR) and the *Benessere Equo e Sostenibile* (BES) framework promoted by ISTAT. However, the territorial dimension of these transformations remains underexplored. Considerable disparities persist between northern and southern regions, as well as between urban and rural areas. Understanding how digitalisation strategies contribute to sustainable well-being at the subnational level is thus essential for designing effective, equitable, and place-based policies.

This study addresses this gap by developing an analytical framework capable of assessing the progress of digitainability across Italian provinces. By integrating PoSet analysis—a non-compensatory, ordinal approach for multidimensional evaluation—with cluster analysis, the research identifies patterns of digital and sustainable development without imposing arbitrary weighting schemes. This methodology captures the complexity of territorial interactions between digitalisation and well-being, allowing for a more nuanced understanding than traditional composite indices.

The main objectives of this work are:

1. To operationalise the concept of digitainability through measurable indicators derived from official statistics.
2. To develop a methodological approach capable of ranking provinces based on multidimensional performance.
3. To identify territorial typologies of provinces through cluster analysis, providing evidence for differentiated policy design.

The study contributes to the ongoing debate on sustainable digital transitions by offering a replicable framework applicable to other national and regional contexts. The remainder of the paper is structured as follows. Section 2 presents the theoretical framework, outlining the conceptual foundations of digitainability and its policy context. Section 3 describes the data sources and methodological approach, including PoSet and cluster analysis procedures. Section 4 reports and discusses the main results, while Section 5 outlines limitations. Section 6 offers policy implications and future perspectives, and Section 7 concludes the paper.

2. Theoretical Framework

2.1 Digitalisation and Sustainability: The Concept of "Digitainability"

Digitalisation represents a structural transformation extending beyond the adoption of technology. It reshapes organisational models, labour structures, communication systems, and learning processes. In the context of sustainable development, digitalisation can act as both an enabler and a disruptor. When appropriately governed, it enhances efficiency in resource use, transparency in governance, and accessibility in education and health services. Conversely, if unregulated, it may exacerbate inequalities and increase environmental burdens (Gupta et al., 2023).

The term digitainability was introduced by Lichtenthaler (2021) to describe the convergence of digitalisation and sustainability as twin megatrends driving socio-economic change. Recent scholarship has deepened this notion by analysing how digital tools can accelerate the achievement of SDGs. For instance, Gupta and Rhyner (2022) developed the Digitainability Assessment Framework to evaluate digital strategies' sustainability outcomes, while Dovleac et al. (2023) explored the educational dimension of digitainability as a driver of inclusivity. The European context further emphasises this interconnection, promoting human-centric digitalisation under the emerging paradigm of Industry 5.0 (Campolucci et al., 2024).

Within this study, digitainability is conceptualised as the synergistic capability of a territory to leverage digital transformation in pursuit of economic, social, and environmental sustainability. It implies a multidimensional integration of policies and practices - spanning from digital infrastructure to human capital development - aimed at improving quality of life and ecological resilience.

Recent works (Otter & Sauvée, 2025; Shashi, 2022) have stressed the role of digitalisation in transforming supply chains, education, and governance systems into more sustainable configurations. However, the localised nature of these transformations - particularly in contexts marked by structural disparities like Italy - requires analytical approaches that can capture heterogeneity and interdependence among dimensions. This justifies the adoption of the PoSet methodology, which respects ordinal relations without collapsing multidimensional data into a single synthetic score.

2.2 Global and European Policy Context for Digitainability

The policy landscape of digitainability operates across multiple governance levels. At the international level, the United Nations' 2030 Agenda for Sustainable Development remains the cornerstone, with its SDGs providing the global framework for integrated action. Mechanisms such as the High-Level Political Forum (HLPF) and Voluntary National Reviews (VNRs) enable monitoring and knowledge sharing among states.

At the European level, the European Green Deal (2019) and the Digital Decade Policy Programme 2030 represent key strategic pillars. The Green Deal aims at achieving climate neutrality by 2050, while the Digital Decade targets four cardinal goals: digital skills, digital infrastructures, digitalisation of businesses, and digitalisation of public services. The interplay between these agendas defines the European approach to digitainability, integrating social, environmental, and technological objectives (European Commission, 2022).

Nationally, Italy's Piano Nazionale di Ripresa e Resilienza (PNRR) translates these priorities into concrete investments, notably through Mission 1 ("Digitalisation, Innovation, Competitiveness, and Culture") and Mission 2 ("Green Revolution and Ecological Transition"). Complementarily, the Benessere Equo e Sostenibile (BES) framework provides statistical indicators for monitoring regional and provincial well-being, enabling alignment with the SDGs. These multi-level frameworks create an enabling environment for implementing digitainability-oriented strategies.

Nonetheless, gaps remain in assessing how effectively these policies translate into tangible improvements in sustainable well-being at the subnational scale. The present study seeks to fill this void through an empirically grounded evaluation of Italian provinces, using quantitative methodologies capable of revealing hidden patterns and inter-regional disparities.

3. Data and Methodology

This section describes the methodological framework adopted to assess digitainability across Italian provinces. A combined quantitative approach was employed, integrating the Partially Ordered Set (PoSet) methodology with hierarchical cluster analysis.
The combination of these two methods provides both a non-compensatory ranking of multidimensional performance and a typology of provinces sharing similar levels of digitalisation and sustainable well-being (Gupta & Rhyner, 2022).

3.1 Data Sources and Indicators

The empirical analysis draws upon official data from the Italian National Institute of Statistics (ISTAT), specifically from two datasets:

- Benessere Equo e Sostenibile Territoriale (BES)
- Sustainable Development Goals (SDGs) indicators, aligned with the United Nations 2030 Agenda.

Both datasets include economic, social, environmental, and institutional dimensions relevant to measuring sustainable well-being and digital readiness.
Indicator selection was guided by three main criteria:

(a) conceptual relevance to both digitalisation and sustainability;
(b) availability at the provincial or regional level;
(c) methodological suitability for ordinal, non-compensatory analysis.

The resulting Digitalisation Index is composed of nine indicators: six from the BES database (available at provincial level) and three from the SDG database (available at regional level).
Regional values were uniformly distributed among the provinces within each region to harmonise the spatial resolution.

Prior to analysis, all indicators were normalised using min–max scaling, ensuring that ordinal properties were preserved. Missing data were minimal and limited to four Sardinian provinces (Carbonia-Iglesias, Medio Campidano, Olbia-Tempio, Ogliastra), which were excluded from the analysis.

Table 1 – Indicators Defining the Digitalisation Index

LABEL	DESCRIPTION	VALUE	SOURCE	YEAR	UNIT
ALP	Adequate literacy proficiency (students in grades III, lower secondary school)	%	ISTAT - BEST	2022	P
ANC	Adequate numerical proficiency (students in grades III, lower secondary school)	%	ISTAT - BEST	2022	P
FNC	Fixed network coverage of ultra-fast internet access	%	ISTAT - BEST	2022	P
CGT	College graduates and other tertiary degrees (25-39 years old)	%	ISTAT - BEST	2022	P
PCE	Participation in continuing education	%	ISTAT - BEST	2022	P
HSD	People with at least a high school diploma (25-64 years old)	%	ISTAT - BEST	2022	P
BDS	Youth and adults with information and communication (ICT) skills, by type of skill - Digital skills at least basic	%	ISTAT - SDG	2021	R
SDY	People with a tertiary STEM degree in a year (20-29 years old)	Per 1000 residents	ISTAT - SDG	2020	R
IU	People aged 16-74 years who have used the internet in the past 3 months at least once a week (including every day)	%	ISTAT - SDG	2022	R

[Table 1: Indicators, Source, Year, and Units]

This approach aligns with previous multidimensional studies emphasising the need for transparent and participatory indicator design (Gupta & Rhyner, 2022).

3.2 PoSet (Partially Ordered Set) Analysis

The PoSet methodology, rooted in order theory, enables the analysis of multidimensional data without aggregating indicators or imposing arbitrary weights (Brüggemann et al., 2021).
Each element (province) is described by a vector of indicators, and comparability between elements is determined through dominance relations.
Formally, let the set of provinces be $C = \{x_1, x_2, \ldots, x_{106}\}$, and let $I = \{a_1, a_2, \ldots, a_k\}$r represent the set of indicators. A province xdominates another y_{if}:

$$a_i(x) \geq a_i(y) \text{ for all } i, \text{ and } a_j(x) > a_j(y) \text{ for at least one } j.$$

If two provinces do not satisfy this condition, they are incomparable (x‖y).
Comparable provinces form chains, while incomparable ones form anti-chains (Dovleac, L., Chițu, I. B., Nichifor, E., & Brătucu, G., 2023).

The height of the PoSet equals the length of the longest chain; the width equals the maximum size of an anti-chain.

Graphically, these relations are represented through the Hasse diagram, which connects comparable elements and leaves incomparable ones unconnected.
This diagram visualises the relational structure among provinces in terms of their multidimensional performance.

3.3 PoSet Analysis Methodology

Definition of the Set and Indicators
In this analysis, Italian provinces $C = \{x_1, \ldots, x_{106}\}$are evaluated within an indicator space $I = \{a_1, \ldots, a_k\}$. For each province $x \in C$, the vector $a_i(x)$represents the ordered indicator values.

Fundamental Axioms of the PoSet
Reflexivity, anti-symmetry, and transitivity apply as follows:
$x_i \leq x_i$; if $x_i \leq x_j$and $x_j \leq x_i$, then $x_i = x_j$; if $x_i \leq x_j$and $x_j \leq x_k$, then $x_i \leq x_k$.
A province $x$dominates another $y$when

$$a_i(x) \geq a_i(y) \forall a_i \in I, \text{ and } a_j(x) > a_j(y) \text{ for at least one } a_j.$$

If for some indicators $a_i(x) > a_i(y)$and others $a_j(x) < a_j(y)$, then $x \parallel y$. Comparable pairs form chains, incomparables form anti-chains; the *height* and *width* describe their structure (Brüggemann et al., 2004).

Graphical Representation
Comparability relations among provinces are visualised via Hasse diagrams, where connected nodes indicate comparability. This allows ranking and classification without compensatory aggregation, preserving ordinal integrity.

Ranking Extraction and Mutual Ranking Probabilities
According to Fattore and Arcagni (2018), ranking extraction employs *mutual ranking probabilities* to estimate how often one province ranks higher than another across all possible linear extensions of the PoSet.
The Matrix of Mutual Ranking Probabilities (MRP) is defined as:

$$M_{ij} = \frac{|\{\lambda \in \Omega(\pi): x_i \leq_\lambda x_j\}|}{|\Omega(\pi)|}, (i, j = 1, \dots, |X|).$$

where $\Omega(\pi)$denotes the set of all possible linear extensions of the PoSet. Each entry M_{ij}expresses the probability that province $x_j$ranks higher than $x_i$across those extensions (Gupta et al., 2023).

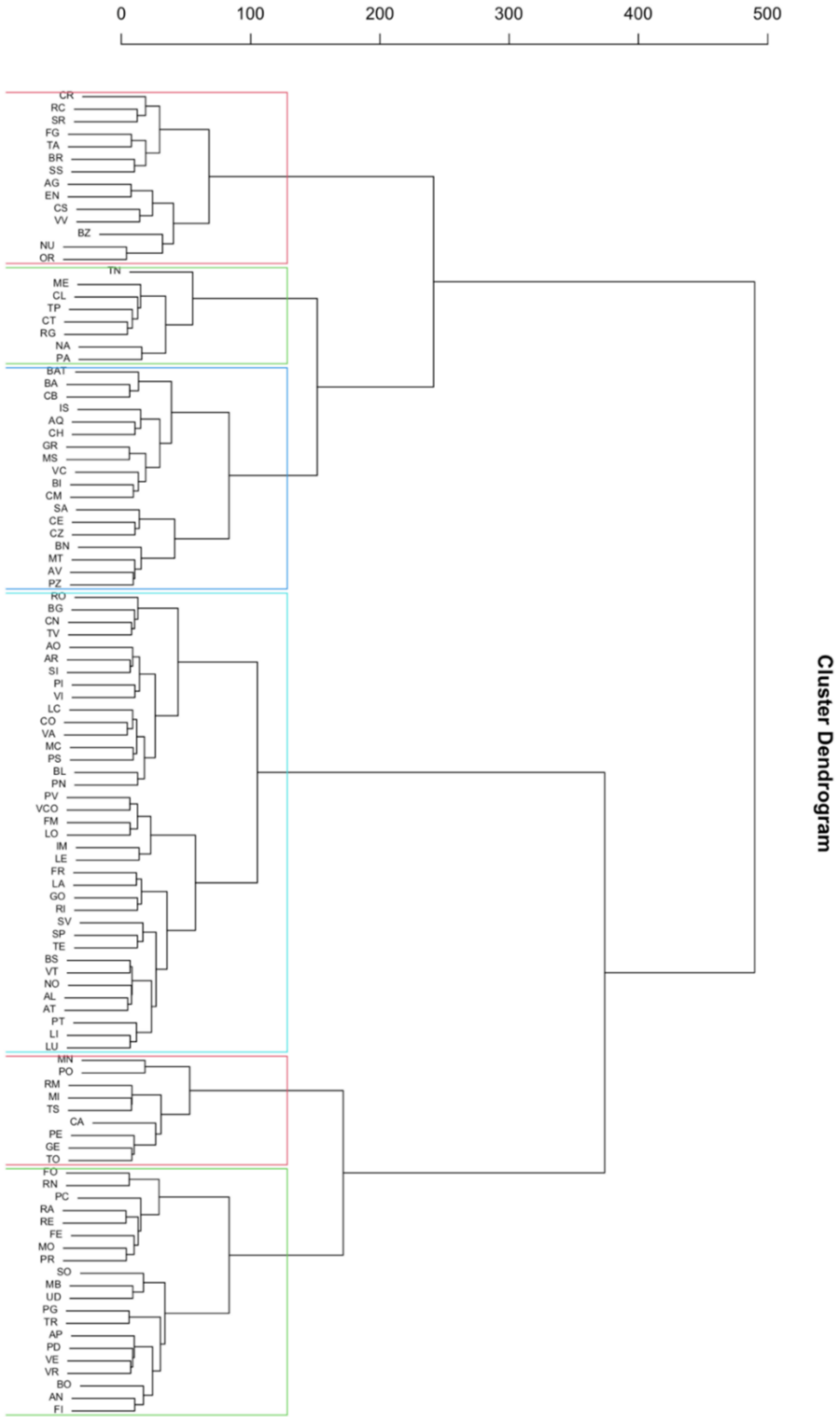
Matrices Used in PoSet Representation
Finite PoSets are represented through three matrices: Incidence (Z), Cover (C), and Mutual Ranking Probabilities (M).

Their relations follow the formulations of Brüggemann et al. (2004). Together, they connect deterministic order relations (Z, C) with probabilistic ones (M), linking structural and stochastic views of the data.

3.4 Cluster Analysis

To complement PoSet results, a hierarchical cluster analysis was applied using the Ward linkage method, which minimises intra-cluster variance and maximises inter-cluster separation. Cluster validation through the Average Silhouette Width and Within Sum of Squares (WSS) methods indicated six optimal clusters (Sá et al., 2021).

Figure 4: Ward Dendrogram Highlighting Six Clusters



The resulting clusters serve to identify homogeneous groups of provinces with similar digitainability profiles, complementing the ordinal insights from PoSet analysis (Campolucci et al., 2024).

4. Results and Discussion

This section presents the main results derived from the PoSet and cluster analyses, followed by an interpretive discussion linking empirical findings to the broader theoretical framework of digitainability. The analysis highlights a clear territorial differentiation in Italy's digital and sustainable development, providing both quantitative evidence and conceptual insight.

4.1. Typologies of Italian Provinces

The hierarchical cluster analysis, conducted through Ward's method, produced six distinct clusters of Italian provinces according to their digitalisation and sustainable well-being profiles.
The Silhouette Width and Within Sum of Squares (WSS) methods indicated that a six-cluster solution offers the best trade-off between cohesion and separation.

Table 2: Average Silhouette Width and WSS Results

Clusters	Avg_Silhoutte
2	0.3287
3	0.2087
4	0.2240
5	0.2514
6	0.2570
7	0.2397
8	0.2332
9	0.2412
10	0.2467

Each cluster represents a typology of provinces sharing similar levels of digitainability:

- Cluster I (Peripheral–Lagging Provinces): mainly located in Southern Italy (e.g., Crotone, Reggio Calabria, Siracusa, Foggia), these areas are characterised by weak digital infrastructures, low educational attainment, and limited ICT skills.

- Cluster II (Emerging–Mixed Provinces): including Messina, Caltanissetta, and Naples, these provinces show intermediate progress, benefitting from recent PNRR investments but still constrained by social and institutional fragilities.

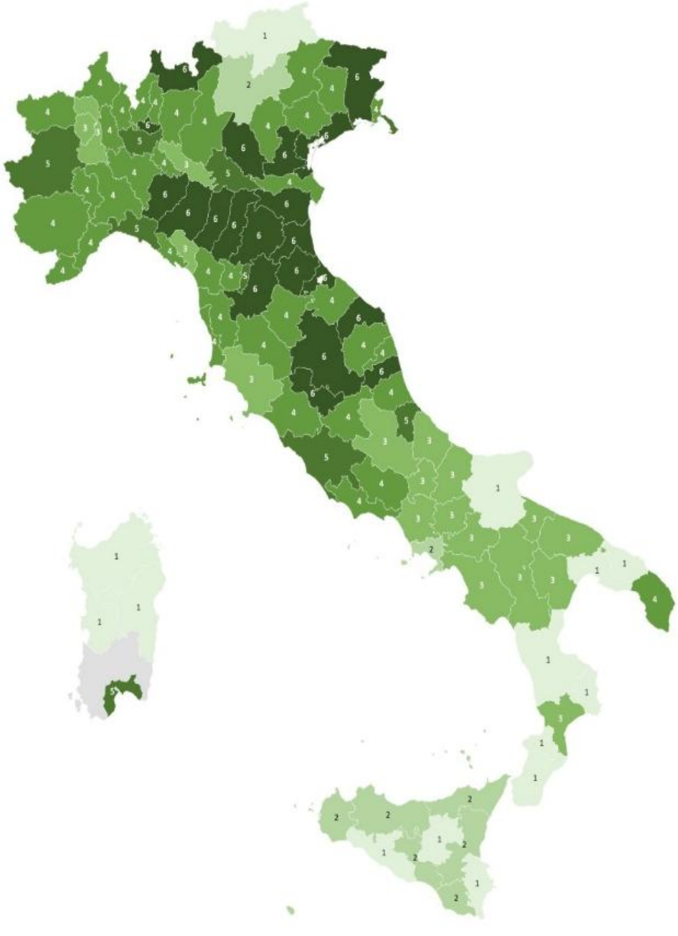
- Cluster III (Intermediate–Transitional Provinces): predominantly Central–Southern territories (e.g., Bari, Campobasso, Chieti, Grosseto), combining improving digitalisation indicators with moderate sustainability scores.

- Cluster IV (Balanced–Developing Provinces): mid-level northern and central provinces such as Treviso, Pisa, and Macerata, where both human capital and digital infrastructure are moderately developed.

- Cluster V (Advanced–Innovative Provinces): large metropolitan areas such as Milan, Rome, and Turin, which act as digital hubs with strong innovation ecosystems and knowledge-intensive industries.

- Cluster VI (Digitainability Leaders): provinces in Emilia-Romagna, Veneto, and Marche (e.g., Bologna, Ancona, Florence) that exhibit high integration of digitalisation and sustainability, aligning with European best practices in green–digital transition.

Figure 5: Map of Italy Showing the Six Clusters of Provinces



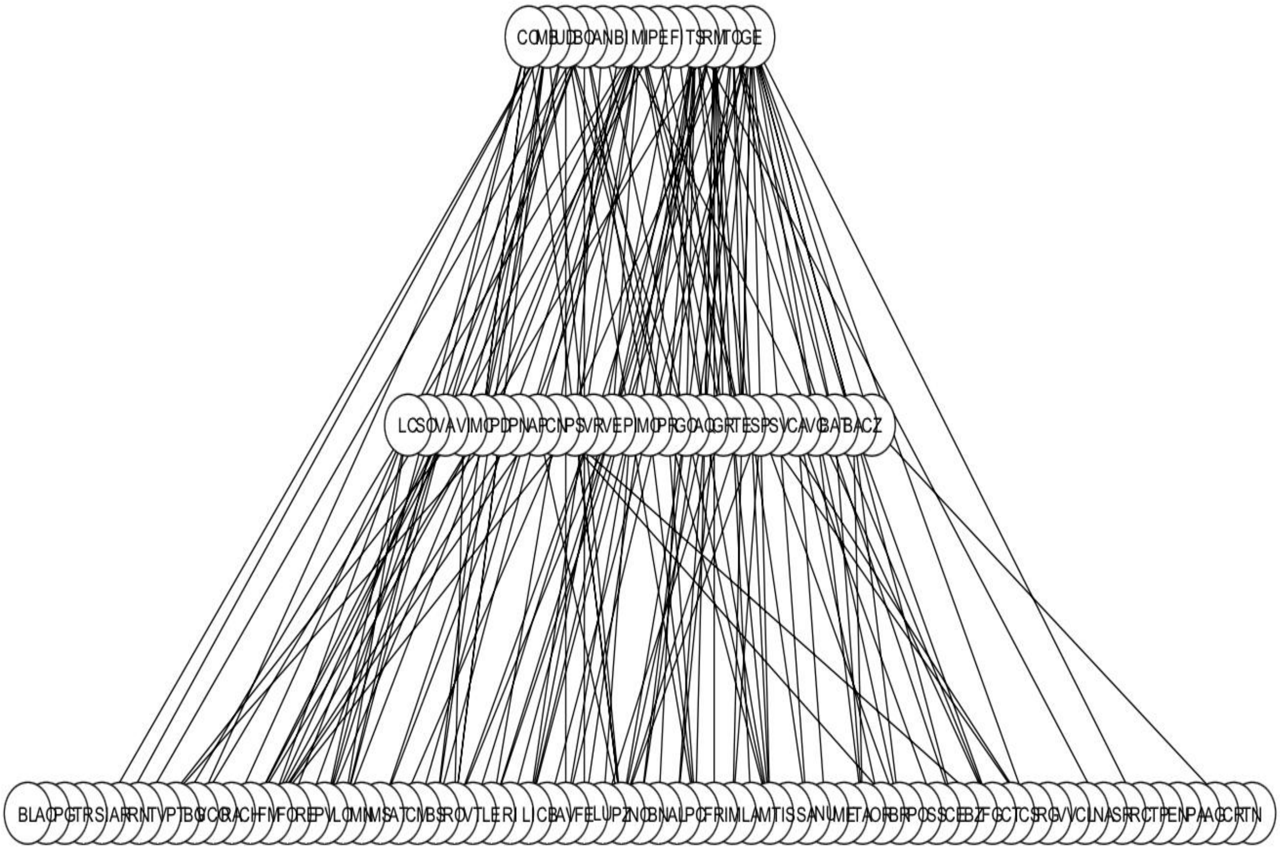
These results confirm a north–south divide consistent with prior analyses of territorial inequality and digital readiness in Italy. The regions of Emilia-Romagna, Veneto, and Lombardy consistently lead in the adoption of digital technologies, supported by strong educational and research systems. By contrast, southern and insular regions remain hindered by infrastructural and socio-economic barriers, highlighting the persistence of multi-scalar disparities.

This territorial segmentation mirrors findings in the European context, where the diffusion of digitainability often correlates with institutional capacity and investment in digital education (Campolucci, Compagnucci, & Spigarelli, 2024).

4.2. PoSet Analysis Results

The PoSet analysis provided a complementary, non-compensatory perspective on provincial rankings, illustrating how each territory performs across multiple dimensions of digitalisation and sustainability.
The Hasse diagram for all Italian provinces revealed numerous incomparable relationships, reflecting the structural complexity of territorial development. Rather than establishing a linear ranking, the PoSet approach exposes clusters of provinces that cannot be directly compared due to trade-offs between indicators.

Figure 6: Hasse Diagram of Italian Provinces Based on PoSet Analysis



Using the Matrix of Mutual Ranking Probabilities (MRP), an approximate probabilistic ranking was extracted. The top ten provinces were dominated by Macerata, Siena, Pordenone, and Venice, all displaying balanced performances across educational, infrastructural, and sustainability indicators.

Table 3: Top Ten Provinces by PoSet Dominance Vector and MRP Ranking

Code	Vector of dominance	Ranking
MC	0,1656	1
SA	0,1580	2
PO	0,1465	3
PN	0,1429	4
PI	0,1421	5
VCO	0,1336	6
VA	0,1281	7
TN	0,1209	8
VE	0,1075	9
SI	0,1033	10

These findings confirm that high digitainability is associated not only with economic development but also with the quality of human capital and the diffusion of digital competencies. In this sense, PoSet analysis provides a more nuanced understanding than conventional composite indices by identifying where strong sustainability outcomes coexist with relatively weaker digital infrastructures, and vice versa. Similar approaches have been adopted in comparative research on the digitainability of the European agri-food sector and regional innovation systems, where non-linear relationships dominate (Otter & Sauvée, 2025).

4.3. Discussion and Interpretation

The empirical evidence confirms that the digital and ecological transitions are deeply intertwined processes, mutually reinforcing but also context-dependent.

Northern provinces benefit from strong synergies between technological capacity and social infrastructure, while Southern and insular provinces show fragmented trajectories.

This pattern echoes the theoretical assumption that digitainability is not merely the coexistence of digitalisation and sustainability but their synergistic integration (Lichtenthaler, 2021). In this sense, the Italian case demonstrates that local systems capable of combining innovation, inclusivity, and environmental awareness achieve better outcomes.

The relevance of human capital is particularly evident. Education and digital competence indicators (ALP, ANC, PCE) exert a significant influence on the provincial rankings, consistent with the argument that digital literacy and lifelong learning are the backbone of sustainable digital transitions (Sá et al., 2021). Moreover, provinces leading in both digital and environmental indicators exhibit governance models that encourage mindful innovation, where technological progress is guided by ethical and ecological considerations (Gupta et al., 2023).

By contrast, the digitainability gap observed in lagging provinces underscores the need to strengthen digital infrastructures and educational systems, particularly in rural and peripheral areas. This aligns with findings from other sectors, such as the fashion industry, where the diffusion of digital tools for sustainable practices remains uneven (Gazzola et al., 2024).

Furthermore, the study confirms that achieving digitainability requires multi-level coordination between policy frameworks and societal actors. Universities and research centres, for instance, act as crucial mediators in translating innovation into sustainable outcomes (Spigarelli, Kempton, & Compagnucci, 2024).

Finally, the integration of AI-powered systems into green infrastructures - such as renewable energy and smart grids - illustrates the next frontier of digitainability. Recent studies have mapped how artificial intelligence optimises renewable energy supply chains, reinforcing digital–ecological synergies (Ghasemian Sahebi et al., 2025).

These insights substantiate the central hypothesis of the study: that digitainability is both a quantifiable territorial phenomenon and a strategic paradigm for sustainable transformation.

5. Limitations of the Study

While this study advances the understanding of digitainability at the subnational level, several methodological and conceptual limitations should be acknowledged. These limitations provide critical directions for refining future research and ensuring the robustness of comparative analyses across territories.

First, the data availability and spatial resolution constitute a primary limitation. The construction of the Digitalisation Index relied on datasets from ISTAT's BES and SDG indicators, some of which were only available at the regional level. In these cases, regional values were uniformly attributed to all provinces within the same region, introducing an assumption of homogeneity that may obscure intra-regional variation. Although this approach aligns with previous studies that adopt proportional distribution to harmonise territorial datasets, it inevitably reduces granularity.

Second, the temporal alignment of indicators represents another constraint. The dataset integrates information from different years (2020–2022), reflecting the asynchronous release of statistical data. As a result, the analysis offers a cross-sectional rather than longitudinal perspective. Future studies could enhance temporal comparability by constructing a time-series dataset to capture the dynamics of digitainability evolution.

Third, while the PoSet methodology provides an innovative, non-compensatory framework for multidimensional assessment, it also has inherent drawbacks. The identification of incomparabilities and dominance relations is highly sensitive to the selection and scaling of indicators. Moreover, PoSet analysis does not generate an absolute ranking or composite score, which can limit its communicative simplicity for policymakers unfamiliar with ordinal logic (Gupta & Rhyner, 2022).
Nevertheless, this methodological choice was deliberate, reflecting the study's aim to preserve the multidimensional integrity of the data.

A fourth limitation lies in the lack of behavioural and qualitative dimensions. The analysis focuses on measurable indicators such as education, connectivity, and digital skills, but does not incorporate attitudinal or institutional variables (e.g., governance quality, innovation culture, or civic participation).

These soft dimensions could significantly influence how digitalisation translates into sustainable outcomes (Shashi, 2022).

Integrating such qualitative aspects through mixed methods - combining surveys, interviews, or participatory evaluation - would enrich the explanatory power of future research.

Fifth, context-specific interpretations should be treated cautiously. The results primarily reflect the Italian socio-economic structure, characterised by marked regional disparities and a strong north–south divide. Thus, while the PoSet–cluster approach is transferable, its indicators and thresholds may require recalibration when applied to other national contexts. Comparative cross-country analyses could further test the generalisability of the digitainability framework (Gupta, Motlagh, & Rhyner, 2020).
Finally, it must be acknowledged that technological and sustainability indicators evolve rapidly. Advances in artificial intelligence, renewable energy integration, and smart infrastructure are redefining the contours of digital transformation (Ghasemian Sahebi et al., 2025).

Consequently, any empirical assessment risks partial obsolescence if not periodically updated with new metrics and technological benchmarks.
Despite these limitations, the chosen framework—integrating PoSet and cluster analysis—offers a transparent and replicable approach for mapping the complex, multidimensional nature of digitainability. Future research should build upon this foundation by expanding the dataset, incorporating qualitative dimensions, and adopting a dynamic, temporal perspective to trace trajectories of digital–sustainable co-evolution.

6. Policy Implications and Future Directions

The empirical findings of this study yield several policy implications that are critical for advancing digitainability in Italy and beyond. The evidence demonstrates that digital transformation and sustainable development are not parallel processes but mutually reinforcing dimensions of territorial well-being. Consequently, policymakers should adopt an integrated approach that aligns digital, environmental, and social objectives under a unified strategic vision.

6.1. Promoting Human-Centric and Inclusive Digitalisation

The first policy implication concerns the need to foster a human-centric approach to digital transformation. Provinces with stronger education systems and higher levels of digital competence exhibit superior digitainability performance, confirming that human capital is the cornerstone of sustainable innovation. In line with the Industry 5.0 paradigm, policies should emphasise not only technological advancement but also social inclusivity, ethical governance, and well-being (Campolucci, Compagnucci, & Spigarelli, 2024).

Education and lifelong learning programs should integrate digital sustainability literacy, equipping citizens and professionals to use technology mindfully and responsibly (Dovleac et al., 2023).

This entails embedding the principles of digitainability in school curricula, vocational training, and university programs to ensure that technological skills evolve alongside environmental and social awareness.

6.2. Addressing Territorial Disparities and Strengthening Local Capacities

The north–south divide identified in the results highlights the necessity for differentiated regional strategies. Lagging provinces require targeted investments in digital infrastructure, connectivity, and skills development. The Italian Piano Nazionale di Ripresa e Resilienza (PNRR) should prioritise territorial cohesion by directing funds toward peripheral areas where digitalisation can act as a lever for social inclusion and green employment.

Decentralised governance mechanisms are equally important. Empowering local administrations to design context-specific initiatives—such as digital hubs, smart municipalities, and community-based innovation labs—can accelerate the diffusion of sustainable digital practices.
This approach resonates with the principles of the Third Mission of universities, which advocate for stronger collaboration between academia, public institutions, and local enterprises in promoting socio-technical transitions (Compagnucci & Spigarelli, 2023).

6.3. Integrating Digital and Green Policy Frameworks

A third implication concerns policy coherence. Digitalisation and sustainability initiatives are often governed by distinct ministries, funding streams, and monitoring systems. This fragmentation limits their mutual reinforcement. To achieve genuine digitainability, Italy—and the European Union more broadly—should institutionalise cross-ministerial coordination mechanisms ensuring that digital investments also contribute to environmental and social targets.

The European Green Deal and the Digital Decade Policy Programme 2030 offer valuable frameworks for aligning digital and green goals. However, these strategies should be implemented through integrated performance indicators that measure not only the diffusion of technologies but also their contribution to sustainable well-being (Gupta et al., 2023).

Such integration could be supported by expanding the BES–SDG statistical framework at subnational levels, ensuring that local indicators capture both digital progress and sustainability outcomes. This would enable policymakers to monitor the multidimensional performance of territories and allocate resources more effectively.

6.4. Encouraging Responsible Innovation and Corporate Engagement

Private sector participation is essential to scaling up digitainability. Firms should be incentivised to adopt digital tools that enhance sustainability performance—such as energy-efficient production systems, circular supply chains, and transparent reporting mechanisms.

Empirical studies in the fashion industry demonstrate that integrating digital technologies with sustainability strategies fosters competitive advantage and corporate resilience (Gazzola et al., 2024).
Moreover, innovation policies should promote responsible entrepreneurship—that is, the development of digital solutions explicitly oriented toward environmental and social value creation. This aligns with recent work highlighting the role of universities in shaping the next generation of entrepreneurs within the digital humanities and sustainability domains (Spigarelli, Kempton, & Compagnucci, 2024).

6.5. Advancing Research and Data Infrastructure

Finally, advancing digitainability requires a solid empirical foundation. Statistical agencies and academic institutions should collaborate to develop dynamic data platforms capable of integrating real-time digital and sustainability indicators.

These systems could incorporate AI-based analytics to monitor the environmental impact of digital technologies and identify policy trade-offs in near real time. Emerging research in AI-driven energy systems provides valuable guidance on this front (Iman Ghasemian Sahebi & Kamali, 2025).
Future research should also explore the role of behavioural and cultural variables—such as digital trust, organisational learning, and social innovation—in mediating the relationship between digitalisation and sustainable well-being. By bridging technical and human dimensions, scholars can help refine the theoretical architecture of digitainability and its practical applications.

7. Conclusions

This study has explored the relationship between digitalisation strategies and sustainable well-being across Italian provinces through an innovative methodological framework combining PoSet analysis and hierarchical clustering. The proposed approach contributes to the emerging field of digitainability, offering a multidimensional lens for understanding how digital transformation and sustainability reinforce one another at the territorial level.

The findings reveal significant territorial heterogeneity. Northern and central provinces demonstrate higher levels of digitainability, driven by strong educational systems, robust digital infrastructures, and innovation ecosystems. In contrast, southern and island provinces lag behind, reflecting persistent disparities in socio-economic and technological development. These results underscore that digitalisation alone is insufficient: without investments in human capital and local governance capacity, the benefits of the digital transition remain unevenly distributed.

From a theoretical standpoint, the integration of PoSet and cluster analysis proved effective in capturing the complexity of multidimensional territorial data. Unlike traditional composite indices, this method respects ordinal relationships and identifies nuanced interdependencies between dimensions. It thereby provides policymakers with a more realistic representation of progress — one that recognises coexistence, trade-offs, and partial advancement rather than simplistic rankings.

In practical terms, the results emphasise the need for coherent and inclusive policy strategies. Investments in digital education, local innovation ecosystems, and environmentally sustainable infrastructures must proceed hand in hand. Territorial cohesion should become a cornerstone of national and regional policies, ensuring that all provinces benefit from the opportunities generated by digitalisation.

Furthermore, the study contributes to consolidating digitainability as a conceptual and operational framework. By linking quantitative indicators to strategic implications, it demonstrates that sustainable digital transformation is achievable when digital progress is guided by ethical, environmental, and social awareness — an idea already advanced in recent European literature on human-centred innovation and responsible digitalization (Lichtenthaler, 2021; Gupta & Rhyner, 2022).

Future research should extend this framework to longitudinal analyses, exploring how digitainability evolves over time, and to cross-national comparisons to assess its broader generalisability. Incorporating behavioural and institutional variables — such as governance quality, social trust, and digital participation — would also enrich the interpretive depth of future studies.

Ultimately, the study affirms that digitainability is not only a policy goal but a transformative paradigm for rethinking how societies balance technological progress with human and ecological well-being. Italy's case illustrates both the challenges and the potential of this transition — a journey where innovation becomes truly sustainable only when it remains profoundly human.

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Appendix A

Supplementary Figures and Tables

Cluster Analysis – Supplementary Materials

Figure 1. Average Silhouette Width Method for Cluster Validation.
This figure illustrates the average silhouette width across different cluster solutions, indicating the degree of cohesion within each cluster.

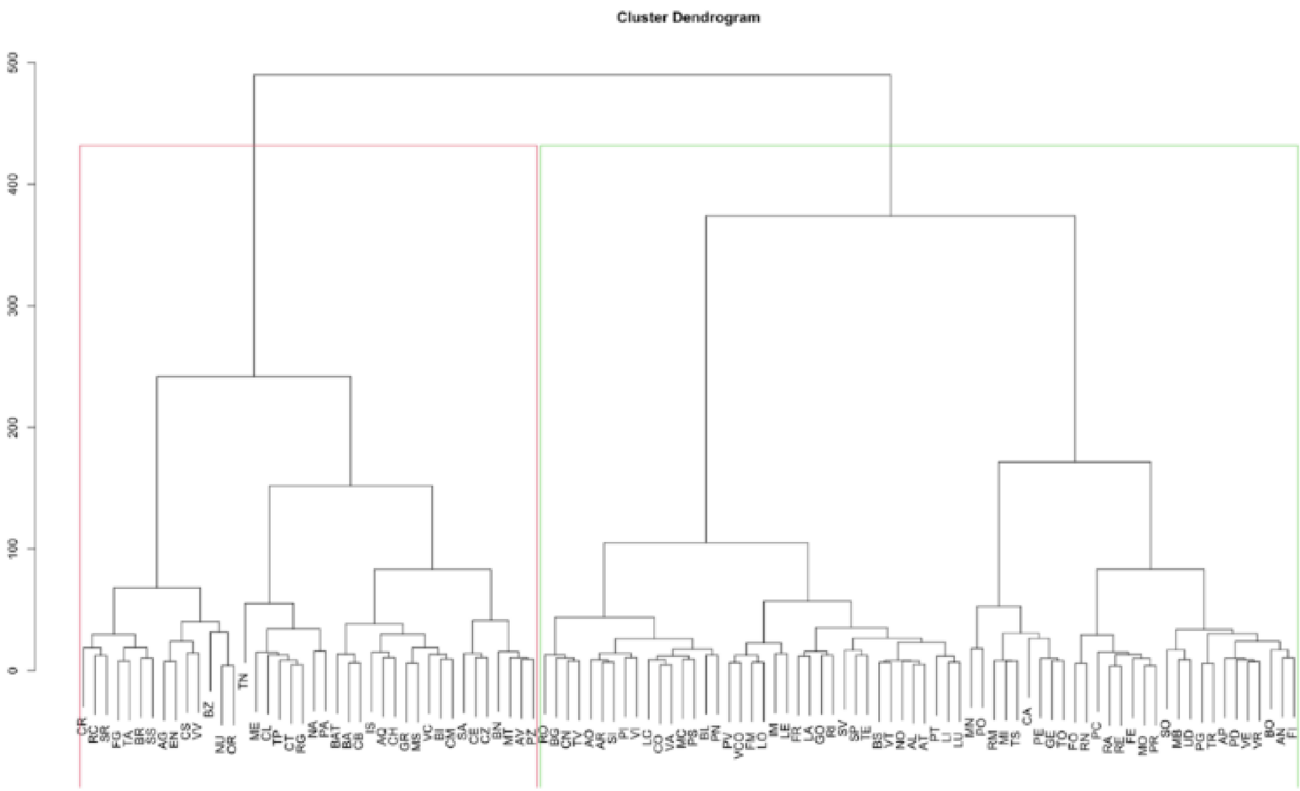


Figure 2. Within-Cluster Sum of Squares (WSS) for Optimal Cluster Selection.
The elbow point of the curve suggests the most appropriate number of clusters to represent the underlying data structure.

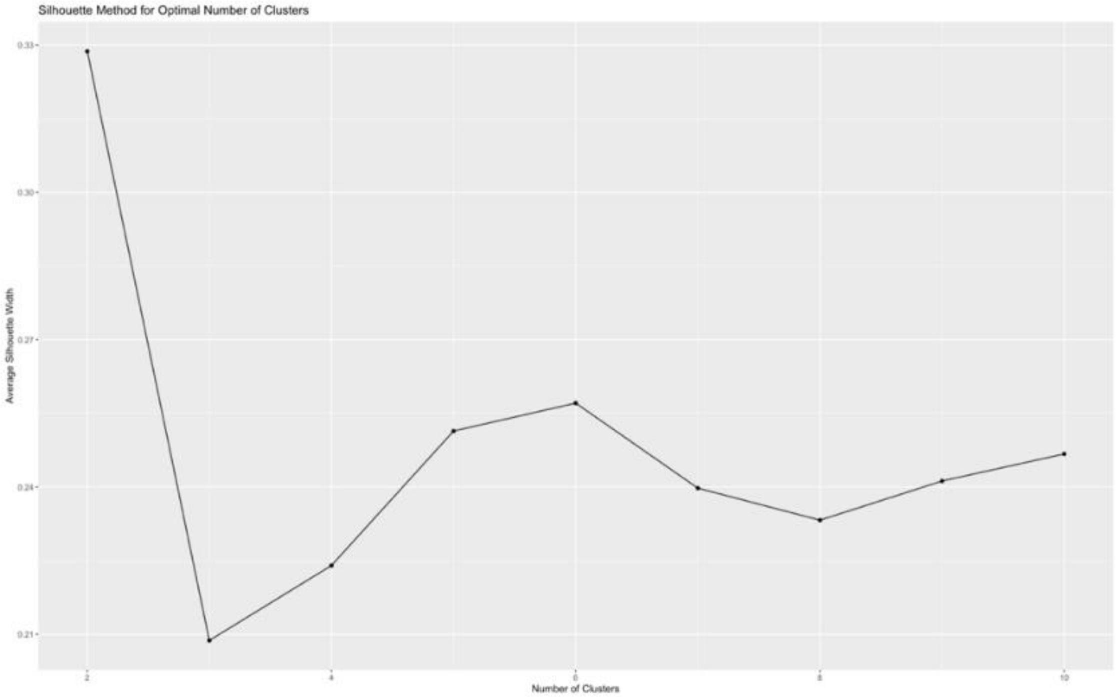
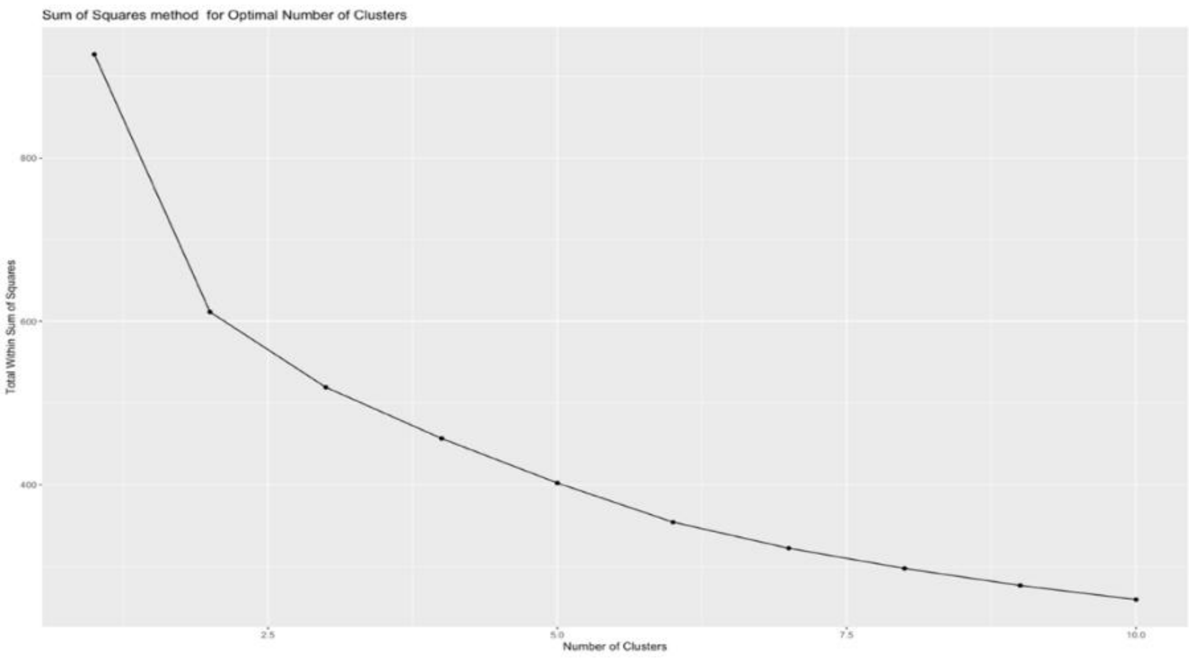


Figure 3. Silhouette Plot for Cluster Validation.
The silhouette plot visually confirms the adequacy of the six-cluster solution adopted in this study.



PoSet Analysis by Macro-Area (NUTS1)

Figure 7. Hasse Diagram for North-Western Italian Provinces.
The diagram shows the partial order relations among 21 provinces in the North-West macro-area.

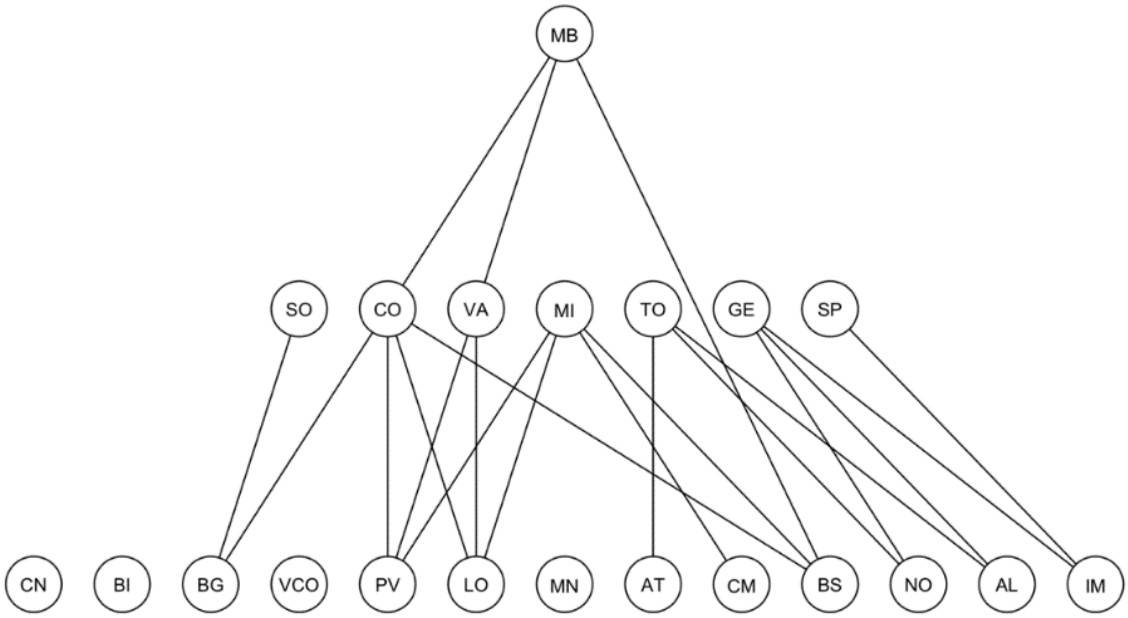


Figure 8. Hasse Diagram for North-Eastern Italian Provinces.
Ranking relations of 20 provinces based on PoSet analysis for the North-East macro-area.

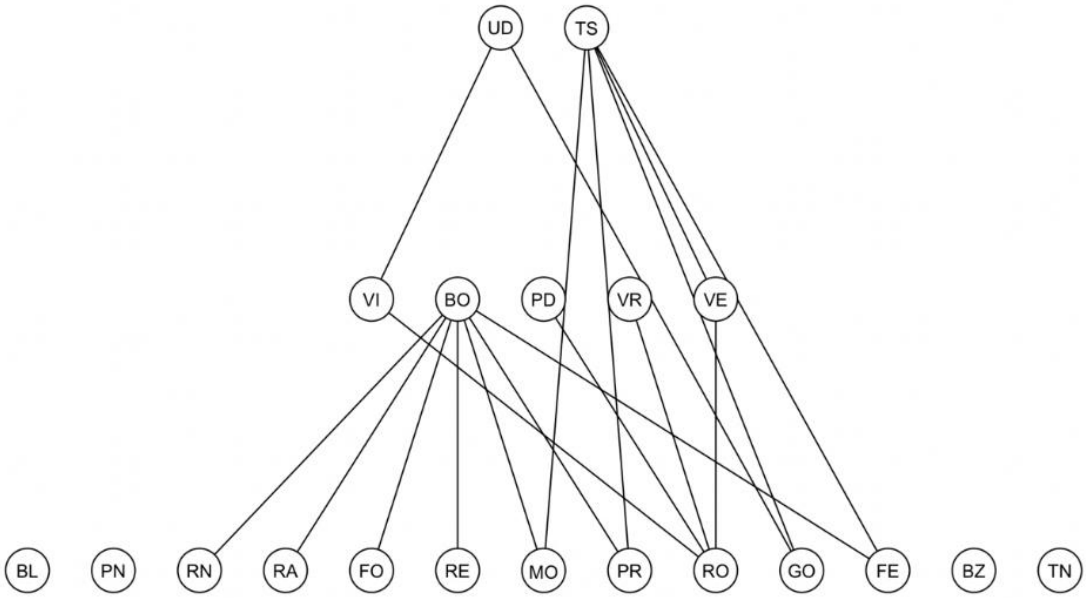


Figure 9. Hasse Diagram for Central Italian Provinces.
Visualization of hierarchical relations among 21 provinces in Central Italy.

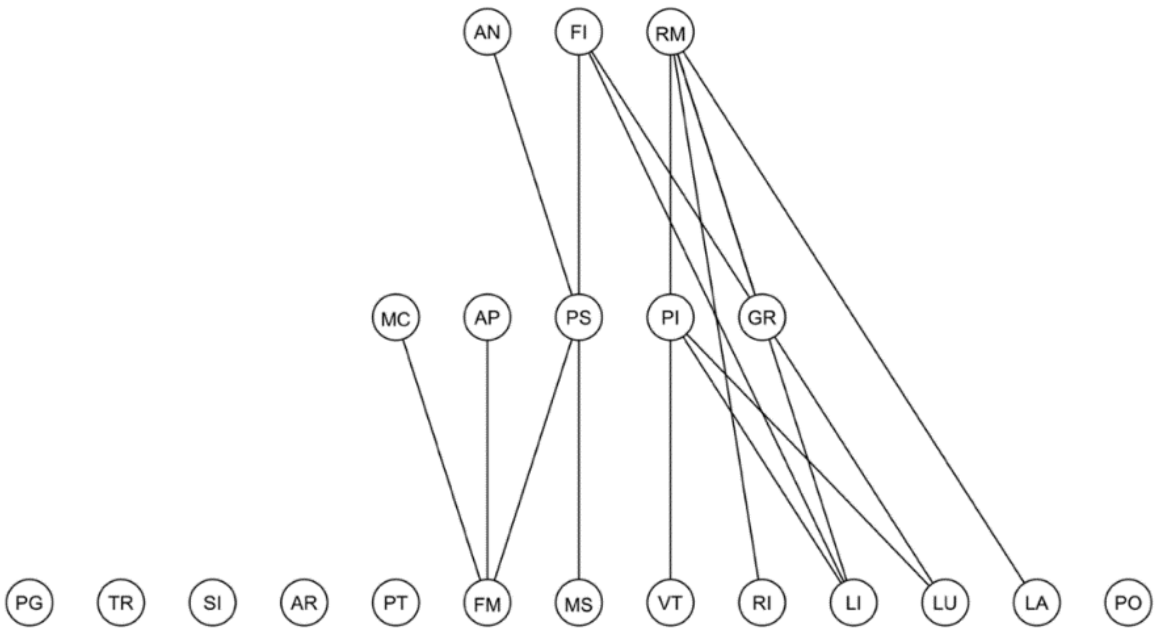


Figure 10. Hasse Diagram for Southern Italian Provinces.
Partial order representation for 23 provinces in Southern Italy, indicating dominance and incomparability patterns.

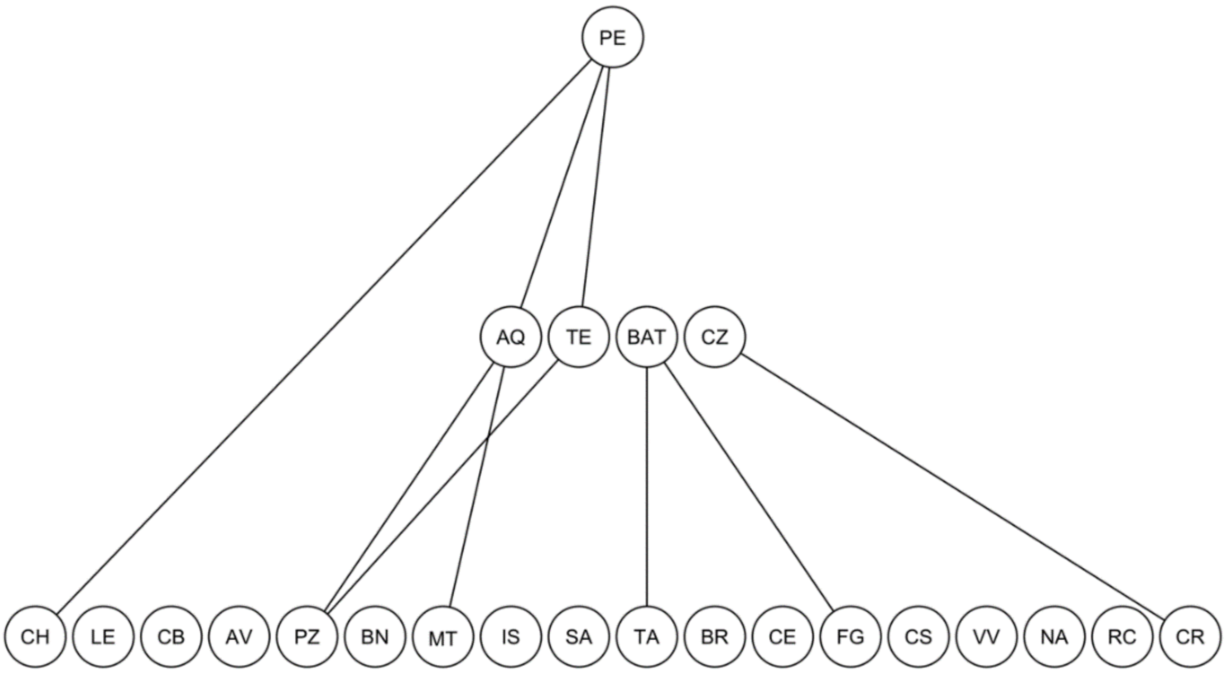
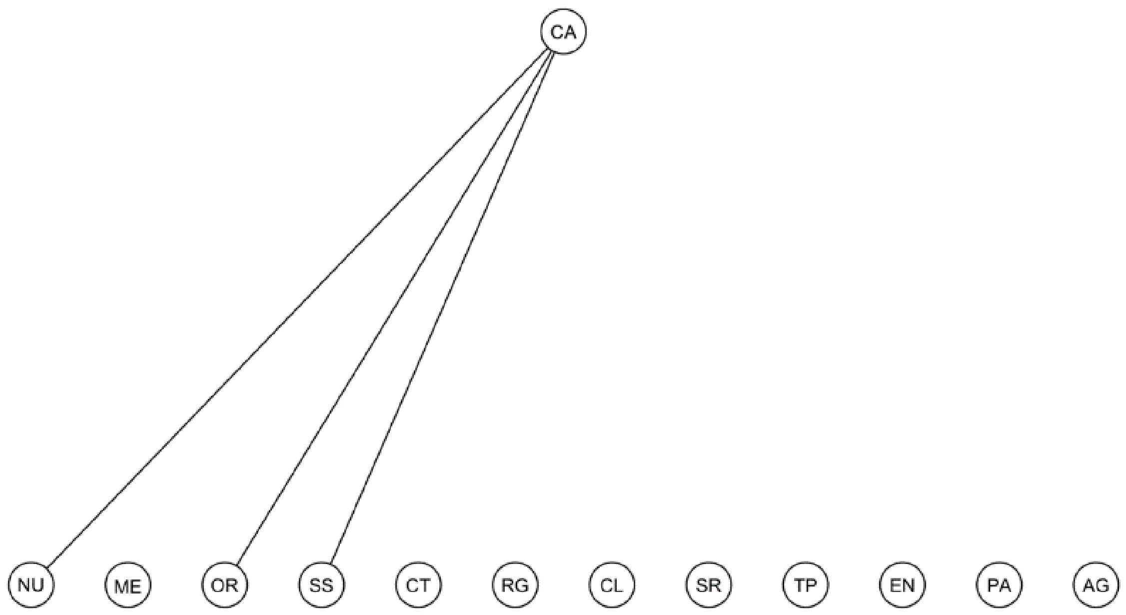


Figure 11. Hasse Diagram for the Islands (Sicily and Sardinia).
The diagram displays PoSet-based rankings of 13 provinces belonging to the Italian islands macro-area.



Provincial Rankings by Macro-Area

Table 5. Vector of Dominance and Ranking of the Italian Provinces in the North-West Zone.
PoSet results showing the relative position of 21 North-Western provinces.

CODE	VECTOR OF DOMINANCE	RANKING
TO	0,3152	1
NO	0,2979	2
MB	0,2901	3
BS	0,2871	4
VA	0,2758	5
SP	0,2385	6
VCO	0,2373	7
BI	0,2365	8
GE	0,2079	9
MI	0,2079	10
PV	0,2079	11
SO	0,2079	12
CN	0,1906	13
CO	0,1878	14
BG	0,1640	15
AT	0,1640	16
MN	0,1604	17
AL	0,1544	18
CM	0,1486	19
IM	0,1232	20
LO	0,1232	21

Table 6. Vector of Dominance and Ranking of the Italian Provinces in the North-East Zone. Results of the PoSet ranking for 20 North-Eastern provinces.

CODE	VECTOR OF DOMINANCE	RANKING
UD	0,3536	1
PN	0,3374	2
VI	0,2881	3
RN	0,2247	4
TS	0,2247	5
RA	0,2144	6
TN	0,2110	7
BL	0,2110	8
BO	0,2110	9
VR	0,2110	10
PD	0,2059	11
PR	0,2059	12
RE	0,2059	13
RO	0,2059	14
VE	0,2022	15
BZ	0,1893	16
GO	0,1893	17
MO	0,1893	18
FE	0,1730	19
FO	0,0724	20

Table 7. Vector of Dominance and Ranking of the Italian Provinces in the Central Zone. Ranking results for 21 provinces in Central Italy.

CODE	VECTOR OF DOMINANCE	RANKING
LU	0,3389	1
PG	0,3093	2
PS	0,2629	3
MC	0,2598	4
RI	0,2280	5
TR	0,2280	6
RM	0,2094	7
PI	0,2094	8
PT	0,2094	9
SI	0,2094	10
VT	0,2094	11
AN	0,2094	12
GR	0,2037	13
PO	0,2020	14
AP	0,2017	15
FM	0,2017	16
LA	0,2017	17
LI	0,1931	18
FI	0,1482	19
AR	0,1164	20
MS	0,0936	21

Table 8. Vector of Dominance and Ranking of the Italian Provinces in the Southern Zone. Dominance vectors and ranking values for 23 Southern Italian provinces.

CODE	VECTOR OF DOMINANCE	RANKING
VV	0,3300	1
LE	0,2947	2
CE	0,2649	3
TA	0,2512	4
RC	0,2251	5
BAT	0,2022	6
BN	0,2022	7
BR	0,2022	8
CZ	0,2022	9
FG	0,2022	10
MT	0,2022	11
PE	0,2022	12
PZ	0,2022	13
SA	0,2022	14
CH	0,2022	15
CR	0,2022	16
AV	0,2022	17
TE	0,1775	18
CS	0,1574	19
CB	0,1574	20
AQ	0,1413	21
IS	0,1321	22
NA	0,1051	23

Table 9. Vector of Dominance and Ranking of the Italian Provinces in the Islands Zone. Ranking results for the 13 provinces belonging to Sicily and Sardinia.

CODE	VECTOR OF DOMINANCE	RANKING
TP	0,4232	1
AG	0,2726	2
CL	0,2726	3
CT	0,2726	4
EN	0,2726	5
ME	0,2726	6
NU	0,2726	7
OR	0,2726	8
SR	0,2726	9
CA	0,2726	10
SS	0,2253	11
PA	0,2253	12
RG	0,2253	13