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NEW CHALLENGES FOR XXI CENTURY CITIES

Multilevel scientific approach to impacts of global warming on urban areas, energy transition, optimisation of land use and emergency scenario

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The cover image shows a composition of two photos of the Temple of Serapis in Pozzuoli (Italy). Giuseppe Mazzeo took them in January 2009 and March 2025. At the top, the 2009 image shows the temple flooded, with the pavement not visible. In the down, the 2025 image shows the temple’s pavement dry and exposed. The Temple of Serapis is one of the leading visual indicators of the bradyseism phenomenon in the Phlegraean Fields. The bradyseism phase, highlighted by comparison, started in the first years of this century, as shown by the data published by the National Institute of Geophysics and Volcanology (INGV) on the website dedicated to the phenomena (https://www.ov.ingv.it/index.php/il-bradisismo).

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Definition of spatio-temporal levels of accessibility. Isochronous analysis of regional transport networks

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Abstract
Accessibility to transport networks affects the ability of citizens to carry out necessary activities in their daily lives. In particular, in small and medium-sized centres where only some essential services retain a proximity attribute, we are seeing an increasing number of daily travels, the distances travelled and the time taken by local citizens for primary (work, health, education, etc.) and secondary (leisure, etc.) mobility needs. In polycentric and widespread territorial contexts, such as those typically Italian, accessibility is therefore synonymous with spatial equity.
In this disciplinary debate, the present research aims to analyse analytically the levels of accessibility of individual administrative units to the main transport networks. To this end, a semi-automated method in GIS environment for the definition of municipal levels of space-time accessibility is proposed based on an isochronic analysis conducted on access nodes to major transport, motorway and rail networks, at the territorial scale. The paper also presents the results obtained from the method application in the Calabrian regional context useful to support the adoption of a planning approach oriented towards territorial integration between mobility needs and the programming of the network of services that typically characterizes the urban planning discipline.

Keywords
Accessibility; Isochronous analysis; Spatial equity.

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1. Introduction

The issue of accessibility to transport networks is significantly influences planning policies at all levels, from the suburban to metropolitan and regional one (Cargnin et al., 2024; Chen et al., 2024; Costa & Delponte, 2024; D'Amico, 2024; Di Ruocco, 2022; Erçetin, 2024; Stiuso, 2024). It has a particularly important role in relation to small and medium-sized centres with predominantly rural vocation, where carrying out all the activities necessary for everyday life moving outside the administrative boundaries is difficult for citizens. In particular, those living in such contexts, also widely marked by a thinning of local services, are forced to an increasing number of daily travels.

Similar reflections encouraged urban and territorial planners to study the effects of accessibility on urban quality of life and social inclusion/exclusion dynamics (Allen & Farber, 2020; Altay & Şenay, 2023; Cascetta et al., 2020; Handy, 2020; Jian et al., 2020; Vitale Brovarone & Cotella, 2020a; Mouratidis, 2021; Wang et al., 2021; Alberti & Marzi, 2022; Pucci et al., 2022). These effects arise not only from primary mobility needs, linked to so-called essential services (education, health, work, etc.), but also from secondary needs, no less important, related to the leisure and recreation of people (Borlini & Memo, 2009). In line with the statement by Allen & Farber (2020), recognising that transport planning has historically focused on increasing mobility offers, alleviating congestion and reducing environmental impacts, too often it has not been considered whether the choices made actually promote widespread and equitable participation in a wide range of day-to-day activities. In fact, in polycentric and widespread territorial contexts, such as those typically Italian, accessibility is synonymous with spatial equity (Canu, 2016).

In the light of these premises, the focus of the paper is not on the presence or location of specific services, but on the connection between places and services useful for meeting daily needs. Therefore, the fundamental elements placed at the centre of the subsequent analysis processes are the possible "routes" of connection, which underlie the relative flows of people that connect places and services. In this respect, Vilhelmson (1999) defined two categories of trips, depending on their degree of temporal and spatial flexibility, which fit well with the anticipated primary and secondary mobility needs. In particular, "fixed" trips are those intended to reach activities where both time and geographical location are fixed and hardly modifiable (for example, relating to travel to school or work). The "non-fixed" trips are those which are flexible in time and destination, typical of leisure activities.

These considerations have been the starting point for the authors' research, which proposes an analytical analysis of the levels of accessibility to the main regional transport networks of the individual administrative units in the Calabrian regional context. In particular, through a semi-automated methodology in GIS environment, the study aims at defining the above-mentioned levels of space-based accessibility time based on an isochronic analysis carried out at the main regional transport network access points, namely motorway and railway.

To this end, the paper proposes preliminary experimental results obtained for the Calabrian context that push towards the adoption of a planning approach oriented to territorial integration between mobility needs and the programming of the network of services that typically characterizes the urban discipline.

Given the content introduced, the paper is structured as follows. Section 2 presents a brief overview of the state-of-the-art in accessibility to non-infrastructural "major" areas, with particular attention to the main methods of analysis based on the construction of isochronic lines for the assessment of accessibility levels. Section 3 presents the semi-automated methodological framework in GIS environment. Specifically, the steps indicated include mapping transport network nodes, distinguishing between motorways and railways; building isochronic lines from each node considering journey times of 15, 30, 45 and 60 minutes by car; the allocation of a level of accessibility for each transport type to each administrative unit. Finally, Section 4 critically examines the experimental results obtained by applying the methodology in order to draw useful conclusions for the experimental context and generalizable for other reference contexts.

2. State of the art summary on the research topic

The issue of accessibility to "major" infrastructure nodes is a crucial topic in spatial planning with specific reference to the transport sector. The current state of the art shows a growing focus on multimodal integration and efficient connectivity, aimed at ensuring smooth and rapid access to strategic infrastructures. Recent studies have shown that accessibility to these nodes significantly affects economic development (Lin et al., 2024) and quality of life of surrounding areas, helping to reduce regional disparities and improve social inclusion (Melzi, 2011). In this respect, the literature highlights how motorway and railway nodes play a major role for sustainable rural development that can enhance the territory (Fazio et al., 2023; Zheng et al., 2024). In particular, the recent study by Huang et al. (2024) has highlighted how motorway and railway accessibility affect urban-rural income inequality and their resulting spatial heterogeneity, affirming that only through the promotion of an integrated system of transport networks can the level of urban-rural fragmentation be reduced.

In this context, advanced spatial analysis technologies such as GIS and network models are increasingly being used to assess accessibility conditions and design targeted interventions (Massaro & Rotondo, 2020). Many studies (Gkiotsalitis & Cats, 2021; Hillel et al., 2021; Pamucar et al., 2021) propose specific methodologies which can, for example, help to design new routes but also optimise the stopping points of different modes of transport, and to estimate the impact of changes in the transit network or urban planning. All these improvement measures promote sustainable urban mobility by contributing to environmental and social benefits and thus to the quality of life of citizens. (Xu, 2014; Montero-Lamas et al., 2024). The transposition of similar methodologies to the territorial scale, with reference to the estimation of the levels of accessibility of the territories to the main connecting infrastructures, allows an indirect measure of the degree of peripherality of the territory. This result provides a direction for planning activities to be directed, for example, towards the provision of additional specific services in more peripheral contexts or new connecting infrastructures.

Accessibility is also a major focus in European and national policies that emphasize the importance of improving infrastructure links, promoting the construction of new transport lines and improving existing infrastructures (Gargiulo et al., 2022). However, there is a complex relationship between accessibility and sustainable rural development due mainly to the disparity in access to these nodes between urban and rural areas, calling for a more equitable and integrated approach from the political class to ensure that all citizens can benefit from the opportunities offered by major infrastructure hubs (Große, 2024). The consequences of increasingly complex political processes that often hinder the real possibility of implementing the degree of accessibility of a territory are borne by smaller centres, or the marginal and internal areas already suffering from social and territorial fragmentation (Cerasoli, 2024).

In order to propose a methodology for assessing the level of accessibility of individual administrative units, the authors adopted the technique of isochronic analysis that underlies the measure of the spatio-temporal efficiency of the coverage of a service in a given area (Śleszyński et al., 2023). This choice is based on a recognition of the methods of analysis based on the construction of the isochrones already proposed in the literature, with a focus on the purpose of the assessment of the degree of accessibility.

This study showed that in some studies (Lahoorpoor & Levinson, 2020; Zhao & Zhou, 2024) the isochronic technique was used as a tool to define the catchment area of specific services in order to assess their demand. Of particular interest is the application by Yang et al. (2022) that uses this methodology to identify the shortest time possible to reach specific housing structures. The purpose of this study is in line with that of the authors' research, as it concerns the definition of an accessibility zoning model to determine the guiding mechanism and the route for optimising rural accessibility, using a "supply and demand threshold" coupling perspective. Furthermore, in this respect, a further specific application in the literature is related to the verification of the efficiency of public or private transport networks. This approach can identify any gaps to be filled in relation

to specific services, manage traffic flows, plan urban spatial development and improve the degree of accessibility to urban and extra-urban transport (Kurlov et al., 2022).
Specifically, the isochrone lines connect places that can be reached at the same time from the same starting point. For planning purposes, it is necessary to automate the mapping of these elements on the territory using GIS applications that ensure the automation of cartographic workflows, with the objective of analyzing and integrating geospatial information (Lü et al., 2019), after setting specific reference times, called cut-off times (Higgins, 2019). With reference to the computational aspects, the authors found that there is almost no study on the elements that influence the various cut-off times, or the time reference thresholds considered in an isochronic analysis. In this regard, Xi et al. (2018) notes that different cut-off times affect the interpretability of accessibility measures in the isochronic approach and that a cut-off time defined for general use may not exist because of the different factors that may come into play in the reference application fields. On the basis of these considerations, as will also emerge in the discussions, with reference to the proposed methodology, future developments in research provide for the implementation of corrective indices which, taking into account the various risk phenomena present in the territory, refine the isochronic analysis by returning more realistic projections to be used in defining relative potential optimal spatial scopes.

3. Methodological framework

In the current context of increasing attention to the development and revitalization of rural areas, which are mainly made up of small and medium-sized centres, the need to develop effective tools that can assess the real degree of accessibility of these centres, in order also to conduct specific analyses on the usability of services present on the territory by citizens (Merengo, 2023). These considerations have led to the birth and affirmation of the well-known Italian National Strategy for Inner Areas (called SNAI), which represents a national policy to combat depopulation and promote strategic interventions useful to make the internal and marginal areas again competitive in a territorial panorama characterized by polycentrism of large cities (Carrosio & Barca, 2020; Vitale Brovarone & Cotella, 2020b). Nevertheless, the authors believe that some of the theoretical assumptions on which SNAI is based have weaknesses in assessing accessibility, both with regard to identifying services limited to essential ones (education, health and mobility) defined in the framework of the strategy and mapping of the areas of intervention, defined through a preliminary classification of the territory based on the distance of the individual administrative units from the main urban centres, calculated in terms of travel times. Also, in order to fill these gaps, based on the above, this paper proposes the definition and first application of a semi-automated methodological framework in GIS environment, designed to analyse the degree of accessibility of administrative units, in relation to the main regional motorway and railway nodes. This methodology is based on an isochronic analysis from specific infrastructural nodes, conducted considering time ranges of 15, 30, 45 and 60 minutes and car journeys. The isochronic assessment is a crucial process for defining levels of spatial accessibility, as it allows distances from various starting points to be visualised and measured within a specific time range. The isochrons are graphic lines that connect all the reachable points within the same time, offering a clear and easily readable graphical representation. The choice of this technique was guided by studies found in literature, partly mentioned above (e.g. Montero-Lamas et al., 2024; Xi et al., 2018), which agree on the usefulness as an analysis tool to assess and identify areas with poor accessibility to services and infrastructure, as well as planning support for the identification of interventions aimed at reducing territorial inequalities and the consequent improvement of citizens' quality of life.

3.1 Steps of the framework

The methodological framework proposed by the authors is structured in consequential steps, which together aim to ensure a complete and accurate assessment of the level of territorial accessibility.

The first phase consists of data collection and includes the collection and digitisation of relevant geographic and infrastructure information, which is then translated into mapping the territorial context of analysis of major transport network nodes, by distinguishing two types: road nodes considering the intersections of the motorway network; railway nodes considering the stations in the regional territory.

Implemented in a GIS environment, the second phase involves spatial analysis of data by building isochrone lines from each transport node previously mapped. Specifically, we proceed to the construction of 4 isochrones for each node, considering car trips and time ranges of 15, 30, 45 and 60 minutes. For the construction of the isochrones a plugin of the software QGIS called TravelTime was used. It is an advanced tool designed to create lines, called isochrones, connecting points within a given travel time and using different modes of transport. This plugin allows users of the software to evaluate the accessibility and connectivity of territories in a precise and efficient way. The main features of the plugin are:

- A multimodal type support, which allows the construction of isochrones based on different means of transport (car, public transport, bicycle, walking, etc.). This allows for precise, comparative analyses on the accessibility of a given area according to the means of transport used;
- A user-friendly, intuitive interface that facilitates the configuration and generation of isochrones. Users can define the desired travel time parameters and select starting points directly on the QGIS map;
- Integration with external data sets of road and public transport networks, allowing for improved level of analysis accuracy;
- A detailed output, which allows the export in various formats (shapefile, GeoJSON, etc.) of the generated isochrones, allowing further processing and analysis within QGis or other GIS software;
- Advanced analysis, in fact, TravelTime allows to perform insights, such as the calculation of service coverage and the identification of less served areas, supporting urban planning activities and infrastructure management.

The use of the TravelTime plugin in QGIS is a significant research advantage, in order to elaborate detailed analyses on accessibility and mobility within a territorial context, providing powerful and flexible tools to achieve accurate results that are useful for strategic planning.

The product from the first two steps was then overlayed on the raster data for the population census provided by EUROSTAT, with data updated to 2021 that has allowed to derive and systematize different demographic information for each administrative unit and for each isochrone considered.

The fourth step consists of assigning the level of accessibility to individual administrative units, based on the percentage of population served and differentiated for each type of transport, based on the distribution of the population in relation to the isochrones and regardless of the extent of coverage of the territory. This classification is characterised by 10 bands, each with an alternation of 10 percentage points between 0 and 100. The classification of administrative units on the basis of this scale is accompanied by an analytical legend, which facilitates the understanding of the results, namely the following levels:

- Very satisfied, containing the 80-90 and 90-100 bands. This level represents the maximum degree of accessibility by users, it is indicated through a bright and dominant color, which highlights the administrative units with the highest possible rating compared to the parameters analyzed;
- Satisfied, containing the 60-70 and 70-80 bands. This level still represents a high degree of accessibility and although it is below the maximum level, the administrative units falling in this category have a significant degree of accessibility compared to the parameters analysed;
- Neutral, containing the 40-50 and 50-60 bands. Located in the middle of the proposed scale, this level represents a condition of accessibility close to sufficient, and is indicated with a colour gradient that degrades towards lighter tones;
- Dissatisfied, containing the 20-30 and 30-40 bands. This level represents a poor degree of accessibility and is indicated by soft colours tending to white. This category includes administrative units which do

not adequately respond to users' needs and are therefore in a position of functional isolation;

- Very dissatisfied, containing the 0-10 and 10-20 bands. This last level represents the minimum degree of accessibility of an administrative unit and is indicated with a colour almost absent that reaches white at zero percentage. This category includes administrative units with a very low percentage of population covered and therefore in a position of severe and total functional isolation in some cases.

As already mentioned, this classification concerns, at the territorial scale, administrative units, which, in this case, also through the use of GIS tools, has been applied to the Calabrian regional context for which the specifications and unpublished maps depicting the different levels of accessibility will be presented in the next section. This process generally facilitates the identification of areas with greater or lesser difficulty of access, leading to the definition of targeted strategies for improving connectivity and access to services, with the aim of reducing territorial inequalities and promoting a balanced and inclusive development of medium and small-scale centres. Specifically, such applications can provide a sound and objective basis for strategic planning and development policies aimed at reducing territorial disparities and promoting equitable access to resources and services for all citizens.

4. Experimental results

As already mentioned, the field of application of the semi-automated methodology in GIS environment was the entire territorial context of the Calabria Region. This section describes the experimental results obtained in the reference context, which are expressed in the construction of analytical data and quantitative tables synthesized in specific maps. Through the use of GIS tools and the construction of isochrone lines based on the main road and rail transport nodes, it was possible to accurately assess the different degrees of accessibility between the different areas of the Region. The data collected revealed significant disparities in connectivity between communities, highlighting local phenomena of functional isolation as well as contexts that benefit from a good degree of accessibility.

The first operation was the digitisation of the main nodes with reference to the motorway network and the rail network. The result was the identification of 208 knots related to railway stations, divided by service provider company: 61 nodes of Ferrovie della Calabria (FDC) and 147 of Rete Ferroviaria Italiana (RFI) and 31 nodes related to motorway interchanges. As shown in Fig.1, while the distribution of motorway nodes is concentrated on the Tyrrhenian side of Calabria, railway nodes are distributed throughout the regional territory, concentrated along the coastal borders and in the central-northern hinterland.

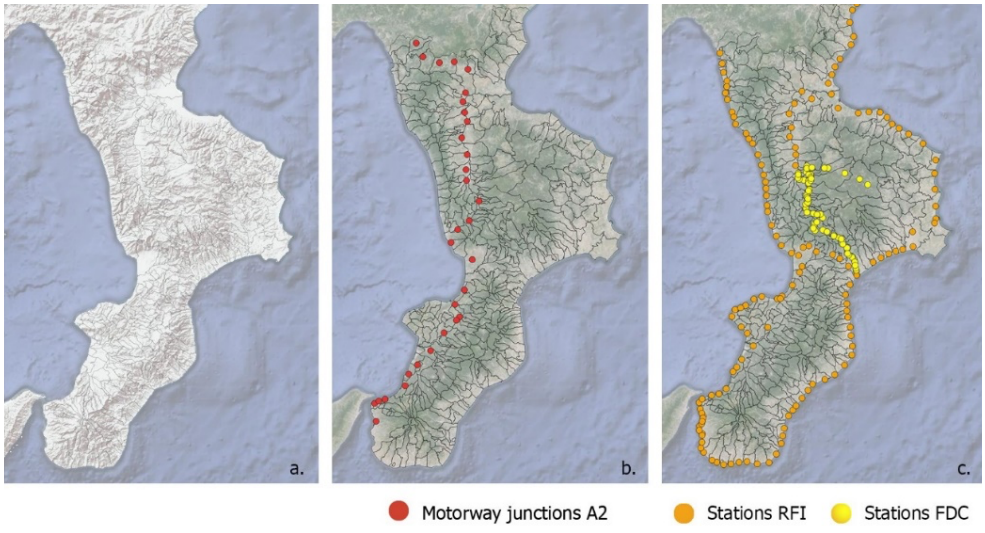

Fig.1 Topographic map of the Calabria Region (a) and digitisation in GIS environment of the main motorway (b) and railway nodes (b) of Ferrovie della Calabria (FDC) and Rete Ferroviaria Italiana (RFI)

Subsequently, through the Travel Time plugin, the isochrone lines relative to each node for each of the two types of nodes considered were built using time ranges of 15, 30, 45 and 60 minutes, choosing as a means of transport the car, and setting as day and time of "departure" on March 18 at 09.00 am.
The isochrones thus elaborated were superimposed with the demographic data on the regional basic cartography. This information was obtained through the vectorization of the raster image updated to 2021 provided by EUROSTAT (Fig.2), also verified with the analogues Istat data which provides, compared to EUROSTAT, additional information on the composition of the population.

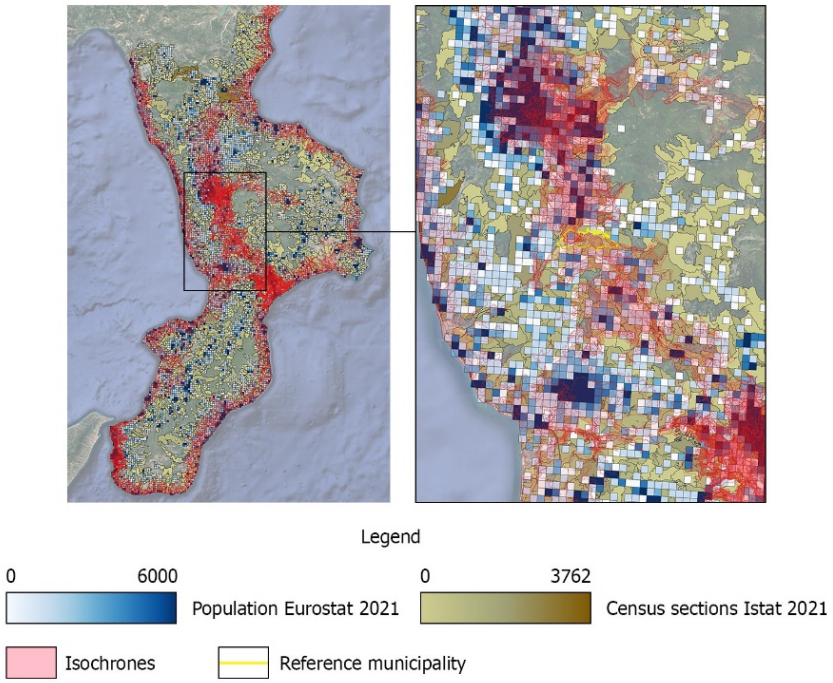

Fig.2 Map of overlap between the isochrone lines and the EUROSTAT and ISTAT population data (2021)

By means of semi-automated processes in GIS environment it was possible to obtain information useful for the assessment of the degree of accessibility of the different administrative units of Calabria. For logistical reasons, it was not possible to include all the information obtained from the above operations in the contribution; only a part of this data is shown below in tabular form.
The overlapping operations carried out in a GIS environment between the isochrones constructed from the infrastructure nodes mapped in the regional context and demographic data have allowed to verify: which isochrones concern the 404 Calabrian Municipalities and how many inhabitants fall within the different isochrones.
In Tab.1, which refers to the railway nodes, are listed in alphabetical order the first five and the last five Municipalities of Calabria, and for each is indicated: the total number of isochrones from which they are reached starting from the reference infrastructural nodes; and the number of inhabitants of the Municipality itself that fall within the area of the isochrones present in its administrative boundaries. The data in Tab.1 clearly show the direct proportionality that exists between the increase of the time range considered and the numerical values related to both the isochrones present in the Municipality and the number of inhabitants falling into them. In this respect, it is noted, for example, that the Municipality of Zumpano, located in the province of Cosenza, and that of Africo, in the province of Catanzaro, have a high degree of accessibility, in fact, the totality of their population already falls within the 15-minute isochronous. In contrast, the Municipalities of Acquaformosa (CS), Acquaro (VV) and Zagarise (CZ) are characterized by a lower level of accessibility, since they do not have a population served within 15 minutes.

Municipality (Province)	Total population	Time Ranges for Railway Nodes			
		15 minutes	30 minutes	45 minutes	60 minutes
		Number of isochrones affecting the Municipality			
		Number of inhabitants falling within the isochrone group			
1. ACQUAFORMOSA (CS)	1,018	-	3	12	31
		-	259	1,018	1,018
2. ACQUAPPESA (CS)	1,295	5	15	26	48
		1,261	1,295	1,295	1,295
3. ACQUARO (VV)	1,848	-	1	11	36
		-	26	1,831	1,848
4. ACRI (CS)	19,056	3	20	52	71
		21	14,571	18,955	18,967
5. AFRICO (RC)	1,535	4	10	15	36
		1,535	1,535	1,535	1,535
…	…	…	…	…	…
		…	…	…	…
400. ZACCANOPOLI (VV)	523	4	10	15	19
		512	523	523	523
401. ZAGARISE (CZ)	1,384	3	21	30	61
		-	1,135	1,335	1,376
402. ZAMBRONE (VV)	1,726	5	10	15	24
		1,709	1,726	1,726	1,726
403. ZUMPANO (CS)	4,658	19	34	50	78
		4,658	4,658	4,658	4,658
404. ZUNGRI (VV)	1,906	3	13	16	28
		1,015	1,906	1,906	1,906

Tab.1 Analysis of the population coverage of isochrones related to railway nodes for each administrative unit in Calabria

The data in Tab.2, which refer to motorway interchanges, show that all Municipalities reported have zero values within the 15-minute time frame, with the exception of Zumpano (CS) which, also in this case, as for rail nodes, its strategic location ensures a high level of accessibility. There are also specific cases, such as that of the Municipality of Africo (RC), which despite having a maximum degree of accessibility to the rail network, is in a condition of functional marginality compared with the motorway network, because it cannot guarantee coverage for its inhabitants even in 60 minutes. For a complete view of the degree of accessibility of all Calabrian centres, please refer to the figures below.

Municipality (Province)	Total population	Time Ranges for Motorway Nodes			
		45 minutes	60 minutes	45 minutes	60 minutes
		Number of isochrones affecting the Municipality			
		Number of inhabitants falling within the isochrone group			
1. ACQUAFORMOSA (CS)	1,018	-	4	10	14
		-	1,008	1,018	1,018
2. ACQUAPPESA (CS)	1,295	-	2	7	12
		-	-	1,130	1,295
3. ACQUARO (VV)	1,848	-	5	8	12
		-	1,487	1,848	1,848
4. ACRI (CS)	19.056	1	6	10	15
		1	10,416	17,796	18,958

5. AFRICO (RC)	1,535	-	-	-	5
		-	-	-	-
…	…	…	…	…	…
		…	…	…	…
400. ZACCANOPOLI (VV)	523	-	-	6	10
		-	-	510	523
401. ZAGARISE (CZ)	1,384	-	-	1	4
		-	-	-	1.244
402. ZAMBRONE (VV)	1,726	-	1	6	11
		-	46	1,726	1,726
403. ZUMPANO (CS)	4,658	2	9	12	15
		4,168	4,658	4,658	4,658
404. ZUNGRI (VV)	1,906	-	4	7	12
		-	63	1,906	1,906

Tab.2 Analysis of the population coverage of isochrones related to motorway nodes for each administrative unit in Calabria

In Tab.3 are the results of the analyses of the catchment area for the individual isochrones constructed from the reference infrastructural nodes. In particular, through this type of analysis it was possible to verify the actual efficiency in terms of population coverage of each mapped node, also to support the planning of strategic interventions aimed at improving the degree of accessibility of a given administrative unit by making a specific node more reachable.

Identification of isochrones (Transport company)		**Time Ranges**			
		15 minutes	**30 minutes**	**45 minutes**	**60 minutes**
		Number of inhabitants falling within the isochrone group			
Railway nodes	Acquappesa (RFI)	14,904	46,720	102,761	331,366
	Acri - Bisignano (RFI)	9,929	221,305	340,279	490,015
	Adami (FDC)	6,350	60,545	128,258	421,833
	Africo Nuovo (RFI)	17,632	32,351	74,557	125,797
	Amantea (RFI)	13,999	38,413	130,539	443,099
	…	…	…	…	…
Motorway nodes	Laino Borgo	1,698	9,302	54,067	125,187
	Mormanno - Laino Castello	3,712	26,085	66,431	161,391
	Campotenese	1,121	34,328	81,218	222,262
	Morano C. - Castrovillari	11,142	44,462	102,518	252,961
	Frascineto - Castrovillari	19,690	57,994	137,215	370,037
	…	…	…	…	…

Tab.3 Analysis of the population coverage of individual isochrones built from railway and motorway nodes

After having collected all the information, some of which is presented in tabular form, the adoption of semi-automated processes developed with QGIS software made it possible to synthesise the data collected and obtain a classification of the administrative units of Calabria. This classification is based on the percentage of inhabitants, in relation to the total population of each Municipality, that falls within the set of isochrones that affect that specific local administrative unit. The above classification of the territory of Calabria is shown below, in relation to the four-time ranges defined.

In Fig.3 reference is made to the isochrones built from railway nodes. Specifically, analysing the results obtained from classification it is noted that within the 15-minute range (Fig.3a), the highest degree of accessibility is concentrated mainly in the regional coastal areas and in the northern hinterland, consistent with the placement of stations in Fig.1. It is also evident that the high number of Municipalities in the 15-

minute range has percentage values between 0% and 20%, a sign of a level of accessibility that is highly insufficient.

This condition improves by extending the time limit to 30 minutes (Fig.3b), despite remaining unsatisfied entire portions of the territory located: at the extreme north in correspondence with the Pollino National Park, in the central eastern part of the Sila National Park and in the southern hinterland in the "Parco delle Serre" and the Aspromonte National Park.

With the time range of 45 minutes (Fig.3c) a maximum degree of accessibility is obtained for almost all centres, in fact, there are only ten Municipalities that do not reach the level "Very satisfied" and even two of them (Fabrizia and Laino Castello) have a percentage value below 10%.

Finally, only by referring to the time range of 60 minutes the entire territory of Calabria reaches a maximum coverage (Fig.3d).

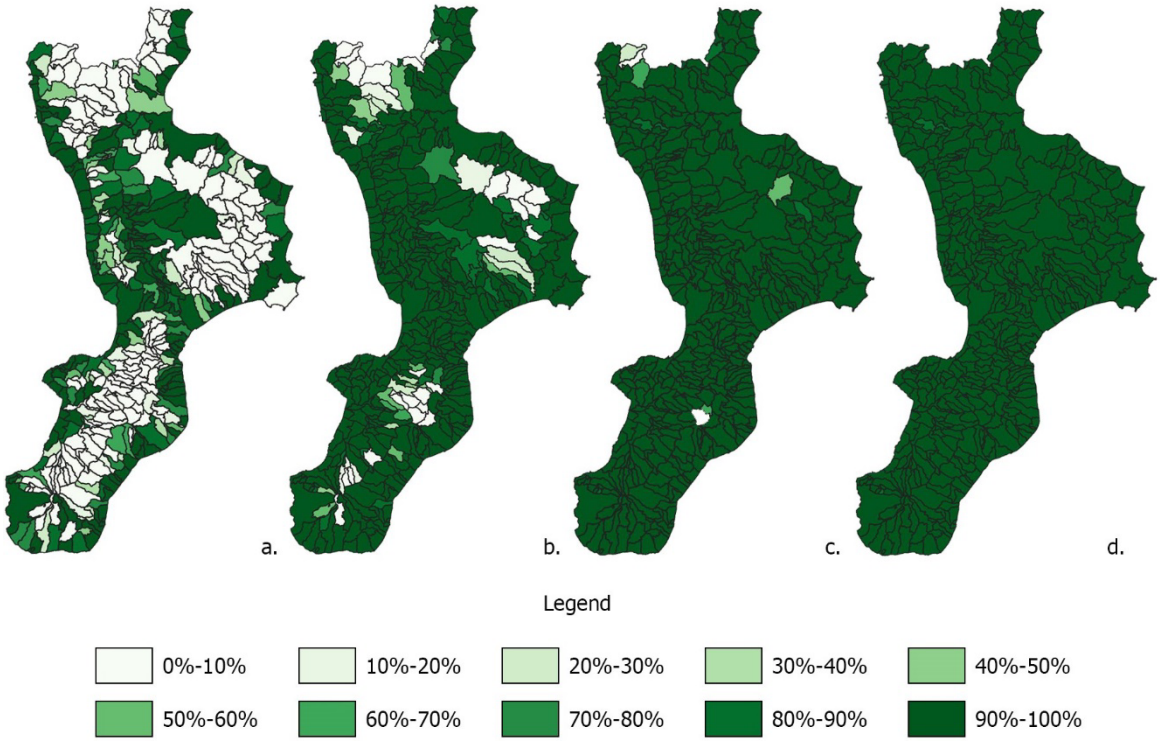

Fig.3 Classification of the administrative units in Calabria with reference to railway nodes according to the following time ranges: 15 minutes (a), 30 minutes (b), 45 minutes (c), 60 minutes (d)

In Fig.4 the same classification of the administrative units of Calabria is shown, but this time with reference to the motorway nodes mapped previously.

The road network in Calabria has several critical points, in terms of general degradation of the network, or tortuosity of the road sections due to the orography of the territory. In this context, the motorway route is a crucial element for determining the degree of accessibility of a given centre, especially considering the lack of mobility services at regional level. In addition, most of the inhabitants of small and medium-sized Municipalities in Calabria travel by car to reach their places of work, leisure or essential services not present in their own centres. Therefore, through the analysis conducted it is possible to verify which are the most accessible areas and those characterized by a marked functional marginality.

In Fig.4a, you can see how the degree of accessibility of administrative units within the 15-minute range is concentrated around the highway axis, leaving the rest of the territory uncovered.

In the interval of 30 minutes (Fig.4b) the same condition occurs, although the catchment area covered increases, but nevertheless the entire Ionic belt of Calabria remains characterized by percentages close to zero, as well as the northern Tyrrhenian belt.

Within the range of 45 minutes (Fig.4c) increases further the degree of accessibility of the Municipalities, although compared to the same analysis made on railway nodes, in this case the number of administrative units with low percentage values in this range is significantly higher. In fact, the Ionic belt and the extreme north of the Tyrrhenian belt are still almost entirely undiscovered.

Finally, analysing the time range of 60 minutes (Fig.4d) it is noticed that, despite the percentage of Municipalities falling in the lower bands has decreased, almost the whole of Silan and four other smaller areas are still characterized by a marked degree of functional marginality. In this respect, the difference with the result obtained by the same analysis in reference to the same interval for railway nodes is obvious.

While the isochronic analysis in the range of 60 minutes ensures a total coverage of the territory of Calabria with reference to railway nodes, the same analysis carried out on motorway nodes highlights a split of Calabria, that despite the large interval of time considered presents almost 20% of the Municipalities in conditions of functional marginality.

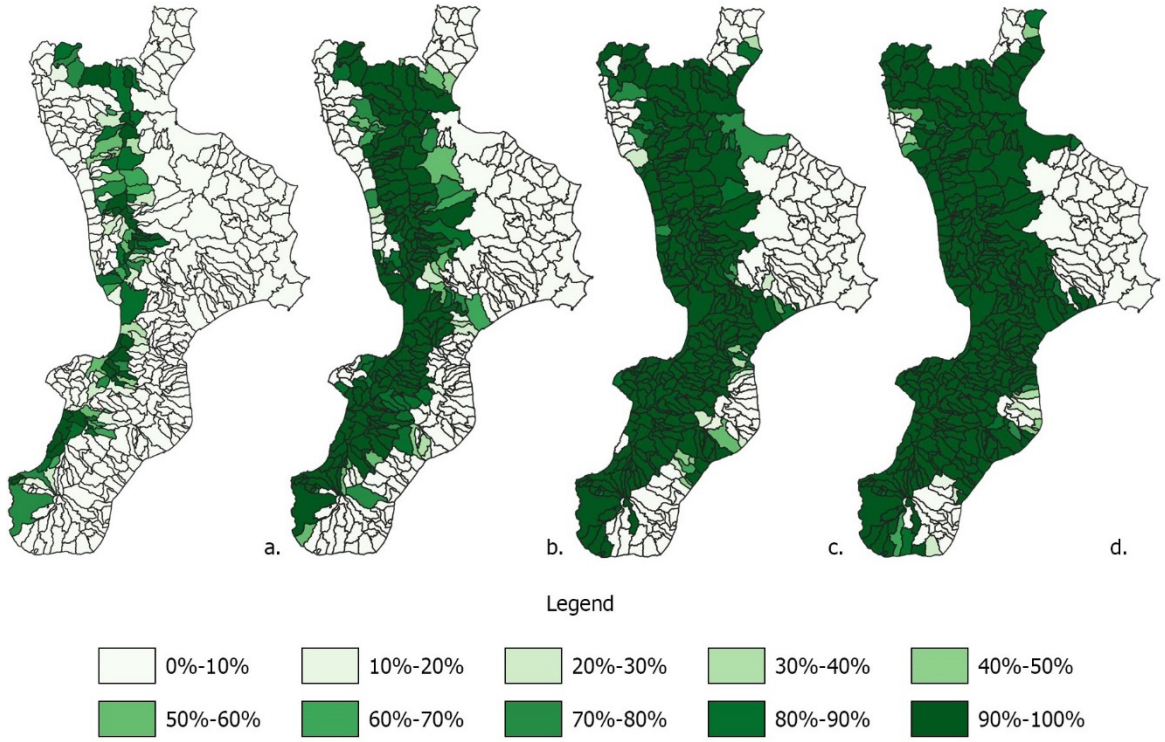

Fig.4 Classification of the administrative units in Calabria with reference to motorway nodes according to the following time ranges: 15 minutes (a), 30 minutes (b), 45 minutes (c), 60 minutes (d)

5. Discussion and conclusion

This study proposed a semi-automated methodology in GIS environment for the analysis of levels of accessibility to the main transport, highway and railway nodes, municipal administrative units based on isochronic analysis, Presenting the results of its application to the context of the Calabria Region.

In this context, it should be specified that the contents presented in this paper are part of a wider research project, which aims to revitalise and transform the most fragile territories, with specific reference to small and medium-sized centres, in sustainable and resilient models. Specifically, future research developments include the definition of potential optimal territorial areas within which to promote inter-communal forms of association for the management of specific functions and services. This approach finds a useful reference in the assumptions of the National Strategy for Inner Areas (called SNAI) that, similarly, identifies institutional associationism as the prerequisite for the definition of project-areas (Palermo et al., 2024). However, the results obtained in this study with regard to accessibility levels highlight the need to include, in such strategic

spatial planning processes, additional municipal contexts not mapped by SNAI, which are affected by similar problems (Fig.5).

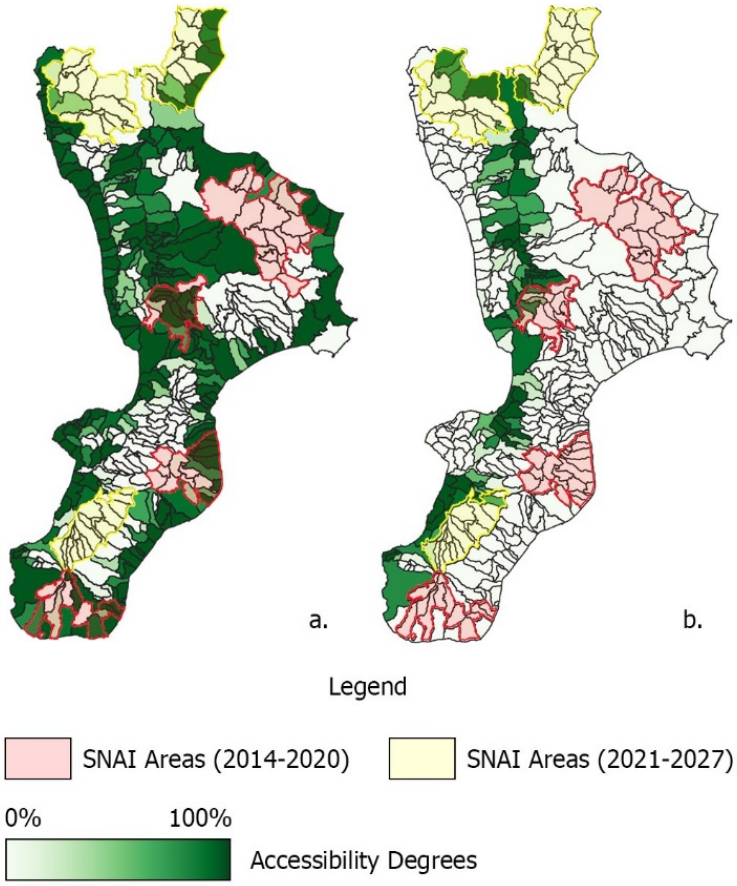

Fig.5 Overlap between the mapping of the National Strategy for Inland Areas (SNAI) related to the programming periods 2014-2020 and 2021-2027 and the degree of accessibility achieved considering the time range of 15 minutes with reference to railway nodes (a) at motorway junctions (b)

The inconsistencies between the municipalities selected for the SNAI in Calabria Region and the proposed results are explained by the different methodological approach underlying the mapping technique. In this case, the use of the isochronic analysis is recommended in literature for several practical purposes in relation to different possible spatial and transport planning needs, to ensure greater spatial equity and a reduction in territorial fragmentation (Śleszyński et al., 2023). In fact, with reference to the experimental context, the results have allowed to highlight significant disparities in connectivity between the various areas of the Region, also attributable to the morphology of the territory, The characteristics of infrastructure networks and spatial distribution of population centres. The results have been presented in a disaggregated form for each of the transport types considered, also in order to highlight the effect induced by the concentration of motorway nodes on the Tyrrhenian side of Calabria and the more homogeneous distribution of railway nodes throughout the region. Indeed, this different distribution has direct implications on the overall levels of accessibility, with some areas benefiting from good transport services and others suffering from significant functional isolation, In most cases, this is the case of small and medium-sized centres located mainly in the mountain areas of Calabria. In this regard, the isochronic analysis has been a valid tool not only to assess levels of accessibility, but also to deduce further elements of reflection useful for planning purposes in the regional context of Calabria.

In particular, with reference to the first aspect, the results obtained, systematized for time intervals of 15, 30, 45 and 60 minutes, provided a detailed representation of the levels of accessibility of administrative units. This

technique showed that most of the Calabrian Municipalities were served by transport nodes within 60 minutes, but with significant variations between them. The integration of demographic data has further enriched the analysis, allowing for an assessment of accessibility in terms of population served. This phase confirmed that the large urban centres tend to have better levels of accessibility, while the medium and small centres have lower levels of accessibility. Especially in these contexts, this result represents a considerable challenge also because of the low population density and the complex local morphological context which tends to increase distances and travel times, making it more difficult to satisfy in terms of service provision (Bertram & Chilla, 2023).

With reference to the second aspect, it is even more evident that the methodology developed can be applied in practice. The results reveal specific local needs to be met in terms of quality of life, and guide planning choices towards optimising the transport sector with the aim of better managing the movements needed by the community, and increasing local, basic and ancillary services, especially in those contexts marked by unsatisfactory levels of accessibility to the main transport infrastructures.

In conclusion, this study highlighted the importance of a planning approach oriented to territorial integration between mobility needs and service network programming. The results suggest that to improve accessibility in the less-served areas of Calabria, it is necessary to promote targeted and integrated development policies which take into account local peculiarities and specific mobility needs. This approach can provide a solid basis for planning and development policies that aim to reduce territorial disparities and promote equitable access to resources and services. It is therefore argued that it is important to incorporate social equity into planning activities, especially in the transport sector, because of the close relationship between accessibility, Ease of reaching the various destinations and risks of social exclusion, which can be understood as the repressed ability to carry out daily activities, also in accordance with what stated by Allen & Farber (2020).

In addition, the proposed methodology can also be applied to other regional contexts, offering a versatile tool for accessibility assessment and supporting the planning of interventions aimed at improving territorial connectivity. In this respect, the results obtained could be a useful input to vary or update the methods underlying the choice of distance thresholds for measuring the degree of peripherality of territories proposed by SNAI, currently calculated in minutes of travel to the nearest pole.

Finally, from the methodological point of view, the application to the regional context of Calabria has made it possible to highlight some aspects to be taken into account for future research presages, also in order to carry out further investigations and add to the analyses carried out. In particular, with regard to the methodological framework, it is envisaged that synthetic indices of space-time accessibility may be computed, at least one for each type of infrastructure node considered. These indices will take account of a weighing system to be defined, for example by applying a multi-criteria analysis. In addition, as anticipated it is planned to implement corrective indices in order to take into account the various types of risk phenomena present on the territory, thus refining the isochronic analysis in order to return more realistic projections of actual travel times.

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Image Sources

Figg.1-5: Authors' elaboration.

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