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Contributions of the configurational approach to territorial imbalances' mapping:

A discussion centred on the Italian cohesion strategy

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ABSTRACT

The European Union's territorial expansion has brought to light the existence of regions characterised by uneven development and asymmetric connections to primary infrastructure networks. In particular, the so-called 'Inner Areas' cover around 60% of the Italian territory and the national cohesion strategy (SNAI) targeting them was developed to combat marginalisation and demographic decline, while enhancing resilience, adaptation to climate-change, and risk mitigation. Nevertheless, its primary focus on service and infrastructure marginality overlooks broader socio-spatial indicators, particularly resources' accessibility and use of different mobility modes, hindering its effectiveness. Within this framework, the paper discusses the potential contributions of the configurational approach to mapping territorial accessibility levels through its application to the Italian case. Specifically, it proposes and tests the use of a configuration-informed composite index for territorial imbalances' mapping, the 'S^3*NAI'. The proposal is rooted in a nationwide Space Syntax Angular Segment Analysis performed on primary-roads elements; whence the Normalised Angular Integration, at global and local metric radii, is employed to assess municipalities' ease of access, accounting for transport network efficiency and connectivity from a human-centred perspective. This aims to move marginality assessments beyond issues of geographical distance and travel-time to include more clearly the social and economic perspective in them. On this basis, the adoption of the configurational approach in mapping marginalities is proposed to enrich and inform the development of national- and regional-level territorial cohesion strategies.*

KEYWORDS

Territorial Imbalances, Configurational Approach, Territorial Cohesion, SNAI, Sustainable development

1 INTRODUCTION

The expansion of the European Union has brought attention to the presence of 'inner peripheries', i.e. regions characterised by uneven development and asymmetric infrastructure connections (Oppido et al., 2020). According to ESPON (2017), 45% of the EU territory falls under one of four delineations related to territorial marginality. Given the scale of this issue, improving territorial cohesion has become a pressing concern for the EU and its countries. Italy, in particular, grapples with significant socio-spatial disparities, with an estimated 60% of the national territory classified as 'inner areas' (Dipartimento per lo Sviluppo e la Coesione Economica, 2013). The Italian National Strategy for Inner Areas (lit. *Strategia Nazionale per le Aree Interne*), henceforth named as SNAI, is a policy based on a spatial classification done to highlight territorial differences within Italy and combat marginalisation and demographic decline, while enhancing resilience, adaptation to climate-change, and risk mitigation, in line with the 2021 National Recovery and Resilience Plan.

While the SNAI is considered a timely and innovative planning instrument, certain methodological and implementation issues have hindered its effectiveness (Esposito De Vita et al., 2020; Carrosio, 2020): its primary focus on service and infrastructure marginality overlooks broader socio-spatial indicators, and particularly resources' accessibility and use of different mobility modes. Consequently, studies have scrutinised and criticised the SNAI classification (Vendemmia et al., 2022) and its further project areas selection (Rossitti et al., 2021), also proposing supplementary solutions to support marginality assessment (Trovato and Nasca, 2022, Moretto et al., 2022, Marucci et al., 2020, Corrado and Sforza, 2022). Pre-existent methodological flaws also survived the 2021-2027 SNAI technical review, which mainly targeted incorrect assumptions regarding the alleged centrality of local administrative centres (Dipartimento per le Politiche di Coesione e del Sud, 2022). Indeed, the above classification consists of two main steps: first, the identification of those municipalities that are poles (A) or intermunicipal poles (B), according to their capacity to offer certain essential services (i.e., secondary education provision, first level hospitals with emergency department acceptance, and platinum, gold, or silver railway stations); second, the division of the remaining municipalities into belt (C), intermediate (D), peripheral (E) and ultraperipheral (F) areas, resting on an accessibility indicator measured in minutes of travel needed to reach the nearest pole. The so called 'inner areas' are the latter three categories of municipalities, respectively according to three commute timeframes (i) from the poles: 20'< i ≤ 40', 40' < i ≤ 75', and i > 75' (Dipartimento per lo Sviluppo e la Coesione Economica, 2014).

The current classification does only partially consider the impact of infrastructure endowments on territorial marginality mapping and may benefit from the integration of measures reflecting locations' relative accessibility logic. The identification of fragile territories is indeed a multiscalar problem that cannot account only for the infrastructure-side spatial imbalance, as highlighted by the forthcoming results of the research of national interest B4R-Branding4Resilience (Ferretti et al., 2022): achieving a comprehensive understanding of the extent and nature of existing territorial imbalances is crucial for strategic planning, and for prioritising the allocation of economic investments to specific areas (Chioni et al., 2023).

Starting from the need for differentiated mapping at different scales with scale-targeted policies, this research – which stems from an international and interdisciplinary collaboration – illustrates how the configurational approach can contribute to a more comprehensive mapping of territorial accessibility levels in these areas. Specifically, it proposes and tests, through a pilot case study, the use of a configuration-informed composite index for territorial imbalances' mapping, which we call 'S^{3}NAI'; the proposal is rooted in a nationwide Space Syntax Angular Segment Analysis (ASA) of the Italian peninsula, including Sicily and Sardinia islands.

Section 2 of the paper presents the theoretical framework of the research, while section 3 provides an overview of the background of the empirical research and analysis methods used to tackle the problem in focus. The results of the paper are presented in section 4, followed by discussion on the outcomes and the conclusion of this pilot study, delineating the future directions of its development, in section 5.

2 THEORETICAL FRAMEWORK

This section presents the theoretical foundations of this study, with a focus on the principles underpinning the integration of spatial configuration properties in mapping territorial imbalances. Particularly, it explains how incorporating these properties enables consideration of two key aspects: network properties of road-infrastructure related to accessibility levels' variations at different scales (Section 2.1); and the hierarchical significance of different elements within the road-circulation network based on their configurational properties (Section 2.2). These dimensions are notably absent in both the former and the current SNAI classifications (Dipartimento per le Politiche di Coesione, 2023), which seems to mainly rely on simple isochronic distance for classification purposes (Dipartimento per lo Sviluppo e la Coesione Economica, 2014, pp. 1–2, Dipartimento per le Politiche di Coesione e per il Sud, 2022, pp. 7–9), despite the evident variations in road-network properties across different parts of Italy.

2.1 Accessibility models and the configurational approach

In urban planning, the term accessibility can be applied to the study of different spatial issues, encompassing housing, land use, and/or transportation. Each lending itself to the use of specific accessibility assessment models (e.g., utility-based, gravity-based, cumulative, and graph theory) describing accessibility in different ways, both conceptually and numerically. For instance, cumulative (or isochronic) models, often used in minute-city mapping (Pezzica et al., 2024), quantify accessibility by considering the number of activities that can be reached from a specific location within a defined distance radius. When they focus on a specific urban function (e.g., employment), these measure accessibility as the distance between a location and the nearest relevant activity. Conversely, graph theory models, such as Space Syntax ones, provide an empirical understanding of accessibility as a (weighted) indicator of spatial separation; presenting a special instance of the geometric accessibility formulation introduced by Jiang et al. (1999). Though this interpretation is not inherently tied to physical urban form, as discussed by Dupuy and Stransky (1996), this assumption may still be applicable when the graph faithfully represents a physical network system. Additionally, a parallel between 'being central' and 'being accessible' is established for nodes in a graph representation; based on the idea that both direct and indirect links to a (road) element determine the ease with which this location can be accessed by all other points in the same system (Batty, 2004). Notably, akin to accessibility, centrality is known to be a multidimensional property and resource of a street network (Crucitti et al., 2006), subject to examination in terms of its uniform or diverse distribution within an urban system. The latter approach seems better aligned with the requirements of our proposed nation-wide accessibility analysis as it enables the calculation of both integral and relative accessibility values. Therefore, this study leverages Space Syntax network centrality indices to measure variations in street network accessibility levels.

2.2 Analysis metrics and spatial hierarchies

According to the literature, certain spatial configuration metrics directly correlate with the distribution of movement flows and land use (Altafini et al., 2021, Kim and Sohn, 2002, Lee et al., 2009). This correlation was found to be particularly evident between street network centrality values, and the spatial arrangement of amenities and economic activities within a given area (Hillier, 2007, Altafini and Cutini, 2021).

Measures from Space Syntax, such as Normalised Angular Integration (NAIN) and Normalised Angular Choice (NACH), calculated at both global and local metric radii, can thus be used to assess the accessibility of locations to amenities, employment opportunities, health and education services, cultural activities, and green spaces. This approach accounts for transport network efficiency and connectivity from a human-centred perspective, aiming to move marginality assessments beyond issues of geographical distance and travel-time and explicitly include social and economic perspectives (Pezzica et al., 2022, Altafini, 2022). Hence, studying street network centrality patterns helps unveiling territorial hierarchies, thereby prompting a more nuanced mapping and interpretation of territorial imbalances, which can reduce current gaps in territorial disparity assessments.

Notably, some recent studies have leveraged configurational centrality metrics to gauge territorial imbalances at the urban-, regional- and national- scales, providing insights for disaster-resilient spatial planning (Pezzica et al., 2022, Cutini and Pezzica, 2020). Within the context of this research, considering these hierarchical relationships as an additional weight in the mapping of inner areas, means distinguishing among areas with an unequal distribution of infrastructure and thus also questioning the SNAI classification into poles of some local administrative centres, especially in central and southern Italy. Which can provide valuable information to guide the allocation of resources in levelling up policies aimed at fostering equitable development. Therefore, the adoption of the configurational approach in mapping marginalities is here proposed to enrich and inform the development of national- and regional-level territorial cohesion strategies.

3 MATERIALS AND METHODS

To illustrate how the configurational approach can contribute to an index of territorial accessibility, this study employs a combination of datasets, specifically integrating the Italian road-circulation network and the SNAI territorial categorisations.

The road-circulation network data, sourced from the OpenStreetMap (OSM) geodata repository, comprises a Road-Centre Line (RCL) (Turner, 2005, Turner, 2007, Turner, 2009) representation of the entire Italian road-system (Figure 1a). Recognising the constraints associated with processing large or complex graphs within reasonable time-lapses (Altafini and Cutini, 2020a, Altafini and Cutini, 2020b), the size of the original dataset was reduced as a pre-processing measure. This entailed a filtering process, retaining only road-elements categorised as motorways and trunks (i.e., highway-based structures), primary-roads, and their respective links. This step helped reducing the network size by 95.9%, shrinking it from 4,986,094 to 202,141 road-elements. Despite this, the reduced road-network retains the primary connections between urban areas on a national scale, depicting their overall urban grid structure and size differences (Figure 1b).

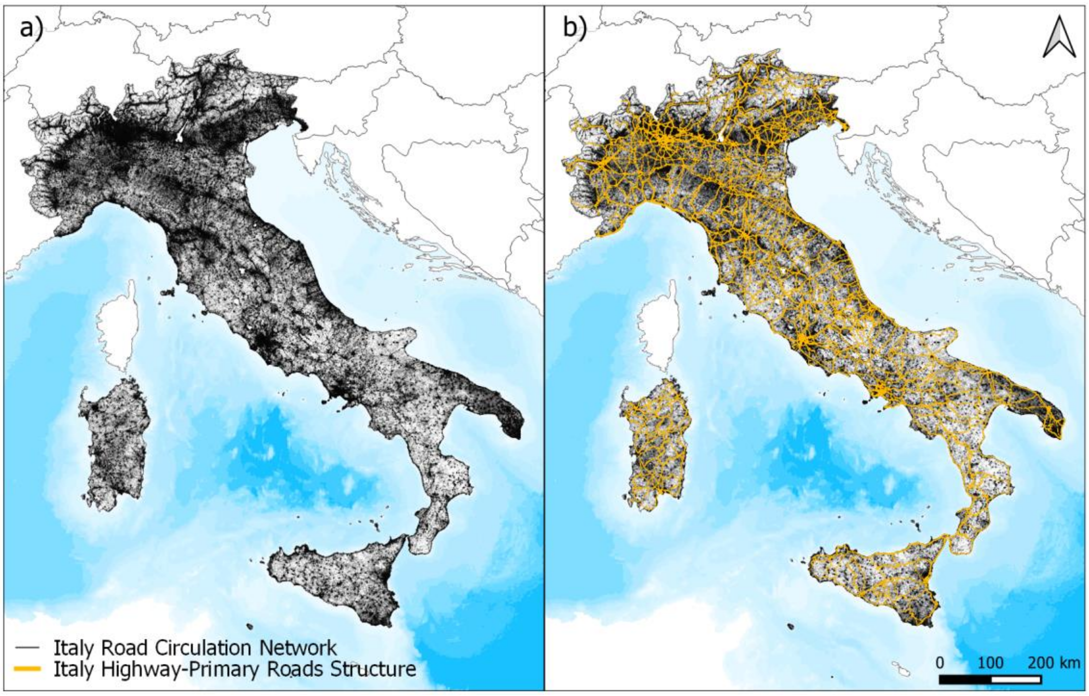

Figure 1: Analysis dataset – road-circulation network from OSM (2023): a) original database; b) subset comprising only highway structures, primary-roads and links.

From this reduced network, three separate road-systems were extracted, comprising the Italian mainland and the islands of Sicily and Sardinia; however, smaller islands were omitted from the analysis. The resulting graphs were then subjected to a geometric simplification process in QGIS (Hacar et al., 2024), to further reduce the number of nodes, given the extensive processing time still required in DepthMapX 0.8 (2020). Indeed, performing an Angular Segment Analysis on highly detailed networks can become rather time-consuming. This is due to the default preset used for the required initial angular segmentation known as *tulip bins* (1024) (Turner, 2001), which results in an exponential increase of road-elements to be processed. Notably, in Italy's original OSM RCL dataset, this angular segmentation increases the count from 4,986,094 to a staggering 54,968,723 road elements. This, coupled with the mean depth calculation algorithm, which has a *big O complexity score* equal to O(n2) (Turner, 2004, p. 17), can lead to an extensive computing time for estimating configurational centrality metrics. Following the initial simplification, the pre-processed dataset was converted to a .dxf format and imported into DepthMapX 0.8.

Given the focus of this work on to-movement accessibility, the empirical research was restricted to the analysis of *Angular Integration* values, in their normalised version (Hillier et al., 2012). This choice allowed the separate analysis of the Italian mainland, Sicily and Sardinia road-networks, facilitating comparisons among systems of different sizes. Normalized Angular Integration (NAIN) was calculated at a global radius (Rn) and for three metric radii: 10km (R10k), 20km (R20k), and 30km (R30k). The formula and theoretical explanation of NAIN, both for Rn and metric radii, can be found in Table 1, while the analysis results are presented in Figure 3. Notably, these three metric radii were strategically selected to align with the three commute timeframes considered in the construction of the SNAI index (Table 2). Moreover, these radii – particularly the 30km radius – are also discussed by Berghauser Pont and Haupt (2023) as guidelines for density analysis of urban areas at regional scales.

Table 1: Angular Segment Analysis' NAIN definition.

Metric	Radius	Concept	References
Normalized Angular Integration (NAIN)	$NAIN_{Rn} = \frac{Node\ Count^{1.2}}{Total\ Depth}$	Measures the farness between elements in a network; in Space Syntax, it denotes the relative accessibility or the movement potential (to-movement) of a road-element, informing how close – in topological terms – or central a road-element is in relation to all others in the system.	Bavelas, 1950 Sabidussi, 1966 Hillier, 2007 Hillier et al., 2012 Yamu and Van Nes, 2017 Van Nes and Yamu, 2021
	$NAIN_{Rmetric} = \log(Angular\ Int.) + 2$	At a metric radius, NAIN can indicate the spatial hierarchies of relative accessibility, movement potentials and, the density of road-elements in the network; it highlights the urban centres' distribution and weight within a region; different radii capture urban areas with different weights.	

Table 2: Metric radii and their corresponding SNAI travel timeframe ranges, colour-coded classes and decompositions.

Radius	R10k			R20k	R30k	Rn
Timeframe	*i* ≤ 20'			20'< *i* ≤ 40'	40' < *i* ≤ 75'	i > 75'
SNAI Classes	Pole (A)	Intermunicipal Pole (B)	Belt (C)	Intermediate Area (D)	Peripheral (E)	Ultraperipheral (F)
	Centres			**Inner Areas**		
Numerical Classes	5	4	3	2	1	0

Once retrieved, the ASA results were imported into QGIS (2024) for visualisation purposes and to combine them with the SNAI datasets. Given the focus of the SNAI classification on both local and regional scales, and its application of equal rules for both mainland and island areas in the classification process, the NAIN values of road-elements in Sicily and Sardinia were ranked and colour-coded based on each system's relative minimum and maximum values. Consequently, each system was treated as a distinct entity (see Figure 3a); however, for the sake of comparison, Figure 3b illustrates how NAIN values would rank against those of the Italian mainland systems, if weighted accordingly to the same depth.

The SNAI datasets comprise a spatial classification of the Italian inner areas, organised according to a mosaic of the Italian municipalities' boundary areas. These datasets cover two periods: 2014-2020 (first index iteration) and 2021-2027 (latest index iteration). They were both sourced from the website of the Italian Department for Cohesion Policies and the South (2023), the former Department of Economic Development and Cohesion (Figure 2). It is noteworthy that, while the SNAI 2014-2020 dataset (Figure 2a) was complete, with all municipalities categorised having an associated index data, the SNAI 2021-2027 dataset (Figure 2b) only included data for the administrative areas where changes in categorisation occurred compared to the first index iteration. So, spatialising the 2021-2027 SNAI classification in QGIS for the proposed study required merging both datasets to fill in missing data.

Following this, the configurational analysis data were associated to the SNAI classification mosaic using the 'Join Attributes by Location' function in QGIS. A summary was generated to compute the mean and median NAIN values for the road-elements that intersected each SNAI area, for each of the considered radii (Rn, R10k, R20k, R30k). Since the mean and median NAIN values presented negligible differences, only the mean NAIN values were used for the merge. These results were then standardised within a range of 0 to 1 and binned into 6 classes (0 to 5), using the natural-breaks statistical division method (see Figures 4-6). This allowed for an equivalence to the 6 ranges established in the SNAI index classification. In turn, the 2021-2027 SNAI index classification was converted into numerical values ranging from 0 to 5 to allow combining data from both datasets (Table 2).

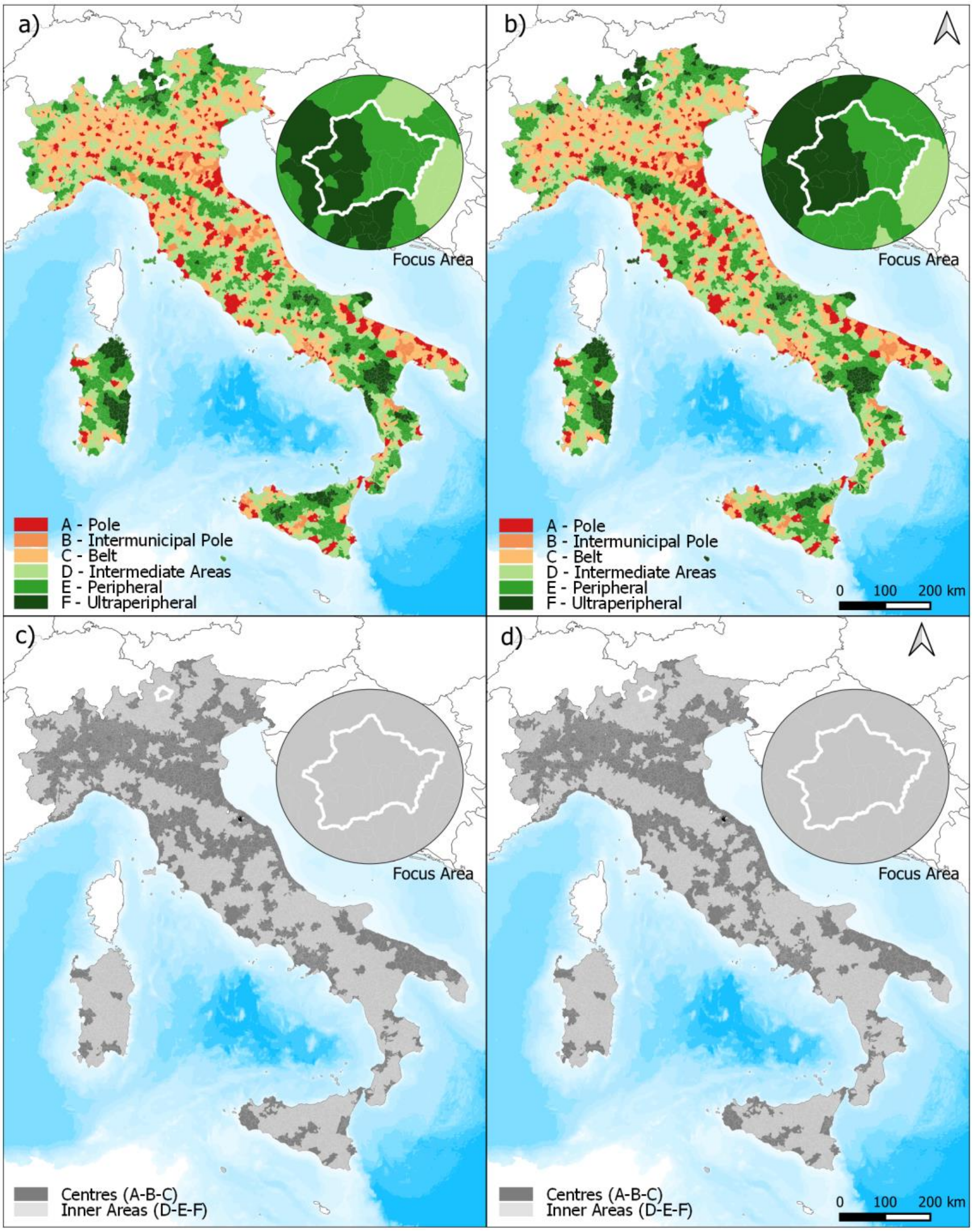

Figure 2: Nationwide picture gallery showing: the 2014-2020 (a) and the 2021-2027 (b) SNAI index categorisations of the Italian municipalities; and the Italian Centres-Inner Areas distribution for the 2014-2020 (c) and the 2021-2027 (d) periods. In the zoom, a focus area corresponding to the Val di Sole inner area.

All the above geoprocessing steps finally culminated in the creation of a composite inner areas index that integrates Space Syntax configurational patterns within the classification of territories to establish differences between centres and peripheries. This combined index is henceforth called 'S^3NAI' index, recalling the fusion of Space Syntax (SS) and SNAI classifications. The S^3NAI index is parametric in nature, constructed by adding the six classes of the SNAI index to the 6 classes of the standardised mean NAIN values. The resultant values are then standardised between 0 and 1 and ranked accordingly.

It is important to mention that certain SNAI areas lacking mean NAIN values – set as 'NULL', indicating that no road-infrastructure within the defined parameters intersects the territory – are defaulted to 0. Considering this, and for exploration purposes, two versions of the S^3NAI index were computed: one incorporating all radii, S^3NAI_g 'Rn' (Eq. 1), and another considering only the three selected metric radii, S^3NAI 'No-Rn' (Eq. 2).

$$S^3NAI_g = SNAI_{2021-2027} + \bar{x}NAIN\ R_n + \bar{x}NAIN\ R_{10k} + \bar{x}NAIN\ R_{20k} + \bar{x}NAIN\ R_{30k} \text{ (Eq. 1)}$$

$$S^3NAI = SNAI_{2021-2027} + \bar{x}NAIN\ R_{10k} + \bar{x}NAIN\ R_{20k} + \bar{x}NAIN\ R_{30k} \text{ (Eq. 2)}$$

The rationale behind omitting the contribution of $\bar{x}NAIN\ Rn$ in Eq. 2 is to adopt a more locally focused approach, which better aligns with the policy objectives of the SNAI. Indeed, the results reveal that its inclusion tends to disproportionately weigh the index towards SNAI areas located in northern Italy, where the highest centrality values at Rn are concentrated (refer to Figure 3). Nevertheless, retaining the contribution of $\bar{x}NAIN\ Rn$ in the S^3NAI_g (global) index, highlights a significant disparity in road-infrastructure density between the north and south of the country, which is relevant for a broader discussion on territorial imbalances in the context of Italy.

4 RESULTS

The qualitative visual assessment of maps illustrating the variations of configurational indicators provides a basis for interpretating the analysis results. This approach also facilitates the inclusion of planning-oriented considerations concerning the presence of natural and cultural assets, and the social fabric, within specific regions, as shown in Figure 9. In its most straightforward application, this approach implies that street network data can be used to rapidly produce figure-ground maps, echoing a tradition initiated by Nolli's 1748 map of Rome. These visual representations enable initial qualitative assessments, offering insights into the coarseness, griddedness, and permeability of street networks. Additionally, as highlighted by Boeing (2019), they become powerful tools for communication and public engagement, conveying complex urban planning and urban data science concepts in a simplified manner. Thus, the interconnectedness of qualitative and quantitative dimensions, explored through map visualisations and their visual assessments, is leveraged to offer a nuanced interpretation of our analysis results, as presented in what follows.

4.1 Angular Segment Analysis results

Figure 3 illustrates the distribution of NAIN values obtained in the national-level ASA. Specifically, both the NAIN Rn maps highlight a significant difference in relative accessibility values' distribution between northern and southern Italy. Centrality cores are predominantly situated in cities like Turin, Milan, Venice, Bologna and Florence, located in the northern and central regions of the country, with limited reach towards the capital, Rome. In these regions, pockets of segregation are present, particularly near Trento on the northern border with Austria (the Trentino-Alto-Adige area) and between the cities of Genova and Bologna (Figure 3a). Important southern urban centres such as Naples and Bari exhibit lower to-movement potential within the national system. Notably, Calabria, the southmost mainland region facing Sicily, stands out as spatially segregated due to its position as the endpoint of the Italian road-network. Equally, several regions in central Italy, such as Abruzzo and Molise, to the east of Rome, appear segregated, as denoted by their lower relative accessibility values (Figure 3a). This spatial arrangement reflects the present, and lingering, contrast between a developed north and an underdeveloped south within Italy's mainland (Bagnasco, 1977).

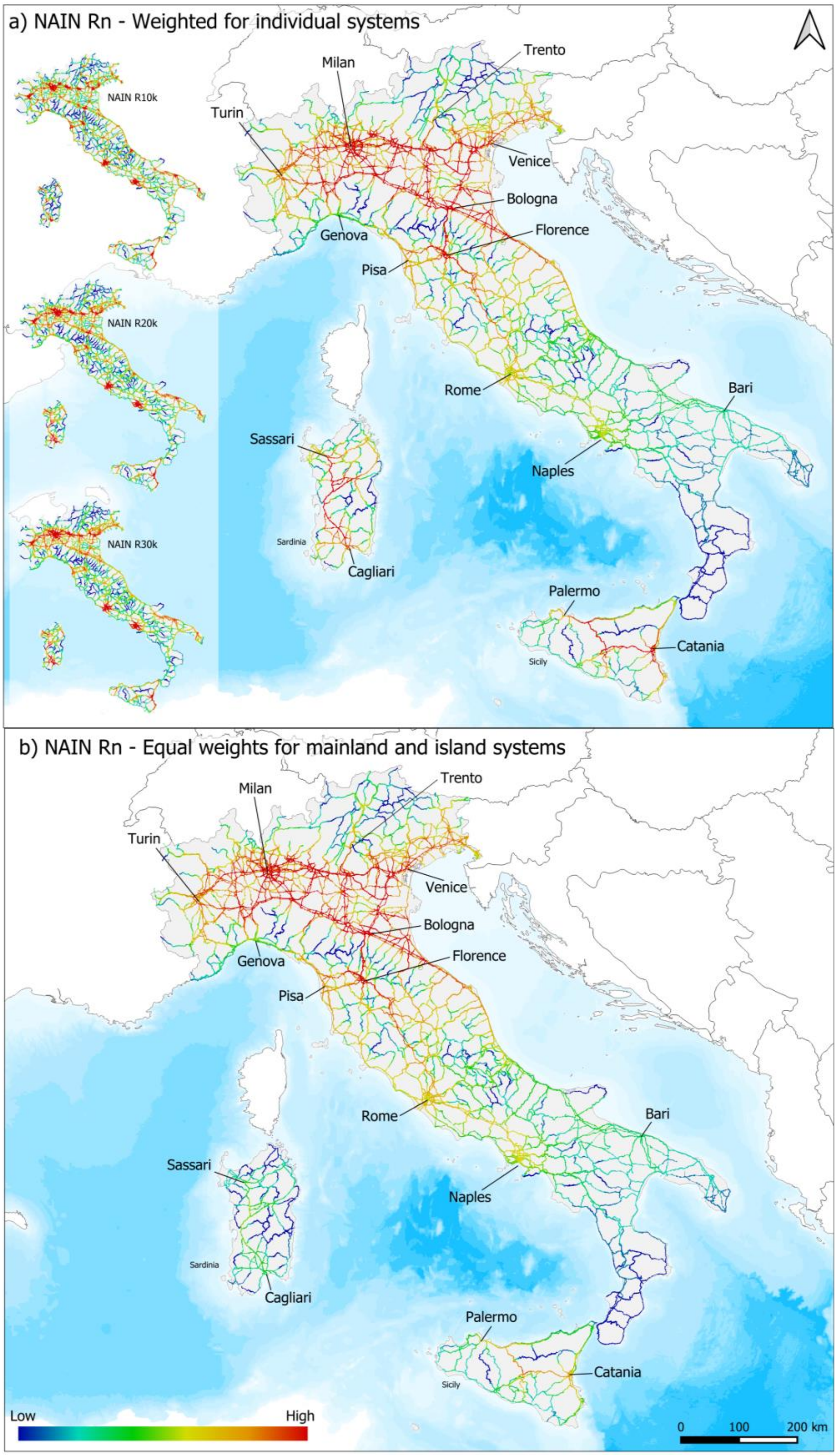

Figure 3: Normalized Angular Integration (Rn) for Italy: a) weighted to each systems' depth, i.e., Italian mainland and major islands (NAIN also at R10k, R20k and R30k); and b) weighted to the mainland depth.

When analysed as closed systems, the Italian islands adhere to their own internal logic of relative accessibility distribution. However, their spatial configuration presents similarities, as the larger urban areas in each island (Palermo-Catania, for Sicily; and Cagliari-Sassari, for Sardinia) are located at the opposite ends of their respective integration cores, which comprises the motorway network establishing their connection (Figure 3a). Nevertheless, when compared to the relative accessibility patterns observed in the Italian mainland, both islands' road-networks exhibit to-movement potentials ranking closer to those in the southern region of mainland Italy (Figure 3b). These characteristics justify the islands' inclusion in policies oriented at addressing the development and mitigation of territorial imbalances in southern Italy. Furthermore, the results indicate that configuration can uncover underlying infrastructural differences that may contribute to existing imbalances.

Configurational analyses based on metric radii of 10, 20 and 30 km (Figure 3a) unveil also a different set of spatial characteristics, shedding light on the hierarchical importance of cities such as Rome, Naples and Bari, as well as certain regional hubs like Pisa, Genova and Trento in terms of their to-movement potentials. Moreover, several sub-centres located in northern and central Italy acquire a significant weight within their regional systems, especially along the Milan-Venice and Milan-Florence axes, functioning as regional poles with higher relative accessibility. Notably, the centrality patterns at radii 20 and 30 km are quite similar (Figure 3a), both closely aligning with the Rn results. For example, in both cases, Trento exhibits a reduced weight compared to the R10k measure, owning to its size and position at the endpoint of the northern Italy centrality core. These results also suggest that, for Italy, the 20km radius is determinant for identifying national-regional scale centralities, while the 10km radius is better suited to inform urban-regional relationships.

Examining the mean NAIN value variations (Figures 4-6) in areas that the SNAI classification presents as homogeneous (Figure 2) reveals important differences in what should be qualified as a pole versus an inner area, as well as distinctions among them from a configurational standpoint. It can be observed that, while several municipalities in central and southern Italy are classified as poles by the SNAI (Figure 2), given their relative importance in terms of services and population to the surrounding region, their overall weight in terms of to-movement potential is limited, whether at an urban-regional scale (R10k – Figure 4), or at a national-regional scale (R20k & R30k – Figures 5 and 6). This highlights that, despite their socio-economic relevance, there is an absence of adequate support from road-infrastructure and corresponding movement potentials, matching their importance.

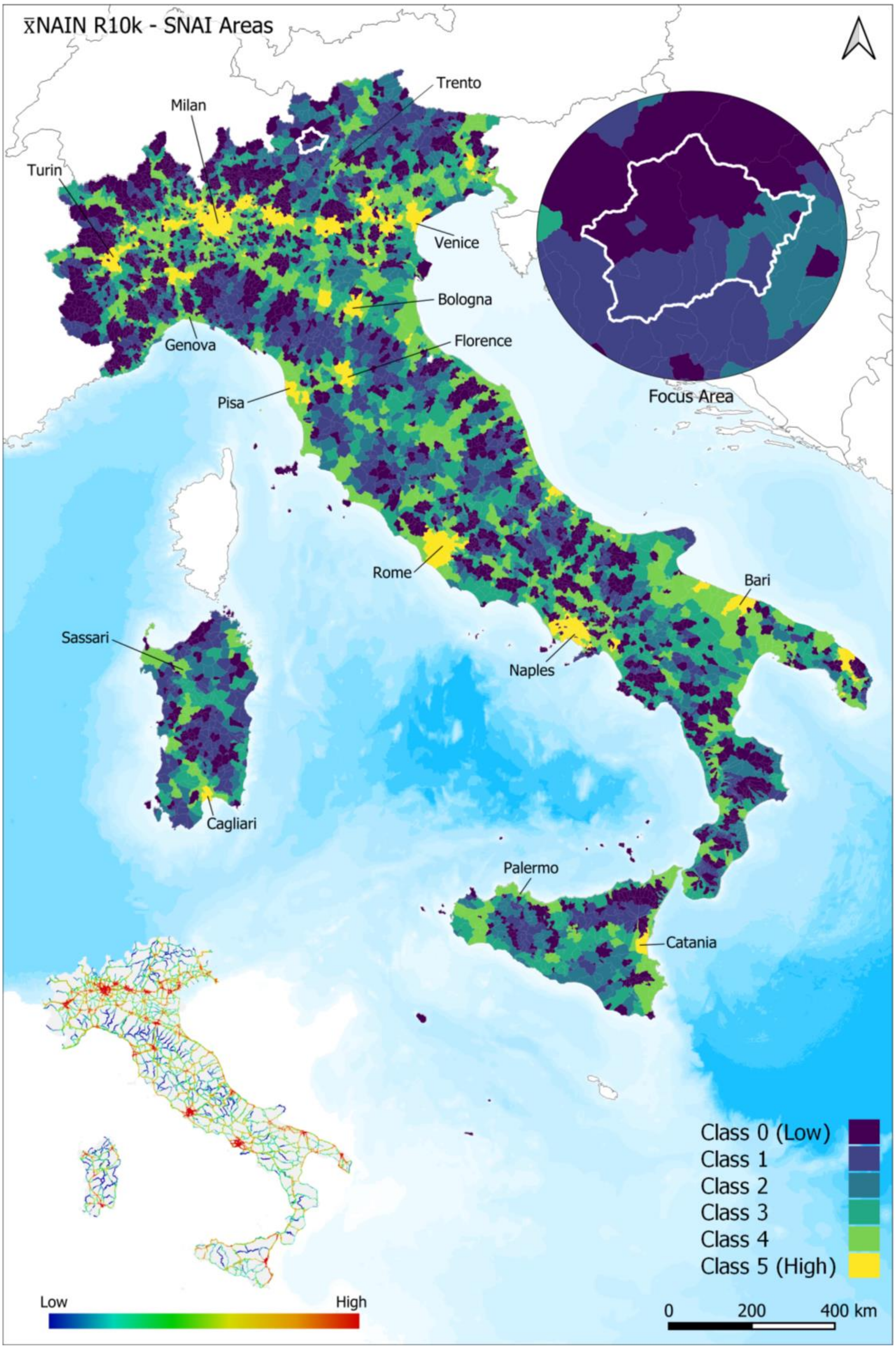

Figure 4: Area classification of the Italian national territory (bigger map) according to the mean values of NAIN R10k (smaller map). Zoom: Val di Sole, Trentino.

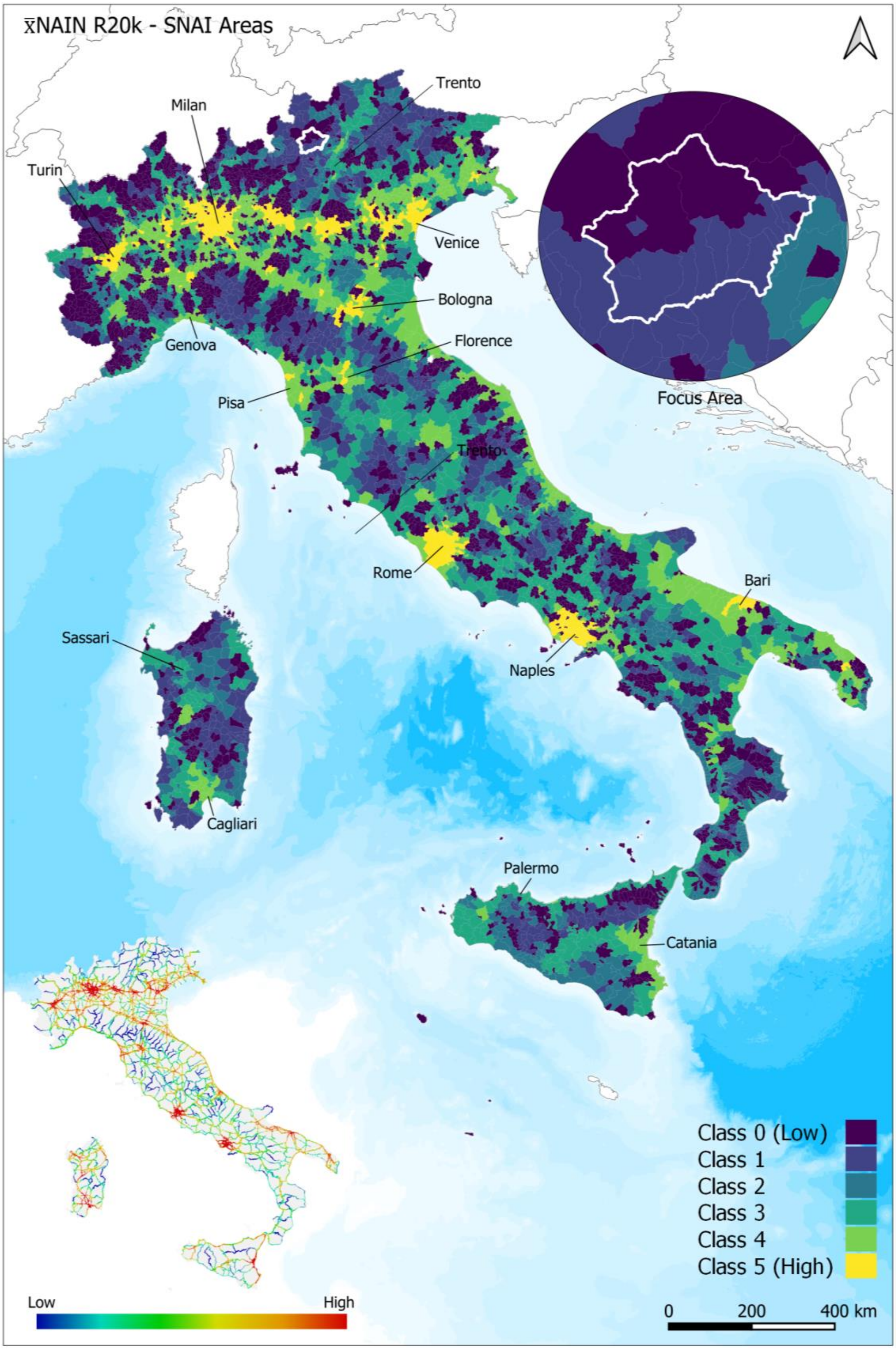

Figure 5: Area classification of the Italian national territory (bigger map) according to the mean values of NAIN R20k (smaller map). Zoom: Val di Sole, Trentino.

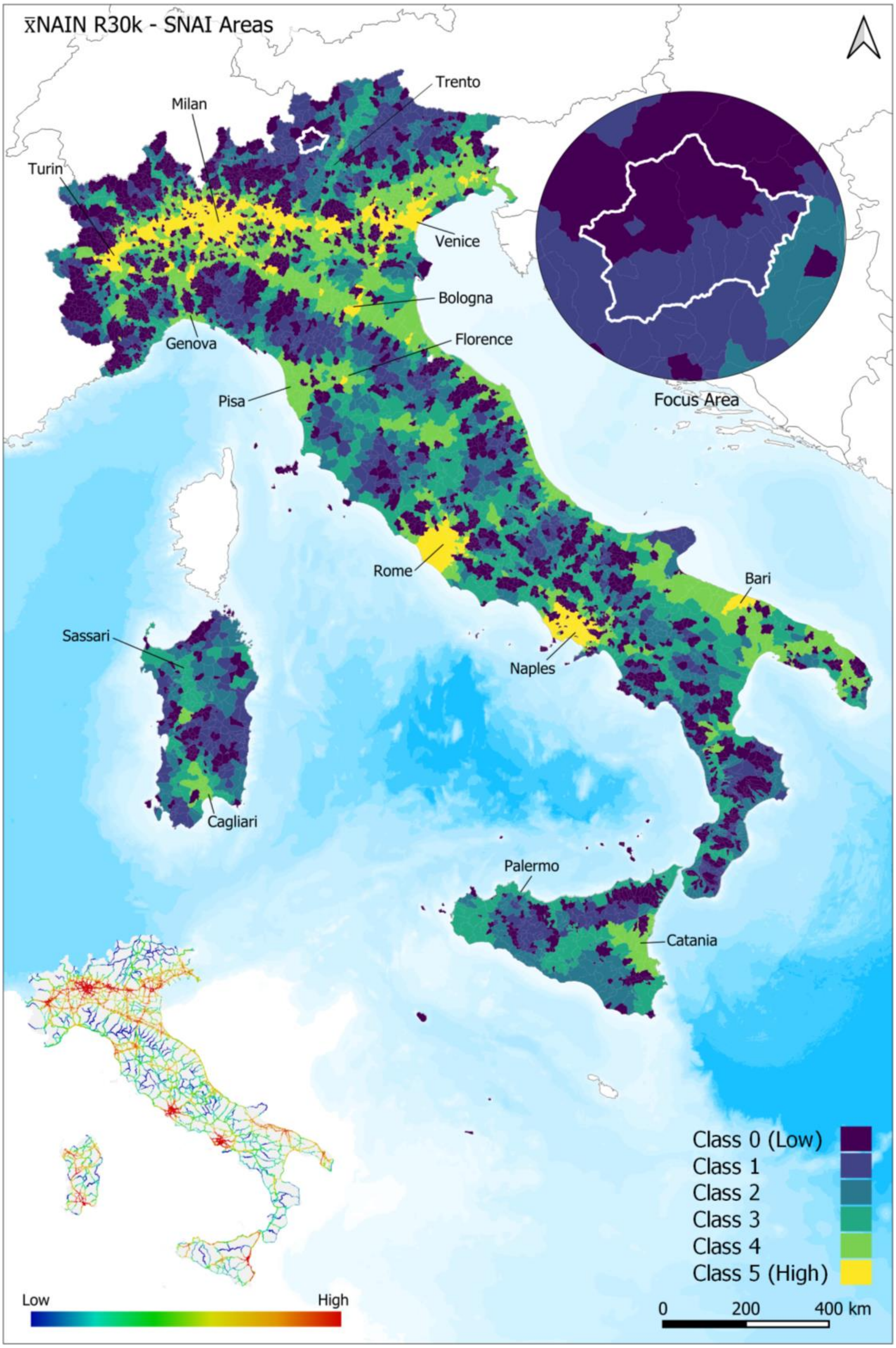

Figure 6: Area classification of the Italian national territory (bigger map) according to the mean values of NAIN R30k (smaller map). Zoom: Val di Sole, Trentino.

In essence, the configurational analysis reveals that, despite being considered poles, areas in central and southern Italy do not present comparable weight – both in terms of road-infrastructure density and movement potentials – to true poles in the national-regional hierarchy such as Milan, Rome, Naples or even smaller cities like Bari or Pisa. This, hence, indicates a limitation of the current SNAI classification, that treats different areas as if they were equal.

Moreover, these limitations extend to the identification of inner areas, and the differentiation among intermediate (D), peripheral (E) and ultraperipheral (F) zones (Figure 2). A noteworthy example is the Val di Sole, a focus area situated in the Trentino Alto-Adige region, depicted in Figures 4-6. In this area, we observe fluctuations in local centrality levels as we transition from smaller (R10k) to larger (R30k) scales, diverging from the pattern indicated by the SNAI categorisation (Figure 2). Specifically, the results of the configurational analyses (in 2 out of three maps) show that the Val di Sole is primarily divided between the two lowest Mean NAIN classes along a longitudinal axis, which approximates the main road connecting the valley to Lombardy in the West and Trento in the East. Municipalities of the northern Val di Sole fall into the lowest class, while those in the southern Val di Sole have slightly higher centrality levels (Figures 5 and 6). A third, even higher class of centrality only appears in the map resulting from the R10K analysis, characterising the municipalities near the eastern 'entrance' to the valley (Figure 4). These results, in the specific case of the Val di Sole, complement and, to some extent, enhance the SNAI classification as discussed below.

4.2 Re-mapping of inner areas through the S^3NAI index

As outlined in section 3, the construction of the S^3NAI index involved combining the results above either by incorporating the analysis results at radius n or by omitting them. The distribution of the S^3NAI_g index in the 'Rn' option (Figure 7) captures particularly well centrality/accessibility variations at a supra-regional scale. Conversely, the 'No Rn' option (Figure 8) more effectively illustrates imbalances at the local administrative level, better aligning with the focus of the current inner area policy (SNAI). This highlights the multiscale nature of the problem and suggests that both alternatives may be valuable for informing decisions to balance territorial imbalances that concern different geographical scales.

Expanding on this notion, the 'No Rn' option seems to comprehensively picture the actual situation in Val di Sole concerning its centrality/accessibility. It not only considers the infrastructural assets accounted for by the SNAI, but also incorporates qualitative and quantitative aspects mapped by the B4R project (Favargiotti et al., 2022, Figure 9). While the SNAI classification alone shows only the subdivision between western ultraperipheral municipalities and eastern peripheral municipalities (Figure 2), primarily along a transversal axis positioned in correspondence with the last stop of the Trento-Malè-Mezzana railway line (Figure 9), the S3NAI index distribution returns a more nuanced picture. In this, the valley appears clearly divided between northern ultraperipheral municipalities (e.g., Peio and Rabbi, which are side valleys and closed systems with no vehicle exit) and southern municipalities. Additionally, the southern municipalities are further distinguished into western peripheral municipalities and eastern intermediate municipalities based on their proximity to Trento, the nearest territorial centre (Figure 8).

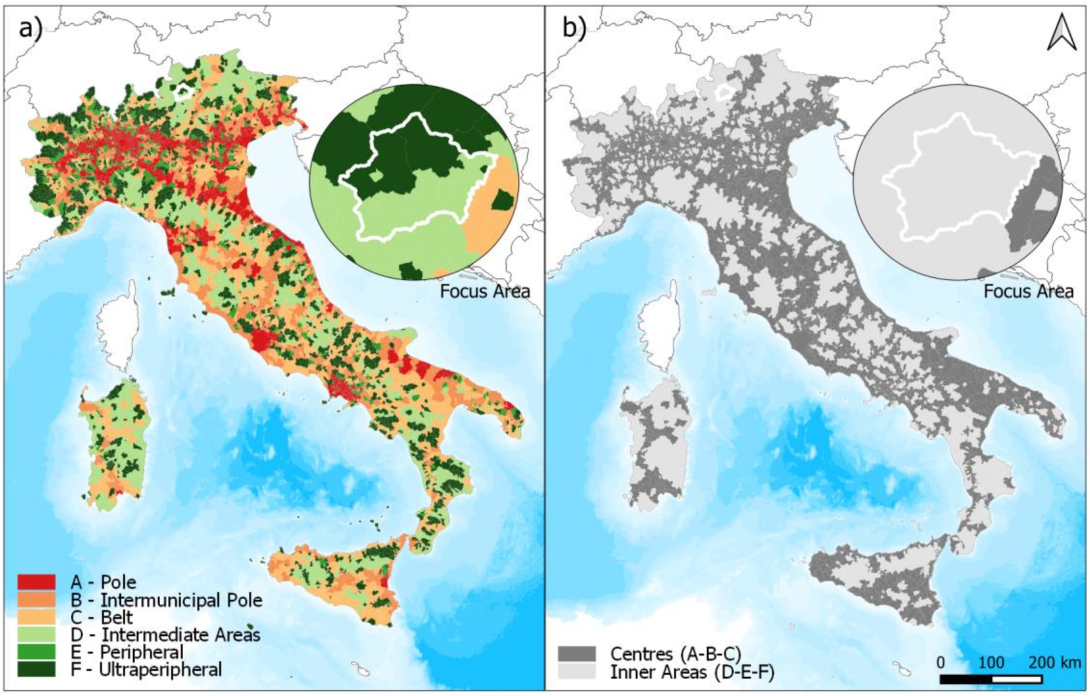

Figure 7: Area classification of the Italian national territory according to the S^3NAI_g index distribution in the 'Rn' option (a), with summary indication of which municipalities are centres and which are inner areas (b). Zoom: Val di Sole, Trentino.

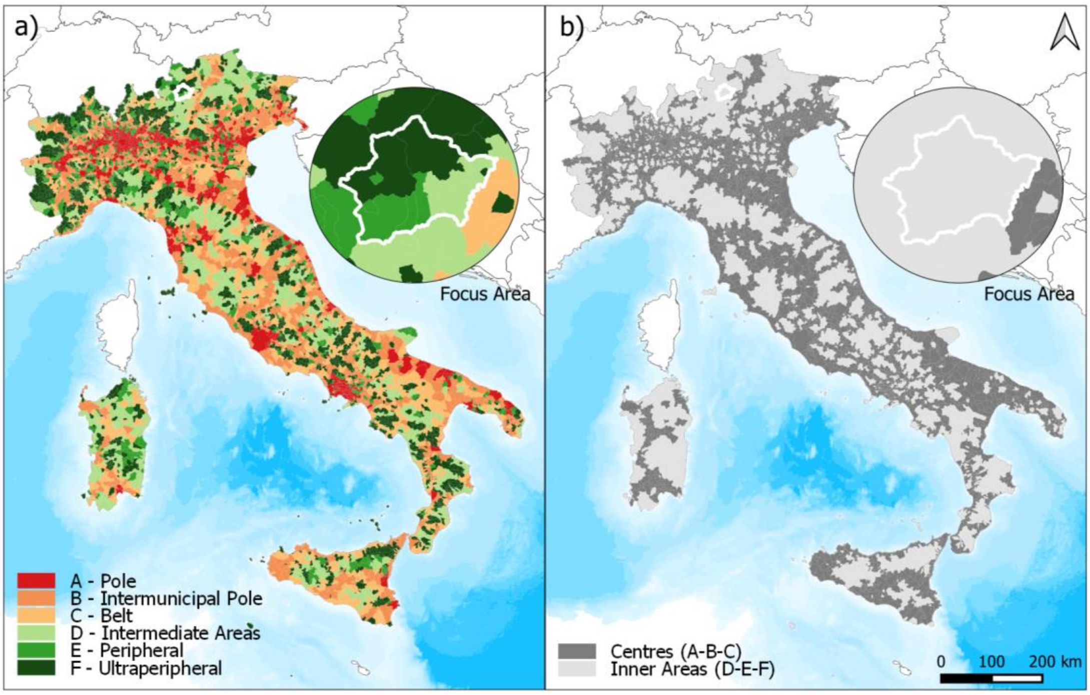

Figure 8: Area classification of the Italian national territory according to the S³NAI index distribution in the 'no Rn' option (a), with summary indication of which municipalities are centres and which are inner areas (b). Zoom: Val di Sole, Trentino.

Overall, the application of the proposed composite index (in both cases) results in many areas undergoing category changes in their classifications (Table 3). This, coupled with the above observations regarding the Val di Sole, suggests the potential for deeper exploration of these findings through the integration of additional analytics and verifications as part of future studies.

Table 3: Percentage of classification changes after the application of the proposed composite index in its two variations.

	SNAI areas	Areas maintaining the SNAI class	Areas subjected to change	% of change
S^3NAI_g 'Rn'	7,904	1,053	6,851	86.6
S^3NAI 'No-Rn'	7,904	947	6,957	88.0

By visually comparing the 'summary' maps showing Centres (A-B-C) and Inner Areas (D-E-F) in Figures 7b/8b and Figure 2d, the changes introduced by the S³NAI index in the classification of the areas becomes evident, better reflecting the contribution of the national (primary) road network infrastructure to areas' spatial accessibility. The greatest shifts in the classification can be noted in the islands, where the areas classified as centres increase significantly. In Sardinia, this is apparent along the south-north road link between Cagliari and Sassari and west-east link between Oristano and Olbia, respectively. Similarly, in Sicily, central areas increase inside the Agrigento-Syracuse-Catania triangle. Coastal regions along the Tyrrhenian and Adriatic seas, connecting the north and south of Italy, also witness an increase of their centrality (even if the prevalence of more segregated areas between Campania, Basilicata and Calabria regions on the west coast remains evident). Moreover, in the north, the introduction of the S^3NAI index allows for a more nuanced delineation of what the SNAI currently identifies as homogeneous central areas, returning peripheral municipalities even within the so-called ‘industrial triangle’ marked by Milan, Turin and Genoa. Finally, with reference to our zoom on the Val di Sole, it is worth noting how central areas appear along the road axis connecting northeastern Italy to Austria via the Trentino-Alto Adige region.

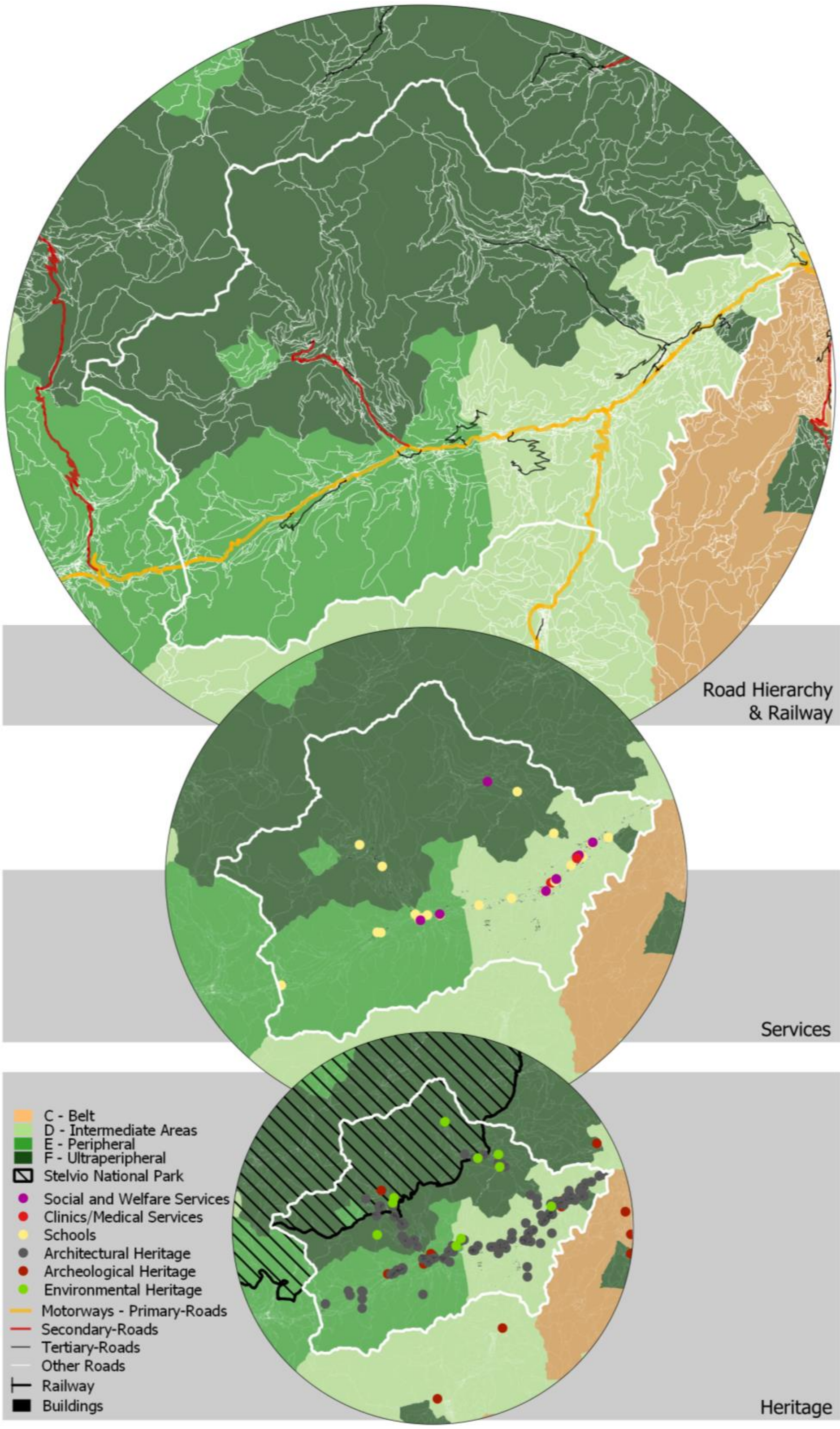

Figure 9: Area classification of the Val di Sole territory according to the S³NAI index distribution in the 'no Rn' option, with the addition of data regarding (educational, medical, and infrastructural) services and (architectural and environmental) heritage retrieved from B4R UniTrento's database coordinated by Sara Favargiotti and curated by Chiara Chioni and Margherita Pasquali.

5 DISCUSSION AND CONCLUSIONS

This paper's proposal of building a composite inner areas index, S^3NAI, that incorporates configurational hierarchies (NAIN measure at different radii) into the mapping of territorial imbalances (SNAI classes), revealed interesting shifts in the current classification of Italian municipalities into inner areas.

Notably, the decision to include or exclude the NAIN Rn as a variable in the proposed index presents distinct advantages and disadvantages that require careful consideration. On the one hand, while the 'Rn' option may not align precisely with the resource-allocation approach set up by the SNAI, the resulting map remains valuable for informing strategies at higher scales, such as the European or national level, including possibly those related to the development of the south of the country. On the other hand, the 'no Rn' approach seems to better serve the aim of this study, as spatial dynamics, in terms of NAIN levels' distribution, are likely to be less influenced by the choice of local administrative boundaries in the categorisation.

Another consideration is the level of resolution of the analysis. While this seems appropriate in the first case, with the analysis lending valuable insights also at the local level, the latter may benefit from the inclusion of secondary (and even lower level) road elements in further iterations. Future studies could use such a detailed analysis to improve the mapping of belt and peripheral areas. This is because the proposal only accounts for the average NAIN values within municipal areas, potentially overlooking variations in accessibility within these regions. The 'challenge' in conducting further research tests therefore lies in finding an optimal balance between accuracy/completeness and feasibility of the analysis when preparing the model for it.

Future research could also test the independence of variables within the proposed S^3NAI index through targeted statistical tests. To ensure this independence a possibility could be to also explore the use of a topological radius in place of the metric one. Yet, defining a topological radius for the analysis of the Italian street network system is particularly complex as the choice should be based on a careful consideration of the depth of the entire network system.

The paper ultimately suggests the potential benefit of integrating configurational analyses based on Space Syntax and travel-time estimates embedded in the SNAI mapping methodology. Indeed, in the specific case of Val di Sole, the proposed approach returns a more accurate and realistic picture than that portrayed by the SNAI: a conclusion validated by on-field experiences acquired during the B4R exploration, co-design, and co-vision of this territory.

Specifically, the proposed approach enables a comprehensive understanding of inner areas' geography and challenges, thereby providing valuable insights for informed and sustainable approaches to infrastructure development that align with broader territorial and development policies and goals aimed at reducing inequalities and promote balanced development across regions. This may include prioritising infrastructure investments in underserved areas to improve connectivity and access to services, not only through the construction of new roads but also by improving sustainable transportation networks and access to services and by developing policies that foster economic growth (e.g., incentives for businesses) and resilience to shocks (e.g., by investing in preparedness and coordination measures). Additionally, it can help promoting environmental conservation by informing strategies aimed at mitigating habitat fragmentation and encouraging alternative transportation modes.

However, the effectiveness of the index should be further tested through additional case studies. Thus, future research may include an analysis of further Italian areas, which have been the object of different research projects by the authors (e.g., other B4R focus areas in Piedmont, Marche and Sicily regions; the municipalities in the Apennines hit by the 2016–2017 central Italy earthquakes; and the inner municipalities of northern Tuscany).

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