

Digitally enabled well-being: A multidimensional analysis

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ABSTRACT

This paper investigates the joint spatial distribution of digital accessibility and territorial quality across the Emilia-Romagna region (Italy), focusing on territorial conditions associated with well-being opportunities. We explore how digital accessibility combines with broader territorial conditions across municipalities. To this end, two complementary indices are developed at the municipal level: a Territorial Value Index (TVI), capturing environmental quality, accessibility to services, housing conditions, and territorial vulnerability; and a Digital Accessibility Index (DAI), measuring broadband infrastructure and digital readiness. Using publicly available statistical and geospatial data, the two indices are combined to identify and map differentiated territorial profiles across the region. The results reveal strong spatial disparities. While some municipalities combine high territorial quality and advanced digital accessibility, others show a sort of "double disadvantage," characterized by both infrastructural fragility and limited quality-of-life conditions. In contrast, several peripheral municipalities emerge as territories with latent potential constrained primarily by insufficient digital accessibility.

1. Introduction

The rapid expansion of digital technologies is reshaping the relationship between the local economy and quality of life. While digitalization is often presented as a driver of economic and social development, its benefits remain unevenly distributed across places and populations [1,2]. The growing diffusion of remote services and digitally mediated work has increased the strategic importance of digital infrastructure for territorial development [3]; [4]. However, digital connectivity alone does not automatically translate into improved living conditions. Rather, its potential depends on broader environmental, social, infrastructural, and housing characteristics of places [5]. Accordingly, the digital divide can be interpreted not only as a technological gap but also as a multidimensional territorial inequality shaping access to opportunities associated with well-being in the digital era [4].

Beyond providing connectivity, digital infrastructure increasingly enables access to digital public services, telemedicine, online education, and other digital services. As these services become more widespread, territorial disparities in digital accessibility may translate into broader inequalities into their access.

Against this background, this paper contributes to the debate on the

societal implications of digital transformation by proposing an integrated descriptive and diagnostic framework for jointly analysing digital accessibility and territorial quality. Our study develops and applies two complementary composite indices at the municipal level, by focusing on the municipalities of the Emilia-Romagna region (Italy). The first is a Territorial Value Index (TVI), designed to measure the multidimensional quality of local living environments through the integration of environmental, infrastructural, social, and territorial vulnerability dimensions. The second is a Digital Accessibility Index (DAI), aimed at capturing the degree of digital readiness and accessibility of municipalities through indicators related to broadband infrastructure, digital connectivity, and accessibility to digitally enabled services.

Consistent with the literature on territorial digital divides, our analysis assumes that the territorial effects of technological innovation depend on broader social, infrastructural, and institutional conditions [3]; [1,4,6]. In line with this view, we adopt a broader territorial perspective based on the joint assessment of the two dimensions, identifying different spatial configurations that may support digitally enabled well-being. Accordingly, the study addresses the following research question: which territorial configurations emerge from jointly assessing territorial quality and digital accessibility? How can these configurations inform place-based policies aimed at supporting digitally

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enabled well-being? The Emilia-Romagna region offers a particularly relevant case study for addressing this issue. Characterized by strong economic performance and significant territorial diversity, this region combines densely urbanized metropolitan systems with extensive rural and mountain areas (e.g., [7,8]). This internal heterogeneity makes Emilia-Romagna an ideal context for exploring how digitalization interacts with territorial characteristics across different contexts.

Methodologically, this study adopts an index-development approach grounded in multidimensional statistical analysis. The construction of the two aforementioned indices follows a replicable procedure involving variable selection, normalization, weighting, and aggregation. This approach is consistent with recent contributions emphasizing the importance of multidimensional territorial indices for identifying spatial inequalities and supporting evidence-based policy design [9]. Variables were selected from official and publicly accessible datasets provided by the Italian National Statistical Institute (ISTAT), the Emilia-Romagna Regional Statistical Office, environmental agencies, and geospatial measurements. The use of multiple aggregation methods allows testing the stability of municipal rankings and reducing sensitivity to the function adopted. The resulting indices are then combined through a matrix-based territorial classification approach, producing a four-quadrant interpretation of municipalities according to their relative positioning in terms of territorial value and digital accessibility.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on digitalization, territorial inequalities, and digitally enabled well-being. The third section presents the methodology employed in the paper: the construction of two composite indices measuring territorial quality and digital accessibility, their objectives and rationale, and the selection of the variables. Section 4 is dedicated to an empirical application of the above indices to the Emilia-Romagna municipalities and to a presentation of the results emerging from the analysis. The final section concludes with policy implications and directions for future research.

2. Literature review

Over the last decades, quality of life has assumed an increasingly important role in residential decision-making, alongside more traditional considerations such as employment opportunities and service accessibility [10–12]. Environmental conditions, urban security, green spaces, healthcare systems, educational opportunities, cultural activities, leisure amenities, and social cohesion are now widely recognized as relevant factors shaping the perceived quality of places [5]. In response to these changing preferences, urban and regional policies have progressively invested in local amenities and territorial quality to enhance territorial attractiveness for residents and investment (e.g. [13]). This evolution is also reflected in a broader shift in the academic literature from purely income-based interpretations of development toward multidimensional approaches to well-being, in which environmental and socio-relational dimensions play a crucial role in determining territorial attractiveness and quality of life [5,14–17].

At the same time, rapid metropolitan expansion has intensified several urban criticalities, including traffic congestion, increasing living costs, pollution, degradation of public spaces, and forms of gentrification that reduce access to housing in central urban areas. These processes have progressively questioned the sustainability of intensive urban growth models, encouraging some categories of workers to consider residential alternatives outside large metropolitan centres [18]. Growing concern about climate vulnerability has further reinforced these trends. Extreme climatic events such as floods, droughts, wildfires, and recurrent heatwaves increasingly affect perceptions of safety, environmental quality, and territorial liveability [19]. As a consequence, climate resilience has become an increasingly important component of territorial attractiveness, complementing more traditional dimensions of quality of life within the broader ecological transition [20].

The increasing importance attributed to well-being and the coherence between personal lifestyles and living environments has contributed to renewed interest in territories previously perceived as marginal, which may offer alternative balances between professional and private life. Empirical evidence suggests that this process has contributed to selective forms of residential decentralization toward peri-urban, rural, and medium-sized urban areas characterized by better environmental conditions and lower housing costs [21,22]. However, these dynamics remain highly differentiated across territories and social groups and do not imply a homogeneous decentralization process [23]. These changes have been further reinforced by the increasing diffusion of remote working, which has weakened, at least for some categories of workers, the traditional spatial constraint linking workplace and residence, expanding the range of feasible residential options and contributing to greater flexibility in residential location choices [20,21,24].

A further element contributing to these transformations is the growing strategic relevance of digital infrastructures in shaping spatial accessibility and residential opportunities. The diffusion of broadband connectivity, high-speed mobile networks, and digitally enabled services has progressively reduced the importance of physical proximity to workplaces, contributing to a broader redefinition of accessibility itself. In many contexts, digital connectivity is increasingly regarded as an essential condition for territorial liveability, alongside traditional infrastructures and public services [3]; [4,25].

More broadly, digitalization increasingly shapes not only economic productivity but also access to services, social participation, education, and opportunities associated with well-being, becoming a structural component of contemporary quality of life [26]; [27]. The literature on smart sustainable cities further emphasizes how digital infrastructures, knowledge-based development, and urban sustainability interact in shaping territorial competitiveness and citizens' well-being [28,29].

The expansion of remote working and digitally mediated activities has consequently increased the possibility of separating residential choices from workplace location. Workers may now consider living in more heterogeneous spatial contexts, including peripheral and non-metropolitan areas, provided that these places guarantee stable and efficient digital connectivity [30]. Under these conditions, digital accessibility may support new forms of territorial rebalancing by increasing the attractiveness of areas traditionally considered geographically peripheral, although these opportunities depend on broader territorial characteristics and local conditions [21].

Nevertheless, access to digital connectivity remains highly uneven across territories, with persistent disparities between urban and rural areas as well as between digitally advanced and digitally disadvantaged contexts. The attractiveness of a territory for residents and, in particular, for remote workers depends not only on the physical availability of digital infrastructure, but also on broader contextual elements such as the quality of digital services and the existence of ecosystems supportive of flexible working practices [31]. Under these conditions, the digital dimension increasingly interacts with environmental, social, and economic characteristics in shaping the overall attractiveness and competitiveness of territories. From this standpoint, the digital divide should not be interpreted exclusively as a technological gap, but rather as a multidimensional territorial inequality involving access to infrastructure, digital skills, institutional capacity, and digitally enabled services. Consequently, digitalization may simultaneously represent an enabling factor for territorial development and a source of new socio-spatial inequalities [23]; [32].

Recent empirical evidence, based on Italian provincial data, further suggests that the effects of broadband expansion depend not only on network availability but also on broader territorial conditions. Bergantino et al. [33] show that broadband expansion does not automatically reduce territorial inequalities, as its effects are mediated by local socio-economic characteristics, human capital, and institutional capacity. Similarly, Bergantino et al. [34] demonstrate that improvements in digital infrastructure do not necessarily translate into uniform

improvements in quality of life, highlighting heterogeneous effects across territories and dimensions of well-being. Taken together, these studies suggest that the effects of digital infrastructure can only be understood within the broader socio-economic and institutional context. The consolidation of remote working after the COVID-19 pandemic has further weakened the traditional relationship between place of work and place of residence. Although these changes do not imply the decline of metropolitan areas [24], they do reveal increasing forms of selective mobility, particularly among workers employed in sectors characterized by high digital compatibility and therefore less dependent on physical proximity to workplaces.

Evidence from the COVID-19 period further highlights a growing tendency to relocate from large metropolitan areas toward smaller cities, peri-urban territories, and rural contexts characterized by higher environmental quality, lower housing costs, and adequate digital connectivity [20,21]. In some cases, these residential choices reflect the desire to return to places of origin or adopt alternative lifestyles; in other situations, they are associated with family needs, health considerations, and broader well-being aspirations. Evidence from the Italian context similarly highlights differentiated residential and territorial dynamics associated with remote working. Jansen et al. [22] show how post-pandemic location preferences increasingly favour non-metropolitan and environmentally attractive areas, while Mariotti et al. [35] find that remote working has often reinforced pre-existing disparities between central and peripheral territories. At the same time, the emergence of coworking spaces and hybrid working ecosystems has contributed to redefining urban functions, local development trajectories, and the geography of daily activities [36], confirming that the benefits associated with digitalization are closely intertwined with local territorial characteristics.

To some extent, these dynamics partially recall Tiebout's [37] idea of "voting with their feet," according to which individuals and households tend to choose locations that better correspond to their preferences regarding public goods, local amenities, and lifestyles. Within the context of remote working, these residential choices increasingly reflect preferences for places offering favourable environmental, social, and digital conditions. Commuting, traditionally accepted as an unavoidable component of working life, is increasingly perceived as a factor negatively affecting quality of life, while access to services and environmental quality in less congested territories is becoming progressively more valued. In this perspective, remote working expands the range of feasible residential choices, but the attractiveness of different locations ultimately depends on the interaction between digital accessibility and the broader territorial environment [21,38].

The growing relevance of these dynamics has stimulated greater interest in multidimensional frameworks for measuring territorial attractiveness and well-being. Territorial attractiveness emerges from the interaction between environmental quality, housing conditions, accessibility to services, safety, social context, infrastructural endowment, and, increasingly, digital accessibility [17,27]. This complexity requires analytical approaches capable of integrating heterogeneous territorial dimensions within coherent and interpretable frameworks [39]. Research on smart city development and territorial sustainability similarly highlights the growing interaction between digital connectivity, urban innovation, environmental quality, and territorial resilience [40]. These contributions point to the need for integrated frameworks capable of jointly assessing territorial quality and digital accessibility.

Despite the growing literature on digitalization, territorial conditions, and quality of life, important research gaps remain. Existing studies have examined digital accessibility, territorial conditions, and well-being, but comparatively less attention has been devoted to their interaction in shaping uneven spatial opportunities and constraints. Moreover, comprehensive frameworks jointly analysing digital accessibility and multidimensional territorial quality at a fine territorial scale remain relatively limited, particularly in regions characterized by strong internal disparities [41,42]. As a result, limited attention has been

devoted to municipalities simultaneously affected by digital fragility and weak territorial conditions, as well as to territories expressing latent well-being potential constrained by insufficient digital accessibility. Against this background, this study develops a Territorial Value Index (TVI) and a Digital Accessibility Index (DAI), to provide an integrated and diagnostic assessment of territorial quality and digital accessibility. The proposed framework identifies territorial configurations that may support or constrain digitally enabled well-being, thereby providing an evidence base for place-based policy interventions.

3. Methodology

3.1. Measuring territorial quality and digital accessibility

The economic literature has highlighted the importance of multidimensional indices and territorial modelling tools for supporting evidence-based public policies and regional planning strategies [9]; [43]. In this vein, recent studies have proposed various methodologies for developing these indices. For instance, Di Tommaso et al. [44] emphasize their role as strategic tools supporting territorial and industrial policy design, while the work of Assiri et al. [8] and Silvestri et al. [45] concentrate on developing methodological approaches based on multidimensional analysis to capture complex local phenomena. In this work, we develop two complementary indices at the municipal level: the Territorial Value Index (TVI) and the Digital Accessibility Index (DAI). The former measures territorial quality in terms of environmental, infrastructural, social, and territorial vulnerability, while the latter assesses the digital accessibility of municipalities using variables related to broadband infrastructure, digital connectivity, and accessibility to digitally enabled services.

To create these indices, we followed the OECD [41] framework, which considers the normalization, weighting, and aggregation of variables as key stages in the development of novel indices. In the initial phase, each municipal-level variable is normalized to account for possible differences in scale and variability; accordingly, each original variable is rescaled to the interval (0,1). This procedure guarantees that values close to 1 correspond to the best-performing observation (i.e., the municipality), whereas values close to 0 correspond to the lowest-performing one. All remaining municipalities obtain transformed values ranging between 0 and 1. We indicate with X_{jk} the value of the k -th variable for municipality j ; therefore, the normalizing function for the k -th variable becomes:

$$\beta(X_{jk}) = \frac{X_{jk} - \min_j(X_{jk}, j = 1, \dots, J) + 1/J}{\max_j(X_{jk}, j = 1, \dots, J) - \min_j(X_{jk}, j = 1, \dots, J) + 2/J} \quad [1]$$

In some cases, $\beta(X_{jk})$ may take values equal to 0 or 1, which are unrealistic; to address this issue, we include correction factors $1/J$ and $2/J$ to the numerator and denominator, respectively.

In the second step of the procedure, the normalized variables are weighted and aggregated using an appropriate aggregation function to compute the TVI and DAI values for each municipality j ($j = 1, \dots, J$). During this stage, weights are assigned to each variable in order to reflect their respective contribution to the index, alongside the selection of the aggregation function. To determine the weighting structure, we adopted a Principal Component Analysis (PCA) approach and a uniform-weight configuration, which assigns equal importance to all variables of each index, as robustness check.

Composite indices usually aggregate correlated indicators, making subjective weighting schemes dependent on expert judgement. PCA addresses this challenge by identifying the latent structure underlying the dataset and extracting a smaller set of orthogonal components that capture the maximum amount of variation contained in the original indicators [46]. The rationale behind PCA is to summarize the highest possible proportion of the variance in the standardized indicators using the smallest possible number of components; hence, the weighting

procedure reflects the statistical dimensions of the data rather than the original dimensionality of the indicator set. In this sense, PCA weights should not be interpreted as measures of theoretical importance but rather as corrections for multicollinearity and information overlap. Although the standard PCA-based weighting system often relies on the loadings of the first principal component, this strategy may overlook an important share of the information contained in the dataset when the first component explains only a limited proportion of the total variance. Following the same approach adopted by previous scholars [47]; [46,48,49], we retain principal components with eigenvalue > 1 and compute indicator weights by combining the loading of each indicator on every retained component with the proportion of variance explained by that component. In the case of TVI, we retained four components explaining 69% of total variance; in the case of DAI, we retained two components explaining 63% of total variance. The resulting weights are then rescaled to sum to one. This approach preserves a larger proportion of the original information while maintaining an objective and statistically grounded weighting scheme. Results show an almost perfect degree of consistency with the uniform-weight configuration for both indices.

The aggregation phase involves the combination of the weighted variables according to a specific combining function [41,42]. In our analysis, we calculated the two indices applying initially an additive transformation.

Additive rule:

$$\delta_1(\beta, w) = \sum_{k=1}^K \beta(X_{jk}) w_k \quad [2]$$

The additive aggregation rule is the most straightforward and intuitive approach, as it consists of the direct summation of weighted standardized variables. Its primary advantage is its simplicity and interpretability; however, it is sensitive to variable scaling and may generate compensability effects, whereby strong performance in one dimension can offset weak performance in another. More generally, the choice of the aggregation function may affect the ranking of observations, as different functional forms can alter the resulting values of the index. To address this concern, we also computed the indices using a logistic transformation. This approach enables us to evaluate the robustness of the additive ranking to changes in the aggregation rule and to assess the reliability of the information provided by the index [50].

Logistic rule:

$$\delta_3(\beta, w) = \sum_{k=1}^K \log \left[\frac{\beta(X_{jk})}{1 - \beta(X_{jk})} \right] w_k \quad [3]$$

The logistic aggregation rule is intended to account for nonlinear relationships among variables. It mitigates the influence of extreme values while placing greater emphasis on relative differences, especially within the central portion of the distribution.

Following the steps described above and making explicit each methodological choice, we built the Territorial Value Index (TVI) and the Digital Accessibility Index (DAI) as an aggregation of the variables described in the subsequent section.

3.2. Empirical context and variable selection

We applied the Territorial Value Index (TVI) and the Digital Accessibility Index (DAI) to 329 out of 330 municipalities of the Emilia-Romagna Region,¹ which are organized into nine provinces: Bologna, Ferrara, Forlì-Cesena, Modena, Parma, Piacenza, Ravenna, Reggio nell'Emilia, and Rimini. Emilia-Romagna is a NUTS 2 region located in north-eastern Italy, distinguished by relatively high per-capita income levels, supported by innovative SMEs with strong international

orientation [51] as well as by high value-added services across multiple sectors [52]; [53]. The region is also widely recognized for its strong social capital and the significant economic role played by local cooperatives [54,55].

Within the 329 municipalities considered in the analysis, 108 are included in Inner Area configurations identified within the 2014–2020 and 2021–2027 cycles of the Italian National Strategy for Inner Areas (SNAI). In this study, SNAI status is used as an external territorial classification rather than as a policy-treatment variable. The SNAI approach identifies territorial remoteness primarily in functional terms, based on accessibility to essential services, and therefore should not be interpreted as equivalent to a morphological classification of mountain municipalities [56–58].

From an environmental perspective, the regional government of Emilia-Romagna has implemented several policies aimed at reducing natural resource consumption, preserving biodiversity, and addressing climate change [59,60]. Furthermore, in 2020 the region adopted a strategic policy document, the “Pact for Work and Climate,” designed to promote economic development in line with the principles of the UN 2030 Agenda for Sustainable Development, with a particular emphasis on environmental quality.

The construction of the Territorial Value Index (TVI) and the Digital Accessibility Index (DAI) required the selection of a set of variables capable of capturing, at the municipal level, the multidimensional conditions shaping territorial well-being opportunities and digital readiness. In line with the literature on multidimensional territorial analysis [39]; [17,41], the selection process was guided by three main criteria: theoretical relevance, territorial interpretability, and data availability.

The objective of the TVI is to capture the overall territorial quality of municipalities by considering environmental conditions, climate comfort, accessibility to essential services, housing conditions, territorial safety, and opportunities for social interaction. Our assumption is that territorial attractiveness depends on the interaction between multiple territorial characteristics shaping everyday living conditions. Consequently, the TVI is not conceived as a measure of economic performance or competitiveness, but rather as an index for assessing the broader territorial ecosystem supporting quality of life. The DAI, by contrast, is designed to measure the degree of digital accessibility and territorial digital readiness. In this case, the objective is to evaluate the extent to which municipalities are equipped to support digitally mediated activities and remote working opportunities through the presence of adequate digital infrastructures and public services. This index, therefore, captures digital accessibility not only in terms of physical broadband infrastructure, but also in relation to the actual territorial capacity to support digital interaction and connectivity.

Overall, 15 variables were selected for the construction of the TVI, while four variables were employed for the DAI. Our data are related to the specific empirical application conducted in this study (the Emilia-Romagna region in Italy); however, similar data can be found in other European and extra-European regions as well. Descriptive statistics, data sources, weights, and expected impacts of all variables are reported in Table 1. Most of the variables were obtained from official and publicly accessible datasets provided by regional and national institutions, including Art-ER (Emilia-Romagna regional agency for innovation), ARPAE (Emilia-Romagna regional environmental agency), ISPRA (Italian Institute for Environmental Protection and Research), and direct geospatial measurements conducted in April 2026. The selected variables cover a relatively recent time horizon, ranging from 2020 to 2026, with most of them referring to 2025 or 2026. Although the reference years are not perfectly homogeneous, most of the territorial phenomena considered evolve relatively slowly over time; and the use of the most recent available observation for each variable allows for a more accurate representation of territorial conditions.

The variables included in the TVI reflect different but complementary dimensions of territorial quality. Population density, for instance, is

¹ The municipality of Sassofeltrio (in the Province of Rimini) has been excluded due to the lack of complete data.

Table 1

Variables included in the Territorial Value Index (TVI) and the Digital Accessibility Index (DAI).

N°	Variable	Rationale/Field	Data year	Min	Max	Mean	Std dev	Sign	Weights		Data source
									PCA	Uniform	
Territorial Value Index (TVI)											
1	Density of population	Population structure	2025	2.78	2791	225.09	326.43	+	0.084	0.067	Art-Er
2	Percentage of municipality's area covered by forests and woods	Environment and Climate	2023	0.00	0.90	0.25	0.27	+	0.079	0.067	Arpae
3	Celsius maximum average temperature in June (26/06/25)	Environment and Climate	2025	21.30	31.0	28.25	2.15	-	0.078	0.067	Arpae
4	Max hydraulic risk (%)	Territorial Vulnerability	2020	0.00	100.00	11.74	17.06	-	0.064	0.067	Ispra
5	Unused municipal area (%)	Territorial Vulnerability	2025	0.37	0.99	0.90	0.07	+	0.077	0.067	Art-Er
6	Average real estate price per square meter (Standard cat, €/sqm)	Housing opportunities	2025	430	6300	1399	671	-	0.067	0.067	Nat. Tax Agency
7	Family doctors per 1000 inhabitants	Health services availability	2025	0.00	8.62	0.80	0.63	+	0.046	0.067	Art-Er
8	Public swimming pools per 10,000 inhab.	Sport services availability	2025	0.00	15.34	0.70	1.66	+	0.063	0.067	Art-Er
9	Nursery school acceptance index	Social services availability	2025	0.00	300	34.85	24.24	+	0.065	0.067	Art-Er
10	Municipal libraries per 1000 inhabitants	Cultural services availability	2025	0.00	1.92	0.23	0.28	+	0.048	0.067	Art-Er
11	Bus stops per sqkm	Public transports availability	2025	0.00	15.69	1.39	1.51	+	0.076	0.067	Art-Er
12	Railway stations per sqkm	Public transports availability	2025	0.00	0.32	0.01	0.03	+	0.057	0.067	Art-Er
13	Car distance from the nearest motorway access (time in minutes)	Distance from national road network's access gate	2026	0.00	98	24.85	18.68	-	0.066	0.067	Maps
14	Car distance from the nearest Hospital (time in minutes)	Distance from sophisticated health services	2026	0.00	64	18.60	12.16	-	0.063	0.067	Maps
15	Car distance from the nearest secondary school center (time in minutes)	Distance from higher school services	2026	0.00	85	16.01	12.27	-	0.068	0.067	Maps
Digital Accessibility Index (DAI)											
1	Fiber broadband coverage (% of homes)	Supply of digital infrastructure	2025	0.00	0.76	0.31	0.19	+	0.223	0.250	Art-Er
2	WIFI public access points per 1000 inhabitants (emiliaromagnawifi network)	Supply of digital wifi access points	2025	0.00	27.82	2.17	2.85	+	0.230	0.250	Art-Er
3	Index of interactivity of municipal services	Supply of digital administrative services	2025	0.19	0.75	0.43	0.10	+	0.276	0.250	Art-Er
4	Digital Public Identity (SPID) Accesses (average on SPID users)	Demand for digital public services	2025	11.50	202.08	111.70	27.51	+	0.270	0.250	Art-Er

Source: Authors' elaboration on different sources

interpreted as a proxy for the potential intensity of social relations and access to public and private services [61,62]. A second group of variables concerns environmental quality and climate conditions. The percentage of municipal area covered by forests and woods captures ecological value and climate comfort. This variable is particularly relevant in the context of increasing attention to environmental sustainability and residential preferences favouring greener and less congested territories [63]. Conversely, average maximum temperatures in June are included as a proxy for summer heat stress, which increasingly affects perceived liveability and climate resilience, especially in highly urbanized and lowland areas [64]. Territorial vulnerability is represented through the inclusion of hydraulic risk indicators. Exposure to hydrogeological and flood-related risks negatively affects territorial attractiveness and long-term resilience, particularly in the context of increasing extreme weather events. This dimension is especially relevant in Emilia-Romagna, where several municipalities located in the Po Valley are exposed to significant environmental vulnerability. Housing accessibility is another relevant component of territorial quality. Average real estate prices per square meter are included in the index as a proxy for the affordability and practical accessibility of housing. Although high real estate values may partially reflect territorial attractiveness, they may simultaneously reduce residential accessibility and generate exclusionary dynamics, especially for younger households and remote workers seeking alternative residential locations [65]. The TVI also incorporates a set of variables related to accessibility to essential services and infrastructures. These include the number of family doctors per inhabitant, bus stops and railway stations per square kilometre, and car travel time to the nearest hospital, motorway access, and secondary school centre. These variables aim to capture the territorial capacity to provide access to healthcare, mobility systems, and educational services,

which represent fundamental dimensions of everyday well-being and territorial liveability [5,38]. Additional variables reflect broader dimensions of quality of life. The presence of public swimming pools, nursery school attendance rates, and municipal libraries contributes to measuring the availability of recreational and cultural opportunities supporting social cohesion and family well-being.

The DAI is constructed using four variables specifically related to digital accessibility and readiness [1,66]. The first variable measures fibre broadband coverage as a percentage of households, capturing the physical availability of high-speed internet infrastructure. Broadband connectivity constitutes a fundamental enabling condition for remote working, access to digital services, online education, and digitally mediated economic activities. The second variable considers the average use of the Italian digital public identity system (SPID), which represents a proxy for the effective diffusion and utilization of digital public services among residents. The third variable – the index of interactivity of municipal services – measures the extent to which local public administrations provide digitally accessible and interactive services. This dimension reflects the institutional and administrative component of digital readiness, highlighting the role of local governance capacity in shaping territorial digital accessibility. Finally, the number of public Wi-Fi access points per inhabitant captures the availability of publicly accessible digital connectivity infrastructures. Public connectivity systems may play an important role in reducing forms of digital exclusion and supporting access to online services, especially in territories characterized by the lack of private infrastructural provision.

The combination of the TVI and DAI allows the development of a tool capable of identifying differentiated spatial configurations of opportunity. By jointly analysing territorial quality and digital accessibility, our analysis contributes to a more comprehensive understanding of the

geography of digitally enabled well-being and provides a basis for place-based policies aimed at territorial cohesion and inclusive digital transition.

4. Results

The application of the two indices shows the existence of highly differentiated territorial configurations within the Emilia-Romagna region. Since the TVI captures a set of territorial conditions, its spatial distribution shows how the attributes included in the index vary across municipalities. By contrast, the DAI captures the degree to which municipalities are equipped to support digitally enabled activities and access to online services. The comparison between the two indices allows us to identify not only areas of territorial strength and weakness, but also the extent to which digital accessibility may complement or constrain local opportunities.

Fig. 1 reveals a highly non-uniform geography of territorial quality across Emilia-Romagna. The municipalities showing the highest TVI values are concentrated along the Apennine mountain belt stretching from the western to the south-eastern part of the region, especially in the provinces of Parma, Bologna, Forlì-Cesena, and Piacenza; moreover, also large municipalities located on the Via Emilia road, where nowadays the highway and high-speed rail run parallel, present high TVI values. If the latter benefit from the concentration of public services, the former benefit from a combination of environmental and territorial characteristics that positively affect the index: landscape and environmental quality, lower summer heat exposure, lower urban congestion, lower cost of housing and, in many cases, relatively good access to social and well-being services despite their peripheral position.

This pattern is particularly relevant because the TVI is not designed to measure economic performance or demographic dynamism, but rather the broader territorial conditions supporting quality of life. Consequently, several municipalities traditionally considered peripheral or marginal display comparatively favourable values across the territorial attributes captured by the TVI. The high ranking of mountain municipalities reflects the important contribution of environmental and climatic dimensions to the TVI, in a context characterized by growing attention to environmental quality and climate resilience.

At the same time, Fig. 1 highlights a weaker performance for many municipalities located in the central plains and in the northern part of the region, particularly within the Po Valley corridor. These areas include some of the most economically dynamic and infrastructurally

dense territories of Emilia-Romagna, but they also experience higher levels of environmental pressure, land consumption, hydraulic vulnerability, congestion, and summer heat stress. Indeed, the concentration of industrial activities and transport infrastructures in these areas negatively affects their overall territorial quality profile.

A more specific focus on the municipalities with the 20 best and worst performances according to our index is presented in Table 2 and Table 3.

The ranking further reinforces the mentioned spatial patterns. The strong presence of municipalities from the Parma province mountain area highlights the importance of environmental and territorial dimensions in shaping the index.

More generally, the dominance of Apennine municipalities located in the Apennine mountains within the ranking indicates that peripheral areas may possess significant territorial capital even when they are not major economic or demographic centres.

The municipalities with the lowest TVI values are concentrated mainly in the lowland areas of Bologna, Ferrara, Modena, Parma, and Ravenna provinces. These municipalities are generally located in the

Table 2
Top 20 municipalities according to the TVI.

Rank	Municipality	Province	Normalized TVI value
1	Bore	PR	0.990
2	Borgo Val di Taro	PR	0.841
3	Bedonia	PR	0.789
4	Alto Reno Terme	BO	0.759
5	Albareto	PR	0.736
6	Compiano	PR	0.699
7	Tornolo	PR	0.688
8	Bagno di Romagna	FC	0.688
9	Valmazzola	PR	0.678
10	Grizzana Morandi	BO	0.666
11	Cattolica	RN	0.637
12	Palanzano	PR	0.635
13	Riolunato	MO	0.628
14	Lizzano in Belvedere	BO	0.617
15	Corte Brugnatella	PC	0.613
16	Santa Sofia	FC	0.605
17	Casalecchio di Reno	BO	0.601
18	San Benedetto Val di Sambro	BO	0.596
19	Berceto	PR	0.592
20	Coli	PC	0.586

Source: Authors' elaboration

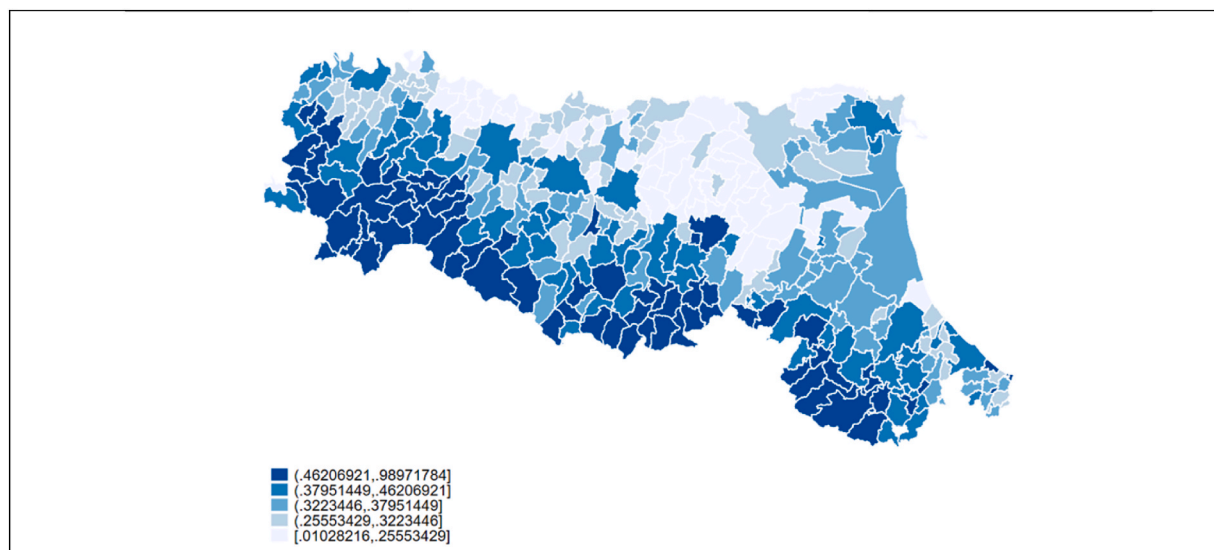


Fig. 1. Territorial quality based on the TVI.

Source: Authors' elaboration

Table 3

Bottom 20 municipalities according to the TVI.

Rank	Municipality	Province	Normalized TVI value
310	Granarolo dell'Emilia	BO	0.176
311	Alfonsine	RA	0.176
312	Baricella	BO	0.165
313	Terre del Reno	FE	0.165
314	Malalbergo	BO	0.150
315	Finale Emilia	MO	0.142
316	Anzola dell'Emilia	BO	0.139
317	Riva del Po	FE	0.138
318	Roccabianca	PR	0.137
319	Bondeno	FE	0.137
320	San Pietro in Casale	BO	0.134
321	Castello d'Argile	BO	0.117
322	Pieve di Cento	BO	0.112
323	Polesine Zibello	PR	0.108
324	Cervia	RA	0.084
325	Galliera	BO	0.068
326	Poggio Renatico	FE	0.055
327	Sala Bolognese	BO	0.050
328	Calderara di Reno	BO	0.034
329	Vigarano Mainarda	FE	0.010

Source: Authors' elaboration

highly urbanized and infrastructure-intensive corridor of the Po Valley, where environmental pressures and territorial vulnerabilities are more pronounced.

Several factors contribute to these lower performances. First, these territories tend to exhibit higher summer temperatures and lower environmental comfort due to urbanization and limited forest coverage. Second, some municipalities face severe hydraulic risk exposure, which negatively affects their territorial safety and resilience profile. Third, the high concentration of industrial and transport infrastructures contributes to environmental stress.

The geography emerging from the Digital Accessibility Index (DAI) differs significantly from the spatial distribution observed for the TVI. While territorial quality tends to favour mountain and environmentally attractive municipalities, digital accessibility is much more concentrated around urban centres, metropolitan corridors, and municipalities characterized by stronger infrastructural and administrative capacities.

Fig. 2 shows that the municipalities with the highest DAI values are located predominantly in the north-eastern and central parts of the

region, particularly around the Bologna metropolitan area and the Ferrara province. This reflects the concentration of broadband infrastructure, digital public services, fibre coverage, and public digital connectivity systems within the most urbanized and administratively central territories. The DAI captures not only physical digital infrastructure but also the broader territorial readiness to support digitally mediated activities. It should therefore be interpreted as a measure of digital accessibility and enabling conditions rather than of actual digital participation or use. As a result, we observe that municipalities with strong institutional capacity and advanced public digital services tend to perform particularly well.

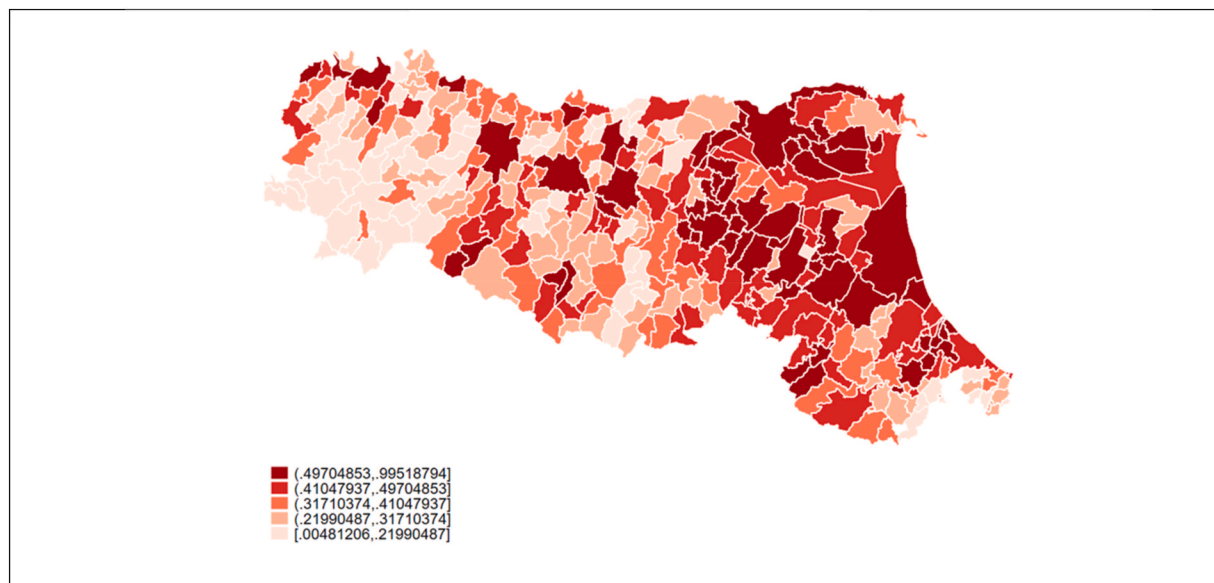
The spatial mismatch between the TVI and the DAI is particularly important from an interpretative perspective. Several municipalities with high territorial quality display relatively weak digital accessibility, while some digitally advanced municipalities exhibit lower territorial quality. This indicates that territorial quality and digital accessibility are unevenly distributed across the region and do not necessarily coincide spatially.

The ranking of the top-performing municipalities according to the DAI (Table 4) confirms the strong role of urban and metropolitan centres in shaping digital accessibility. Ferrara, Bologna, Parma, Reggio Emilia, Piacenza, and Modena (six out of nine province capital cities) all appear among the top positions, reflecting their advanced digital infrastructure, higher levels of service interactivity, and stronger integration into regional digital networks.

The presence of municipalities such as Casalecchio di Reno, San Lazzaro di Savena, Castel Maggiore, and Castenaso, all belonging to Bologna conurbation, which is the main metropolitan hub of the region, highlights the diffusion of digital accessibility beyond the central urban core into the broader metropolitan area. These municipalities benefit from their proximity to Bologna, while also maintaining strong infrastructural integration and advanced service provision.

At the same time, some smaller municipalities such as Premilcuore and Ligosanto also perform surprisingly well. This shows that high digital accessibility is not exclusively associated with large urban centres as comparatively high DAI values also occur in some smaller municipalities.

The municipalities with the lowest DAI values are concentrated in the western part of the region, particularly in the province of Piacenza and Parma. Several of these municipalities belong to SNAI Inner Area configurations, many of which overlap with mountain territories

**Fig. 2.** Digital accessibility based on the DAI.

Source: Authors' elaboration

Table 4

Top 20 municipalities according to the DAI.

Rank	Municipality	Province	Normalized DAI value
1	Ferrara	FE	0.995
2	Bologna	BO	0.879
3	Casalecchio di Reno	BO	0.818
4	San Lazzaro di Savena	BO	0.741
5	Lagosanto	FE	0.738
6	Castel Maggiore	BO	0.729
7	Parma	PR	0.716
8	Castenaso	BO	0.714
9	Reggio nell'Emilia	RE	0.681
10	Premilcuore	FC	0.659
11	Ozzano dell'Emilia	BO	0.651
12	Piacenza	PC	0.650
13	Vigarano Mainarda	FE	0.650
14	Cento	FE	0.649
15	Faenza	RA	0.639
16	Imola	BO	0.633
17	Bellaria-Igea Marina	RN	0.630
18	Modena	MO	0.614
19	Castel Guelfo di Bologna	BO	0.610
20	Ostellato	FE	0.601

Source: Authors' elaboration

Table 5

Bottom 20 municipalities according to the DAI.

Rank	Municipality	Province	Normalized DAI value
310	Gattatico	RE	0.138
311	Morfasso	PC	0.131
312	Fabbrico	RE	0.129
313	Fontanellato	PR	0.124
314	Ottone	PC	0.121
315	Gemmano	RN	0.109
316	San Martino in Rio	RE	0.098
317	Pellegrino Parmense	PR	0.096
318	Bettola	PC	0.095
319	Coli	PC	0.086
320	Bardi	PR	0.085
321	Montese	MO	0.084
322	Caorso	PC	0.084
323	Morciano di Romagna	RN	0.082
324	Cadeo	PC	0.061
325	Vernasca	PC	0.059
326	Borgo Val di Taro	PR	0.057
327	Cerignale	PC	0.051
328	Rivergaro	PC	0.050
329	Bedonia	PR	0.005

Source: Authors' elaboration

Table 6

TVI–DAI profiles of SNAI and non-SNAI municipalities.

	SNAI (N = 108)	Non-SNAI (N = 221)
High TVI – High DAI (HH)	23.1%	18.6%
Low TVI – High DAI (LH)	12.0%	36.2%
Low TVI – Low DAI (LL)	6.5%	37.1%
High TVI – Low DAI (HL)	58.3%	8.1%
Mean TVI	0.476	0.307
Mean DAI	0.316	0.391

(Table 6) characterized by low population density and infrastructural issues. The low performances of municipalities such as Bedonia, Cerignale, Rivergaro, Borgo Val di Taro, and Vernasca (Table 5) highlight the persistence of territorial digital divides even within a relatively advanced and economically developed region such as Emilia-Romagna. In these contexts, weaker broadband infrastructure, limited public digital services, and lower digital connectivity indicate less favourable conditions for remote working and digitally mediated access to services.

This result is interesting because most of the aforementioned

municipalities simultaneously display high TVI values. They offer favourable environmental conditions but remain constrained by insufficient digital accessibility. These municipalities, therefore, represent a distinctive territorial profile in which comparatively favourable TVI values coexist with weak digital accessibility. This mismatch identifies contexts where digital accessibility may constitute a relevant dimension for place-based policy attention, without implying that improvements in digital provision would necessarily generate economic improvements.

The combined analysis of the TVI and DAI (Fig. 3) provides the most informative perspective on the geography of digitally enabled well-being within Emilia-Romagna. Indeed, the two dimensions captured by the TVI and the DAI should not be considered in isolation, but rather as interacting factors. The joint distribution of the two indices makes it possible to identify municipalities in which favourable territorial conditions coexist with either stronger or weaker digital accessibility. The framework therefore highlights territorial mismatches without observing the residential choices or behavioural responses associated with them.

The four-quadrant framework in Fig. 3 allows municipalities to be interpreted according to the interaction between territorial quality and digital accessibility rather than considering the two dimensions separately. The dashed lines correspond to the mean values of the normalized PCA-based additive TVI and DAI distributions, respectively, and are used to distinguish municipalities with relatively high and low values of each index. Municipalities located in the upper-right quadrant combine relatively high territorial quality and good digital accessibility. These territories show the most balanced combination of favourable environmental and residential conditions and advanced digital infrastructure. They therefore combine territorial conditions that may be favourable to digitally mediated activities and well-being opportunities.

The lower-left quadrant identifies municipalities affected by forms of “double disadvantage,” characterized by both relatively low territorial quality and weak digital accessibility. These territories combine cumulative fragilities related to environmental conditions, service accessibility, infrastructural endowments, and digital provision. Such cumulative disadvantages may increase their exposure to territorial marginalization and indicate a potential need for integrated policy interventions.

The lower-right quadrant is especially important from a policy perspective. Municipalities positioned here exhibit high territorial quality but comparatively weak digital accessibility. This group includes several mountain municipalities as well as municipalities classified as Inner Areas, which combine favourable environmental and residential conditions with more limited digital infrastructure. This configuration is particularly frequent among municipalities included in SNAI areas, many of which are also located in the Apennine mountain system. They identify places in which improvements in broadband infrastructure and digital public services may complement already favourable territorial endowments.

Finally, municipalities located in the upper-left quadrant combine relatively high digital accessibility with weaker territorial quality. These are often highly urbanized or infrastructure-intensive municipalities where advanced digital provision coexists with environmental pressures, congestion, higher housing costs, or territorial vulnerability. In these contexts, policies aimed at improving environmental quality, climate resilience, and accessibility to local amenities and housing conditions may be as relevant as further technological investments.

Overall, the joint distribution of TVI and DAI shows that territorial conditions potentially supporting digitally enabled well-being cannot be reduced either to economic centrality or to digital infrastructure alone. Rather, they depend on the combination of technological accessibility and broader environmental, social, and infrastructural characteristics. This perspective supports a more polycentric and place-sensitive interpretation of regional development, in which peripheral and non-metropolitan areas may display favourable territorial potential when adequate digital accessibility is combined with broader local assets.

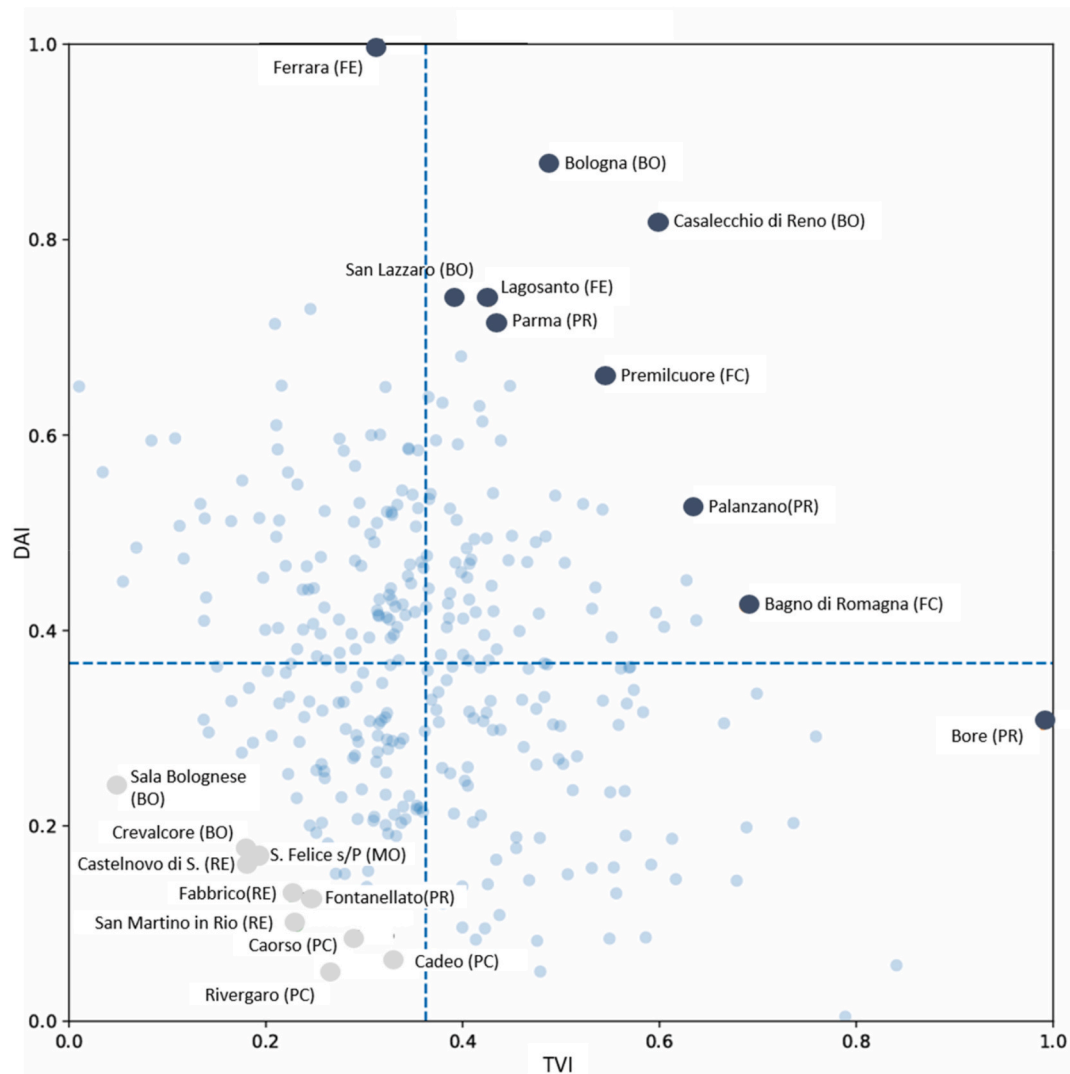


Fig. 3. TVI-DAI scatter plot using mean-based thresholds.
Source: Authors' elaboration

To assess the sensitivity of the four-quadrant classification to the choice of thresholds, we replicated the analysis using the median of each index instead of the mean. The resulting territorial configuration is highly stable: 305 out of 329 municipalities (92.7%) remain in the same quadrant, while only 24 municipalities (7.3%) are reclassified. Moreover, all reclassifications occur between adjacent quadrants, with no municipality moving between diagonally opposite territorial profiles. These results indicate that the main territorial patterns identified by the four-quadrant framework are robust to the use of an alternative threshold specification. The median-based classification and the corresponding transition matrix are reported in [Appendix A.1](#).

To further examine the territorial interpretation of the four-quadrant framework, we compared municipalities included in SNAI areas with the remaining municipalities in the regional sample. SNAI status is not used in the construction of either TVI or DAI and therefore provides an external territorial classification against which the resulting profiles can be descriptively assessed (although SNAI and mountain classifications are conceptually distinct, they substantially overlap in the regional sample; the detailed cross-classification is reported in [Table A2.1](#)).

The comparison reveals a distinct pattern. SNAI municipalities display a higher average TVI (0.476 versus 0.307) but a lower average DAI (0.316 versus 0.391) than non-SNAI municipalities. This asymmetry is even clearer in the quadrant distribution: 58.3% of SNAI

municipalities fall into the high-TVI/low-DAI configuration, compared with only 8.1% of non-SNAI municipalities. Conversely, the low-TVI/low-DAI “double disadvantage” configuration includes only 6.5% of SNAI municipalities, compared with 37.1% of non-SNAI municipalities. The association between SNAI status and quadrant membership is statistically significant ($\chi^2 = 115.1$, $p < 0.001$; Cramér's $V = 0.59$).

These findings suggest that, within Emilia-Romagna, Inner Areas are not predominantly characterized by generalized territorial disadvantage. Rather, they are disproportionately associated with a configuration combining comparatively favourable territorial attributes with weaker digital accessibility ([Appendix A.2](#)).

The higher TVI observed among SNAI municipalities should be interpreted in light of the multidimensional structure of the index: while remoteness and weaker service accessibility may penalize peripheral locations, other components—such as environmental amenities, climatic conditions and housing affordability—may favour them. The result therefore refers to the specific territorial attributes captured by the TVI and should not be interpreted as evidence of higher overall welfare or observed residential attractiveness [67]; [58].

5. Discussion and conclusions

This paper investigates the relationship between territorial quality

and digital accessibility by applying a multidimensional analysis to the municipalities of the Emilia-Romagna Region. Starting from the assumption that digitalization does not automatically generate territorial cohesion or improvements in quality of life, our study proposes an integrated descriptive and diagnostic framework for identifying how territorial quality and digital accessibility combine across municipalities.

The results show that territorial quality and digital accessibility do not systematically coincide spatially: comparatively favourable TVI profiles occur in several mountain and inner municipalities, while stronger digital accessibility is more characteristic of metropolitan, peri-urban, and infrastructurally central areas.

The SNAI analysis further qualifies this pattern. Inner Areas municipalities exhibit higher average TVI but lower DAI values and are strongly concentrated in the high-TVI/low-DAI quadrant, showing that functional peripherality does not necessarily coincide with uniformly weak territorial endowments, while digital accessibility remains a comparatively important constraint for many of these municipalities.

At the same time, the analysis therefore shows that strong digital accessibility does not necessarily coincide with favourable values across the territorial dimensions captured by the TVI.

The joint TVI-DAI framework identifies contrasting territorial mismatches, from municipalities combining weaknesses in both dimensions to high-TVI/low-DAI profiles that are markedly over-represented among SNAI municipalities. This differentiation provides a basis for identifying place-specific policy priorities without implying the effects of particular interventions.

From a policy perspective, the framework supports a place-based reading of the digital transition by distinguishing municipalities according to the specific combination of territorial quality and digital accessibility they exhibit. Rather than prescribing particular interventions or estimating their effects, it can help identify where digital accessibility or other territorial dimensions represent comparatively weaker components and may therefore warrant differentiated policy attention.

Methodologically, the paper contributes to the literature by proposing a multidimensional framework for jointly analysing digital accessibility and territorial quality at a fine territorial scale, identifying configurations that would remain partially hidden if the two dimensions were considered separately. The framework can thus support evidence-based regional analysis and territorial planning.

Nevertheless, some limitations should be acknowledged. First, the analysis is cross-sectional and therefore does not capture the dynamic

evolution of territorial conditions over time. A longitudinal database covering a longer time period, with the possibility of having yearly data for all variables, would enable researchers to create dynamic indices and thus investigate how the relationship between digital accessibility and territorial quality evolves longitudinally. Second, the study focuses primarily on structural territorial conditions and does not directly measure subjective perceptions of well-being or individual behavioural responses. Integrating survey-based information on residential preferences, mobility intentions, and perceived quality of life could further enrich the analysis. Third, although the Emilia-Romagna Region represents a particularly relevant case study due to its internal territorial heterogeneity, future comparative applications to other regional or national contexts would help assess the generalizability of the framework.

Future research may extend the framework through longitudinal and comparative applications, additional dimensions such as digital skills and social inclusion, and explicit analysis of spatial dependence. Linking the indices to demographic, behavioural, or subjective well-being outcomes would also allow relationships that remain outside the scope of the present analysis to be tested directly.

Overall, the paper argues that the digital transition should be examined in relation to the broader territorial context in which digital infrastructure and services are embedded, including environmental, social, and institutional conditions. Understanding these territorial configurations can provide an evidence base for differentiated policies addressing digital accessibility and broader territorial inequalities.

CRediT authorship contribution statement

Antonella Ardizzone: Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Stefano Ghinai:** Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Francesco Silvestri:** Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Mattia Tassinari:** Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

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Appendices.

A.1 Sensitivity analysis of the quadrant classification

The four-quadrant classification presented in Fig. 3 uses the mean values of the normalized PCA-based additive TVI and DAI distributions as thresholds for distinguishing municipalities with relatively high and low values of the two indices. To assess whether the resulting territorial typology depends on this specific choice of cut-off, we performed a sensitivity analysis replacing the mean with the median of each index.

The baseline mean-based thresholds are 0.3625 for TVI and 0.3667 for DAI, while the corresponding median-based thresholds are 0.3443 and 0.3631, respectively. Figure A1 compares the two classifications. The left-hand panel reproduces the baseline configuration based on mean thresholds, whereas the right-hand panel applies median thresholds. Municipalities whose quadrant classification changes under the alternative specification are highlighted and labelled in the right-hand panel.

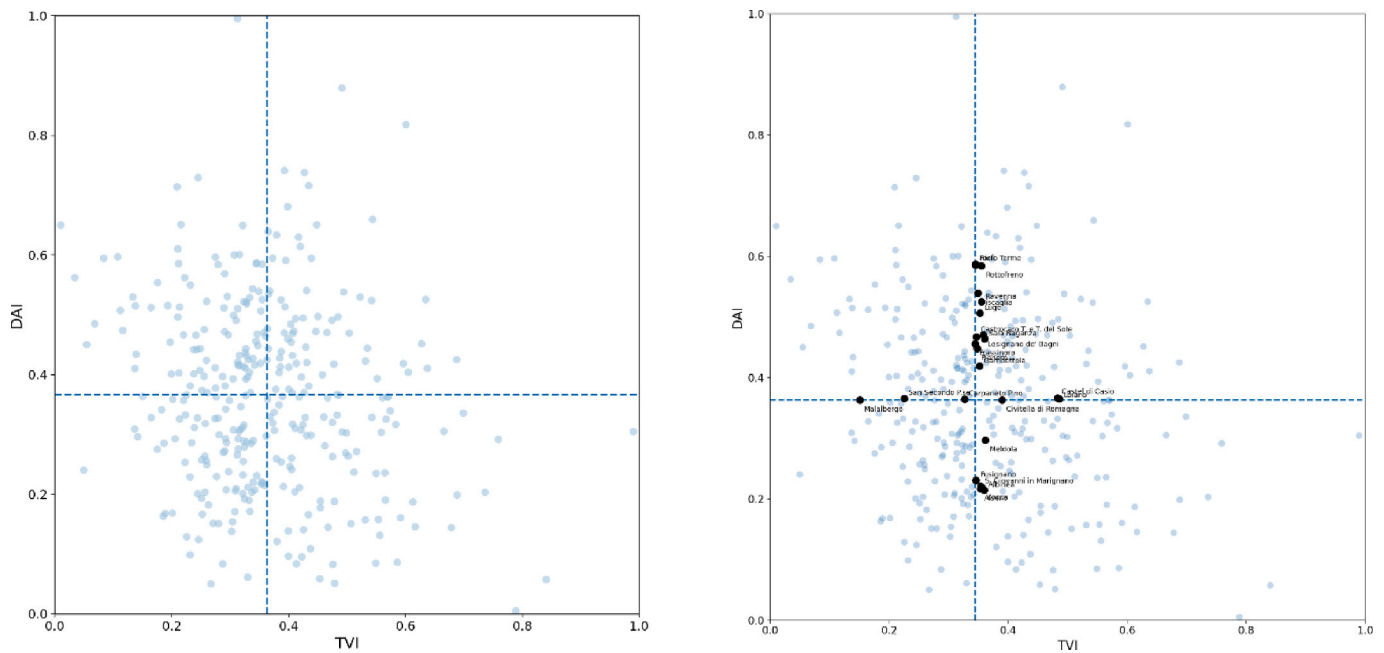


Fig. A1. TVI–DAI scatter plots using mean-based thresholds (left) and median-based thresholds (right). Municipalities changing quadrant under the median-based specification are highlighted and labelled in the right-hand panel.
Source: Authors' elaboration

The comparison indicates a high degree of stability. Of the 329 municipalities included in the analysis, 305 (92.7%) remain in the same quadrant when the median is used instead of the mean, while 24 municipalities (7.3%) are reclassified. Importantly, all reclassifications occur between adjacent quadrants: no municipality moves between diagonally opposite territorial profiles. This indicates that the alternative thresholds mainly affect the allocation of observations located around the boundaries separating the four territorial configurations, rather than altering the overall structure of the classification.

Table A1 reports the transition matrix between the baseline and alternative classifications. The strong concentration of observations along the main diagonal further confirms the stability of the four-quadrant typology.

Table A1
Transition matrix between mean-based and median-based quadrant classifications.

		Median Thr.				Total
		High TVI–High DAI	Low TVI–High DAI	Low TVI–Low DAI	High TVI–Low DAI	
Mean Thr	High TVI–High DAI	66	0	0	0	66
	Low TVI–High DAI	12	81	0	0	93
	Low TVI–Low DAI	0	3	80	6	89
	High TVI–Low DAI	3	0	0	78	81
Total		81	84	80	84	329

Overall, the sensitivity analysis shows that the substantive territorial patterns discussed in the paper are robust to an alternative and distributionally less sensitive threshold specification. Replacing the mean with the median leaves more than nine out of ten municipalities in their original quadrant and produces only local movements across neighbouring categories. The main interpretation of the four territorial configurations is therefore not dependent on the specific use of mean values as classification thresholds.

A.2 Inner Areas and territorial profiles

This section examines whether the territorial profiles identified through the TVI-DAI framework differ systematically between SNAI and non-SNAI municipalities. SNAI is used as an external territorial classification rather than as a policy-treatment variable; accordingly, municipalities identified as Inner Areas in either the 2014-2020 or 2021-2027 programming cycle are included, irrespective of actual policy implementation.”

Inner Areas and mountain municipalities are conceptually distinct and identified according to official classifications: the former follow the SNAI classification issued by the Department for Cohesion Policies and the South (Presidency of the Council of Ministers), based primarily on functional remoteness and accessibility to essential services; the latter follow the national mountain classification in force prior to the 2025 reform (not yet been adopted at the time the research was completed) based on morphological and geographical criteria. Nevertheless, the two classifications overlap substantially in Emilia-Romagna.

Table A2.1
Cross-classification of SNAI and mountain municipalities.

	Non-mountain	Mountain	Total
Non-SNAI	199	22	221
SNAI	10	98	108
<i>Total</i>	<i>209</i>	<i>120</i>	<i>329</i>

Source:
Authors'
elabora-
tion on
official
classifi-
cat-
ions.

The two classifications agree for 297 of the 329 municipalities (90.3%). Among SNAI municipalities, 98 out of 108 (90.7%) are also mountain municipalities, while 98 out of 120 mountain municipalities (81.7%) belong to SNAI configurations.

The two categories should therefore not be treated as interchangeable, although their substantial empirical overlap helps explain the similarity of some spatial patterns in the regional case.

Table A2.2
Distribution of SNAI municipalities by accessibility class.

SNAI accessibility class	No.	% of SNAI municipalities
Centre	2	1.9
Intermediate	27	25.0
Peripheral	61	56.5
Ultra-peripheral	18	16.7
<i>Total</i>	<i>108</i>	<i>100.0</i>

Source: Authors' elaboration on official classifications.

The distribution across accessibility classes is highly uneven, with only two municipalities in the Centre category. For this reason, the empirical comparison is conducted between SNAI and non-SNAI municipalities rather than across the four individual accessibility classes, which would provide a weak basis for inferential comparison in this regional sample.

[Table A2.3](#) reports the normalized PCA-weighted additive TVI and DAI used in the main analysis. SNAI municipalities display a higher average TVI (0.476 versus 0.307) but a lower average DAI (0.316 versus 0.391) than non-SNAI municipalities. Differences between the two groups are statistically significant for both indices ($p < 0.001$), but while the TVI difference is especially pronounced (Cohen's $d = 1.51$), the DAI difference is more moderate (Cohen's $d = -0.49$).

Table A2.3
TVI and DAI scores by SNAI status.

	SNAI (N = 108)	Non-SNAI (N = 221)	Effect size (Cohen's d)
TVI - Mean	0.476	0.307	1.51
DAI - Mean	0.316	0.391	-0.49

The higher TVI observed among SNAI municipalities should be interpreted in light of the multidimensional structure of the index. While remoteness and weaker service accessibility may penalize peripheral locations, other components, including environmental amenities, climatic conditions and housing affordability, may favour them. This result therefore concerns the specific territorial attributes captured by the TVI and should not be read as evidence of higher overall welfare or observed residential attractiveness. Such coexistence between functional remoteness and valuable territorial assets is also emphasized in recent studies of Italian Inner Areas [67]; [58].

The relationship is even clearer when SNAI status is examined against the four TVI-DAI profiles. [Table A2.4](#) reports count and within-group percentages using the mean-based thresholds adopted in the main analysis (TVI = 0.3625; DAI = 0.3667).

Table A2.4

Distribution of SNAI and non-SNAI municipalities across TVI-DAI quadrants (thresholds = mean values of normalized TVI and DAI distributions).

	High TVI/High DAI	Low TVI/High DAI	Low TVI/Low DAI	High TVI/Low DAI	Total
SNAI	25 (23.1%)	13 (12.0%)	7 (6.5%)	63 (58.3%)	108
Non-SNAI	41 (18.6%)	80 (36.2%)	82 (37.1%)	18 (8.1%)	221
Total	66	93	89	81	329

Source: Authors' elaboration on official classification.

The distribution differs markedly between the two groups. Almost three out of five SNAI municipalities (58.3%) belong to the high-TVI/low-DAI quadrant, compared with only 8.1% of non-SNAI municipalities. Conversely, only 6.5% of SNAI municipalities fall into the low-TVI/low-DAI quadrant, compared with 37.1% of non-SNAI municipalities. SNAI municipalities are nevertheless heterogeneous: 23.1% fall into the high-TVI/high-DAI quadrant, showing that functional remoteness does not necessarily imply weak digital accessibility.

Quadrant membership differs significantly between SNAI and non-SNAI municipalities ($\chi^2 = 115.1$, $p < 0.001$), with a strong association between SNAI status and territorial profile (Cramér's $V = 0.59$).

Data availability

Data will be made available on request.

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