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NAVIGATING MOUNTAINS: TOPOGRAPHY, ACCESSIBILITY, AND SOCIOECONOMIC PATTERNS IN THE EUROPEAN ALPS

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Abstract: This paper examines the link between topography, accessibility, and socioeconomic development in the European Alps. Using fine-scale GIS analyses combined with regional statistics on socioeconomic indicators, we performed a correlation analysis. Our findings suggest that while topography affects accessibility, it does not directly determine socioeconomic development. This holds true for both inner-Alpine and peri-Alpine municipalities. From a spatial development perspective, our findings highlight that accessibility alone cannot ensure positive socioeconomic development dynamics. We conclude that in mountainous areas, socioeconomic development must be discussed in the context of broader themes, such as economic path dependencies and other sectoral specificities.

Keywords: spatial development, montology, mountain studies, morphology, demography, economy, employment, multi-indicator analysis.

Introduction

The influence of topography on socioeconomic development is a widely debated topic in human geography (Thornton et al., 2022). In most geographical studies, it is accepted that nature does not determine human socioeconomic development; therefore, geo-determinism is largely rejected. Nonetheless, topography can influence spatial connections, which implies that sustainable development approaches must adapt to environmental conditions (Radcliffe et al., 2010; Meyer & Guss, 2017). This is particularly evident in areas with specific geographical features, such as mountain, coastal, or border areas, where barriers – including mountains, the sea, or major rivers – affect human mobility (Gløersen et al., 2004; Adler et al., 2022; Bertram et al., 2024). This becomes particularly relevant to policy in terms of access to infrastructure such as primary schools or railway stations in the inner areas of the European Alps, where substantially longer travel times are required when compared to peri-Alpine areas (see ESPON Alps 2050, 2018). Notably, these differences in accessibility influence quality of life in mountainous areas and may lead to spatial inequities.

Territorial cohesion aims to reduce regional inequalities within the European Union (EU) by creating policies that promote economic and social convergence (Madanipour et al., 2022; Jakubowski & Wójcik, 2024). However, this remains challenging given national and regional differ-

ences. Macroregional strategies are a European instrument that aims to strengthen transnational cooperation and to identify and overcome common challenges (Cotella, 2018; Gänzle et al., 2019). The situation becomes even more complex when considering additional spatial categories, such as urban versus rural, border versus non-border regions, coastal regions, mountain areas, and others. These spatial types are characterized by specific features that come with certain challenges, including housing shortages in metropolitan areas, demographic decline in peripheral regions, accessibility constraints in mountain areas, or cross-border multi-level governance mismatches in border regions (Chilla et al., 2022; Hippe et al., 2022; Crossey & Weber, 2024). As a consequence, specific spatial contexts require tailor-made policies to address their multifaceted challenges as effectively as possible.

This situation is particularly evident in the European Alps, where multiple countries, geographical specificities, and complex governance structures impact spatial development dynamics. The European Alps are often described as peripheral due to their geographical characteristics, particularly in terms of topography and hampered accessibility patterns (Pecher et al., 2013). At first glance, this may appear accurate when viewed in the shadow of major European metropolitan areas. However, the Alps must be differentiated between the inner-Alpine region, delineated along the relief boundary, and the wider Alpine region covered by the EU Macroregional Strategy for the Alpine Region (EUSALP; Dematteis, 2018). In mountainous areas, urban corridors and major infrastructure are concentrated in valley floors (Lambracht & Chilla, 2025). Although this offers opportunities, such as multi-sectoral functioning in close proximity (Kohler et al., 2017), it also amplifies challenges – particularly those related to limited available space and spatial planning complexities (Kruse & Pütz, 2014; Chilla & Streifeneder, 2018). Considering these mountain-specific geographical characteristics, spatial development in the Alps must address multiple themes when exploring regional potentials. Therefore, several conceptual approaches emerge, integrating various considerations essential for sustainable spatial development and planning (Nared et al., 2015).

First, a balanced spatial development approach must include multi-sectoral issues, especially in transnational regions such as the European Alps. The region encompasses various soft spaces that complement administrative spatial categories and national policy systems (Gänzle et al., 2019). These include the EUSALP, the Alpine Convention, the Interreg Alpine Space Programme (ASP), and several other Interreg cross-border programs. This variety of government and transnational (or cross-border) governance structures requires a sound basis for decision-making processes. Ultimately, the objective of such structures is to foster sustainable development that harmonizes ecological, economic, and social dimensions (Balsiger, 2012). This is complemented by adaptive governance processes that evolve in response to socioeconomic change, thereby ensuring the long-term viability of sustainable practices (Baur & Binder, 2013). Such governance includes the consideration of the unique topography of the Alps, characterized by high altitudes and steep slopes. These environmental conditions pose considerable challenges that require careful assessment in development and planning processes, supporting the use of topographic indicators to enable sustainable spatial organization (Lambracht, 2024).

Second, addressing adaptation to climate change is critical for mountain regions since they are particularly vulnerable to environmental and economic issues. This requires a comprehensive exploration of spatial and social dynamics to develop effective adaptation strategies, as well as the promotion of stakeholder engagement and the exchange of expertise, across the Alpine region (Balbi & Giupponi, 2010; Nared et al., 2015). Additionally, integrated risk management shifts the paradigm from traditional engineering-focused hazard protection to inclusive strategies that incorporate land use management to effectively separate dangerous areas from zones designated for settlement and economic activity. This evolution reflects a broader understanding of risk,

emphasizing the importance of assessing exposure and vulnerability within complex risk dynamics (Keiler & Fuchs, 2018; Pütz et al., 2025). Complementarily, sustainable landscape planning highlights the need to value ecosystem services, such as avalanche protection, scenic beauty, and carbon sequestration, when identifying optimal locations for new developments (Grêt-Regamey et al., 2008; Schirpke et al., 2019).

To better understand the complexities and interdependencies of regional challenges in the spatial development of mountain areas, we address the following research questions: 1) What kind of relation exists between topography, accessibility, and socioeconomic development in the European Alpine region? and 2) Are there differences between inner- and peri-Alpine areas? To answer these questions, we operationalize topography as topographic potential area (TPA) and elevation, accessibility as driving time by car to urban centers and highways, and socioeconomic development as population and employment trends. All analyses are conducted at a high spatial granularity at the municipality level (i.e., LAU level). The objective of this paper is to investigate the potential links between topography, accessibility, and socioeconomic development by conducting a correlation analysis at the highest spatial resolution possible.

Conceptual framework

Accessibility specificities in mountain regions

Mountain regions are commonly described as areas with geographical specificities (Gløersen et al., 2004; Dematteis, 2018). In particular, elevation and steep relief directly influence regional development in mountain areas such as the European Alps (Lambracht, 2024). These effects become particularly evident when multi-sectoral interests, such as land use, the equitable distribution of services of general interest, and transformations in industrial areas or agricultural landscapes, intersect (Modica, 2019; Job et al., 2022). Notably, such dynamics affect both ecosystem services and residents' well-being (Bender & Haller, 2017; Schirpke et al., 2021; Lambracht & Chilla, 2025). Many of those potential conflicts can be reflected under the concept of accessibility specificities in mountain regions (Vickerman et al., 1999). These specificities are addressed in several strands of current scientific debates.

First, infrastructure accessibility is considered a policy tool for closing development gaps and fostering territorial cohesion (Dijkstra et al., 2013; Nogués & González-González, 2021). In particular, large-scale infrastructure projects (e.g., the Brenner Base Tunnel) are one major element of accessibility and connectivity in mountain regions, but with a specific scope. For such projects, the focus is less on local and regional access and more on trans-Alpine connectivity in the framework of the Trans-European Transport Network (TEN-T; Ravazzoli et al., 2017; Dianin & Chizzali, 2025). However, in mountain areas, large-scale infrastructure projects are often expensive to develop (Farrington & Farrington, 2005). While in some (mostly touristic) regions in the European Alps, communities benefit from well-functioning railway systems (Cavallaro & Dianin, 2020), private car use remains dominant in most areas, particularly for the 'last mile' in more peripheral valleys (Mattioli et al., 2020). From a social perspective, those without access to cars, whether due to age, economic, or cultural reasons, are disproportionately affected by limited transport options (Verma & Taegen, 2019).

Second, the accessibility of (regional) centers affects spatial development in mountain regions. Administrative, financial, and political functions tend to concentrate in these centers. In non-mountainous regions, these functions are often located in larger agglomerations, coordinated

by national planning systems (Voll, 2012; Deboosere et al., 2018; Pot et al., 2021). In mountain areas, centralized planning systems reach their limits, and a decentralized approach that includes small and medium-sized towns as functional centers can represent a possible solution (Perlik et al., 2001; Chilla et al., 2022).

Third, access to essential services, such as healthcare and medical provisions, varies significantly across regions, illustrating how geographical constraints can perpetuate inequalities (ESPON Bridges, 2019; Vitale Brovarone & Cotella, 2020). Limited accessibility restricts access to services of general interest, thereby affecting local development (Dax, 2017). Although spatial planning aims to ensure equal living conditions, the complexity of achieving this is significantly higher in mountain areas (Vidal-Legaz et al., 2013; Sil et al., 2016). Moreover, while fair access to healthcare, education, and retail facilities is a relevant basis for sustainable urban-rural synergies (Vitale Brovarone & Cotella, 2020), infrastructure development is particularly challenging due to topographical constraints and dispersed settlement patterns (Perlik, 1999; Bertram et al., 2023).

In general, accessibility also depends on technological and cultural factors (Philip & Williams, 2019), the impacts of natural hazards (Wyss et al., 2022), and multi-level governance structures (Sala et al., 2024). Spatial development strategies that prioritize accessibility can reduce travel times, improve service provision, and support more balanced regional development (Gutiérrez & Urbano, 1996; Bertram & Chilla, 2023). While providing service levels equivalent to those in metropolitan areas remains difficult (Gløersen, 2012), a balanced polycentric settlement structure can deliver adequate and acceptable standards (Seidenberger, 2010; Vaz & Matos, 2015; Bertram & Chilla, 2023).

This highlights the research interest in understanding the relationships between topography, accessibility, and current socioeconomic development patterns. If these accessibility specificities are closely linked to mountain geography, this implies that the interdependencies between accessibility and socioeconomic dynamics differ significantly between mountain and lowland areas (Dematteis, 2018; Chilla & Lambracht, 2025).

Socioeconomic specificities in mountain regions

In the European Alps, socioeconomic specificities become particularly evident when highlighting a range of factors, particularly including the topographic conditions, but also climate change, cultural traditions, population mobility, and economic shifts (Baur & Binder, 2013; Bender & Haller, 2017; Čede et al., 2018; Membretti & Lucchini, 2018). These complexities interact with spatial development paradigms that aim to respond to multiple challenges.

First, a set of complexities relates to path dependencies, cultural embeddedness, and population dynamics. Historical settlement patterns and socio-demographic systems, which are rooted in cultural traditions, continue to influence socioeconomic regional development strategies, particularly in agriculture and tourism (Bender & Haller, 2017). Recent trends include lifestyle mobilities, whereby individuals relocate to mountain communities or engage in mountain agriculture, thereby influencing local cultural landscapes and socioeconomic structures (Grüner, 2023). In some regions, in-migration has started to emerge as a new demographic trend, contrasting with the long-standing patterns of outmigration (Steinicke et al., 2012; Bender et al., 2025). In parallel, amenity migration has increasingly been observed, adding further complexity to local socioeconomic dynamics (Perlik, 2019; Drouet & Barrioz, 2024).

Second, economic and land use challenges remain critical. Industrialization processes and an increase in service sector labor have shifted employment away from the primary sector, leading to the less intensive use of meadows in some areas, which affects biodiversity (Baur & Binder,

2013; Bätzing, 2017). Moreover, despite regulatory efforts, the expansion of second homes has further contributed to spatial strains and complexities, increasing infrastructure demand and affecting local communities and tourism dynamics (Borsdorf, 2013). These processes often result in concentration effects in peri-Alpine metropolises or valley floors, triggering spatial competition, particularly regarding land availability and uneven demographic trends (Perlik & Messerli, 2004; Borsdorf & Haller, 2020; Chilla & Heugel, 2022).

Third, mountain regions are exposed to dynamic risks linked to natural hazards. Threats such as floods, landslides, and glacial hazards are becoming more pronounced due to climate change and socioeconomic developments (Dubo et al., 2023). Managing these risks requires acknowledging the changing nature of risk drivers, such as increasing exposure and vulnerability (Keiler & Fuchs, 2018).

These socioeconomic specificities in mountain areas contribute to highly complex spatial settings, where spatial inequality – particularly in peripheral areas – represents a substantial risk. Moreover, diverging political systems and governance challenges often lead to uneven development opportunities and social disparities. This becomes evident in the macro-region of the European Alps, where a divide exists between urbanized areas, which are typically located on the fringes or in lowland peri-Alpine areas, and depopulating high-altitude territories in inner-Alpine areas (Messerli, 2015; Perlik, 2018; Lambracht & Chilla, 2025). In this context, the concept of 'inner peripheries' – describing territories characterized by structural deprivation processes and unequal living conditions – has gained prominence (Copus et al., 2017; Madanipour et al., 2022).

Data and methods

Operationalization

With our operationalization, we aim to provide an evidence-based foundation for arguments linked to regional development, derived from the interdependencies between topography, accessibility, and socioeconomic patterns. In this paper, we first examine the relationship between topography, accessibility, and socioeconomic development in the European Alpine region. Second, we also identify differences between inner- and peri-Alpine areas.

All calculations are done for the perimeter of the EUSALP. The results will be discussed for inner-Alpine regions (the Alpine Convention perimeter) and peri-Alpine regions (EUSALP perimeter without the area of the Alpine Convention). To cover all dimensions addressed in the research question, the following operationalization was conducted:

- **Topographic indicators** include a) the share of TPA indicating the share of area with a steepness of less than 30% to total area (Lambracht, 2024) and b) the mean elevation for every municipality (i.e., LAU). Higher elevations and a greater proportion of steep relief imply limited scope for development (i.e., the area is theoretically unsuitable for construction).
- **Accessibility** means potential accessibility. It is calculated as the mean travel time by car for all municipalities in the perimeter to a) towns with 100,000 inhabitants or more, b) towns with 10,000 inhabitants or more, and c) highway ramps. Presenting accessibility as mean car travel time helps to demonstrate individual accessibility without a dependency on national train planning systems and increases comparability (Ravazzoli et al., 2017).

- **Socioeconomic development** figures are defined as a) population change and b) employment change. The data for both indicators are available for the years 2011 to 2021.

Table 1 presents detailed indicator characteristics, including the spatial coverage, description, resolution, and timeframe for each indicator. The indicator on employment change revealed one difficulty: for France and Italy, the first year of the referenced period (2010 and 2012, respectively) is slightly different due to data availability issues. In European statistics, the lack of data and the harmonization challenges arising from different national definitions – as seen in employment statistics – pose difficulties not only for researchers but also for decision-making, particularly at the transnational and cross-border levels (Berzi et al., 2026).

Analyses

The analysis is based on Geographic Information System (GIS) methods to calculate driving time by car, the share of TPA, and the mean elevation for every LAU (i.e., municipality) in the EUSALP perimeter. Furthermore, it includes elements of descriptive statistics, with a particular focus on correlation coefficient calculations for all indicators.

The analyses used in this paper include the following methods:

- The **Zonal Statistics** tool, in spatial analyst tools in ArcGIS Pro 3.6.1, was used to calculate the topographic indicators. This tool helps to calculate values by using information from a base raster shapefile for an underlying vector shapefile. Here, the mean calculation was used for the elevation, while the sum operation was used for the share of TPA. For the share of TPA, the underlying raster shapefile (DEM-Slope) encompassed information about the slope, while for the elevation data, a digital elevation model (DEM) with information about the elevation data was included. DEMs are a digital representation of a terrain's surface, showing elevations as numerical values. Both raster shapefiles have a resolution of 30m (Eurostat, 2025). The data were transferred to Microsoft Excel files for the calculation of both indicators and then rejoined for visualization.
- The **Distance Accumulation** tool, in spatial analyst tools in ArcGIS Pro 3.6.1, was used to calculate the accessibility indicators. Generally, this tool is used to create a raster that represents the cumulative distance from a specific point or series of points to each cell in the raster. To calculate mean driving time, the stored speed values in the cost raster must be included in kilometers per hour (km/h; 120 km/h for highways and motorways, 70 km/h for roads outside of built-up areas, and 30 km/h for roads inside of built-up areas). When applying the distance accumulation tool, the following occurs. First, the tool uses the values in the speed raster to calculate the time it takes to get from one point to the next cell. Second, the resulting grid then shows the cumulative time it takes to reach each cell point based on the given speed. To obtain the information for each LAU, the resulting grid must be transferred to a vector shapefile and intersected with the municipality shapefile. Thereafter, with the exported Microsoft Excel file, the mean driving time for each LAU was calculated and then rejoined in ArcGIS Pro for visualization.
- **Secondary statistics** sources were used to obtain data for the socioeconomic indicators. For population change, the European statistical office (Eurostat) provides municipal-level data for all EU countries, including Switzerland, and for all years. Data on employment – in this case, the employed persons at the workplace – had to be individually collected through the national statistical offices of the respective countries. Thus, some inaccuracies due to differing methodologies and data availability had to be considered. However, the change between the years 2011 and 2021 was calculated in Microsoft Excel and then joined in ArcGIS Pro for visualization.

Table 1. Indicator details and metadata descriptions

Indicator		Description	Spatial extent	Definition and comment	Resolution	Year(s)	Source
Accessibility		Driving time by car to the nearest town with a) 10,000 inhabitants, b) 100,000 inhabitants, and c) highway ramps	EUSALP area	–	Municipal level, LAU	2025	Own calculations.
Socioeconomic indicators	Population change	Increase or decrease of inhabitants	EUSALP area	Overview of LAUs and population, situation as of 31 December; population data (reported by the countries) are purely indicative, Eurostat does not revalidate these data	Municipal level, LAU	2011–2021	Eurostat (2025).
	Employment change	Increase or decrease of employed persons	Austria	Number of people in employment at place of work or school as of 31 October	Municipal level, LAU	2011–2021	Statistik Austria (2025).
			France	Number of employees at the workplace for the years 2010, 2015, and 2021; numbers above 500 can normally be used with confidence, whereas numbers below 200 should be treated with caution, as they may not be significant due to the imprecision of the survey; comparisons between small territories should be avoided	Municipal level, LAU	2010–2021	INSEE (2025).
			Germany	Employees subject to social security contributions at the place of work, reporting date 30 June	Municipal level, LAU	2011–2021	Destatis (2025).
			Italy	Number of persons employed of local units of active enterprises (annual average values)	Municipal level, LAU	2012–2021	ISTAT (2025).
			Liechtenstein	Information on the number of employees is taken from the Liechtenstein business register after the reporting date of 31 December; employees are defined as persons who work in Liechtenstein regardless of their place of residence (domestic principle)	Municipal level, LAU	2011–2021	Office of Statistics Liechtenstein (2025)
			Slovenia	Persons in employment by municipalities, reporting date 30 June	Municipal level, LAU	2011–2021	SiStat (2025).
			Switzerland	Employees at workplaces by municipality	Municipal level, LAU	2011–2021	Swiss Federal Statistical Office (2025).
Topography	Share of topographic potential area (TPA)	Share of area with an inclination less than 30% to the total area	EUSALP area	–	Municipal level, LAU	2025	Own calculations based on Eurostat (2025).
	Mean elevation	Mean elevation of the TPA	EUSALP area	–	Municipal level, LAU	2025	Own calculations based on Eurostat (2025).

Source: authors' own elaboration.

- **Correlation coefficients** were calculated to analyze interdependencies between topography, and accessibility, and socioeconomic indicators. The coefficient range is between -1 and 1. If a variable approaches these values, it indicates a complete positive or negative correlation, respectively. If the value is 0, there is no correlation. Values below 0.3 indicate a weak correlation, values between 0.3 and 0.7 indicate a moderate correlation, and values between 0.7 and 1 indicate a strong correlation (Backhaus et al., 2021). Notably, correlation does not imply causation. Through this analysis, we aim to provide indications that can be considered alongside current scientific debates and further analyses.

All indicators resulting from these methods reveal a) specific patterns that can be discussed with regard to their territorial impact and b) were used to discuss their interdependencies. This applied analysis aims to reveal patterns of interlinkages between topography, accessibility, and socioeconomic status for all LAUs in the EUSALP region.

Results

Topographic patterns

Figure 1 presents a) the TPA in green (1-A), b) the mean elevation in blue (1-B), and c) the binary visualization of both topographic indicators (1-C) for each municipality in the EUSALP region.

The proportion of TPA in each municipality indicator shows the roughness of the terrain, or in other words, the proportion of land with an inclination of less than 30% (Fig. 1, 1-A). The core area of the Alps is clearly visible, as are the larger main valleys, which are highlighted by darker green within the brighter Alpine municipalities. The Alpine fringes, which mark the beginning and end of the steeper relief, are particularly visible. Peri-Alpine low mountain ranges can also be identified, such as the Black Forest in Germany, the Massif Central in France, the Jura Mountains between Switzerland and France, and the Ligurian Alps and Apennines in Italy.

Additionally, Figure 1 (1-B) shows the mean elevation in blue. At first glance, the Alpine fringes are not as clearly visible as on the TPA map; instead, valleys are more visible. This shows that relying solely on one type of data to identify a mountain range can be misleading. For example, in the western and eastern parts of the Alps, the elevation is comparably flat.

Combining the TPA approach with elevation data provides a comprehensive overview of the region's relief (Fig. 1, 1-C). It provides a visualization of this, using a binary approach. The colors must be interpreted against two different gradients, which creates a color matrix. The bluer the color, the higher the elevation, and the pinker the color, the higher the share of steep relief. Therefore, if a municipality has a high mean elevation and a high TPA share, it appears dark blue. Conversely, a municipality with a low mean elevation and a low TPA share appears slightly pink.

This map also provides a detailed view of the wider Alpine region and allows one to distinguish between the various mountainous areas within this region. The high-Alpine areas are located along the Alpine arc, while the surrounding peri-Alpine regions can be described as either flattened or sharply cut off. Additionally, some low mountain ranges can be identified and characterized by their different features, such as flat areas with medium elevation and steeper areas with lower elevation in eastern Austria.

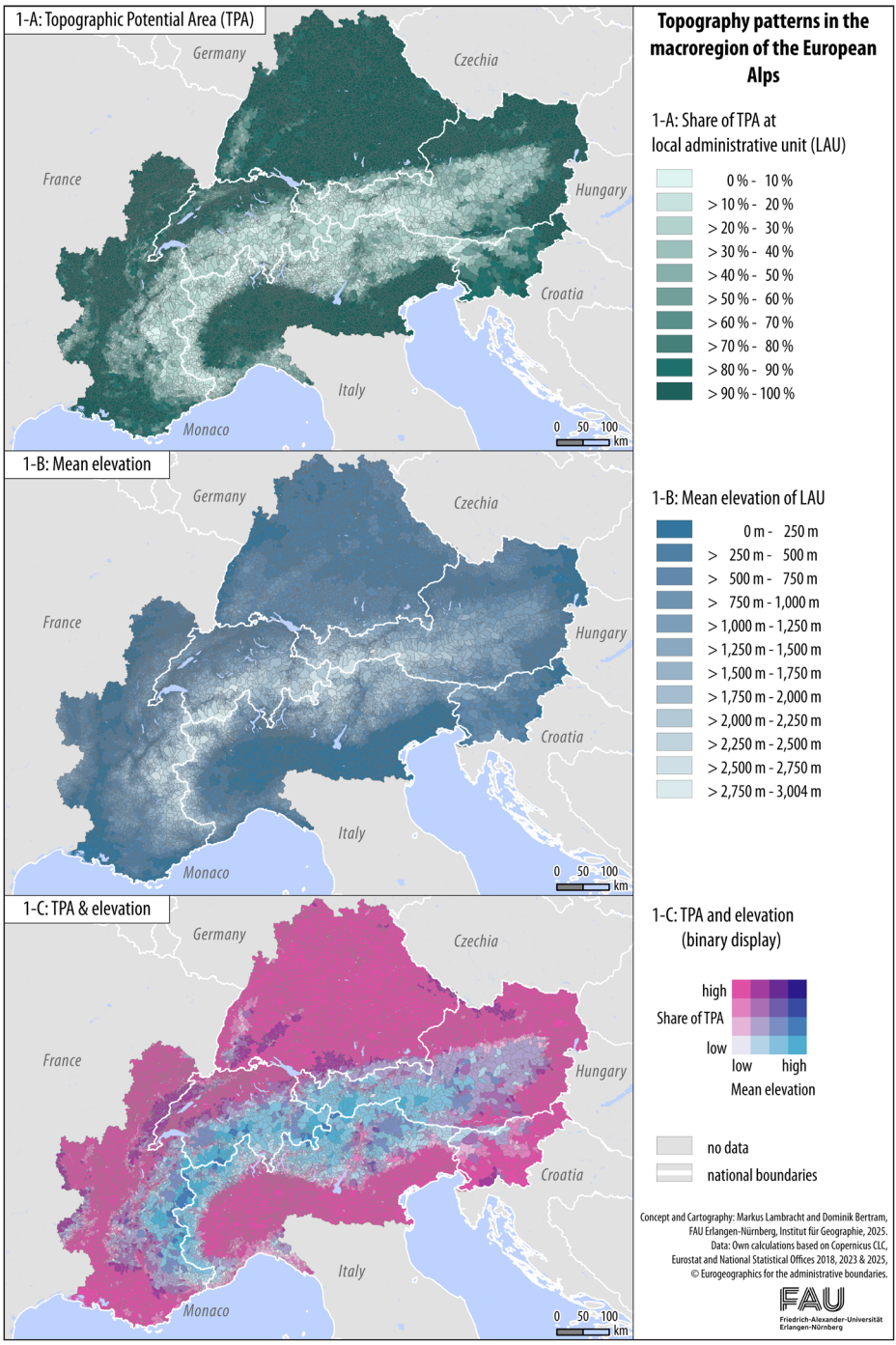

Figure 1. Topography patterns in the EUSALP region: 1-A the TPA, 1-B the mean elevation, 1-C the binary visualization of both topographic indicators
Source: authors' own elaboration.

Accessibility patterns

Figure 2 presents the calculated medium car driving time from each municipality in the EUSALP region, shown as minutes to a) towns with a minimum of 100,000 inhabitants (2-A), b) towns with a minimum of 10,000 inhabitants (2-B), and c) highway ramps (2-C). The color gradient differentiates municipalities with shorter (yellow) and longer (dark blue) travel times.

Figure 2 (2-A) highlights rural regions, such as the inner-Alpine arc, as well as peripheral areas in eastern Bavaria, large parts of France, and regions in eastern and western Italy. In the inner-Alpine region, only a few cities have populations exceeding 100,000, including Annecy (FR), Bolzano/Bozen (IT), Grenoble (FR), Innsbruck (AT), Salzburg (AT), and Trento (IT). Most of the other larger urban areas are concentrated directly on the edges, including some major cities such as Ljubljana (SI), Lyon (FR), Marseille (FR), Milan (IT), Munich (DE), Turin (IT), Vienna (AT), and Zurich (CH).

Map 2-B shows areas with a higher density of towns with a minimum of 10,000 inhabitants in Germany, Italy, Slovenia, parts of Switzerland, and southern France. Large parts of Austria, the inner-Alpine regions of Switzerland, and rural areas of France are characterized by limited accessibility.

Map 2-C shows that nearly the entire Alpine region has good accessibility to highway ramps. However, some areas with limited access and driving times over 1 hour can be identified. The regions of Eastern Grisons (CH) and the Dolomites (IT) show particularly dark signatures. The southern portions of the inner-Alpine area in France and some parts of Austria are also included. Outside the Alps, inhabitants of regions close to the Czech border in Bavaria and Austria need to drive longer distances to access the next highway ramp. Furthermore, within the EUSALP region, some areas have limited accessibility, such as the Black Forest in Baden-Württemberg (Germany) and the French Jura region between Switzerland and France.

In summary, all three maps clearly show the main Alpine ridge, as well as more rural and peripheral areas.

Socioeconomic patterns

Figure 3 introduces the spatial structures of the two socioeconomic indicators for the 2011–2021 period: population development (3-A) and the development of employed persons (3-B). Both maps show high national and regional differences.

Map 3-A is characterized by extreme national differences and a north-south gradient. The population numbers of Germany, France, and Slovenia are growing particularly rapidly, while the other states are characterized by significant regional differences. In Switzerland, growth or decline depends on whether a municipality is located in the lower northern regions or in the more inner-Alpine regions of Grison or Tessin. In Italy, larger peri-Alpine agglomerations such as Milano or Torino – but also the inner-Alpine corridor including Bolzano/Bozen and Trento – exhibit positive developments. Compared to other peri-Alpine metropolises such as Munich or Ljubljana, these areas pull their positive developments from their direct neighbors, which are characterized by population declines.

The more rural areas, as well as areas located in the Alps, show a strong population decline. The trend in Austria is quite similar to that of Italy, particularly near the larger agglomerations of Vienna, Salzburg, Villach, Klagenfurt, and Innsbruck, where population numbers are consistent or increasing. All other regions appear to be characterized by population decline. Surprisingly, some inner-Alpine Austrian areas in the east show a high increase in population figures, which was unexpected in these regions. This could be explained by long-standing structural change processes, which are now responding through adaptation dynamics.

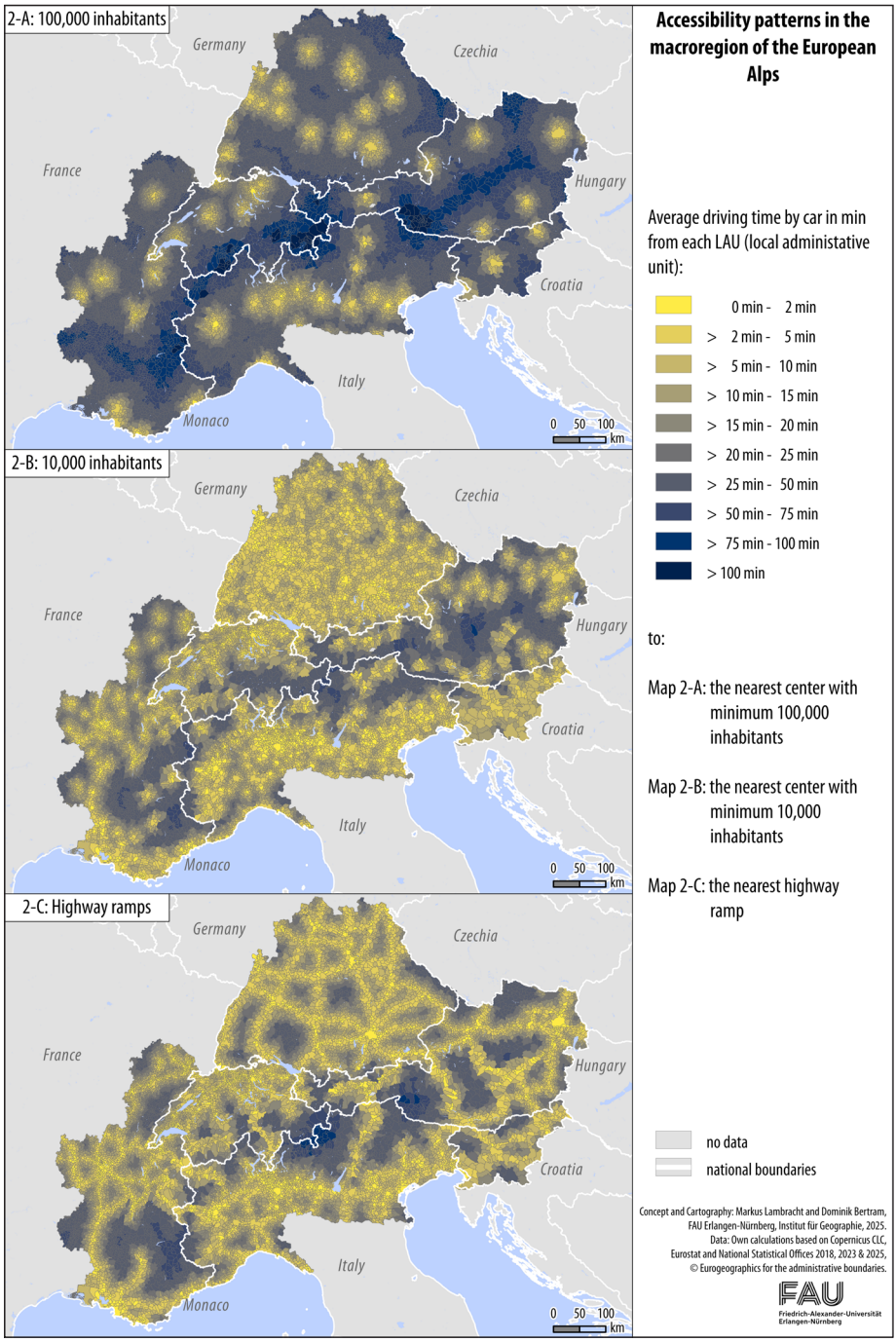

Figure 2. Accessibility patterns in the EUSALP region: 2-A, towns with a minimum of 100,000 inhabitants; 2-B, towns with a minimum of 10,000 inhabitants; 2-C, highway ramps
Source: authors' own elaboration.

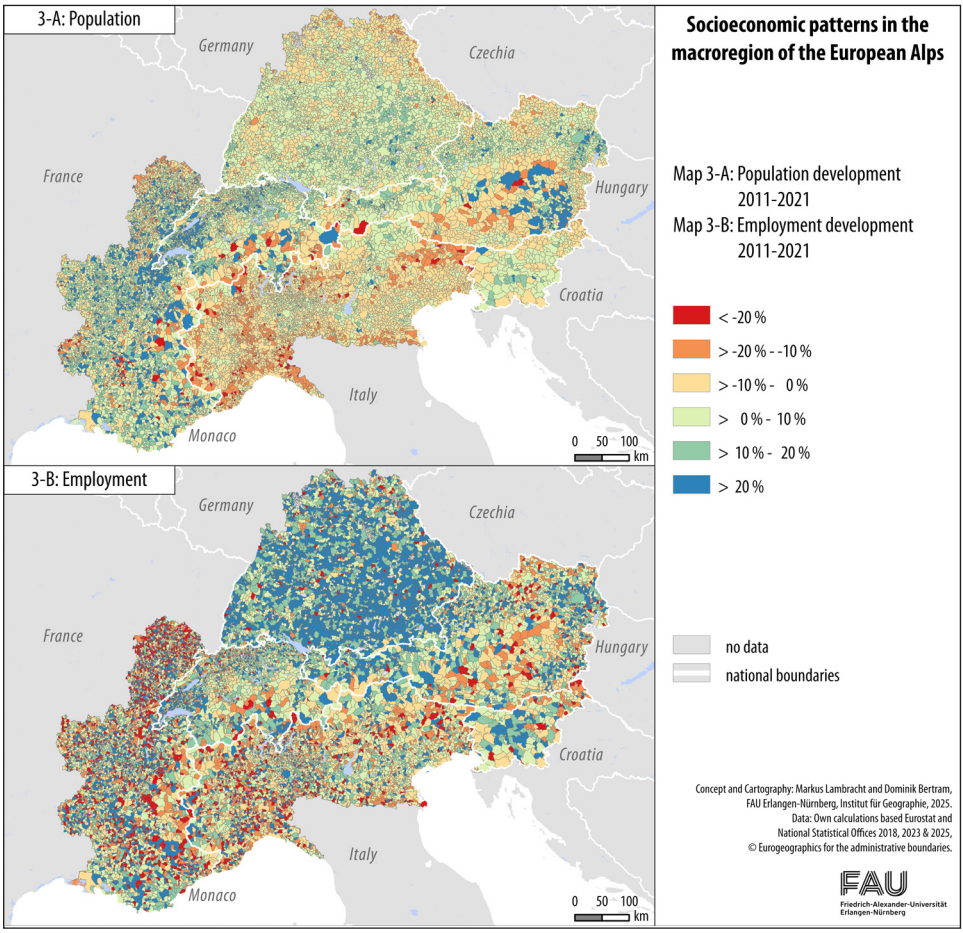

Figure 3. Socioeconomic patterns in the EUSALP region: 3-A, population development; 3-B, the development of employed persons
Source: authors' own elaboration.

In Map 3-B, which visualizes the employment figures, the structure is much more complex. While national affiliation seems to influence employment development, the regional and local differences are very diverse. Germany and Slovenia show positive trends, whereas France and Italy are characterized by an overall negative trend. In Austria, France, Italy, and Switzerland, location remains an influential factor. If a municipality is located in close proximity to larger axes such as the Bernadino Pass, the Mürz River Valley, the Grenoble-Lyon region, or to agglomerations such as Marseille, Vienna, or Milano, the employment figures exhibit growth.

Multi-indicator analyses

Figure 4 presents the total, inner-Alpine, and peri-Alpine correlation coefficients for all indicators. The darker the gray color in the tables, the closer the coefficient is to -1 or 1, indicating a higher degree of correlation. In general, some interesting patterns can be observed. First, within the accessibility indicator group, some moderate correlation is evident (0.56; 0.63; 0.56). This implies

Correlation coefficients ***TOTAL***		**Accessibility indicators**			**Socioeconomic indicators**		**Topography indicators**	
		10,000 inhabitants	100,000 inhabitants	Highway ramps	Population change	Employment change	Share of TPA	Mean elevation
Accessibility indicators	10,000 inhabitants	1						
	100,000 inhabitants	0.56	1					
	Highway ramps	0.63	0.56	1				
Socioeconomic indicators	Population change	-0.03	-0.09	-0.08	1			
	Employment change	0.02	0.01	0.01	0.00	1		
Topography indicators	Share of TPA	-0.39	-0.38	-0.41	0.10	0.01	1	
	Mean elevation	0.48	0.47	0.49	-0.02	0.00	-0.77	1

Correlation coefficients ***INNER-ALPINE***		**Accessibility indicators**			**Socioeconomic indicators**		**Topography indicators**	
		10,000 inhabitants	100,000 inhabitants	Highway ramps	Population change	Employment change	Share of TPA	Mean elevation
Accessibility indicators	10,000 inhabitants	1						
	100,000 inhabitants	0.53	1					
	Highway ramps	0.58	0.54	1				
Socioeconomic indicators	Population change	-0.03	-0.09	-0.10	1			
	Employment change	0.00	-0.01	-0.01	0.02	1		
Topography indcators	Share of TPA	-0.33	-0.33	-0.36	0.18	0.02	1	
	Mean elevation	0.46	0.50	0.46	-0.09	-0.02	-0.71	1

Correlation coefficients ***PERI-ALPINE***		**Accessibility indicators**			**Socioeconomic indicators**		**Topography indicators**	
		10,000 inhabitants	100,000 inhabitants	Highway ramps	Population change	Employment change	Share of TPA	Mean elevation
Accessibility indicators	10,000 inhabitants	1						
	100,000 inhabitants	0.50	1					
	Highway ramps	0.62	0.52	1				
Socioeconomic indicators	Population change	-0.03	-0.09	-0.06	1			
	Employment change	0.03	0.01	0.02	-0.01	1		
Topography indcators	Share of TPA	-0.15	-0.15	-0.24	0.06	0.01	1	
	Mean elevation	0.27	0.22	0.35	0.10	0.00	-0.37	1

Figure 4. Correlation coefficients
Note: gray color indicates the degree of correlation: the darker the color, the closer the correlation coefficient is to -1 or 1.
Source: authors own elaboration.

that the lower the driving time by car to a town with 100,000 or 10,000 inhabitants, the lower the driving time to the next highway ramp. Second, the topographic indicators show a relatively high negative correlation coefficient (-0.77). This means that the higher the mean elevation of a municipality, the lower the share of TPA. However, these two findings are not very surprising.

However, concerning the interdependencies between the three groups of accessibility, socioeconomics, and topography, some interesting findings can be confirmed.

First, with regard to **topography and accessibility**, there is a moderate negative correlation between the share of TPA and the accessibility of towns with 100,000 inhabitants (-0.38), towns with 10,000 inhabitants (-0.39), and highway ramps (-0.41). Additionally, a moderate positive correlation between the mean elevation of a municipality and the accessibility of towns with 100,000 inhabitants (0.47), towns with 10,000 inhabitants (0.48), and highway ramps (0.49) is confirmed. This implies that if these statistical calculations are seriously considered, relief has impacts on the accessibility of municipalities. Specifically, the higher a municipality is located, or the rougher the terrain (lower TPA), the longer it takes to drive to the nearest highway ramp, town, or metropolis.

Second, concerning **topography and socioeconomic development**, correlation analyses of the share of TPA and population development (0.10) as well as employment change (0.01) show no correlation. The case for mean elevation is even clearer: no correlation with population change (-0.02) or employment change (0.00) is confirmed. This indicates that for municipalities in this region, the location within the relief is not decisive for their socioeconomic development.

Third, for **accessibility and socioeconomic development**, the correlation coefficient for population changes and the accessibility of towns with 100,000 inhabitants (-0.09), towns with 10,000 inhabitants (-0.03), and highway ramps (-0.08), as well as for employment change and the accessibility of towns with 100,000 inhabitants (0.01), towns with 10,000 inhabitants (0.02), and highway ramps (0.01), indicates no statistical connection between both indicators. These results suggest that having better access to cities, towns, or highways does not necessarily determine a municipality's socioeconomic development.

Fourth, the analysis of **inner- versus peri-Alpine territories** reveals that elevation serves a much more important role in inner-Alpine regions, and that the correlation coefficients are significantly higher regarding the share of TPA and the mean elevation. These results imply that topography seems to be a critical factor affecting the accessibility of higher-level infrastructure, in particular in inner-Alpine regions. Nevertheless, socioeconomic development is not addressed by these interdependencies in both inner- and peri-Alpine regions.

Discussion and conclusions

Our paper aims to identify general and spatially comprehensive relations between topography, infrastructure, settlement development, and socioeconomic development in a highly complex region with regard to transnational and cross-border governance, as well as natural complexities. According to the ongoing scientific debate, location (i.e., within specific topographical conditions, in peripheral areas, or near borders) and accessibility (i.e., to higher-order infrastructure, regional centers, or major urban nodes) influence the socioeconomic development of regions. Notably, the findings of this study both confirm and challenge several assumed interdependencies discussed in the literature.

First, our analysis confirms that topography influences accessibility. Relief conditions create a 'fringe effect' (also known as funnel constellations) between peri- and inner-Alpine areas, intensifying pressures on land use dynamics (Bertram et al., 2025). In areas with sharp elevation changes and steep slopes, stakeholders often have competing interests, such as conservation versus development, which complicates land use decisions (Job et al., 2022; Lambracht & Chilla, 2025). In these interface areas, the funnel effect increases pressure on transport routes (Bertram et al., 2025). As demand for connectivity grows, competition intensifies among various interests, ranging from residential development to ecological preservation, due to limited space. Furthermore, infrastructure projects in mountainous regions present unique challenges. The costs of building roads and railways are considerably higher due to geographical difficulties and safety concerns. These projects must also address ecological vulnerabilities to ensure that they do not exacerbate issues such as noise and air pollution, which are more prevalent in these sensitive environments (Heimann et al., 2010). Additionally, suitable sites for connectivity measures are less common in mountainous regions than in non-mountainous areas, which further complicates transport infrastructure planning. Events such as the renovation of the Lueg bridge in Austria emphasize how even minor disruptions can significantly impact accessibility, thus illustrating the fragility of connectivity systems in such contexts (Ma et al., 2023). Understanding these factors is essential for effective development and planning in mountain areas, particularly with regard to transnational and cross-border cooperation.

Second, our findings indicate that topography does not have a statistically significant influence on socioeconomic development. This raises important questions regarding the underlying reasons for this result. One possible explanation involves path dependencies. Many successful regions host hidden champions, which are local firms that thrive due to specific historical, cultural, or economic conditions rather than topographical advantages (Meili & Mayer, 2017). These enterprises can independently drive regional development, regardless of the surrounding landscape. Additionally, tourism plays a complex role. While mountainous areas may attract tourists, the socioeconomic benefits are not distributed evenly. Moreover, reliance on tourism can create instability in local economies, making them vulnerable to fluctuations that are unrelated to topographical features (e.g., closing of skiing sites due to climate change; Willibald et al., 2021). Another important issue is the rise of alternative working cultures, such as remote working, which further complicates this relationship. Remote working disconnects labor markets from specific locations, leading to amenity migration, whereby individuals relocate to enjoy the lifestyle offered by mountain regions. While this can bolster local economies, it may also lead to a disconnect between the workforce and the existing community, thereby impacting social cohesion and infrastructure demands (Membretti et al., 2023). Furthermore, it is important to recognize that the Alps are a diverse region. Averages in data across different countries can mask significant differences between the northern and eastern Alps, which often have different development trajectories from their southern and western counterparts. Such variations demonstrate that socioeconomic success is not solely dictated by topographical factors. Finally, the concept of 'inner peripheries' in mountainous areas illustrates the complex relationship between tradition and landscape. While these areas can attract tourism, they also present ecological sustainability challenges, showing that the attraction of mountain regions is not linked to their topography in a straightforward manner. Thus, understanding these complicated factors is crucial for effective policy-making and the development of mountainous areas.

Third, our results indicate that accessibility does not significantly correlate with socioeconomic development. This implies that better access to cities, towns, or highways does not necessarily lead to better socioeconomic development for a municipality. Several interconnected factors can be discussed against this phenomenon, and many of the previously discussed arguments remain relevant. Accessibility alone does not guarantee socioeconomic success; rather, it is often intertwined with other factors, such as local economic conditions, historical context, and the presence of 'hidden champions.' While better access to urban centers, towns, or highways might seem advantageous, it does not inherently create opportunities for growth or development (Deboosere et al., 2018). Furthermore, limited accessibility can disproportionately affect certain demographics, particularly young people and the elderly. Spatial inequality in connectivity can result in car dependency, whereby individuals without access to personal vehicles face significant barriers to employment, education, and services (Mattioli et al., 2020). This limitation can perpetuate cycles of disadvantage for those unable to travel freely, thereby deepening – rather than bridging – socioeconomic divides. Additionally, the quality and nature of the connections matter. For instance, a municipality may have good transport links that do not align with job growth or residential needs, leading to a mismatch between labor supply and demand. Therefore, mere access does not equate to effective socioeconomic strategies. Successful approaches must consider the broader context of regional development, including demographic and social issues. Although connectivity is crucial, its impact must be considered alongside local conditions and demographic requirements to achieve meaningful socioeconomic progress.

Taken together, the three dimensions of the discussion suggest that regional development in the European Alpine region depends on a broad set of factors that are both Alpine-specific and influenced by wider European dynamics. Global interconnectedness, which is evident in aspects such as the growth of online marketing, offers new opportunities for local businesses to access wider markets (Salder & Bryson, 2019). Moreover, tax policies play a vital part in shaping local economies and attracting residents (Löffler et al., 2016; Krapf & Staubli, 2025). Historical legacies also significantly impact current economic landscapes, often providing businesses with established community networks that they can leverage (Mayer & Meili, 2016; Bätzing, 2017). Furthermore, the availability of local resources and the promotion of short supply chains are essential for fostering sustainable economic practices. Ongoing shifts in economies, such as deindustrialization or changing from winter to year-round tourism, further highlight the need for local economies to diversify and reduce their dependence on any single economic activity (Modica, 2019). Furthermore, a strong cultural connection to one's home region can enhance community engagement, thereby supporting local initiatives and promoting social cohesion (Birnbaum et al., 2021; Membretti et al., 2023). Integrating these elements into development strategies can enable Alpine regions to create sustainable and resilient transnational and cross-border pathways for future growth within the framework of European territorial development aims.

Understanding the operationalization of topography is crucial for grasping the intensity of mountain environments. Mountains are not uniform across regions; also, interface areas, plateaus, and low-lying areas with steep relief have an impact. Against this background, our findings support existing research on the EUSALP area and the Alpine Convention. The findings also extend existing mountain studies research, making the interdependencies with the relief more explicit. Notably, the successful development of a mountain region is not statistically dependent on its location within the relief, nor is it related to connections to peri-Alpine metropolises or transport infrastructure. As the discussion shows, the current situation is very complex, and many measures must be considered for the region as a whole, but also in every individual case. The question

of which factors are decisive for regional development remains open since neither topographical characteristics nor accessibility to medium-sized and large centers, nor to higher-level transport infrastructure, can be directly linked to socioeconomic development.

Despite its value, our study comes with certain limitations and points to avenues for further research. First, this fine-scale, harmonized, pan-Alpine comparative research design could be extended by including additional socioeconomic indicators, such as tourism development, nominal labor compensation, and commuting data. Since this research article focuses on private transport, addressing public transport accessibility – particularly by rail – could provide an interesting approach to further elaborate on the accessibility perspective in the European Alps. Given that the Alps have an established rail network (see Ravazzoli et al., 2017; Cavallaro & Dianin, 2020), developing approaches to make topographic, socioeconomic, and rail accessibility patterns comparable at a fine-grained level to analyze their interlinkages represents a promising avenue for further research. Second, combining accessibility and topography with new data approaches, such as flow data based on navigation data, telephone data, and social media data (e.g., Twitter and Meta), could provide new insights into socioeconomic development patterns from a functional perspective, particularly with regard to push and pull factors for residents and tourist mobility. Third, a qualitative research approach could be used to study the reasons for existing mobility and demographic patterns. For example, one could examine why people live and work where they do, or the role of accessibility in these decisions. Fourth, it could be of added value to discuss existing case studies against the overarching spatial patterns highlighted in this study. Fifth, it is important to discern whether these developments are specific to the European Alps or can be applied to other mountainous regions around the world, as well as other territories with geographic specificities, such as regions around coastlines, large lakes, and borders.

Since the decisive factors for successful regional development remain uncertain, this paper also highlights, the relevance of policy and governance. Some research on regional development emphasizes the national affiliation of a region. Other studies argue that the local setting and the interplay of factors beyond topography and accessibility impact the socioeconomic development of a region, whether it is located in the mountains or not (Balsiger, 2012; Dax, 2017; Borsdorf & Haller, 2020; Lambracht & Chilla, 2025). Ultimately, cross-border and transnational cooperation formats aim to foster common goals and strategies. This is an ambitious objective confirmed by this study. The setting of the European Alps is complex, and a coordinated development perspective backed by the political support of individual nation-states could generate sustainable development paths for all regions – inner, interface, or peri-Alpine.

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