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Examining the impact of large-scale transport infrastructure projects on job accessibility in Crete, Greece

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Examining the impact of large-scale transport infrastructure projects on job accessibility in Crete, Greece

Abstract

Job accessibility plays a vital role in enhancing commuting flows and integrating local labour markets. For this reason, public authorities often invest in large-scale transport infrastructure projects to improve accessibility for workers and visitors. Nonetheless, such improvements may raise important questions about the spatial distribution of benefits delivered. This study probes how these projects affect job accessibility at the submunicipal level, focusing on the island of Crete in Greece. Three major transport project scenarios are evaluated, as well as combinations of them: (1) the (ongoing) construction of a new motorway network, (2) a new international airport in Heraklion and an associated motorway linking several municipal units with this airport, and (3) a hypothetical railway line traversing most of the island's surface. The analysis draws on detailed data originating from the National Census and employs advanced GIS-related techniques and accessibility indices based on a gravity model to evaluate job access for various building types as employment opportunities. Equity is assessed at both horizontal and vertical dimensions, incorporating Gini, Palma and concentration indices as well as spatial autocorrelation analysis. The results show that, while the projects significantly enhance job accessibility, the benefits are unevenly distributed, with notable disparities between the island's eastern and western parts. Nevertheless, multimodal solutions based on rail and improved motorway options favour equity in the region. These findings can offer valuable insights for policymakers, planners, and investors, by highlighting the need for integrated and inclusive transport strategies that consider multi-scale impacts and diverse mobility needs.

Keywords: Job accessibility; transport infrastructure; spatial equity; spatial analysis; gravity models.

Μελέτη των επιδράσεων έργων μεταφορικών υποδομών μεγάλης κλίμακας στην πρόσβαση από την κατοικία στην εργασία στο νησί της Κρήτης

Περίληψη

Η προσβασιμότητα από την κατοικία στην εργασία συνδέεται στενά με τις καθημερινές συνθήκες μετακίνησης και διαδραματίζει κομβικό ρόλο στην ολοκλήρωση των τοπικών αγορών εργασίας. Για τον λόγο αυτό, οι δημόσιες αρχές επενδύουν συχνά σε έργα μεταφορικών υποδομών μεγάλης κλίμακας, με στόχο τη βελτίωση της προσβασιμότητας για τους εργαζόμενους και τους επισκέπτες. Ωστόσο, τέτοιες βελτιώσεις ενδέχεται να εγείρουν σημαντικά ερωτήματα σχετικά με τη χωρική κατανομή των παρεχόμενων οφελών. Η παρούσα εργασία διερευνά τον τρόπο με τον οποίο τα έργα αυτά επηρεάζουν την προσβασιμότητα στην εργασία σε επίπεδο δημοτικής ενότητας, εστιάζοντας στο νησί της Κρήτης. Αξιολογούνται τρία βασικά σενάρια έργων μεταφορών, καθώς και συνδυασμοί αυτών: (1) η (υπό εξέλιξη) κατασκευή ενός νέου δικτύου αυτοκινητοδρόμων (Βόρειος Οδικός Άξονας Κρήτης-ΒΟΑΚ), (2) ένας νέος διεθνής αερολιμένας στο Ηράκλειο και ένας αυτοκινητόδρομος που θα συνδέει διάφορες δημοτικές ενότητες με αυτόν τον αερολιμένα, και (3) μια υποθετική σιδηροδρομική γραμμή που διασχίζει το μεγαλύτερο μέρος της επιφάνειας του νησιού. Η ανάλυση βασίζεται σε λεπτομερή δεδομένα που προέρχονται από την Εθνική Απογραφή Πληθυσμού-Κατοικιών της ΕΛΣΤΑΤ το 2021, και χρησιμοποιεί προηγμένες τεχνικές εκτίμησης σχετικές με Συστήματα Γεωγραφικών Πληροφοριών (GIS) καθώς και δείκτες προσβασιμότητας βασισμένους σε ένα μοντέλο βαρύτητας. Απώτερος σκοπός είναι η αξιολόγηση της πρόσβασης από την κατοικία στην εργασία για διάφορους τύπους κτιρίων ως ευκαιρίες απασχόλησης. Η ισότητα αξιολογείται τόσο σε οριζόντια όσο και σε κάθετη διάσταση, με τη χρήση των δεικτών Gini, Palma και συγκέντρωσης, καθώς και μέσω της ανάλυσης χωρικής αυτοσυσχέτισης. Τα αποτελέσματα δείχνουν ότι, ενώ τα έργα βελτιώνουν σημαντικά την πρόσβαση από την κατοικία στην εργασία, τα οφέλη κατανέμονται άνισα, με αξιοσημείωτες ανισότητες μεταξύ του ανατολικού και του δυτικού τμήματος του νησιού. Ωστόσο, οι πολυτροπικές λύσεις που βασίζονται στον σιδηρόδρομο και στις βελτιωμένες επιλογές οδικής μετακίνησης ευνοούν την ισότητα πρόσβασης στην περιοχή. Τα ευρήματα αυτά μπορούν να προσφέρουν πολύτιμες πληροφορίες στους υπεύθυνους χάραξης πολιτικής, τους χωροτάκτες και τους επενδυτές, υπογραμμίζοντας την ανάγκη για ολοκληρωμένες και χωρίς αποκλεισμούς στρατηγικές μεταφορών που λαμβάνουν υπόψη τις επιδράσεις σε πολλαπλές κλίμακες και τις ποικίλες ανάγκες κινητικότητας.

Λέξεις-κλειδιά: Προσβασιμότητα, μετακινήσεις από την κατοικία στην εργασία, υποδομές μεταφορών, χωρική ισότητα, χωρική ανάλυση; μοντέλα βαρύτητας.

1. Introduction

Accessibility is considered a principal indicator for measuring the socio-economic outcome of transport improvements. Access to employment opportunities plays a vital role in facilitating commuting, changing travel patterns and shaping local labour markets (Li & Dodson, 2020). To improve this access, public authorities often invest in large-scale transport infrastructure projects aiming to enhance connectivity for both residents and visitors and stimulate economic growth, particularly in underserved areas (Kadyraliev et al., 2022). By improving access to jobs, education, and services, such investments have the potential to narrow regional inequalities and support a more balanced territorial development (González-González & Nogués, 2019; Škorupa et al., 2023).

While much of the academic and policy focus concerns urban or suburban areas, accessibility at the (sub)municipal level, particularly in nonmetropolitan and peripheral/rural areas, remains an equally critical yet often overlooked topic (Vitale Brovarone, 2021; Tsigdinos & Kourounioti, 2026). In such areas, limited transport options and fragmented infrastructure governance can exacerbate socioeconomic disparities, constraining residents' ability to reach jobs and essential services. Given that the effect of such improvements may significantly vary with geographical scale and be unequally distributed across local communities, measuring the heterogeneity of these benefits across more detailed spatial units and different population groups becomes crucial to ensure equity. This process is even more important in insular/remote areas, such as islands, which typically face persistent and severe challenges concerning limitations to their infrastructure capacity and agglomeration economies, lack of hinterland and raw/intermediate resources, and constraints in socio-economic opportunities (Baldacchino, 2020, Tsekeris, 2023).

Moreover, although transport infrastructure projects are considered as a major driver of local growth, their impact is largely assessed in terms of standard measures of travel time savings, overlooking other aspects and hidden risks that may emerge. Such risks may involve benefits that are not equitably distributed, so that certain communities may remain marginalised or even experience relative disadvantages (Bruzzone et al., 2023; Damvakari et al., 2025; Martens & Di Ciommo, 2017; Pereira et al., 2019; Škorupa et al., 2023; Wee et al., 2011). Other aspects may also encompass distortions in the regional economic integration process and changes in the attractivity of local markets. Therefore, the spatial analysis of the accessibility landscape and its transformation over time requires a holistic approach to properly incorporate wider impacts into the project evaluation and ensure how the largest and fairest outcomes can be attained.

For this purpose, the present study aims to probe how major transport projects can influence job accessibility at a high (submunicipal) level of spatial resolution and potentially lead to varying impacts across local administrative (or commuting) areas. The island region of Crete in southern Greece presents a particularly relevant case to contribute to the evaluation of both the local job accessibility enhancement and the potential adverse equity impacts of large-scale transport projects, given its geographical fragmentation, the limited infrastructure capacity, and the increased socio-economic diversity across municipalities. Specifically, the study focuses on two major transport projects under development: first, the construction of a comprehensive motorway network currently absent from the island and, second, the development of a new international airport in Heraklion, along with an associated motorway connecting adjacent regional units. Additionally, a third, hypothetical scenario is explored, involving the implementation of a railway line across a significant portion of the island, albeit this option is not currently being included in the formal planning agenda. Combinations of the proposed transport

projects are also considered and evaluated in terms of accessibility improvements and equity effects.

The analysis employs a unique database originating from the National Census of Population and Buildings and uses advanced GIS-related techniques and accessibility indices based on a gravity model to evaluate job access for various building types as employment opportunities. The analysis verifies that it is essential to assess not only the overall gains in accessibility, but also the spatial distribution and equity implications of these gains. Adopting a holistic and spatially disaggregated approach to accessibility analysis can provide critical insights for transport policy and regional planning (Freiria et al., 2022). It further enables stakeholders to better understand who benefits, who may be left behind, and how future interventions can be more balanced and inclusive, contributing to the broader goal of sustainable regional development.

The contribution of the current research lies in three major points (also discussed in subsection 2.7). First and foremost, we analyse job accessibility in an island peripheral area at a regional scale, thus, enriching the existing body of literature, which mostly focuses on urban or metropolitan areas. Second, we utilise scenarios that describe probable and preferable future conditions. By doing so, we facilitate the project evaluation process. To date, studies usually examine current situation without envisioning the future. Finally, we incorporate various equity metrics that provide a holistic picture regarding the distributional impacts of large-scale transport projects.

Regarding the structure of the paper, Section 2 provides a concise literature review of analysing accessibility and equity beyond urban areas at the regional setting and explaining main factors affecting these relationships from the transport planning viewpoint. Section 3 presents the study area and various scenarios of transport infrastructure development in the island, together with the methodology and analysis tools and metrics adopted to measure different aspects of job accessibility and equity. Section 4 includes the results, together with robustness analyses and the discussion of key findings. Section 5 summarises and concludes with policy implications.

2. Literature review

2.1. From urban to regional. Different scale, different needs

Rural, suburban and peri-urban areas differ considerably from metropolitan centres and dense urban cores in terms of their spatial, sociodemographic and infrastructure characteristics (Lin et al., 2025; Tulus & Ramadan, 2021; Vasárus et al., 2018). Unlike metropolitan centres, these areas tend to have lower population densities, dispersed spatial patterns, reduced economic diversification and limited public transport services (Carlucci et al., 2019; Chen et al., 2022; Li et al., 2024a). Such structural differences translate into varied accessibility conditions and travel behaviour. At the regional level, rural accessibility is often car-dependent, with longer travel times and fewer modal choices, exacerbating issues of social exclusion and labour market participation (Farber & Páez, 2011). Suburban and peri-urban areas, though closer to urban cores, still face challenges related to transit connectivity and land-use fragmentation (Liu et al., 2022). These spatial typologies require distinct approaches in both analysis and policy responses to ensure equitable access to employment and services. Thus, the examination of key spatial issues from a regional perspective is quite different than zooming into cities or core urban areas.

2.2. Basics of job accessibility

Job accessibility refers to the ease with which individuals can reach employment opportunities, considering spatial distribution of jobs, transport network and travel constraints such as time, cost or mode availability (Zhang et al., 2024; Tsigdinos et al., 2024; Liu & Yu, 2025). It is a basic concept in both transport planning and regional development, linking infrastructure, land use and job flows. High levels of job accessibility are associated with improved labour market outcomes, reduced commuting burdens and increased social inclusion (Jin & Paulsen, 2017). Henceforth, job accessibility encompasses two fundamental pillars: the location of (or matching between) homes and jobs, and the accessibility or spatial interaction between them (Slovic et al., 2019; Kosmidis et al., 2025).

At a foundational level, the concept of spatial accessibility was first introduced by Hansen (1959), who defined it as the potential for spatial interaction between supply and demand. Since then, accessibility has evolved into a multidimensional and context-dependent concept with various models proposed to quantify it (Soukhov et al., 2025). The most commonly used measures entail: Cumulative opportunity measures, which count the number of jobs reachable within a given time or distance; Gravity models, which account for both the attractiveness of destinations (e.g., job density) and the friction of travel (e.g., distance decay, generalised travel cost); Utility-based models, grounded in behavioural economics; and Distance-based metrics, focusing on direct or shortest paths (Kapatsila et al., 2023; Mazzulla & Pirrone, 2024; Mitropoulos et al., 2023; Vale et al., 2016).

Among these measures, gravity models remain popular due to their theoretical underpinning, flexibility and intuitive representation of accessibility (Olsson, 2016). In this regard, this research will incorporate a gravity-model framework where accessibility is conceptualised as the potential for individuals or groups situated in a given location to interact with available opportunities (Hansen, 1959). Subsequent research has advanced this perspective, demonstrating that the accessibility of a given zone within a transport system is a function of the spatial interaction between an origin zone and all other zones, moderated by a (generalised) trip cost decay function (Geurs & van Wee, 2004; Tsigdinos et al., 2024; Kosmidis et al., 2025). As aforementioned the available opportunities here would be the number of jobs per cost unit of analysis (see Section 3).

2.3. Job accessibility beyond urban areas

While (job) accessibility research has largely concentrated on urban or metropolitan contexts, there is an emerging need for expanding this exploration to the regional scale. A few studies have scrutinised that topic and their main points are summarised here. From a methodological perspective, Dai et al. (2025) developed a multi-modal, multi-scalar intercity accessibility framework. On a European level, Biosca et al. (2013) conducted a comprehensive analysis across seven diverse case studies, examining various accessibility indicators for both private and public transport. They found that while urban areas generally enjoy better accessibility, significant disparities exist between urban and rural regions, particularly in terms of access to jobs and services. On a cross-country level, namely, Austria, the Czech Republic, Germany and Poland, Jacobs-Crisioni et al. (2016) simulated future population distributions and measured accessibility changes under different spatial development scenarios. They indicated that while local population changes have a limited effect on average accessibility, they remarkably influence territorial inequalities related to accessibility.

Another study, narrowed to Greece though, by Panagiotopoulos and Kaliampakos (2018) explored the association of accessibility at a regional scale in the country, highlighting how geographical remoteness contributes to spatial inequalities. They found there are benevolent correlations between remoteness and factors such as income, education and infrastructure, pointing out the challenges faced by remote areas. Shifting our interest to Spain, Monzón et al. (2013) formulated a comprehensive methodology that assesses both efficiency (measured by accessibility improvements) and equity (distribution of these improvements) using geographical information systems (GIS). They found that while High Speed Rail (HSR) extensions generally improve overall accessibility and reduce spatial inequalities, certain cities may still experience relative disadvantages, underscoring the need for balanced planning that considers both efficiency and equity in future HSR projects.

2.4. Transport equity analysis in regional job accessibility

Transport equity constitutes a fundamental dimension of the just city (Johnson et al., 2025) and is intrinsically linked to the notion of spatial accessibility (Curl, 2018). Broadly speaking, transport equity encompasses the policies, infrastructure, and services essential to the inclusivity of transport systems (Freiberg et al., 2024). From a normative standpoint, the sufficientarian approach to equity argues that everyone should have a basic level of access that enables them to avoid severe disadvantages and pursue a self-determined life (Johnson & Svara, 2011). This view is echoed in Martens (2016)'s concept of transport equity, which insists on guaranteeing a minimum access threshold for all individuals. In contrast, the egalitarian perspective advocates for the equal distribution of resources and opportunities across society (van Wee & Geurs, 2011), highlighting fairness in outcomes rather than just minimum standards. In practice, equity in transport planning is commonly classified into two main types:

- Horizontal equity, which promotes equal provision of transport services to all individuals, regardless of their specific needs or abilities (Dadashpoor & Rostami, 2017). This aligns with the egalitarian framework.
- Vertical equity, which recognises and seeks to address differences in needs, capacities, and socio-economic status across population groups (Farber et al., 2014). It reflects a sufficientarian view by focusing on outcomes for disadvantaged or vulnerable users.

In this context, accessibility serves not only as a key performance metric for evaluating transport systems, but also as a valuable lens for assessing their equity impacts (Niehaus et al., 2016; Vecchio et al., 2020). By analysing who gains access to what and at what cost, researchers and planners can better understand whether infrastructure investments contribute to more equitable outcomes at the subregional (municipal or submunicipal) levels. As a methodological underpinning, horizontal and vertical perspectives can be used as complementary measures of transport equity (Zibandehkhooy & Chen, 2026), In particular, the horizontal perspective provides the broader picture, while the vertical perspective explores socioeconomic implications in greater depth.

2.5. Transport equity implications beyond urban areas

Equity has been thoroughly examined, under a spatial perspective, on an urban or metropolitan scale highlighting spatial disparities and insufficiencies (e.g., DeWeese et al., 2022; Pritchard et al., 2019; Tsigdinos et al., 2024; Samat & Rosli, 2025). Notwithstanding, less attention has been paid to the regional scale and the rural setting. Yet these areas often face more profound

accessibility challenges due to structural disadvantages, including dispersed populations, limited transport networks and reduced public service provision. Equity challenges in non-urban contexts often intersect with broader issues of territorial cohesion and regional policy (Rodríguez-Pose et al., 2024). As also stated at the beginning of this section, the regional scale demands specific attention and consequently, urban insights cannot properly explain the regional transport realm.

In this context, a limited number of studies have shed light on transport equity implications in the regional scale. Zhao and Yu (2020), in their paper on mobility equity in rural China, demonstrate how inequalities emerge across demographic groups due to uneven distribution of transport services and limited vehicle ownership. Their findings underscore the importance of tailored policies, such as targeted public transport improvements and equitable car ownership schemes to bridge mobility gaps in rural settings. Similar trends can be observed in other rural and island regions worldwide, where limited accessibility compounds socio-economic vulnerability. For instance, Carroll et al. (2021) identified hotspots of transport disadvantage in rural Ireland, showcasing potential areas for clear-cut sustainable mobility policies.

Furthermore, even already mentioned, it should be remembered that Monzón et al. (2013) demonstrated that new HSR scenarios favour transport equity conditions in the Spanish territory. Moreover, Bills (2024) tested a full-scale activity-based travel demand model to analyse the equity outcomes of various transport options and spatial development scenarios in the San Francisco Bay Area. The author demonstrated the importance of applying specific equity standards in scenario evaluations, while pointing out that choice of standards matters. Finally, Wang and Zhang (2019) conducted an analysis using weighted average travel time and the coefficient of variation to assess changes in accessibility and equity before and after HSR implementation in China. They found that while overall accessibility improved by approximately 24.56%, the spatial distribution of these gains was uneven, resulting in a 28.12% increase in accessibility inequality.

2.6. Envisioning the future: Scenario development

Last but not least, when looking into accessibility and equity implications of transport projects, especially, the large ones influencing an entire region, scenario planning constitutes a strategic approach for envisioning and assessing potential future developments, by investigating a range of hypothetical situations, underlying assumptions, and their prospective outcomes (Tori et al., 2025). This approach is particularly pertinent to the present study when considering issues of accessibility and spatial equity. Furthermore, scenario planning necessitates creative thinking, acknowledging that “the future cannot solely be anticipated or forecasted but can also be planned” (Lyons et al., 2021). Within this framework, the backcasting approach is especially valuable, as it provides a means of defining a desired future state and subsequently determining the steps required to achieve it (Broman and Robèrt, 2017). Typically, this process entails an examination of existing conditions, the formulation of several potential future pathways, and the identification of policy measures expected to produce the intended outcomes (Höltl et al., 2017).

Job accessibility through scenario development is often neglected in transport research (Hu & Sun, 2023). There are some exceptions like Tsigdinos et al. (2024) and Kosmidis et al. (2025), who examined urban areas though. When it comes to the regional level, these studies are even fewer. Some of the most relevant ones are the following: Monzón et al. (2013) used a scenario-based approach in Spain to evaluate HSR scenarios. In the same line, Wang and Zhang (2019) examined different HSR scenarios in China. Tsigdinos and Kourounioti (2026) examined accessibility and

equity impacts of future proximity and connectivity planning scenarios. Jacobs-Crisioni et al. (2016) incorporated a scenario-based approach for investigating the association between transport accessibility and population dynamics, while Bills (2024) explored the effects of four transport and spatial development scenarios on transport equity.

2.7. Research gap

As evidently demonstrated, job accessibility and its equity implications have been widely examined in metropolitan and urban contexts; nonetheless, significantly less attention has been paid to regional contexts, such as semi-urban, semi-rural and island regions. This entails a clear research gap, as these areas are characterised by lower population densities, longer travel distances, limited modal choice and a higher dependence on specific transport links, all of which can fundamentally influence accessibility dynamics and social equity connotations. Particularly in island regions, geographical isolation, capacity-constrained networks and reliance on maritime or air connections create "bounded" accessibility conditions. As a result, existing evidence offers limited guidance on how transport investments or policy choices affect job accessibility and distributional outcomes in these contexts. To address this gap, the current study adopts a scenario-based approach, using alternative (road and rail-based) transport pathways to test how different development strategies and policy choices may shape job accessibility and equity in island regions.

3. Data and methodology

3.1 Analytical framework

The present analysis is grounded on an analytical framework and a rich dataset that includes detailed information on commuting flows, land use, and socio-economic variables for the Region of Crete, at the submunicipal (LAU-2) level of detail, as obtained from the National Population Census conducted by the Hellenic Statistical Authority (ELSTAT) in 2021. These data are processed using advanced Geographical Information Systems (GIS) tools to facilitate the computation of accessibility metrics, based on carefully defined assumptions about the scope and characteristics of the proposed transport infrastructure projects.

The process begins with the definition of the study area, focusing on municipal units as the basis for spatial analysis. This is followed by accessibility calculation, where different formal planning scenarios are examined. Spatial analysis and gravity models of spatial interaction are employed to quantify accessibility levels across municipalities. The final stage involves a comprehensive equity measurement, rooted in geospatial and welfare economics. The methodological framework illustrated in Figure 1 outlines a multi-stage approach to evaluating spatial equity of new transport projects.

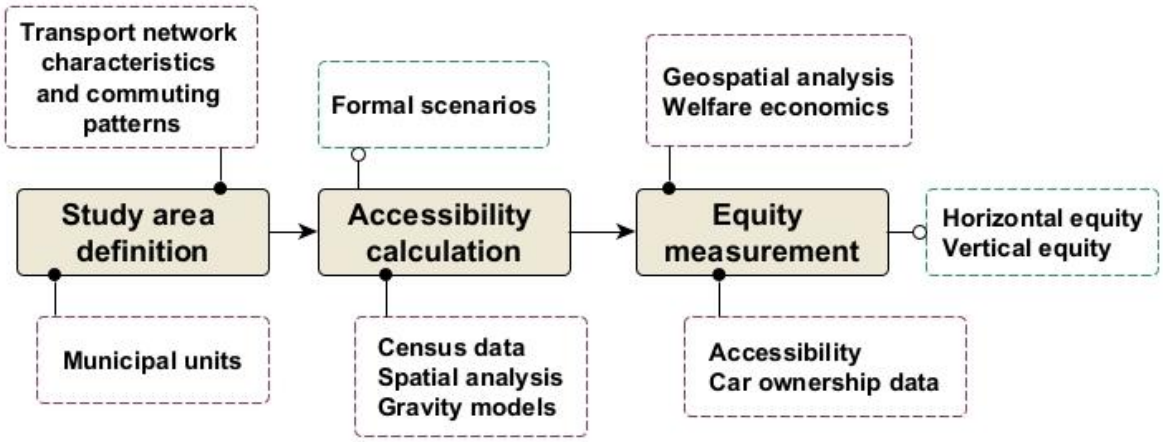

Figure 1: Methodological flowchart for the accessibility and equity measurement.

The methodology is supported by a diverse dataset, including accessibility metrics and census data (car ownership data). In particular, the study employs a gravity-based model to estimate job accessibility, incorporating different types of building uses, such as commercial offices, retail spaces, public services and industrial facilities, as indicators of employment opportunities. To assess equity implications, the analysis begins with horizontal equity, measured with the use of the Gini coefficient and Lorenz curves. It then moves on to explore vertical equity dimensions, focusing on specific population groups, like carless households, using the Concentration Index, the Palma index, the Bivariate Moran's I index and the Bivariate Local Indicators of Spatial Association (LISA) for spatial statistical analysis.

3.2. Study area

The study focuses on the Region of Crete, situated in Southern Greece (Figure 2). Crete is the largest Greek island, with a total land area of 8,311.53 km^2, and represents a significant administrative and socio-economic unit within the country. Administratively, Crete is divided into four (NUTS-3) regional units (Chania, Rethymno, Heraklion, and Lasithi) and further subdivided into 72 municipal units (LAU-2 level). The island's urban structure is characterised by four major cities: Chania, Rethymno, Heraklion, and Agios Nikolaos, with Heraklion functioning as the regional capital and primary economic hub. According to the Census data, the population of Crete has remained relatively stable over the last decade, with 623,065 inhabitants recorded in 2011 and 624,410 inhabitants in 2021. During the same period, the employment rate increased from 84% in 2011 to 89% in 2021, reflecting an overall improvement in labour market conditions. Nevertheless, the region continues to face structural challenges in terms of transportation infrastructure. The motorway network remains incomplete, and the island lacks a railway system, which constrains both intra-regional connectivity and accessibility to remote/outermost areas. The capacity limitations have implications for mobility, regional integration and economic development.

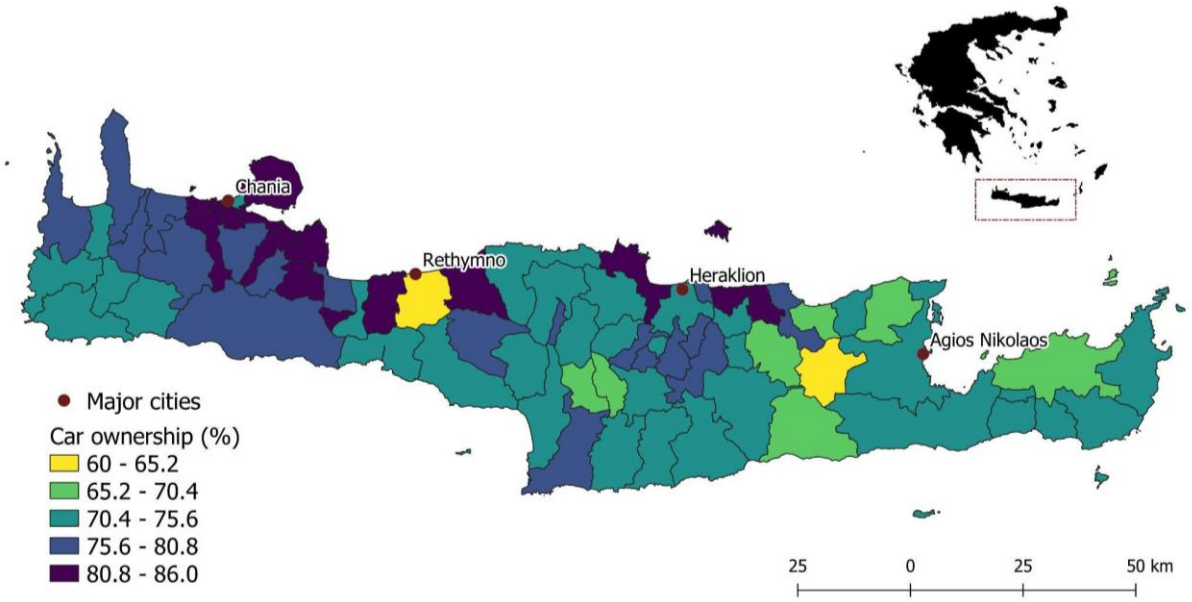

Figure 2: Study area and car ownership in the Region of Crete (data: ELSTAT, 2021)

In addition, equity implications are examined through car ownership, which exhibits noticeable spatial variation, reflecting both the island's socioeconomic patterns and the uneven distribution of transport alternatives. As illustrated in Figure 2, municipalities in the central and northern part of the island, particularly around the cities of Heraklion and Chania, tend to display higher levels of car ownership, often exceeding 75% (ELSTAT, 2021). These areas are characterised by larger urban centres, dispersed suburban settlements and economic activities that increase reliance on private vehicles (Tsigdinos & Kourounioti, 2026). On the contrary, several municipalities in the southern part show comparatively lower car ownership rates (Figure 2). Given the absence of adequate public transport (Tarasi et al., 2021), these areas with low car ownership might narrow the transport options and work possibilities of their residents.

3.3. Scenario development

The scenario development is grounded in the need to explore how different transport investment priorities may shape future spatial and accessibility outcomes (Lyons et al., 2021). The scenarios were constructed to reflect a spectrum of plausible, preferable and future pathways, each aligned with distinct strategic takeaways in transport planning. Together, they offer a structured framework for examining how alternative infrastructure decisions could influence mobility patterns, territorial equity, and wider development trajectories.

The starting point (S0) represents a "do-nothing" scenario, in which current deficiencies in both the motorway and rail networks persist. This baseline is essential for assessing the consequences of inaction and for benchmarking the relative impact of more interventionist strategies. Beyond this baseline, the scenarios diverge into two principal branches, each associated with different policy preferences. The road-focused branch (S1-S2) reflects a continuation of prevailing trends in many regions, where road infrastructure investment is often seen as the most immediate or politically feasible option (Ministry of Infrastructure and Transport, 2019). Scenario S1 ("Pave roads") introduces a substantial road upgrade programme, adding 301.6 km of new motorway infrastructure to complement the existing 50.6 km network; it represents a moderate enhancement of motorway connectivity. Scenario S2 extends this road-focused approach by incorporating a 33.4 km primary connector road to the new (under

development) Heraklion airport, reflecting an emphasis on strengthening regional accessibility to major gateways. These scenarios prioritise road transport efficiency along the island's dominant east-west axis, following established mobility patterns and reinforcing connections between major urban centres. They are regarded as the most probable scenarios, given their consistency with conventional infrastructure priorities and incremental planning approaches.

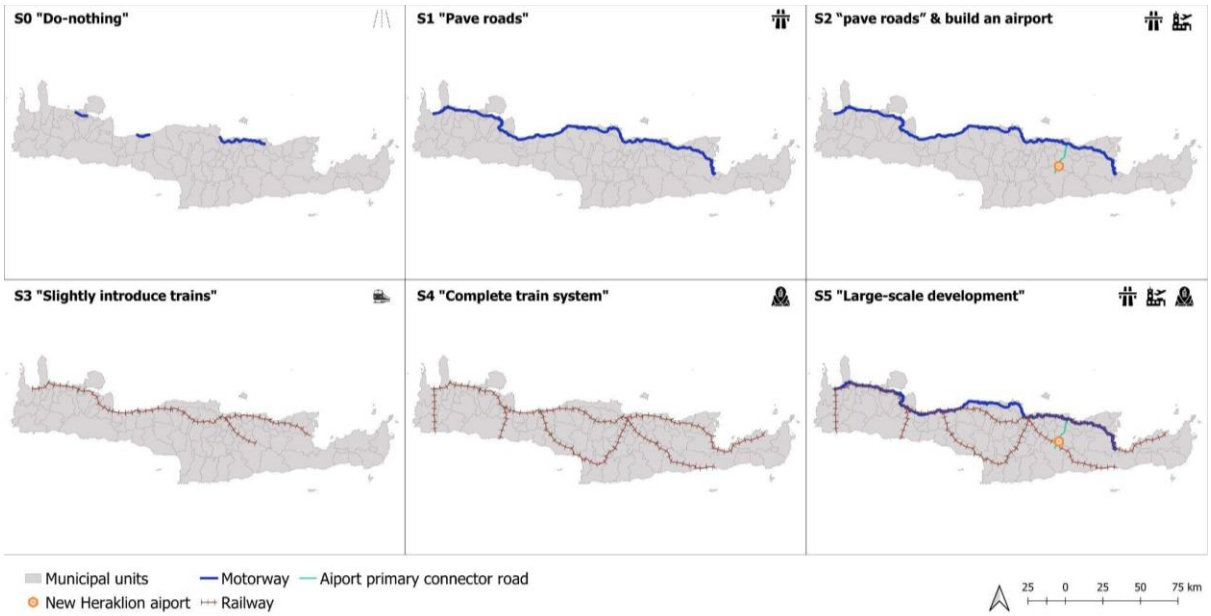

Figure 3: Description of Scenarios (Data: ELSTAT, 2021; Openstreetmap)

The rail-oriented branch (S3-S4) is constructed as the preferable pathway in relation to sustainability, accessibility and long-term territorial cohesion[1]. Scenario S3 ("Slightly introduce train") introduces a limited rail network of 248.9 km with 17 stations, providing strategic connectivity to selected urban and rural centres. It envisions a modest upgrade, through the selective introduction of railway services, offering insight into the effects of gradual modal diversification. Scenario S4 ("Complete train system") provides a complete rail system, which comprises 503.3 km of track and 27 stations, creating a continuous north-south and east-west lattice that serves both coastal and interior regions. It represents a more transformative shift, with a fully developed rail network designed to serve as the backbone of regional mobility. These scenarios capture the potential benefits of rebalancing investment priorities towards public transport and reducing dependence on road-based systems.

Finally, Scenario S5 ("Large-scale development") combines the full motorway programme, the airport connector and the complete rail system, constituting a large-scale development vision that maximises transport integration across modes, simultaneously covering the entire island. This scenario represents a stress-test of the transport system under conditions of extensive and simultaneous development. It allows us to assess the spatial implications of incremental versus comprehensive infrastructure strategies on regional accessibility and probe the limits of multimodal network development as well as possible synergistic or conflicting effects when both modes are expanded concurrently. Figure 3 demonstrates the actual scenarios to be tested. These six scenarios represent a progressive sequence of transport development strategies for

[1] https://www.tanea.gr/2008/12/06/greece/to-treno-tha-sfyriksei-stin-kriti/

Crete, ranging from a “do-nothing” condition (S0) to an ambitious multimodal investment pathway (S5).

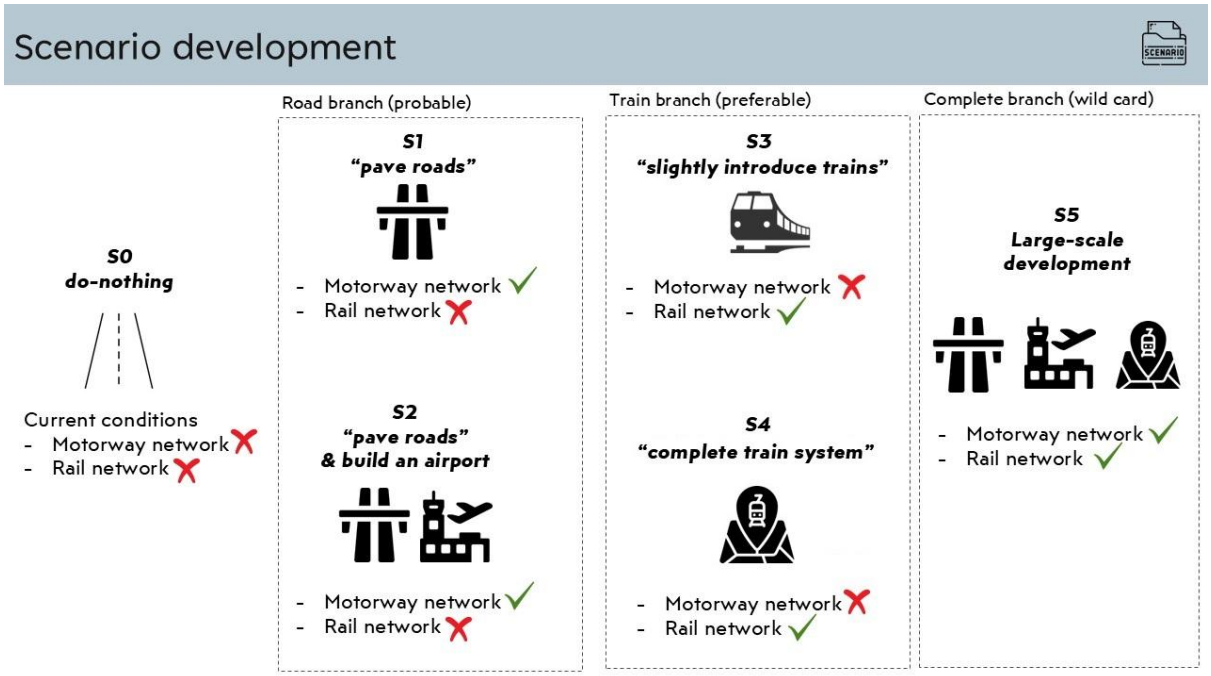

Figure 4: Conceptual scenario development

Collectively, these scenarios offer a coherent conceptual framework that captures a wide range of potential futures, from incremental change to transformative investment (Figure 4). Their development facilitates a comparative assessment of how alternative strategic choices may differentially affect accessibility and spatial equity, thereby supporting a deeper understanding of the policy levers most capable of shaping desirable long-term outcomes. The selection of these scenarios reflects both the current infrastructure commitments and plausible future considerations relevant to regional planning in Crete. The motorway and primary road upgrades are included because they are already under construction or formally planned, making their assessment essential for understanding near-term accessibility outcomes. In contrast, the train scenarios represent hypothetical, yet widely discussed options in public debate, despite not being part of any official development programme. Including these rail alternatives enables an exploration of their potential contribution to spatial equity and multimodal connectivity, providing evidence-based insight into proposals that frequently appear in local policy discourse. Taken together, the scenario set captures both the infrastructural realities shaping Crete’s transport future and the transformative possibilities implied in ongoing public discussions.

3.4. Accessibility measurement

In this study, based on the current literature review (Section 2), accessibility is conceptualised as the ability to reach employment opportunities, precisely, locations (buildings) that host workplaces, from a given origin zone (*i*) to all potential destination zones (*j*). Zones, i.e., municipal units with fewer (more) job locations at the same distance, are considered less (more) accessible or attractive ones. The given approach aligns with widely adopted location-based accessibility models frequently applied in relevant studies (e.g., Geurs & van Wee, 2004; Guzman et al., 2018; Kosmidis et al., 2025). Accessible opportunities are considered here as unconstrained, since

there is no constraint with respect to some total regional or zonal aggregate. To quantify the accessibility level, we employ the following equation, as outlined in Guzmán et al. (2017):

$$A_i = \sum_j O_j * exp(-\beta C_{ij}) \quad (1)$$

O_j: denotes the number of opportunities available in zone *j*. In this study, we use the count of buildings containing workplaces, i.e., retail/offices, public services, and factories within each zone. Buildings with workplaces are considered as an appropriate proxy (Chen & Akar, 2017; Tsigdinos et al., 2024; Iimi, 2025) and the data were obtained from the National Census of ELSTAT in 2021.

β: cost sensitivity (or spatial decay) parameter β. This parameter is set equal to 1 as per other relevant studies[2].

C_{ij}: generalised travel cost, which, for simplicity, is expressed in terms of travel time (minutes) (Kosmidis et al., 2025).

To be more precise, equation (2) can express the generalised travel cost in more detail:

$$\text{If } mode = car, then, C_{ij} = T_{ij}, \ or \ mode = train, \ then, \ C_{ij} = t_{ik} + t_{lk} + t_{lj} \quad (2)$$

T_{ij}: is the driving time

t_{ik}: is the access time, i.e., the time travelled by car from the starting zone centroid *i* to the nearest railway station *k* following the fastest path.

t_{lk}: is the in-vehicle time, i.e., the time travelled through the railway system from station *k* to egress station *l*. Waiting time and required transfers are included in this variable as a hypothetical frequency of 3 / 5 trains/hour, meaning approx. 10 / 6 minutes of waiting time (along major/secondary routes) and a 2-minute penalty, respectively.

t_{lj}: is the egress time, i.e., the time travelled by car from the nearest railway station *l* to the ending zone centroid *j* following the fastest path.

The travel time component of the analysis is computed using a fastest-path algorithm implemented in the open-source QGIS environment. Road network speeds were carefully assigned to individual road segments according to their functional street classification (120-90 km/h for motorways, 90-60 km/h for primary arterials, 60-50 km/h for secondary arterials, 50 km/h for tertiary arterials and 30 km/h for local streets), allowing realistic travel times to be estimated across the network. The train speed values vary: major routes (northern corridor in

[2] Equation (1) explicitly accounts for spatial externalities, i.e., possible spatial spillover effects across municipal units, thus, reducing the potential for biased results in the econometric estimation (Combes et al., 2008; Matas et al., 2018; Baum-Snow et al., 2020). Moreover, relevant studies, it has been shown that such an accessibility indicator constitutes a good proxy for more model-dependent accessibility measures derived from formal structural gravity trade models (Eaton and Kortum, 2002; Donaldson and Hornbeck, 2016). The specification in equation (1) has been widely proved to be qualitatively robust to the use of alternative (or more sophisticated) transport cost functions and distance-decay parameter values (more than unity), thus, providing reliable estimates of accessibility (Bruna et al., 2016; Matas et al., 2018; Baum-Snow et al., 2020).

Figure 3 from Chania to Heraklion and the airport) are assigned High-Speed Train values (around 250 km/h), while the rest routes are assigned conventional modern train speed values (around 150 km/h). These indicative values have been adopted by official reports such as the European Court of Auditors (2018) and the UNECE (2022).

Based on these travel times together with the waiting and transfer time, an origin-destination (O-D) matrix is constructed for the larger settlements within each municipal unit, capturing pairwise travel costs between origins and destinations. For simplicity and given the regional scope of this research, congestion effects are not included in the travel time calculations (in line with Tsigdinos et al., 2024). The computation and the descriptive analysis of the indexes is carried out in the statistical programming language R.

To better depict the new accessibility landscape, we further adopt the proportional accessibility difference D_A (Gkavra, et al. 2025), which is computed by the following equation:

$$D_A = [(A_i - A_0)/A_0] * 100 \quad (3)$$

where A_i is the accessibility value of a future scenario and A_0 is the accessibility value of the do-nothing scenario. Notably, the focus on scenario differences allows us to assess the effects of each separate intervention and to determine who benefits and who does not, relative to the baseline. Last but not least, the proposed approach solely relies on cost-based changes in job access, as the number of opportunities is assumed to be constant after the implementation of each project scenario. In this sense, the specific approach offers a comparative static analysis of the impact of transport improvements on the local accessibility and equity. A dynamic analysis should incorporate changes in potential accessibility due to the (re)allocation and growth of opportunities (e.g., following the new airport operation and associated land use changes, and new economic activities along the impact zone of the new projects) across the municipal units of the study region.

3.5. Equity analysis

The equity analysis is explicitly grounded here in comparing the outcomes of different scenarios to identify which policy option performs better than other ones from a distributive perspective. The changes at accessibility levels and distribution are examined through multiple equity lenses, including distributional measures (Lorenz and Gini), ratio-based indicators (Palma index), concentration metrics and spatial autocorrelation (bivariate LISA). As mentioned above, horizontal and vertical dimensions are complementary. By incorporating both approaches, the present study offers a holistic view of large-scale infrastructure impacts and –to a greater extent– a more complete evaluation. This approach can be found in similar papers (Li et al., 2024b; Tsigdinos et al., 2026). Together, these approaches reveal not only whether accessibility increases on average, but also whether such improvements disproportionately favour already advantaged municipalities or population groups. The scenario-based equity assessment framework is therefore essential for distinguishing efficiency-driven improvements from genuinely inclusive accessibility gains, as well as for identifying transport strategies that better align with regional cohesion and/or social justice objectives. All equity measurements were conducted in the statistical programming language R.

3.5.1. Gini index

Firstly, we investigate the horizontal equity by the Gini index, which is considered as a proper indicator for disadvantage (Azmoodeh et al., 2021; Milias et al., 2025). The Gini index is a single mathematical metric to represent the overall degree of inequality (Dixit & Sivakumar, 2020; Hörcher & Graham, 2021). The Gini index can be calculated using the following equation (Delbosc & Currie, 2011):

$$G = 1 - \sum_{k} (X_k - X_{k-1}) * (Y_k + Y_{k-1}) \quad (4)$$

X_k: is the cumulative proportion of population in zone k

Y_k: is the cumulated proportion of the accessibility difference (between each future scenario and the do-nothing scenario) in zone k.

Horizontal equity may not be adequate to capture these changes. Therefore, we choose to employ more measures related to vertical equity, like the Palma index, and the Concentration Index together with spatial analysis (Bivariate Moran's I).

3.5.2. Palma index

The Palma ratio is a simple index commonly used to evaluate income inequality within a population (Sitthiyot & Holasut, 2020). It was firstly defined as the ratio of the income (or any similar characteristic) share held by the top 10% of earners to that held by the bottom 40%. Hence, it offers a straightforward measure of disparity between the wealthiest and poorest segments in a community. In this study, we adapt the Palma ratio to assess the vertical inequity in the difference of access to jobs between the do-nothing scenario and each future pathway. By comparing accessibility differences among groups with differing socioeconomic characteristics, such as car ownership status, we can determine whether specific segments face systematic disadvantages. The applied formula based on Palma ratio is given as (Kosmidis et al., 2025):

$$P_k = \frac{Average\ accessibility\ of\ top\ 10\%\ car\ owners}{Average\ accessibility\ of\ bottom\ 40\%\ car\ owners} \quad (5)$$

3.5.3. Concentration index

Complementary to the Palma index, this study employs the Concentration Index to assess vertical inequity in relation to job accessibility. This index captures the extent to which a variable, such as accessibility or a socio-economic indicator, is distributed across income groups or suitable proxies like car ownership (Cornut & Madre, 2016). Similar to the calculation of the Gini coefficient, the concentration index ranges from -1 to +1. A value of +1 indicates that the variable is entirely concentrated among the wealthiest, -1 reflects complete concentration among the poorest, and 0 signifies perfect equality (Damvakari, et al., 2024). In the present analysis, the concentration index is used to evaluate how job accessibility differences vary across the municipal units of Crete through the lens of car ownership. The index is computed following the approach outlined by Karner et al. (2025) and is given as:

$$CCI_a = \frac{8}{n^2(m_x - n_x)} \sum_{i=1}^{n} a_i w_i, \quad (6a)$$

$$w_i = r_i - \left[\frac{(n+1)}{2}\right] \quad (6b)$$

where:

n is the number of the zones within the study area,
m_x is the upper bounds of the accessibility difference variable,
n_x is the lower bounds of the accessibility difference variable,
a_i is the accessibility difference of zone *i*,
w_i is the weight attributed to the accessibility difference of zone *i*,
r_i is the socioeconomic rank position of zone *i* (in terms of car ownership).

By integrating the Palma ratio and the Concentration index into our analysis, we can gain a comprehensive understanding of vertical inequity for each future scenario.

3.5.4. Bivariate Moran's I-LISA

Apart from the above welfare economics indices, we also apply the Bivariate Local Moran's I, a well-known statistical method in spatial analysis used to examine the local spatial association between two related variables (Slovic et al., 2019). Unlike the traditional Moran's I, which measures spatial autocorrelation for a single variable, the bivariate version captures how one variable in a given location is spatially related to another variable in surrounding areas, thus revealing localised patterns of spatial dependence (Anselin et al., 2014). This index provides insights into the spatial clustering of inequities and is calculated for each location i using Equation 7 (Luo & Yang, 2013).

$$I_i = \frac{(x_i - \bar{x})}{\sum_{j=1}^{n} (y_i - \bar{y})^2 / n} \times \sum_{j=1}^{n} W_{ij} (y_i - \bar{y}) \qquad (7)$$

I_i is the Bivariate Local Moran's I statistic for zone i

x_i and y_i are the values of the two variables, e.g., accessibility differences and income at zone i

$\bar{x}$ and $\bar{y}$ are the means of the two variables across all zones

W_{ij} represents the spatial weights between zone i and neighbours j (queen contiguity weights in this case)

n is the total number of zones

This equation identifies whether there is a spatial clustering of similar values (e.g., High-High or Low-Low), contrasting values (High-Low or Low-High) or a lack of spatial association, using a 5% significance threshold (Zhang et al., 2018). In this study, the Bivariate Moran's I is applied to explore how differences in accessibility between the do-nothing scenario and future strategies correlate with car ownership.

4. Results

By and large, the findings reveal that the proposed infrastructure projects significantly enhance the overall job accessibility. However, the improvements are unevenly distributed throughout the region, with notable disparities being particularly present at the eastern and western areas of the island, thus, raising important concerns about spatial equity. Below, we illustrate in detail the outcomes related to the accessibility measurements (4.1) and the equity indices (4.2), while discussion of key findings and policy implications follow in order (4.3).

4.1. Accessibility measurements

Figure 5 compares the distribution of regional transport accessibility across the six scenarios, illustrating how different policy or network configurations reshape accessibility outcomes.

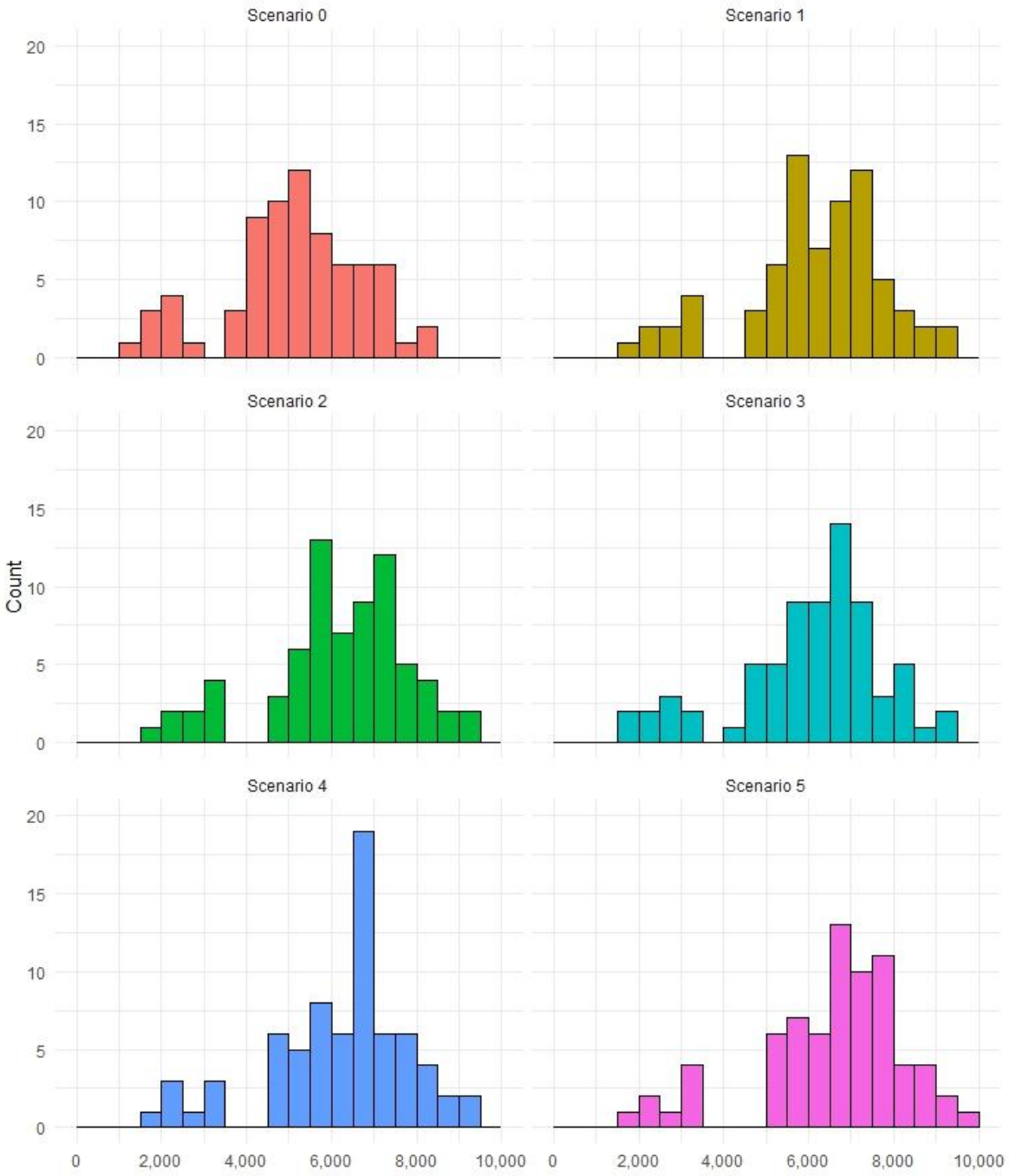

Figure 5: Accessibility histogram of each scenario

Figure 5 shows that, across all scenarios, distributions are quite symmetric, demonstrating a single spatial structure rather than multiple regimes. However, the shape of the distributions varies notably. A prominent rightward shift emerges from Scenario 0 to Scenario 5. Scenarios 0-2 are concentrated at lower accessibility levels, whereas Scenarios 3-5 are centred at slightly higher values. This shift indicates that scenarios incorporating a railway system might benefit the Region of Crete, through leading to enhanced accessibility and reduced travel times. Tellingly, Scenario 5 enhances accessibility and simultaneously limits disparities between municipal units. Finally, these histograms underscore that, while infrastructure investments can enhance

overall accessibility, the degree of spatial benefit varies, showcasing the importance of combining performance-based strategies with equity-oriented evaluation. This is the reason for coupling accessibility measurement with equity metrics.

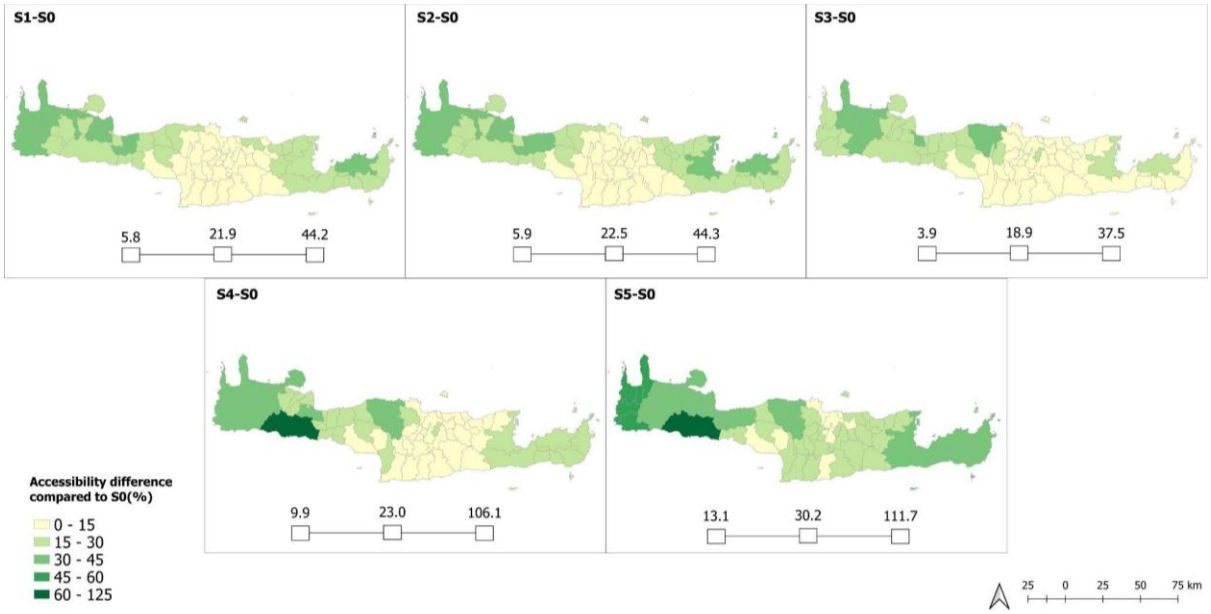

Figure 6: Map illustration of accessibility differences among various scenarios

Next, we demonstrate the outcomes regarding the accessibility differences, with scenario S0 as the baseline (Figure 6). The comparison of accessibility differences across the six scenarios (S1–S5, each measured relative to the do-nothing S0) illustrates a clear, geographically differentiated pattern of improvement across the island of Crete. In the early road-focused scenarios (S1 and S2), gains remain moderate and spatially uneven, with improvements primarily concentrated along the northern corridor, where the motorway and primary road networks provide the greatest travel-time reductions. These scenarios yield relatively small minimum and maximum improvements (S1: 5.8-44.2%; S2: 5.9-44.3%), indicating that upgrading road infrastructure alone tends to reinforce existing accessibility advantages rather than achieving some broad accessibility convergence or spatial integration across the island.

The introduction of rail infrastructure is found to produce more pronounced and widely distributed accessibility gains. Specifically, Scenario S3, which represents a limited rail deployment, improves the level of accessibility, particularly in areas around new stations, raising the maximum improvement to 37.5%, while maintaining a modest average gain. However, the fully implemented rail network in scenario S4 generates a step change: improvements exceed 100% in the mostly affected areas, significantly lifting accessibility in the inland and the southern regions of it, which traditionally exhibit weaker road connectivity. The latter outcome signifies the potential of rail to rebalance the accessibility landscape beyond the dominant northern coastal corridor.

The comprehensive multimodal investment represented by scenario S5 yields the strongest overall performance (minimum: 13.1%, average: 30.2%, maximum: 111.7%). The combination of upgraded motorway and primary roads with a complete rail network produces synergistic effects, bringing about substantial improvements in both the high-demand regional corridors (at the northern part of the island) and the previously peripheral rural areas. These results highlight

that integrated multimodal strategies, rather than single-mode expansions, offer the most effective pathway for achieving substantial and spatially equitable accessibility enhancement across the island.

4.2. Results of equity indexes

4.2.1. Gini index

First, we illustrate the outcomes referring to horizontal equity and, particularly, the Gini index and the Lorenz curves. Figure 7 displays the Lorenz curves and corresponding Gini coefficients for accessibility changes relative to the baseline, weighted by the total number of inhabitants. According to this figure, all scenario differences display Lorenz curves that deviate considerably from the line of perfect equality, indicating an uneven distribution of accessibility gains across the population. Gini values are consistently high (approximately 0.67-0.69), suggesting that a relatively small share of the population captures a disproportionate share of accessibility improvements, regardless of scenario.

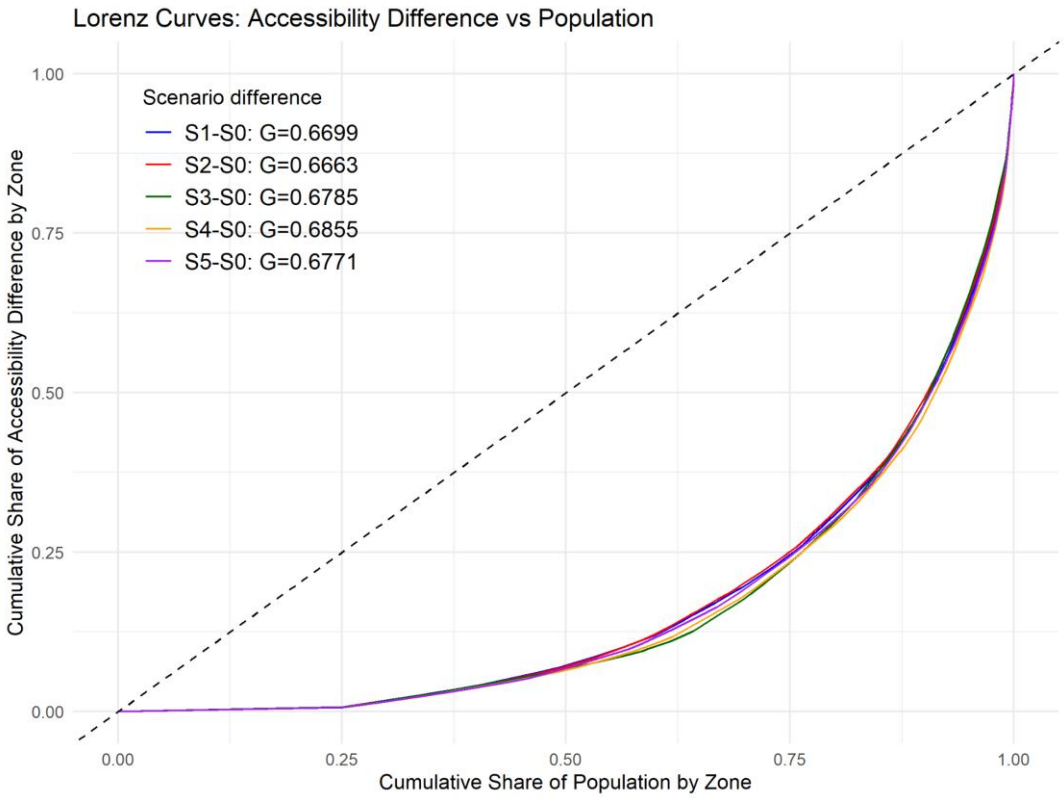

Figure 7: Lorenz curves of accessibility differences among various scenarios

Differences between scenarios are nonetheless informative. Scenario S2 shows the lowest Gini coefficient, indicating a marginally more equitable distribution of accessibility changes, while Scenario S4 exhibits the lowest horizontal equity. Scenarios S3 and S5 take intermediate positions, with only limited reductions in concentration relative to the current situation. Coupled together, Lorenz curves and Gini index values reveal that, although some scenarios slightly mitigate inequity, accessibility gains remain strongly skewed, underscoring the difficulty of

achieving distributive equity through network changes alone. Horizontal equity cannot provide a complete picture though. Therefore, vertical equity is also investigated below.

4.2.2. Palma index

As shown in Figure 8, all Palma index values exceed 1, indicating persistent inequality in regional transport accessibility, with higher levels concentrated among the most advantaged municipal units. The highest Palma value is observed in Scenario S1 relative to Scenario S0, suggesting that this configuration disproportionately benefits already well-served areas. Scenarios S2 and S3 show slightly lower but still high ratios, pointing to limited redistribution effects. A clear downward trend emerges in Scenarios S4 and S5, with Scenario S5 exhibiting the lowest Palma index value. This outcome indicates a relative narrowing of the accessibility gap between the top 10% and the bottom 40% of municipal units. While inequity is not eliminated, the latter scenarios appear more effective in promoting a balanced spatial distribution of transport accessibility. Thus, the Palma index results complement the distributional evidence from the histograms, underscoring that scenario development influences not only the average accessibility levels but also the degree of spatial inequity.

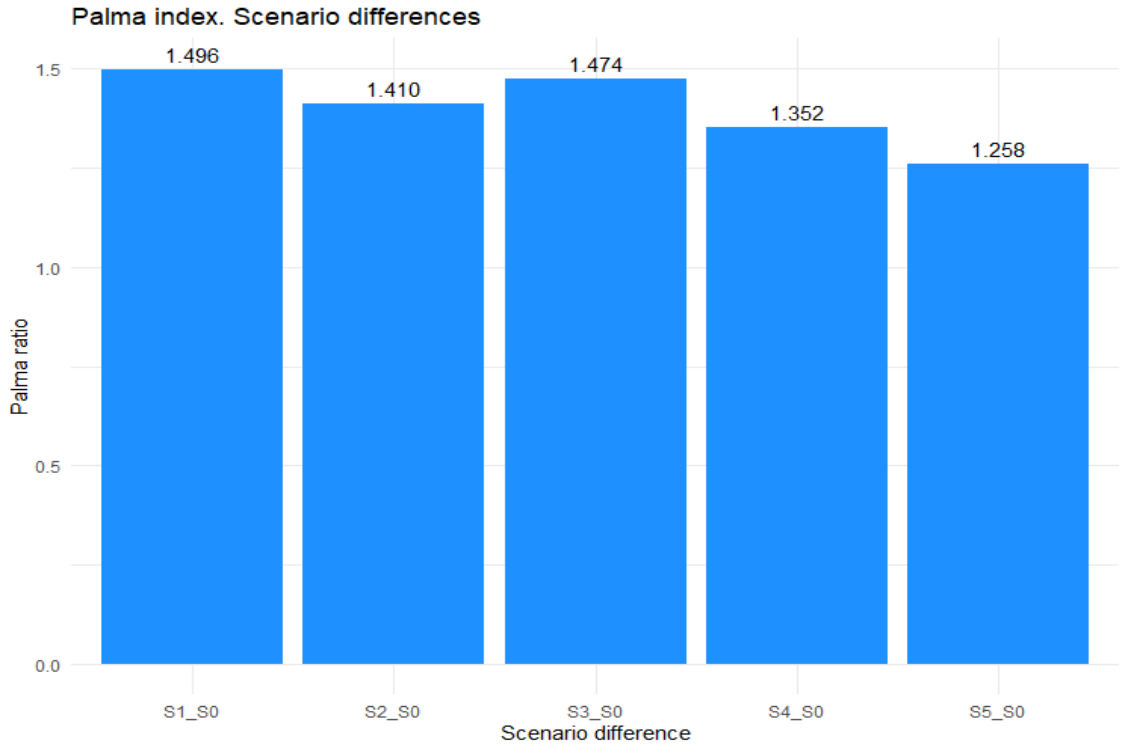

Figure 8: Palma index of accessibility differences among various scenarios

4.2.3. Concentration index

Looking at the concentration index of transport accessibility differences across the various scenarios (Figure 9), we observe only positive values, which confirms that accessibility gains lean towards already favoured areas, having a prolonged advantage of higher car ownership. The strongest concentration is observed in Scenario S3, suggesting that this scenario amplifies spatial inequity by disproportionately benefiting high car-ownership municipal units. Scenarios S1 and S2 also show relatively high concentration values, indicating limited progress toward a

more equitable redistribution of accessibility changes. Conversely, Scenarios S4 and S5 display markedly lower concentration indices, approaching zero (similarly to the Palma index). This outcome indicates a substantially more balanced distribution of accessibility changes across municipal units with different levels of car ownership. While not fully neutral, these scenarios reduce the pro-advantaged bias observed in earlier investment pathways. Together with the Palma index results, the concentration index offers robust evidence that multimodal scenarios are more effective in mitigating accessibility inequity, underscoring the importance of integrating equity considerations into regional transport policymaking.

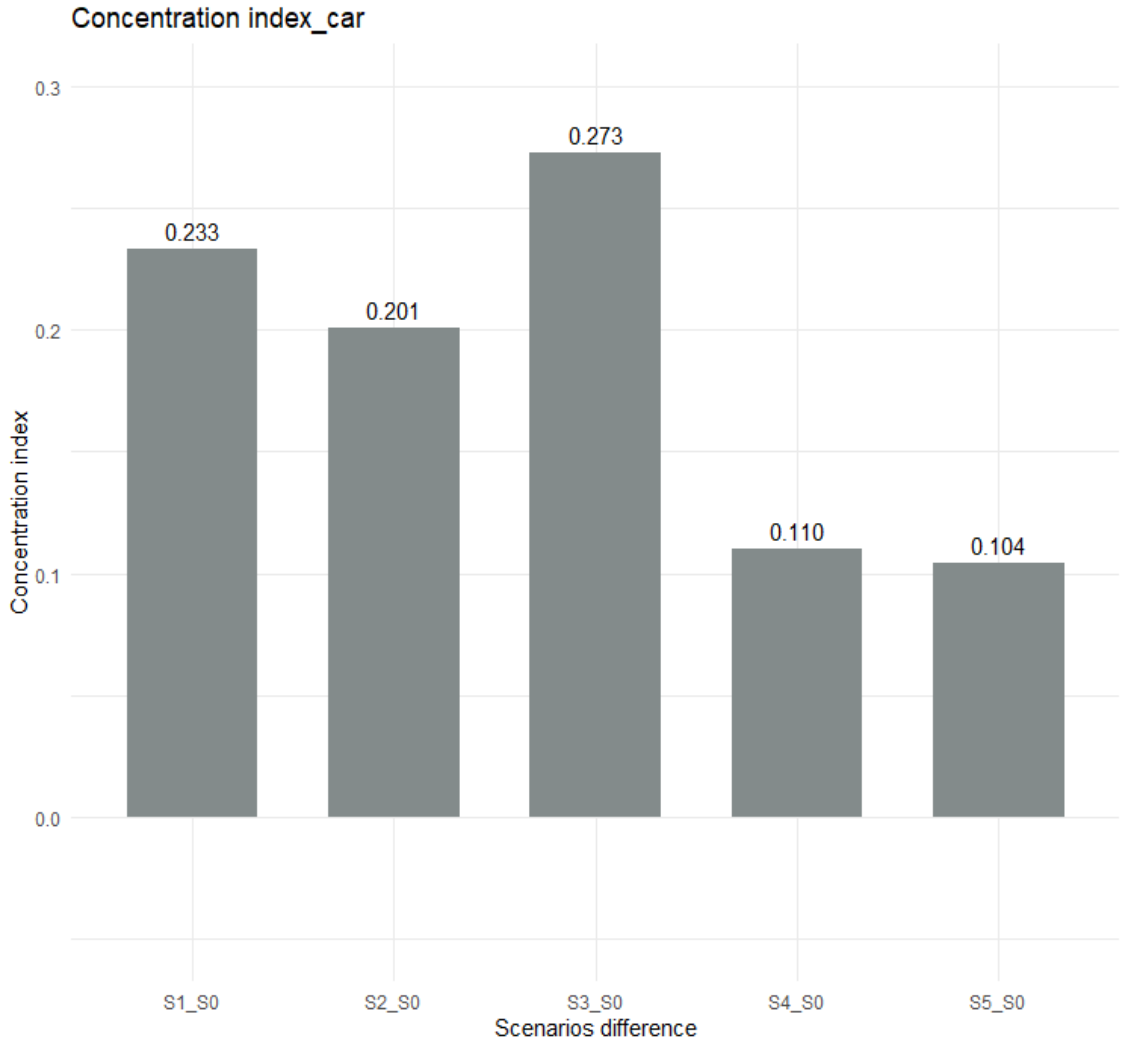

Figure 9: Concentration index of accessibility differences among various scenarios

4.2.4. Bivariate LISA test results

Striving to strengthen the vertical equity dimension, we demonstrate the Bivariate Local Moran's (LISA) test results in Figure 10. The findings demonstrate the spatially associated changes in transport accessibility and car ownership across the various scenarios relative to the existing conditions. All scenarios demonstrate clustered values as global Moran's value are above 0.25 and $p<0.05$. The set of maps in Figure 10 reveal a consistent spatial structure, with significant

high-high spatial clusters concentrated in the western part of the region, indicating municipal units where accessibility gains are strongly associated with high levels of car ownership.

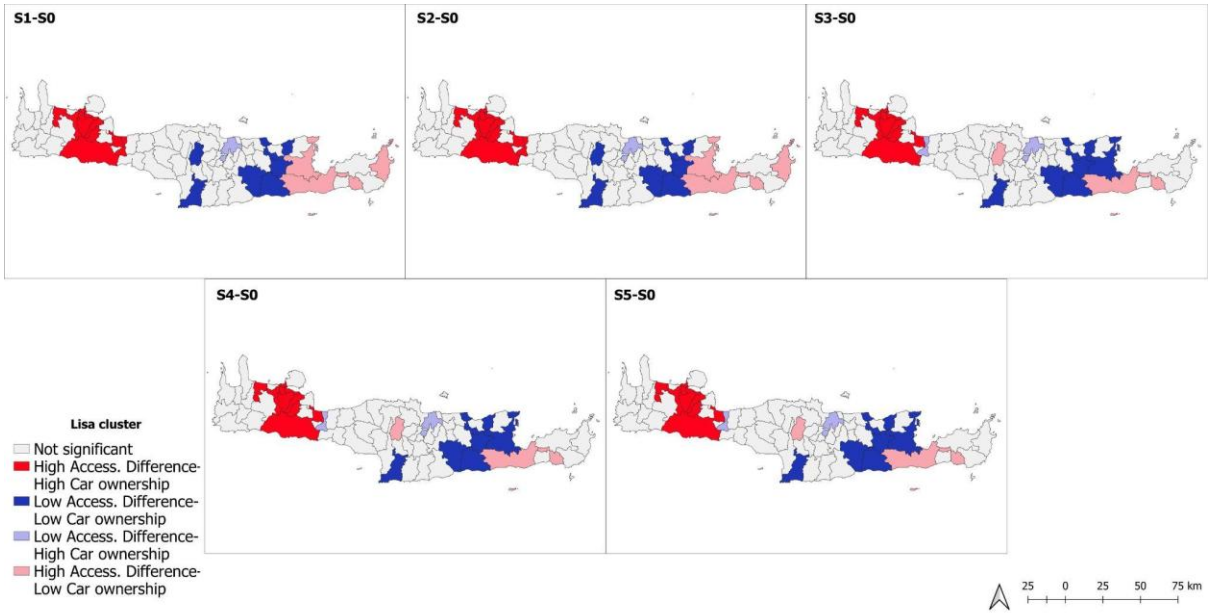

Figure 10: Bivariate Moran's I (LISA) of accessibility differences among various scenarios

These clusters are most extensive in Scenarios S1 to S2, suggesting that car-based strategies reinforce existing spatial advantages, by coupling accessibility improvements with already high car dependence. At the same time, though, these two scenarios showcase high-low clusters that favour less advantaged municipal units. Conversely, while the rest of the scenarios show a reduction in the number of high-high clusters, the number of high-low clusters gets smaller. This outcome signifies the persistence of spatial disparities and, therefore, highlights the need for combining welfare economic indices with spatial analysis. Consequently, all these metrics together provide a comprehensive overview of the distributional effects of accessibility.

4.3. Discussion of key findings

This study provides new empirical evidence on the relationship between large-scale transport infrastructure, job accessibility and equity in a regional and insular context. It addresses a well-documented gap in the accessibility literature that has mainly focused on metropolitan areas and urban settings (Vitale Brovarone, 2021; Tsigdinos & Kourounioti, 2026). By analysing the case of Crete at the submunicipal level, the findings directly call for accessibility assessments which better reflect the intricate spatial, demographic and infrastructural specificities of non-metropolitan regions (see also Lin et al., 2025; Tulus & Ramadan, 2021).

A first key finding is that all transport investment scenarios improve job accessibility relative to the do-nothing baseline, confirming the fundamental role of transport infrastructure in shaping access to employment opportunities. This result aligns not only with the classical accessibility theory (Geurs & van Wee, 2004), but also with more recent empirical studies showing that reductions in travel time and generalised transport cost enhance labour market reach (Jin & Paulsen, 2017; Zhang et al., 2024). However, similarly to the evidence from other regional-scale analyses (Biosca et al., 2013; Jacobs-Crisioni et al., 2016), these improvements are found to be spatially uneven, with accessibility gains disproportionately concentrated in already well-connected areas, particularly along the northern coastal corridor of Crete.

This uneven spatial pattern confirms earlier findings that transport investments in regional and rural settings tend to follow existing development corridors and settlement hierarchies (Panagiotopoulos & Kaliampakos, 2018; Rodríguez-Pose et al., 2024). Thereupon, peripheral island municipalities, which already face structural disadvantages related to longer distances, limited modal choice and reduced economic density benefit less from road-based interventions. This finding reinforces the argument that regional accessibility potential differs fundamentally from the corresponding urban one and that the urban-centred planning rationale cannot be directly transferred to island or peripheral regions without risking increased territorial disparities (Carlucci et al., 2019; Chen et al., 2022).

A second key finding concerns the differentiated effects of transport modes and network design. Road-focused scenarios (S1–S2) produce moderate accessibility gains that largely reinforce pre-existing spatial advantages. This outcome corroborates findings from previous studies showing that car-oriented investments often favour municipalities with higher car ownership and stronger economic profiles, thereby amplifying spatial inequities (Farber & Páez, 2011; Zhao & Yu, 2020). On the contrary, scenarios incorporating rail infrastructure (S3-S5) facilitate the development of a multimodal transport system, yielding substantially higher and more spatially extensive accessibility improvements, particularly in southern areas of the island characterised by relatively limited connectivity.

Strikingly, these results confirm and extend current evidence from regional-scale rail studies, such as Monzón et al. (2013), who demonstrated that rail investments can improve accessibility while supporting territorial cohesion, albeit unevenly. Likewise, the findings of this study align with Jacobs-Crisioni et al. (2016), who showed that accessibility gains from transport expansion scenarios can deliberately influence territorial inequalities even when average accessibility improves. In the case of Crete, the introduction of rail could stimulate a more polycentric accessibility structure at the island scale. This improvement may function as a potential driver of of the island's economic integration and the emergence of new labour markets (Kveladze et al., 2025). Improved transport connectivity can also support agglomeration economies, facilitate job matching and expand functional economic areas.

Specific attention should be paid to the complete system scenario (S5). This pathway emerges as the most effective strategy, in terms of overall accessibility performance. Tellingly, this finding supports scenario-based research emphasising the importance of multimodal integration for regional accessibility and equity outcomes (Lyons et al., 2021; Tori et al., 2025). Rather than any single-mode dominated accessibility improvements, the results indicate that synergies between road and rail systems are critical for expanding functional labour markets across diverse territorial contexts. This finding reinforces earlier arguments that accessibility should be evaluated as a system-wide outcome rather than as the result of isolated infrastructure projects (Freiria et al., 2022).

Shifting to equity, the findings highlight an intriguing disconnection between accessibility gains and distributive justice. Horizontal equity remains weak across all scenarios, with consistently high Gini coefficients, indicating that accessibility improvements are concentrated among a limited share of the population. This finding confirms a growing consensus in the literature that accessibility enhancements do not automatically translate into equitable outcomes (Wang & Zhang, 2019). In this sense, the results confirm that efficiency-oriented investments may reinforce existing disparities, through favouring growth in already well-connected areas, if equity considerations are not carefully planned and explicitly embedded in the planning process (Rodríguez-Pose, 2018).

By contrast, when looking into the socio-economic details, vertical equity outcomes show more encouraging patterns, particularly under the complete rail and multimodal scenarios. Lower Palma and concentration index values in Scenarios S4 and S5 indicate that accessibility gains are more evenly distributed between municipal units with high and low car ownership. This finding supports the sufficientarian perspective on transport equity (Martens, 2016), suggesting that comprehensive transport solutions can benefit structurally disadvantaged groups, even if overall equality is not achieved. Similar conclusions are found in studies carried out in rural and region-wide contexts, where multimodal and public transport investments have been shown to mitigate accessibility disadvantages linked to income, car ownership and remoteness (Carroll et al., 2021; Tsigdinos & Kourounioti, 2026).

The spatial clustering patterns exemplified through bivariate LISA tests further reinforce these conclusions. Road-based scenarios exhibit strong high–high clusters linking accessibility gains with high car ownership, consistent with findings from equity-focused accessibility studies in both urban and non-urban contexts (Niehaus et al., 2016; Vecchio et al., 2020). Nonetheless, rail-based scenarios somehow weaken this association, demonstrating a partial decoupling of accessibility improvements from car dependence. This conclusion confirms the value of combining welfare-economic indicators with spatial analysis, as advocated by Monzón et al. (2013) and Damvakari et al. (2024) to capture the full distributional impact of transport interventions.

In a broader perspective, the findings reflect that accessibility improvements and equity outcomes do not necessarily evolve hand in hand. While road-based investments considerably enhance accessibility, they tend to reinforce existing spatial disparities. Multimodal strategies, particularly those incorporating rail, perform better in promoting vertical equity, even though horizontal inequality remains substantial. This echoes broader debates in transport planning that highlight the limits of infrastructure-led solutions and the need for integrated policy approaches combining transport, land use and regional development (Rodríguez-Pose et al., 2024).

Evidently, this study confirms and extends existing regional accessibility research by showing that multimodal, integrated transport systems offer a promising pathway for improving job accessibility and moderating socio-spatial inequities in island regions. Nevertheless, the persistence of high horizontal inequality underscores that infrastructure alone cannot deliver spatial equity, thus stressing the need for equity-sensitive planning frameworks tailored to regional and insular contexts (in line with Wang & Zhang, 2019). In this regard, land-use and economic planning is rather critical. Summing up, we may suggest that accessibility-oriented planning should be complemented by explicit equity considerations. At present, most planning frameworks prioritise efficiency and aggregate accessibility gains, often neglecting the distributive impacts of investments. To address this gap, planning institutions should adopt inclusive planning strategies that systematically evaluate who benefits from accessibility improvements and who remains disadvantaged. In addition, stronger support should be directed toward multimodal transport solutions, which have demonstrated potential to enhance accessibility more comprehensively than unimodal approaches.

5. Conclusion

The present study comprises one of the first original attempts to integrate the evaluation of large transport projects in an island region (Crete) with accessibility and equity measurements through spatial analysis and welfare economics. By bringing these dimensions together within a unified analytical framework, the research seeks to highlight how major infrastructure investments,

including single (road) and multimodal (road-rail) options, can influence spatial justice and territorial development. The outcomes underline that improvements in accessibility translate into different conditions associated with equity. Multimodal solutions emerge as a promising response to accessibility and vertical inequalities, offering more flexibility and comprehensive coverage and reducing dependence on a single transport mode across different socioeconomic groups and geographical contexts.

However, horizontal equity is slightly favoured by road transport scenarios. Therefore, equity requires comprehensive policy attention beyond mere network enhancement. Methodologically, the proposed framework contributes by employing a diverse set of tools, thereby increasing the robustness of the analysis and enhancing the reliability and interpretability of the results. From a practical perspective, the insights generated can inform public decision-makers, planners and investors who seek straightforward and consistent methods for evaluating the accessibility impacts of transport project portfolios. The study highlights the need for more integrated and inclusive planning approaches that consider multiple geographical scales, ranging from regional to submunicipal levels, while promoting equitable access through a diverse mix of transport modes and plans. Given the observed difficulty of achieving distributive equity through network changes alone, more integrated policies may combine land-use planning with transport system expansion, considering the redistribution of jobs, housing, and services, alongside investment in multimodal interoperability to balance opportunities across regions and social groups.

In future research, more scenarios could be tested, especially non-formal ones that might influence the current transport planning rationale in the long-term, since no single scenario can solely address the job accessibility problem. First, future work should incorporate detailed cost dimensions within a cost–benefit analysis (CBA) framework, such as the construction cost and environmental cost (savings) associated with each transport mode. In turn, this approach would allow for a more comprehensive evaluation of the trade-offs between accessibility gains, distributional outcomes, and financial feasibility. Second, econometric techniques could be implemented for explaining the variability in commuting patterns so that further enhance the robustness of results. Particular attention should be paid to comparative analyses across different territorial contexts, including other island regions and rural areas, where accessibility dynamics may diverge significantly from urban settings. Third, the analysis of labour market areas warrants deeper scrutiny, as these regions exhibit heterogeneous accessibility responses and are critical for understanding the spatial distribution of opportunities. Methodologically, future research should pursue an extension toward integrated regional transport and land-use models, which would capture the bidirectional interactions between mobility systems and spatial development. Finally, the development of regional computable general equilibrium models that endogenise transport costs would provide a more holistic framework, linking accessibility changes directly to economic performance and regional development outcomes. Ultimately, the pursuit of both accessibility and equity remains an ongoing challenge that must be addressed at both political and technical levels.

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