The Democratic Dimension of the 15-Minute City model

A Preliminary Spatial Analysis of Accessibility, Voter Turnout, and Electoral Volatility across selected European cities

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Master Thesis by

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to obtain the degree of Master of Science in Engineering and Policy Analysis (EPA)

at the Delft University of Technology,

to be defended publicly on Friday December 5, 2025 at 3:30 PM.

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Project Date :	May - Dec, 2025
MSc Program :	Engineering & Policy Analysis (EPA)
Faculty:	Technology, Policy and Management

A Nonna Anna,
“γνῶθι σαυτόν” (know thyself) !

Abstract

This thesis investigates whether everyday access to urban services can help explain patterns of democratic engagement in European cities. It treats accessibility not only as a functional condition of daily life but also as a spatial indicator of how present public institutions are in citizens' neighborhoods. The study asks to what extent proximity to essential services is associated with voter turnout and electoral volatility, interpreted respectively as symptoms of democratic disengagement and democratic discontent. Empirically, it combines walking Proximity Time measures from the Sony CSL accessibility dataset with electoral results for Paris, Berlin, and Rome, mapped on a fine hexagonal grid. Rental costs are used as a proxy for local income in order to check whether accessibility effects simply mirror socioeconomic composition. The analysis relies on descriptive statistics, cartographic exploration, and correlation matrices that link accessibility to turnout and volatility across different service domains, distinguishing between services provided or strongly regulated by the state and private amenities.

The results show that accessibility is related to democratic behavior but in a context-dependent way. In Paris and Rome, longer travel times to state-related services are generally associated with lower turnout and, in Rome, with strongly concentrated belts of high volatility in peripheral areas. Berlin displays an opposite configuration in which more distant zones record slightly higher participation, a pattern that reflects its polycentric structure and relatively stable residential communities. Across all three cities, rental costs explain only a small fraction of the variation in accessibility, which suggests that planning legacies and urban morphology play an independent role. Overall, the findings provide suggestive but strictly correlational evidence. They indicate that accessibility can act as a territorial channel through which institutional presence is experienced, while also highlighting the need for longitudinal and quasi-experimental research designs to establish whether changes in accessibility have causal effects on democratic engagement.

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List of Abbreviations

EU: European Union
EV: Electoral Volatility
MSc EPA: Master of Science in Engineering and Policy Analysis
OSM: Open Street Map
OSRM: Open Source Routing Machine
POI: Point of Interest
PT: Proximity Time
Sony CSL: Sony Computer Science Laboratories
TNC: Total Net Change

1

Introduction

Cities are complex systems where a sizable number of factors are interrelated into an organic whole (Jacobs, 1961). In Europe, the urbanization rate has stabilized since the early 2000s, so contemporary change is driven more by internal structure than by continued urban expansion (World Bank, 2025). Cities in the old continent carry a deep car-centric legacy that has reshaped planning practice and everyday life for more than a century. Designing streets and networks around automobility reorganized urban hierarchies, privileged linear and perpendicular grids, and accelerated low-density expansion at the metropolitan fringe (J. R. Brown et al., 2009; Newman & Kenworthy, 2015). As road space filled with private vehicles, cities absorbed mounting social and economic costs: congestion converted hours into lost productivity, household budgets stretched under fuel and maintenance outlays, and dependence on petroleum locked mobility into volatile energy cycles (Appleyard, 1980; Gössling, 2020). Sprawl converted green reserves and agricultural land, fragmenting habitats and degrading ecosystem services while stretching utilities, schools, clinics, and transit across ever larger footprints that are costly to serve equitably (L. R. Brown, 2003). Critiques from urbanists and environmental planners converged on a similar diagnosis: car-first urbanism weakens street life, undermines local social networks, and deepens inequalities between neighborhoods differentiated by access, safety, and environmental burden (Jacobs, 1961; Newman et al., 2017).

Automobile dependence also reshaped time. Trips that once linked nearby destinations became longer and more single-purpose; daily activities were sorted into distant zones, making routine tasks contingent on vehicle ownership and reliable traffic conditions (Newman & Kenworthy, 2015). In this configuration, the costs of distance fall unevenly. Higher-income households better absorb ownership and time costs, while low-income households face steeper trade-offs among commuting, caregiving, and access to services. Costs that appear in budget ledgers as fuel and repairs and in lived experience as missed appointments, fewer choices, and reduced participation in civic life (Appleyard, 1980; Gössling, 2020). The environmental externalities of this model—air pollution, greenhouse emissions, and land take—reinforce the same disparities, concentrating exposure where traffic volumes and arterial roads intersect vulnerable communities (L. R. Brown, 2003; Newman et al., 2017).

The COVID-19 pandemic exposed these structural vulnerabilities with unusual clarity. Lockdowns and supply disruptions revealed how distant, single-use urban patterns struggle to secure basic access when movement is constrained, while forcing rapid experiments in reallocating street space, adjusting transit operations, and repurposing public realms to sustain daily life under health protocols (Allam, 2020; Allam & Jones, 2020). In many cities, the emergency also illuminated a path forward: measures that brought essential goods and services closer, diversified local options, and reduced compulsory travel proved not only feasible but popular. As planners and officials took stock, proximity-oriented approaches moved from niche pilots to mainstream agendas, framed less as a lifestyle choice and more as risk management for equity, health, climate, and resilience (Newman & Kenworthy, 2015; Newman et al., 2017). Therefore, twenty-first-century urban challenges can be grouped into four linked pressures: time poverty, unequal access, environmental stress, and the fragility of long-walking-distance systems. The current task is to reassemble urban form and service provision so routine needs are reachable locally and reliably, while avoiding new exclusions that replicate those produced by automobile dependence (Appleyard, 1980; Jacobs, 1961; Newman et al., 2017).

Against this backdrop, the concept of a "15-minute city" has emerged as a clear egalitarian concept. Chrono-urbanism proposes that quality of life improves when living, working, education, healthcare, commerce, and leisure are reachable by foot or bicycle within a short time radius; the program couples proximity with diversity, density, and digitalization, inviting cities to reorganize around time to services rather than around traffic volumes or long commutes (Moreno et al., 2021). Part of its appeal is practical. After the pandemic reshaped habits and exposed access gaps, a time-based frame traveled well: it promised near-term improvements for families and older residents, aligned with climate and air-quality objectives (Marzolla et al., 2024), and resonated with the felt constraint of time poverty. Time is easy to communicate and to plan around. Where distance and network complexity are hard to explain, minutes are intuitive; they let planners, politicians, and residents talk about the same thing without translation (Moreno et al., 2021). The proximity principle is universal and applicable across contexts; Bruno et al. provide a global framework that categorizes essential services and computes a universal PT for cities worldwide (Bruno et al., 2024), and they operationalize it through *Whatif*, an open interactive platform that makes these indicators explorable for cities worldwide ("Whatif - Sony CSL platform", n.d.).

Despite its conceptual appeal, this concept has raised significant concerns regarding the unequal distribution of benefits and the risk of reinforcing socio-spatial divides enanching spatial segregation (Pozoukidou & Chatziyiannaki, 2021). Evidence from large-scale mobility traces suggests that intensified local living can interact with social structure in unintended ways. When most consumption trips take place within a compressed activity space, low-income residents may end up encountering a narrower social world and experiencing stronger segregation unless connectors—regional public transport, affordable links across the city's cores—remain open and reliable (Abbiasov et al., 2024). In parallel, critical urban work reminds us that social mix does not happen by itself. Local amenity upgrades and new "complete neighborhoods" can capitalize land values and attract higher-income demand; without safeguards against displacement and without redistribution of public effort, the benefits of proximity may be captured unequally, and inequalities may deepen (Casarin et al., 2023). Methodological reflections add a further caution: equal minutes do not guarantee equal opportunities. Two districts can both be "15-minute" for healthcare and yet differ sharply in capacity, price, or reliability; without attention to quality and to how opportunities are weighted, time-based parity can mask new forms of exclusion (Bruno et al., 2024). As Hill et al. argue, truly inclusive cities must move beyond proximity: accessibility should not only reduce travel time but also embed values of care, participation, and quality of experience in the urban fabric (Hill et al., 2024). These counterparts do not cancel the proximity agenda. They insist on governance: that tenure, affordability, and inter-neighborhood connectivity decide whether proximity becomes inclusion or insulation.

A similar lesson emerges when we shift from mobility to democracy: compressing daily life inside a 15-minute zone without maintaining strong connectors outside the neighborhood can narrow social exposure, intensify segregation, and over time foster spatial polarization. Large-scale mobility evidence shows that when activity spaces contract, low-income residents encounter fewer interactions across social groups and a more homogeneous set of destinations, which raises the risk that localism hardens social boundaries unless regional public transport and affordable links across the city remain open and reliable (Abbiasov et al., 2024). Critical urban analyses reach a parallel warning: hyperlocal "complete neighborhoods" can concentrate advantage and displacement pressures unless citywide safeguards redistribute opportunities and protect a right to the city beyond the immediate district (Casarin et al., 2023). In such contexts, the democratic signal tends to follow territorial lines. Across Europe, places that feel left behind because of slow declines in jobs, in services, or in perceived attention translate dissatisfaction into electoral behavior, with participation and protest filtered by neighborhood effects and local context (Dijkstra et al., 2020). Within this landscape, abstention may reflect disenchantment where marginalized groups concentrate or operate as protest where local public services and shops have receded; in both registers, the geography of services and the ability to move beyond the local catchment shape how political behavior is expressed (Bourdin & Tai, 2022).

These strands invite a shift in how the '15-minute' discussion is evaluated. If access to services functions not only as a mobility convenience but also as a perceptual proxy for institutional presence in everyday life, then persistent shortfalls should be legible in democratic outcomes. Where access is thin, residents encounter more friction and fewer ordinary touchpoints with public authority; where it is thick, institutions are routinely met and easier to trust. Rather than declaring a causal verdict, the present study offers a first, spatial reading at the city and neighborhood scale. Across different European capitals, it asks whether variation in access to state-provided and private-provided services aligns with patterns of abstention and instability of electoral preferences over time, once simple socioeconomic contrasts are acknowledged, while remaining attentive to spatial dependence in the data. The aim is to see whether a political signal emerges from the distribution of services that would justify more demanding identification in subsequent work.

From this narrative, the guiding question follows:

To what extent does accessibility to services, as a proxy for institutional presence, influence civic engagement and electoral discontent in European cities?

The relevance of this question extends beyond the cases at hand. In the Horizon Europe Work Program for Cluster 2 (Culture, Creativity, and Inclusive Society), the topic on *economic inequalities and their impact on democracy* calls for a better understanding of links between inequality and participation, the identification of drivers of political disengagement, and the design of inclusive, resilient governance models. By treating accessibility as a territorial form of inequality that citizens feel every day, this thesis speaks directly to that agenda and to the broader European effort to connect urban equity with democratic health.

This thesis contributes a reframing of urban accessibility as both a functional attribute and a proxy for perceived institutional presence and evaluates this premise through two linked hypotheses. First, it tests whether poor accessibility to essential services lowers the perceived presence of public institutions, fostering civic alienation and, in turn, lower voter turnout (H1). Second, it examines whether low levels of service provision, measured as longer PT to different categories of services, generate spatially concentrated discontent that appears as higher electoral volatility (H2). Empirically, this research focuses on three case studies (Paris, Berlin, and Rome) and draws on walking PT data to services provided by Sony CSL, mapped on a 200-meter-wide hexagonal grid. Electoral turnout is analyzed using official precinct geometries, preserving the administrative boundaries relevant to participation. EV, instead, is computed on the same hex grid used for accessibility. The stance of the research is non-causal: results are interpreted as structured patterns that motivate experimental designs in future work. The remainder proceeds by detailing data and PT construction, laying out the empirical strategy and spatial diagnostics, presenting results and sensitivity checks, and closing with implications for equity-oriented governance and avenues for causal identification.

2

Problem Analysis

2.1. Context

Cities concentrate people, institutions, and economic activity in built fabrics that evolved under different historical constraints. In European cities, this density coexists with persistent spatial asymmetries (Ehrlich & Overman, 2020; Guastella et al., 2019). Central areas typically host administrative, cultural, and economic cores, where state visibility and service provision are highest. Outer belts, by contrast, tend to experience longer travel times, weaker public presence, and thinner social infrastructure. Inequality thus emerges not only from income or housing disparities but also from the everyday effort required to reach schools, clinics, parks, shops, or public transport (Jacobs, 1961; Newman et al., 2017). Accessibility becomes, in this sense, both a spatial measure of opportunity and a perceptual indicator of how present institutions are in citizens' daily lives.

Urbanization rate growth in Europe, however, has largely reached maturity. As shown in Figure 2.1, the share of the population living in cities across EU member states has increased steadily since the 1960s but has changed little over the last two decades. The right-hand panel of the figure reports the annual rate of change: after 2000, the growth rate has stabilized, confirming that the process of demographic concentration has stabilized. Europe is, therefore, *post-urbanizing*: population growth no longer drives urban change. Instead, the evolution now concerns the internal organization and inequalities within cities rather than the expansion of their boundaries (World Bank, 2025).

This transition from urban growth to urban restructuring has profound implications for policy. In mature urban systems, the challenge is no longer to expand infrastructure but to make existing territories more equitable and resilient. The long legacy of car-centric planning has left European cities with metropolitan structures that fragment daily life into distant zones, making access to basic services and institutions contingent on private mobility (Gössling, 2020; Newman & Kenworthy, 2015). The result is a geography of advantage and delay: areas well connected to public amenities and collective transport benefit from everyday proximity to institutions, while peripheral areas experience distance as both a logistical and civic constraint.

The COVID-19 pandemic exposed this imbalance with exceptional clarity. Lockdowns and restricted movement revealed how fragile distant, single-use urban forms were in ensuring access to essential goods and services. Conversely, neighborhoods that concentrated daily functions locally proved more resilient and inclusive (Allam & Jones, 2020). This experience reignited interest in proximity-based models such as the "15-minute city," which reframe accessibility as a dimension of urban equity rather than merely a mobility outcome (Bruno et al., 2024; Moreno et al., 2021). The principle underlying this shift is straightforward: when basic needs—healthcare, education, outdoor spaces, cultural life, and commerce—are reachable by foot within a short time radius, cities become more livable, sustainable, and cohesive.

Yet, proximity alone does not guarantee inclusion. As research warns, concentrating services within small catchment areas without ensuring affordable cross-city mobility can intensify segregation and limit

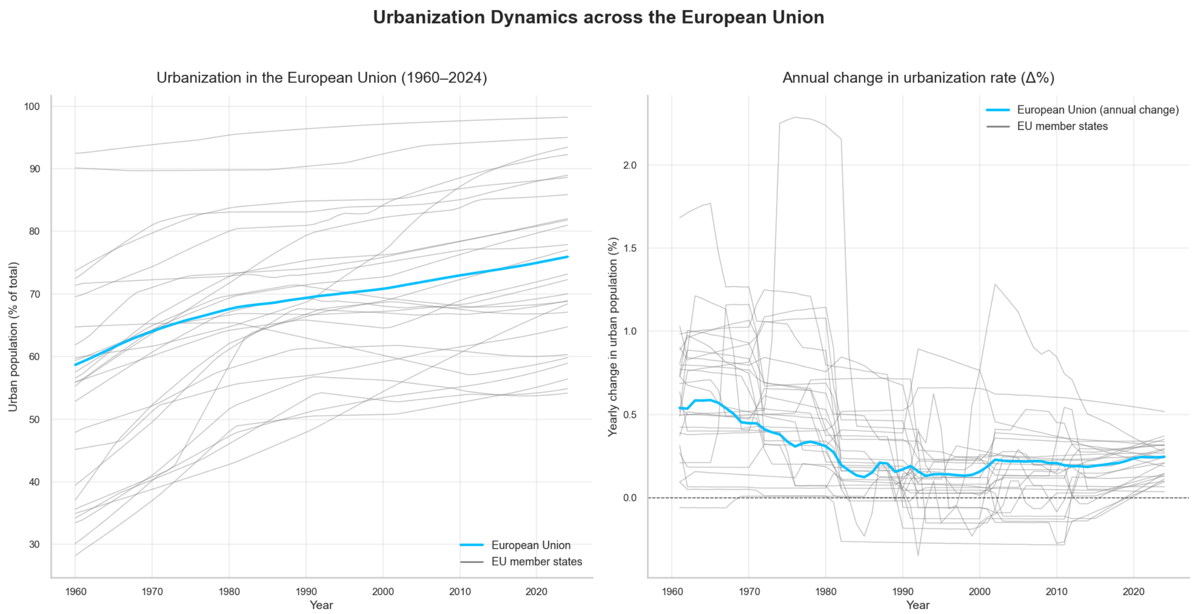


Figure 2.1: Urbanization dynamics in the European Union (1960–2024). The left panel illustrates the steady increase in the share of the urban population, while the right panel depicts the annual rate of change, highlighting the stabilization of growth and the transition toward a post-urbanization phase. Source: World Bank, derived from *United Nations, World Urbanization Prospects* (World Bank, 2025).

social exposure, especially among lower-income residents (Abbiasov et al., 2024; Casarin et al., 2023). The balance between local accessibility and metropolitan connectivity thus defines whether proximity becomes a vector of inclusion or insulation. In the same way, accessibility to state-provided services—schools, clinics, cultural venues, and public transport—serves as a perceptual proxy for institutional presence: when these are unevenly distributed, trust and participation tend to mirror the geography of access (Bourdin & Tai, 2022; Dijkstra et al., 2020).

This perspective situates accessibility at the intersection of spatial justice and democratic vitality. It emphasizes that urban inequalities are no longer only about where people live but about how effectively institutions remain visible and reachable in their everyday environment. As European cities move further into a post-urbanization phase, the central policy question becomes how to reconfigure existing urban forms to restore proximity, balance connectivity, and reinforce the spatial foundations of civic engagement.

2.2. Past Research and Knowledge Gap

2.2.1. Literature Search Strategy

The literature search that underpins this research was carried out with the objective of identifying and reviewing academic contributions situated at the intersection of spatial accessibility, civic engagement, voter turnout, and electoral volatility. The aim was to build a coherent understanding of how spatial inequality—measured through access to services and infrastructure—interacts with patterns of discontent and distrust in democratic systems. The process combined targeted keyword searches with iterative reference tracing to ensure both breadth and depth in the selection of relevant sources.

Two main streams guided the search. The first explored the relationship between socioeconomic and demographic factors and political participation, examining how spatial differences influence voter abstention. The second focused on the concept of electoral volatility and its territorial manifestations, paying particular attention to how local socio-economic and infrastructural conditions shape protest voting and institutional trust. Searches were performed primarily on Google Scholar and Scopus, chosen for their comprehensive coverage of peer-reviewed publications and their capacity to trace citations across related studies. Search strings were used, combining terms such as “accessibility and turnout,” “turnout and inequality,” “spatial accessibility and civic engagement,” and “electoral volatility and civic engagement.” The scope was restricted to English-language journal articles published between 2000 and 2025, though several earlier works were retained when conceptually foundational. In addition to these direct searches, a complementary snowballing strategy was employed. The bibliographies of the most relevant and frequently cited papers were systematically examined to identify additional studies that met the conceptual and methodological criteria of this review.

Across both research streams, approximately eighty records were initially retrieved. Duplicates were removed, and abstracts were screened to identify studies directly addressing the spatial or territorial dimensions of participation, abstention, or volatility. Particular attention was paid to contributions that incorporated accessibility indicators—such as travel time, service density, or network-based metrics—within models of civic behavior, or that explicitly analyzed the role of space in shaping engagement and discontent. After reviewing only the introduction and conclusion sections to assess relevance and methodological coherence, around twenty papers were retained for in-depth analysis. The resulting corpus includes both empirical and theoretical works that collectively frame accessibility as a determinant of civic inclusion and institutional visibility.

2.2.2. Related Works

A substantial body of research across urban studies, political geography, and electoral behavior highlights that spatial accessibility, understood as the ease with which residents can reach essential services and opportunities, plays a fundamental role in shaping civic engagement and democratic participation. Rodríguez-Pose shows how territorial inequality and uneven institutional presence shape political discontent and participation, arguing that places systematically bypassed by development and public investment tend to exhibit lower trust and weaker engagement (Rodríguez-Pose, 2018, 2020). When essential infrastructures and public services erode or become unevenly distributed across space, these places appear to “not matter,” and citizens’ incentives to participate in democratic processes diminish accordingly. Building on this argument at the metropolitan scale, Bourdin and Tai identify service-deprived areas in the Paris region where persistently high abstention reflects a cumulative process of neglect (Bourdin & Tai, 2022), while Bourdin and Torre theorize that democratic discontent has territorial “roots” precisely in places where everyday interactions with the state are scarce, discontinuous, or absent (Bourdin & Torre, 2025). Complementing these contributions, Bartle, Birch, and Skirmuntt show that spatially concentrated socio-economic inequalities interact with neighborhood-level segregation to depress turnout, reinforcing the idea that democratic engagement is structured by everyday geographies rather than by individual characteristics alone (Bartle et al., 2017).

Evidence on the role of proximity further strengthens this perspective. Dyck and Gimpel provide clear empirical proof that longer distances to polling locations, higher travel costs, and logistical barriers significantly reduce participation, especially among voters with limited mobility or resources (Dyck & Gimpel, 2005). Pereira and co-authors show that mobility interventions such as free public transit on election day increase turnout disproportionately among disadvantaged groups, indicating that accessibility modifies not only the material cost of participation but also citizens’ perceptions of institutional responsiveness and fairness (Pereira et al., 2023). In this sense, accessibility operates through both functional and symbolic mechanisms: it affects how easy it is to engage in formal politics and how present and attentive the state appears to be in citizens’ daily environments.

Methodologically, a growing literature demonstrates that the spatial determinants of turnout and abstention require analyses at fine levels of granularity. Mansley and Demšar show that precinct-level modeling of turnout in London uncovers local patterns that are invisible at more aggregated scales (Mansley & Demšar, 2015), while Di Brisco and Migliorati develop a spatial mixed-effects framework to capture context-specific effects in electoral data (Di Brisco & Migliorati, 2020). Waggoner illustrates how unsupervised clustering can be used to identify latent spatial patterns in political and social datasets (Waggoner, 2021), providing tools for systematically detecting clusters of participation and abstention that align with accessibility gradients and socio-spatial segregation. In parallel, Fanelli and co-authors document how core–periphery structures in cities emerge from the uneven distribution of infrastructures and services, producing systematic inequalities in access that cut across urban regions (Fanelli et al., 2025). Together, these contributions underscore the importance of high spatial resolution and the need to move beyond administrative boundaries in order to understand the geography of democratic engagement.

On the other hand, EV provides an additional lens through which the spatial dimension of political behavior can be interpreted. Tavits and, separately, Mainwaring and co-authors distinguish between within-system and extra-system volatility, capturing respectively vote redistribution among established parties and shifts toward new or anti-system movements (Mainwaring et al., 2017; Tavits, 2008). Powell and Tucker, as well as Núñez, Simon, and Pilet, connect volatility to institutional reforms and the erosion of partisan alignments, highlighting how changes in electoral rules and party systems destabilize voter loyalties (Nunez et al., 2014; Powell & Tucker, 2014). Cerruto and Raniolo interpret volatility in Southern Italy as a shift from clientelistic "exchange" to more assertive forms of "voice," suggesting a protest dimension in fluid voting patterns (Cerruto & Raniolo, 2018). Kriesi situates these dynamics within a broader discussion of democratic crisis in Europe, emphasizing how volatility and non-participation reflect deeper dissatisfaction, particularly in marginalized territories (Kriesi, 2020). Spatial analyses by Dijkstra, Poelman, and Rodríguez-Pose, and by Bertus and Kovács, confirm that economically peripheral or infrastructurally neglected regions display higher levels of electoral instability, linking volatility to uneven development and weak service provision (Bertus & Kov'acs, 2022; Dijkstra et al., 2020). These findings suggest that volatility and turnout share common roots in the geography of opportunities, accessibility, and institutional visibility.

Urban-level analyses further reinforce this spatial perspective. Mansley and Demšar, and Di Brisco and Migliorati, show that abstention and volatility tend to cluster along specific socio-spatial divides rather than being evenly distributed across metropolitan spaces (Di Brisco & Migliorati, 2020; Mansley & Demšar, 2015). These clusters frequently align with gradients of accessibility and infrastructure quality, as well as with core–periphery structures documented in urban science (Fanelli et al., 2025). At the same time, Bruno and co-authors develop a universal framework for inclusive fifteen-minute cities, showing that proximity-based planning can enhance equity and resilience but may also reproduce existing inequalities if accessibility improvements remain uneven or are concentrated in already advantaged neighborhoods (Bruno et al., 2024). This work resonates with the broader "geography of discontent" framework proposed by Rodríguez-Pose, which links political disengagement to declining services, diminished mobility, and perceived territorial neglect (Rodríguez-Pose, 2018, 2020).

Taken together, these contributions establish a robust empirical and conceptual foundation for treating accessibility as a key dimension of democratic life. They show that spatial accessibility shapes how citizens encounter institutions, perceive inclusion or exclusion, and translate these experiences into turnout decisions, support for political alternatives, or protest behavior. At the same time, they reveal important limitations that motivate the present study. Accessibility is still rarely operationalized through fine-grained proximity measures to everyday services that match the scale of daily life; comparative analyses across multiple metropolitan contexts remain limited; and the relationship between accessibility and electoral volatility has received less empirical attention than the link with turnout. These gaps provide the starting point for the research questions and analytical strategy developed in the next subsection.

2.2.3. Knowledge Gap

Recent research has made substantial progress in linking spatial inequalities to political behavior, showing how territorial disparities in wealth, infrastructure, and social capital shape patterns of participation and trust. Rodríguez-Pose documents how long-term neglect of certain regions translates into anger, resentment, and rising support for populist actors (Rodríguez-Pose, 2018), while Dijkstra, Poelman, demonstrate that regions left behind in terms of employment, education, and access to opportunities exhibit systematically higher levels of support for anti-system parties (Dijkstra et al., 2020). Bourdin and Tai extend this reasoning to the metropolitan scale, identifying neglected areas within the Paris region where high abstention reflects cumulative territorial disadvantage rather than purely individual-level apathy (Bourdin & Tai, 2022). Together, these studies provide a solid foundation for understanding how spatial inequalities condition democracy, but they often rely on aggregate socio-economic indicators or broad measures of regional decline rather than on high-resolution measures of accessibility to everyday services at the scale of daily life.

In parallel, the fifteen-minute city has emerged as an influential framework in urban planning, promoting equitable access, local vitality, and sustainable mobility. Moreno and co-authors conceptualize the fifteen-minute city as a model in which daily needs can be met within short walking or cycling distances, with the aim of enhancing sustainability, resilience, and place identity in post-pandemic cities (Moreno et al., 2021). Subsequent work has refined and operationalized this framework, exploring how proximity-based planning can reduce car dependence, lower emissions, and improve quality of life. Yet, the potential democratic implications of the model remain largely unexplored. Most empirical applications focus on environmental or socio-economic impacts, while the links to turnout, political engagement, and electoral volatility are rarely examined directly. Furthermore, existing studies are often confined to single-city case studies and rely on administrative units that are too coarse to fully capture neighborhood-level inequalities in accessibility and civic behavior.

This study advances this emerging research agenda by explicitly examining the democratic dimension of the fifteen-minute city model and analyzing how proximity to essential services relates to both voter turnout and electoral volatility. The contribution unfolds along two complementary extensions. First, the study employs a high-resolution spatial framework that captures urban conditions at a level of detail seldom used in political behavior research: electoral turnout is analyzed at the precinct level, while accessibility and electoral volatility are measured on a uniform hexagonal grid. This fine-grained approach makes it possible to detect micro-territorial inequalities that remain hidden when relying on aggregated administrative units, thereby aligning the analysis with the core principle of the fifteen-minute city model, which operates at the scale of neighborhoods and everyday life. Second, the study adopts a comparative multi-city design covering three major European capitals (Paris, Berlin, and Rome), each characterized by distinct spatial morphologies, governance structures, welfare arrangements, and patterns of political competition. By extending the analysis beyond a single case, the research assesses whether the relationship between accessibility and democratic behavior is context-specific or whether it exhibits consistent patterns across different metropolitan systems. Importantly, this work should be understood as an initial step toward investigating this link: the aim is not to make causal claims but to evaluate the plausibility of systematic associations between accessibility patterns and democratic engagement. Taken together, these two extensions—greater spatial precision and cross-city comparison—provide an integrated framework for assessing how the principles of the fifteen-minute city intersect with democratic engagement and offer new, albeit preliminary, evidence on how everyday accessibility may shape political participation in contemporary European cities.

2.3. Conceptualization of the Research and Research Objectives

2.3.1. Conceptualization of the Research

This research conceptualizes the urban environment not merely as a container of economic activity, but as the physical manifestation of the social contract between the state and its citizens. The central premise of this study is that `spatial accessibility` functions as a tangible proxy for `institutional presence`. In this framework, the daily effort required to reach essential services, such as schools, healthcare facilities, and public transport, signals to residents the extent to which they are included in the collective urban democratic process.

The conceptual model operates on two distinct pathways linking the built environment to political behavior:

1. **The Disengagement Pathway (Turnout):** When state-provided services are spatially distant or difficult to access, residents may perceive a withdrawal of the public sector from their territory. This ”spatial retreat” of the state fosters a sense of neglect and alienation, which translates into civic withdrawal and distrust. In this context, low accessibility is hypothesized to correlate with low voter turnout, as the physical friction of accessing public goods mirrors the friction of participating in democratic life. Abstentionism serves as a diagnostic symptom of political distrust rooted in spatial neglect.
2. **The Discontent Pathway (EV):** Alternatively, spatial marginalization may not lead to silence but to instability. In areas where essential services are scarce, the resulting dissatisfaction may manifest as a rejection of established political incumbents. Here, low accessibility is conceptualized as a driver of EV, where voters frequently switch preferences in search of better representation. EV serves as a diagnostic symptom of political discontent rooted in spatial neglect.

To operationalize this framework, preliminary checks were conducted to assess the extent to which local income levels explain accessibility, ensuring that spatial effects are distinguishable from socio-economic composition. Subsequently, to empirically verify the Disengagement and Discontent pathways, a correlation analysis was performed based on a specific categorization of amenities: *private-provided* versus *state-provided* services. Crucially, the definition of "state-provided" adopted here extends beyond facilities directly managed by public administration; it encompasses services that are regulated, tendered, or subsidized by the state to guarantee universal and homogeneous coverage. This taxonomy allows the research to distinguish between the mere *functional* utility of proximity (the convenience of a 15-minute walk) and its *symbolic* value (the tangible visibility of the welfare state). While private amenities contribute to general urban vitality, it is the accessibility to `state-provided services` that is expected to carry the strongest political weight. By treating the city as a complex socio-technical system, this model ultimately proposes that urban planning decisions regarding service location are, effectively, decisions about democratic inclusion.

2.3.2. Research Objectives

Building on the conceptual gap identified above, this research aims to advance the understanding of how spatial accessibility to services relates to democratic engagement and institutional trust. While previous studies have highlighted the role of spatial inequality in shaping political behavior, few have examined accessibility as the everyday channel through which citizens experience the presence—or absence—of public institutions. By reframing accessibility as both a functional condition and a perceptual indicator of inclusion, this study explores whether disparities in service provision can help explain territorial differences in civic participation and electoral stability across European cities.

As mentioned previously in the introduction, the analysis is guided by two central hypotheses. First, it tests whether poor accessibility to essential services lowers the perceived presence of public institutions, fostering civic alienation and, in turn, lower voter turnout (H1). Second, it examines whether low levels of service provision—measured as longer PT to different categories of services—generate spatially concentrated discontent that manifests as higher electoral volatility (H2). Together, these hypotheses aim to uncover whether accessibility functions as a spatial and perceptual mechanism linking institutional presence to patterns of political disengagement and democratic instability.

To operationalize these aims, the research adopts a comparative spatial approach, focusing on three major European capitals—Paris, Berlin, and Rome. It integrates accessibility data from Sony CSL's PT layers with electoral outcomes at multiple spatial scales to capture the relationship between service distribution, civic participation, and volatility within each urban system. The empirical strategy combines descriptive and spatial statistical methods to identify structured regularities and contextual variations, offering an initial but robust basis for future causal investigation.

From these objectives derive five research questions that guide the empirical analysis:

1. What is the general relationship between average accessibility and electoral abstention across major European cities?
2. How the spatial distribution of services within cities reflect existing income disparities?
3. To what extent does the perception of service availability, inferred from proximity to services, relate to electoral abstention and protest voting in the selected case studies?
4. How closely can walkable access to services be linked to perceived institutional presence and electoral volatility across different urban contexts?
5. To what extent does income emerge as a key explanatory factor for both electoral volatility and voter turnout in the analyzed European cities?

2.4. EPA Relevance

The Master of Science in *Engineering and Policy Analysis (EPA)* at TU Delft trains students to understand, model, and govern complex socio-technical systems. Its learning objectives focus on the integration of analytical rigor and societal relevance: students are expected to (i) analyze interdependent systems combining technical, social, and institutional dimensions; (ii) develop and apply quantitative models to support policy decisions under uncertainty; (iii) translate evidence into actionable recommendations for policymakers and stakeholders; and (iv) reflect critically on the governance implications of analytical tools and assumptions. The program therefore operates at the intersection of engineering, data science, and public policy—transforming technical knowledge into instruments for equitable and sustainable decision-making.

This research is directly aligned with those objectives. Cities epitomize complex socio-technical systems: they link physical infrastructures, institutions, and individual behavior through nonlinear feedbacks that shape collective outcomes. By examining how accessibility to public services influences civic engagement and political stability, this thesis applies the EPA approach to one of the defining governance challenges of contemporary Europe. The work combines engineering-style modeling of spatial accessibility with the policy analysis of democratic behavior, showing how quantitative evidence can illuminate social mechanisms such as institutional trust, inclusion, and participation. It demonstrates how systemic reasoning and data-driven modeling can be used not only to describe urban inequalities but also to guide interventions toward more cohesive and democratic urban systems.

The thesis embodies the EPA philosophy in three ways. First, it applies *systems thinking*, by conceptualizing accessibility, institutional presence, and civic engagement as components of an interdependent urban system. Second, it demonstrates *data-driven policy modeling*, using standardized proximity indicators and spatial diagnostics to derive insights relevant for multilevel governance. Third, it stresses *policy relevance*, translating technical results into knowledge that can inform equity-oriented decision-making. Through this integrative approach, the research exemplifies the EPA mission of bridging quantitative modeling and societal problem solving.

The main audiences of this research are public institutions and political actors operating at different territorial levels, as detailed in Appendix A. At the supranational level, the European Union plays a central role in maintaining democratic legitimacy and territorial cohesion across member states while managing cohesion funds and regulatory frameworks. The results of this study can support the EU's objective—outlined in the Horizon Europe Cluster 2 program on "Economic inequalities and their impact on democracy"—by providing insights into how spatial inequalities in service provision may contribute to civic disengagement and reduced institutional trust. At the national level, ministries, planning authorities, and statistical agencies can use the findings to identify territories where uneven accessibility aligns with patterns of democratic discontent, improving the targeting and design of policies for territorial equity. At the local level, municipal governments, responsible for service delivery and urban planning, can draw on these diagnostics to prioritize investments that strengthen both social inclusion and civic participation. National political parties may also benefit from this analysis by interpreting spatial patterns of abstention and volatility to better understand and address the territorial roots of political alienation. Taken together, these institutional and political actors form a multilevel governance system in which accessibility, participation, and institutional trust are deeply interconnected. The evidence generated by this research provides them with an empirical foundation for designing policies that foster more inclusive, equitable, and democratically resilient cities.

3

Methodology

This chapter defines the analytical workflow linking data, model, and results (figure 3.1). The study integrates geospatial, electoral, and socioeconomic sources to quantify the relationship between urban accessibility and voter turnout and electoral volatility. Steps include data acquisition, cleaning, spatial standardization, normalization, and correlation analysis.

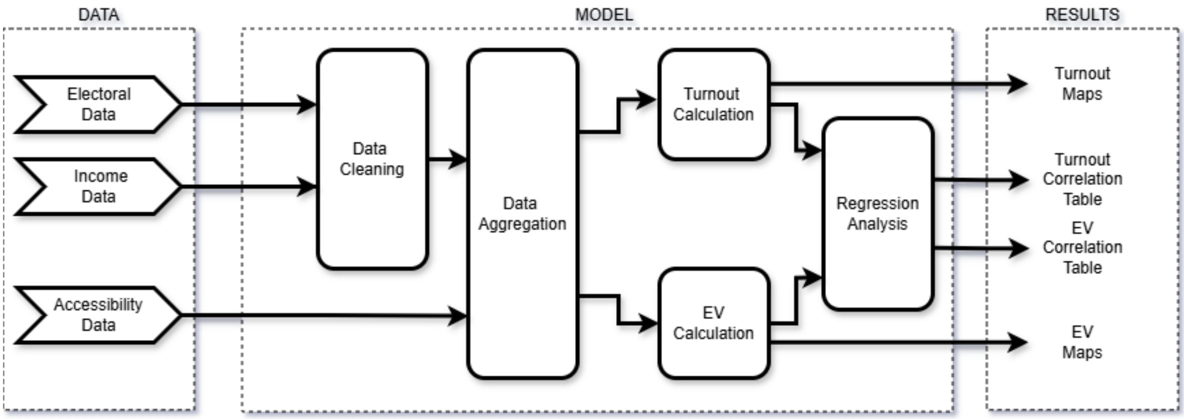


Figure 3.1: Comprehensive methodological workflow linking data acquisition, preprocessing, and analytical outputs. The diagram illustrates how heterogeneous datasets (electoral records, geospatial accessibility layers, and income proxies) are ingested, cleaned, and spatially standardized before being merged onto appropriate geometries. The pipeline bifurcates into two analytical branches (Turnout and EV) each aligned with distinct spatial supports (precincts for turnout and hexagonal grid for EV). The final outputs consist of spatial maps, correlation matrices, and interpretation tables that together quantify how urban accessibility relates to civic engagement across cities.

Immediately following the workflow in Figure 3.1, the methodological structure of the study proceeds through a sequence of clearly defined steps detailed in the subsequent sections of this chapter. Section 3.1 describes the collection of electoral, accessibility, and income data from official and open sources, outlining the heterogeneity and spatial granularity of the inputs. Section 3.2 introduces the accessibility layers, computed as walking PT on a hexagonal grid and harmonized across nine service categories. Section 3.3 details the city-specific processing pipeline used to clean, standardize, and spatially align raw electoral files with the corresponding geometries for Paris, Berlin, and Rome. Section 3.4 describes the aggregation models that link accessibility to electoral outcomes, preserving precinct geometries for turnout and using a fixed hexagonal grid for EV to avoid inconsistencies from changing precinct boundaries. Section 3.5 introduces the statistical framework used to compute correlations between PT and the two electoral indicators. Finally, Section 3.6 presents the interpretation schemes that guide the reading of signs and magnitudes in the empirical results. Together, these components will form the methodological system that integrates heterogeneous datasets onto a common analytical structure.

3.1. Data and Sources

3.1.1. Electoral Data

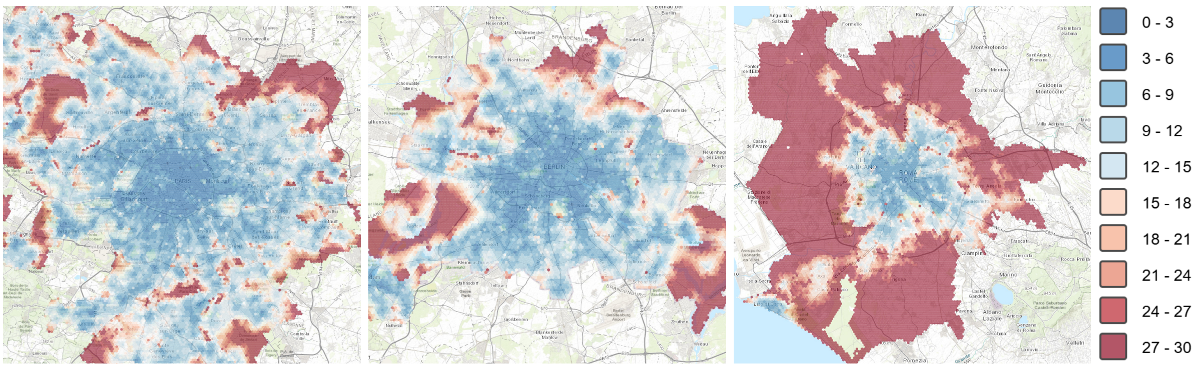
Electoral data were collected at the most disaggregated administrative level available, allowing for spatial alignment with accessibility grids and socio-economic indicators.

- **Paris:** electoral and spatial data were retrieved from the *Paris Data* portal (https://opendata.paris.fr/; (Paris Data, 2025)), the official open-access platform of the City of Paris providing datasets at the *bureau de vote* level.
- **Berlin:** electoral data were obtained from the *Berlin Open Data* portal (https://daten.berlin.de/; (Berlin Open Data, 2025)), which offers publicly available datasets on municipal and federal elections.
- **Rome:** electoral data were sourced from the *Sezioni Elettorali Italiane (SEI)* database published by Pinto (Pinto, 2023), providing geocoded election results for all Italian precincts.

Each dataset includes total votes, valid votes, turnout rates, and the vote shares of political parties. For the case of Rome, the official source from the Italian Ministry of the Interior was not selected, as no official shapefile of electoral precincts was available. Instead, the geospatial layer developed by Pinto (Pinto, 2023) was used, which reconstructs precinct boundaries by aggregating and geocoding the address-level data released by the Ministry.

3.1.2. Accessibility Data

All three cities' accessibility data were developed by Sony CSL (Bruno et al., 2024). Accessibility is measured as Proximity Time (PT, minutes) on a custom hexagonal grid with 200 m cell side, while POIs are sourced from OSM. For each hexagon and for nine service categories (outdoor activities, learning, supplies, eating, moving, cultural activities, physical exercise, services, and healthcare), the 20 nearest POIs are identified, and average walking time is computed using the Open Source Routing Machine (OSRM) based on OSM data. The general accessibility layer is calculated as the mean PT across all nine categories, and the city-level PT as the population-weighted average of hexagon scores. Only walking travel times are considered in this study, and no city-specific rescaling is applied. Figure 3.2 uses PT layers from the Sony CSL portal ([https://whatif.sonycsl.it/15mincity/]; (Bruno et al., 2024)).



(a) Paris (b) Berlin (c) Rome (d) Scale

Figure 3.2: Walking Proximity Time (PT) for Paris, Berlin, and Rome on a 200 m hexagonal grid. Darker red colors correspond to longer PT and lower accessibility. The figure highlights the internal spatial contrasts of the three cities: compact and highly accessible areas in central Paris, a more polycentric pattern in Berlin, and a fragmented accessibility structure in Rome. PT values come from the Sony CSL 15-Minute City dataset and represent the average walking time to the nearest POIs. The maps illustrate intra-urban contrasts in proximity to essential services, with values derived from the Sony CSL 15-Minute City dataset (https://whatif.sonycsl.it/15mincity).

Because PT is used as a proxy for the presence of institutions and essential amenities in local areas, only walking PT (`PT_f`) is considered. Walking reflects baseline, universal access independent of vehicle ownership and thus better captures institutional reach. For hypothesis testing, variables are grouped into state-provided versus private-provided services.

The distinction between *state-provided* and *private-provided* does not necessarily reflect direct public

Table 3.1: Accessibility variables, provider domain, and meaning

Code	Variable	Provider	Meaning (examples)
a_f	average_f	-	General Accessibility (average)
b_f	culture_f	State-provided	Cultural services (museums, theaters, cinemas)
c_f	education_f	State-provided	Educational services (schools, universities)
d_f	healthcare_f	State-provided	Healthcare facilities (hospitals, clinics, pharmacies)
e_f	outdoor_f	State-provided	Outdoor spaces (parks, recreational areas)
f_f	physical_f	Private-provided	Physical exercise facilities (gyms, sports centres)
g_f	eating_f	Private-provided	Eating services (restaurants, cafés)
h_f	services_f	Private-provided	General Services
i_f	supplies_f	Private-provided	Supply services (shops, retail)
l_f	transport_f	State-provided	Public transport

management. Some facilities classified as state-provided may result from indirect public decisions, such as concession agreements, public tenders, or subsidized programs that ensure their accessibility as part of the institutional supply of services.

3.1.3. Income and Accessibility

To control for socio-economic disparities, the average rental cost per square meter was used as a proxy for income.

- **Paris:** rental values were available at the arrondissement level from the *Encadrement des loyers* dataset on https://opendata.paris.fr/ . For each electoral precinct or hexagonal cell, income was computed as a weighted average of arrondissement rents, using the intersection area as weight when the unit overlapped multiple arrondissements:

$$I_u = \frac{\sum_a (A_{ua} \cdot R_a)}{\sum_a A_{ua}} \tag{3.1}$$

  where R_a is the median rent of arrondissement a and A_{ua} is the intersection area between unit u and arrondissement a. For units entirely contained within a single arrondissement, income was directly assigned as:

$$I_u = R_a \tag{3.2}$$

  with a being the arrondissement containing u.

- **Berlin:** rental cost data were scraped from Airbnb listings and used as a proxy where conventional rent-by-area data were unavailable. Listings were geocoded (WGS84, EPSG:4326), converted to a GeoDataFrame, and aligned to the hex-grid CRS. Records with missing prices were dropped. To focus on a comparable basket, listings were filtered to *Apartment* as property type, *Private room* as room type, and *Accommodates* = 2. For distance computations, both listings and hexes were projected to a metric CRS (UTM 33N, EPSG:32633), and hexagon centroids were computed. For each geographical unit u, the income proxy was defined as the inverse-distance-weighted mean of the ten nearest listings:

$$I_u \;=\; \frac{\sum_{i=1}^{10} w_{ui}\, R_i}{\sum_{i=1}^{10} w_{ui}}, \qquad w_{ui} = \frac{1}{d_{ui}},\; d_{ui} > 0,$$

  where R_i is the listing price and d_{ui} is the Euclidean distance between the centroid of unit u and the listing i in meters; zero distances were replaced by a small ε to avoid division by zero. The 5th–95th percentile range of prices was used only for map color scaling and did not affect the computation of I_u. Note that, unlike Paris and Rome, this proxy is expressed in euros per night (short-term rental); levels are therefore not directly comparable to (€/m^2), and the analysis relies on within-city standardization when combining variables.

- **Rome:** Geolocated rental data were manually collected from `casa.it`. For each geographical unit u, the income proxy was estimated as a distance-weighted mean of the five nearest rental points:

$$I_u = \frac{\sum_{i=1}^{5}\left(\frac{R_i}{d_{ui}}\right)}{\sum_{i=1}^{5}\left(\frac{1}{d_{ui}}\right)} \tag{3.3}$$

where R_i is the rent value of observation i and d_{ui} is the distance between the point i and the centroid of unit u.

All values were standardized in euros per square meter. However, a single common income proxy was not available across the three cities. In Paris, the proxy comes from arrondissement-level reference rents provided by the administration (€/m^2). In Rome, it derives from geolocated advertised long-term rents scraped from `casa.it` (€/m^2). In Berlin, it is based on short-term Airbnb prices for private rooms accommodating two persons (€/night). This heterogeneity limits direct cross-city comparisons and should be treated as a limitation; nevertheless, the city-specific conclusions remain valid because the analysis reads within-city spatial patterns and relies on local standardization.

OLS model: Income vs Accessibility

To evaluate whether income alone can account for spatial differences in accessibility, a simple Ordinary Least Squares (OLS) model was estimated separately for each city and each accessibility domain. For each hexagon u, the specification takes the form

$$\text{PT}_u^{(k)} = \alpha_k + \beta_k I_u + \varepsilon_u^{(k)}, \tag{3.4}$$

where $\text{PT}_u^{(k)}$ is the Proximity Time (PT) for accessibility category k, I_u is the income proxy for unit u, α_k is the intercept, β_k is the slope coefficient, and $\varepsilon_u^{(k)}$ is an error term capturing all residual variation not explained by income.

In matrix form, for a given category k, the model can be written as

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon},$$

where

$$\mathbf{y} = \begin{bmatrix} \text{PT}_1^{(k)} \\ \vdots \\ \text{PT}_n^{(k)} \end{bmatrix}, \qquad \mathbf{X} = \begin{bmatrix} 1 & I_1 \\ \vdots & \vdots \\ 1 & I_n \end{bmatrix}, \qquad \boldsymbol{\beta} = \begin{bmatrix} \alpha_k \\ \beta_k \end{bmatrix},$$

and n is the number of hexagons. The OLS estimator chooses $\hat{\boldsymbol{\beta}}$ to minimise the sum of squared residuals

$$\text{SSR}(\boldsymbol{\beta}) = \sum_{u=1}^{n}\left(\text{PT}_u^{(k)} - \alpha_k - \beta_k I_u\right)^2 = \|\mathbf{y} - \mathbf{X}\boldsymbol{\beta}\|^2.$$

The solution is given by the standard normal equations:

$$\hat{\boldsymbol{\beta}} = \begin{bmatrix} \hat{\alpha}_k \\ \hat{\beta}_k \end{bmatrix} = (\mathbf{X}^\top\mathbf{X})^{-1}\mathbf{X}^\top\mathbf{y}. \tag{3.5}$$

Once $\hat{\alpha}_k$ and $\hat{\beta}_k$ are obtained, fitted values and residuals are

$$\hat{\mathbf{y}} = \mathbf{X}\hat{\boldsymbol{\beta}}, \qquad \hat{\varepsilon}_u^{(k)} = \text{PT}_u^{(k)} - \hat{\alpha}_k - \hat{\beta}_k I_u,$$

and the residual sum of squares becomes

$$\text{RSS} = \sum_{u=1}^{n}\left(\hat{\varepsilon}_u^{(k)}\right)^2 = \|\mathbf{y} - \hat{\mathbf{y}}\|^2.$$

Under the usual OLS assumptions (in particular, errors with zero mean, constant variance, and no systematic correlation with I_u), the error variance can be estimated as

$$\hat{\sigma}^2 = \frac{\text{RSS}}{n-2}, \tag{3.6}$$

where $n-2$ is the number of degrees of freedom (two parameters are estimated: α_k and β_k). The covariance matrix of the coefficient estimates is then

$$\widehat{\mathrm{Var}}(\hat{\boldsymbol{\beta}}) = \hat{\sigma}^2(\mathbf{X}^\top\mathbf{X})^{-1}, \tag{3.7}$$

and the standard error of the slope $\hat{\beta}_k$ is obtained as

$$\mathrm{SE}(\hat{\beta}_k) = \sqrt{\big[\widehat{\mathrm{Var}}(\hat{\boldsymbol{\beta}})\big]_{22}},$$

that is, the square root of the second diagonal element of $\widehat{\mathrm{Var}}(\hat{\boldsymbol{\beta}})$.

In this framework, $\hat{\beta}_k$ measures the average change in PT associated with a one-unit increase in the income proxy, holding all other factors implicit and unchanged. A negative coefficient ($\hat{\beta}_k < 0$) indicates that higher-income hexagons tend to enjoy shorter travel times (better accessibility) for that service category; a positive coefficient indicates the opposite pattern. The intercept $\hat{\alpha}_k$ can be interpreted as the expected PT for a hexagon with income proxy equal to zero (after standardisation, this is mainly a technical reference point and is not of substantive interest).

The coefficient of determination R^2 quantifies the share of variance in $\text{PT}_u^{(k)}$ that is linearly associated with the income proxy I_u. Let

$$\bar{\text{PT}}^{(k)} = \frac{1}{n}\sum_{u=1}^{n} \text{PT}_u^{(k)}$$

denote the sample mean of PT. The total sum of squares is

$$\text{TSS} = \sum_{u=1}^{n}\big(\text{PT}_u^{(k)} - \bar{\text{PT}}^{(k)}\big)^2,$$

and R^2 is defined as

$$R^2 = 1 - \frac{\text{RSS}}{\text{TSS}}. \tag{3.8}$$

Values of R^2 close to zero imply that income explains only a very small fraction of the spatial variation in accessibility, whereas values closer to one indicate a tight linear alignment between income and PT.

The reported p-values are derived from a t-test on the slope coefficient. Under the null hypothesis $H_0 : \beta_k = 0$ and the standard OLS assumptions, the test statistic

$$t = \frac{\hat{\beta}_k}{\mathrm{SE}(\hat{\beta}_k)} \tag{3.9}$$

follows (approximately) a Student t-distribution with $n-2$ degrees of freedom. The two-sided p-value is computed as

$$p = 2\big(1 - F_{t_{n-2}}(|t|)\big),$$

where $F_{t_{n-2}}$ is the cumulative distribution function of the t-distribution with $n-2$ degrees of freedom. Small p-values indicate that the observed $\hat{\beta}_k$ would be unlikely if the true slope were exactly zero, given the sample size and model assumptions.

In this thesis, the OLS model is therefore used to estimate how and how much the accessibility types are related to income. It provides a transparent way to assess (i) the direction of association between income and accessibility (sign and magnitude of $\hat{\beta}_k$), and (ii) the extent to which income alone can account for observed accessibility gradients (R^2), while recognising that any remaining unexplained variation is captured by the residual term $\varepsilon_u^{(k)}$ and may reflect planning legacies, infrastructure, zoning, and other unobserved determinants of accessibility.

3.2. Data Cleaning, Aggregation and Standardization

3.2.1. City-by-City Processing

To ensure replicability and rigorous data standardization, a dedicated processing pipeline was implemented for each city case study, for each election type. We structured the workflow around Jupyter Notebooks (`.ipynb`). While the architecture generally assigns scripts to broader election categories, a granular approach was adopted where necessary: specifically, if a particular combination of city, election type, and year required unique handling due to data format anomalies or specific processing needs, a dedicated notebook was created for that specific election instance.

The implementation of this pipeline relies heavily on the Python scientific computing ecosystem. Key libraries utilized for the entire processing workflow include `pandas` for efficient data manipulation, cleaning, and aggregation, and `geopandas` for all vector-based geospatial operations, such as spatial joining and boundary merging. Furthermore, the `numpy` library was used for high-performance numerical computations, and the `matplotlib` and `seaborn` libraries were employed for data visualization checks during the data integration phase.

Each notebook follows a standardized execution pattern designed to harmonize heterogeneous administrative data. The scripts ingest the raw electoral results—typically provided in formats such as CSV, JSON, or Excel—and, where necessary, import the corresponding geospatial vector files defining the electoral precinct boundaries for that specific year. The processing logic performs essential data cleaning operations, including the conversion of data types (e.g., casting string identifiers to integers to ensure accurate merging keys) and the standardization of variable names. Crucially, the scripts calculate key derived metrics, such as the voter turnout, directly from the raw count data. The pipeline concludes by exporting a unified `GeoJSON` file for each election, which encapsulates the precinct geometries enriched with the processed electoral information, serving as the consistent input for the subsequent analysis.

Paris

The implementation for Paris relied on the *bureau de vote* (polling station) as the granular unit of analysis, crucial for linking electoral outcomes to localized accessibility data. The initial processing involved ingesting raw electoral data, often fragmented across multiple files, necessitating the use of the unique identifier, `ID_BVOTE`, for harmonization and merging with the corresponding GeoJSON spatial boundaries.

European Elections (2014, 2019, 2024). The processing of European election data benefited from a high degree of structural consistency in the source files provided by the administration, which facilitated longitudinal integration compared to other election types. Despite this standardization in the raw format, the analytical pipeline required a specific reconciliation step to address the fragmentation of the party system and the variance in list names across years. The workflow involved aggregating the extensive array of individual candidate lists into consistent political families or standardized party labels, a necessary operation to compute the Electoral Volatility metric robustly. To ensure the reliability of this classification, a coverage check was implemented at the polling station level, verifying that the reclassified lists accounted for the vast majority of the total expressed votes, thus minimizing the signal loss from unclassified minor parties.

Legislative Elections (2017, 2022, 2024). The workflow for the Legislative elections was designed to handle the specificities of the multi-constituency vote within the city. The processing pipeline strictly filtered the datasets to retain only the results of the first round (*premier tour*), capturing the primary voter mobilization potential before the strategic realignment typical of runoff ballots. The core technical task focused on the rigorous cleaning and standardization of the polling station identifiers (`id_bvote`), which necessitated explicit type conversion and string formatting to ensure a perfect one-to-one match with the official geospatial vector files. The primary output of this process was the computation of the voter turnout rate for each precinct, derived directly from the raw counts of voters and registered electors, providing a granular spatial indicator of civic participation.

Municipal Elections (2008, 2014, 2020). The analysis of municipal voting patterns focused on the election cycles of 2014 and 2020. The 2008 election was excluded from the final dataset due to the current unavailability of the official electoral precinct shapefiles from the municipality, which prevented the accurate spatial georeferencing of the results required for the study. For the processed years, the workflow involved a filtering of the dataset to retain exclusively the results of the first round (*premier tour*). This decision was made to capture the baseline civic engagement at the local level, unaffected by the strategic voting behaviors often observed in runoff elections. The primary metric derived was the voter turnout, calculated as the ratio of the number of voters (`NB_VOTANT`) to the number of registered electors (`NB_INSCRIT`). Data cleaning required specific attention to the polling station identifiers (`ID_BVOTE`), which were standardized to ensure a perfect match with the geospatial vector files representing the precinct boundaries specific to each election year. The final output consisted of a spatially enabled dataset linking local participation rates to the exact geographic footprint of the polling stations.

Berlin

The data processing for Berlin was structured to address the specific administrative format of the German electoral data, taking the *Stimmbezirk* (voting precinct) as the primary spatial unit. The entire workflow was implemented in Python, utilizing `pandas` for data manipulation and `geopandas` for the integration with the official vector geometries provided by the *Amt für Statistik Berlin-Brandenburg*.

The crucial step of linking the tabular electoral results with the spatial precinct polygons was achieved through a relational join. However, a ready-made common identifier was not consistently present across all raw datasets. In several instances, the unique spatial key had to be synthetically reconstructed by concatenating two distinct hierarchical columns: the District identifier (`Bezirk`) and the local Precinct identifier (`Wahlbezirk`). This operation required rigorous string formatting, specifically the padding of these components with leading zeros to generate a standardized 5-digit code that matched the attributes in the official shapefiles. The final spatial dataset was created by merging the electoral dataframe onto the precinct geometries using this key, thereby associating civic participation metrics directly with their corresponding urban footprint.

European Elections (2014, 2019, 2024). For the European elections, the processing pipeline focused on standardizing the raw data structures, which varied slightly across the three election cycles. The scripts ingested the results files and performed extensive cleaning of column names and character encodings to handle German-specific special characters. The primary data operation involved parsing the vote counts to calculate the voter turnout rate, defined as the ratio of valid voters (`Wählende`) to the number of registered citizens (`Wahlberechtigte`). The final dataset was generated by joining these calculated metrics with the precinct geometries based on the harmonized identifiers.

Legislative Elections (2017, 2021, 2025). The workflow for the Federal Legislative elections (*Bundestagswahl*) required a specific filtering step to align with the German electoral system. The code explicitly isolated the results of the *Zweitstimme* (second vote), which determines the party distribution in parliament, separating it from the candidate-specific first vote. Data processing involved cleaning the precinct codes to match the official spatial keys and computing the local turnout rates. The final step consisted of a spatial join to associate these participation metrics with the physical boundaries of the Berlin voting districts.

Municipal Elections (2016, 2021/2023). The processing of the Municipal elections (*Abgeordnetenhauswahl*) followed a similar logic to the legislative workflow but addressed the specific timeline of the Berlin state elections, including the repeat election of 2023. The scripts filtered the datasets to retain only the valid *Zweitstimme* results for the state parliament. The core analytical task was the calculation of the turnout rate for each precinct. These values were then geo-referenced by merging the electoral dataframe with the corresponding shapefiles, resulting in a spatially explicit dataset of civic participation for each election year.

Rome

The data processing for Rome was executed to integrate electoral results with the spatial fabric of the city. The fundamental unit of analysis was the *Sezione Elettorale* (electoral precinct). The core of the geospatial integration relied on a shapefile defining the boundaries of these precincts, specifically based on the 2011 census geometries which serve as the standard reference for the period analyzed.

The linking of tabular electoral data to spatial polygons was performed through a relational join. Both the electoral results files and the precinct shapefiles contained a common key, the precinct identifier (`sezione`). To ensure a successful merge, this identifier was rigorously standardized across all datasets by casting the column to a string format and padding it with leading zeros to match the character length of the spatial attributes.

To ensure data completeness and reliability across all election types, a specific *spatial imputation strategy* was implemented to handle anomalies, such as missing values or turnout rates falling outside a plausible range (set between 0.15 and 0.85). Rather than relying on simple global averages, invalid entries were iteratively replaced using a weighted mean derived from spatially contiguous neighbors (precincts sharing a geometric boundary). The total number of registered voters (`TOTALE`) served as the weighting factor, allowing the imputed values to accurately reflect the localized voting patterns of the immediate urban surroundings.

European Elections (2014, 2019, 2024). The processing of European election (*Elezioni Europee*) data involved ingesting raw administrative Excel files containing the results for the three election cycles. The workflow focused on cleaning the precinct identifiers to ensure consistency with the spatial baseline. The primary metric computed was the voter turnout, calculated as the ratio of voters (`votanti`) to registered electors (`iscritti`).

Legislative Elections (2013, 2018, 2022). For the Legislative elections (*Elezioni Legislative*), the workflow focused on the Chamber of Deputies (*Camera dei Deputati*) results. The processing pipeline prioritized the calculation of the turnout rate for each precinct. Data cleaning involved filtering the raw datasets to ensure only the relevant voting figures were retained and standardizing the precinct IDs to handle inconsistencies between different source files. The final spatial join linked these participation metrics to the precinct polygons.

Municipal Elections (2013, 2016, 2021). The processing of Municipal elections (*Elezioni Amministrative*) addressed the specific administrative timeline of Rome. The workflow computed the turnout rate for the first round of voting in each cycle. Similar to the other election types, the critical technical operation was the alignment of the tabular precinct codes with the spatial file codes. Once harmonized, the data were merged to produce a geo-referenced dataset of local civic participation.

3.3. Analytical Framework

3.3.1. Computation of Electoral Volatility

Electoral volatility is measured using the Pedersen index, defined on party vote shares across two consecutive elections (Pedersen, 1979). Let $P_{i,t}$ be the percentage vote share of party i at election t. The total net change (TNC) in the party system is:

$$\mathrm{TNC}_t = \sum_{i=1}^{n} |P_{i,t} - P_{i,t-1}| \,. \tag{3.10}$$

Volatility is one-half of this total net change:

$$EV_t = \tfrac{1}{2}\,\mathrm{TNC}_t, \qquad 0 \leq EV_t \leq 1. \tag{3.11}$$

This expression captures the overall redistribution of electoral support between parties from $t-1$ to t. The factor of one-half prevents double counting, since every vote lost by one party is simultaneously gained by another. Without the division by two, both the loss and the corresponding gain would be counted separately, thus overstating the true magnitude of change in the party system. In other words, the Pedersen index measures the percentage of the electorate that effectively changed its party preference between two elections, providing an intuitive interpretation of systemic electoral mobility.

The measure equals the cumulated gains of all winning parties (equivalently, the cumulated losses of all losing parties) between $t-1$ and t (Pedersen, 1979). Interpretation and cross-time comparability can be affected by party splits, mergers, and electoral alliances; such events are tracked and harmonized where necessary (Pedersen, 1979). A complete party-mapping and the treatment rules appear in Appendix C. Coalition agreements between parties are recognized strictly for mechanical aggregation of official vote totals; no political assumptions or reclassifications beyond documented coalitions are introduced.

As documented by the vote-share evolution plots in Appendix C for the elections considered, parties contesting only a single election typically obtain very small shares. To avoid spurious volatility from ephemeral lists, such one-off parties are excluded from the EV computation. This exclusion does not materially affect EV_t because the induced contribution to TNC_t is negligible given their minimal share shift. Further details can be found in Appendix C.

3.3.2. Aggregation Model

Accessibility is linked to electoral outcomes through two complementary aggregation schemes, selected to match the statistical unit of each outcome and to preserve comparability across election rounds. Turnout is analyzed on precinct geometries, while electoral volatility is computed on the fixed hexagonal grid used for accessibility. This choice avoids artifacts from changing precinct boundaries across rounds and keeps the proximity measure and the electoral metric on a common spatial support when required.

Turnout: precinct-level aggregation of Accessibility

Let $\mathcal{H}_b = \{\, h : A_{hb} > 0 \,\}$ denote the set of hexagons h that intersect precinct b, where A_{hb} is the intersection area between h and b. Let a_h be the walking PT in hexagon h. Accessibility for precinct b is computed as the area-weighted mean of PT over all intersecting hexagons under the assumption of homogeneous population within b:

$$a_b = \frac{\sum_{h \in \mathcal{H}_b} a_h \, A_{hb}}{\sum_{h \in \mathcal{H}_b} A_{hb}}. \tag{3.12}$$

The resulting a_b represents the walking-time accessibility for precinct b.

Electoral turnout is analyzed on precinct geometries, which represent the smallest administrative units where citizens are formally registered to vote. In each city, precinct boundaries are defined by local electoral authorities under national regulations, with the goal of ensuring balanced numbers of voters, territorial continuity, and physical accessibility to polling stations. Although boundaries may slightly change over time due to demographic or administrative adjustments, precincts remain the operational spaces where participation is organized and recorded.

Let $\mathcal{H}_b = \{\, h : A_{hb} > 0 \,\}$ denote the set of hexagons h that spatially intersect electoral precinct b, where A_{hb} is the intersection area between h and b. Let a_h be the walking Proximity Time (PT) in hexagon h. Accessibility for precinct b is then computed as the area-weighted mean of PT over all intersecting hexagons, assuming homogeneous population within each precinct:

$$a_b = \frac{\sum_{h \in \mathcal{H}_b} a_h \, A_{hb}}{\sum_{h \in \mathcal{H}_b} A_{hb}}. \tag{3.13}$$

The resulting a_b represents the walking-time accessibility for precinct b.

The decision to preserve the native precinct geometry, rather than projecting turnout data onto the hexagonal accessibility grid, follows an institutional rationale. Their purpose is to ensure a balanced distribution of voters and an efficient organization of the voting process. Turnout is an administrative behavior that takes place within the legal boundaries where voters are registered and polling stations are located. Aggregating participation on the same institutional geometry, therefore, maintains the political meaning of the indicator and avoids artifacts that would arise from spatial interpolation onto an artificial grid. While precinct boundaries may vary slightly between election rounds, this does not compromise comparability, as each configuration reflects the legitimate geography of civic participation at that time.

Electoral volatility: hex-level aggregation with areal interpolation

Electoral volatility is evaluated on the fixed accessibility grid to avoid artifacts from precinct changes between elections. Vote counts are first reallocated from precincts to hexagons by areal weights:

$$V_{i,h,t} \;=\; \sum_{b\in\mathcal{B}} V_{i,b,t}\, w_{hb}, \qquad w_{hb} \;=\; \frac{A_{hb}}{\sum_{h'\in\mathcal{H}_b} A_{h'b}}, \tag{3.14}$$

where:

- $i \in \{1,\ldots,n\}$ indexes parties,
- $b \in \mathcal{B}$ indexes electoral precincts,
- $h \in \mathcal{H}$ indexes hexagons in the PT grid,
- $\mathcal{H}_b = \{\, h : A_{hb} > 0 \,\}$ is the set of hexagons intersecting precinct b,
- $V_{i,b,t}$ are votes for party i in precinct b at election t,
- A_{hb} is the intersection area between hexagon h and precinct b,
- w_{hb} are precinct-specific areal weights that satisfy $\sum_{h\in\mathcal{H}_b} w_{hb} = 1$.

Hexagon-level party shares and Pedersen volatility are then computed on the same grid as accessibility:

$$P_{i,h,t} \;=\; \frac{V_{i,h,t}}{\sum_{j=1}^{n} V_{j,h,t}}, \qquad V_h \;=\; \tfrac{1}{2}\sum_{i=1}^{n}\bigl|P_{i,h,t} - P_{i,h,t-1}\bigr|\,, \tag{3.15}$$

with $P_{i,h,t}$ the vote share of party i in hexagon h at election t. The volatility expression is the standard Pedersen index between $t-1$ and t (Pedersen, 1979). Accessibility for volatility analyses is taken as a_h (PT, minutes) at the same hex level, so both the dependent variable V_h and the explanatory metric a_h share identical spatial support.

The choice to aggregate electoral volatility on the hexagonal grid, rather than on precinct geometries, follows both practical and analytical considerations. Precinct boundaries often change between election rounds due to administrative revisions or demographic adjustments, which makes direct inter-round comparisons unreliable. A fixed hexagonal grid offers a stable spatial framework that allows volatility to be computed consistently over time and directly aligned with accessibility measures.

Alternative strategies were considered, such as constructing synthetic precincts derived from the intersection of precinct maps across different elections. However, this approach was deemed too artificial, as it would produce irregular geometries and potentially distort the spatial distribution of votes. By contrast, redistributing vote counts onto a uniform grid ensures spatial continuity, avoids topological inconsistencies, and allows civic dynamics to be compared across rounds using a consistent and interpretable reference system.

3.3.3. Correlation and Model Choice

Pearson's correlation between two variables x and y over N observations is defined as

$$r(x,y) = \frac{\sum_{k=1}^{N}(x_k-\bar{x})(y_k-\bar{y})}{\sqrt{\sum_{k=1}^{N}(x_k-\bar{x})^2}\,\sqrt{\sum_{k=1}^{N}(y_k-\bar{y})^2}}\,. \tag{3.16}$$

For this study, denote by a an accessibility category (service type) and by $p \in \{\text{turnout}, \text{volatility}\}$ an electoral outcome. Across geographical units $u = 1,\ldots,U$, define

$$r_{a,p} = \frac{\sum_{u=1}^{U}\bigl(x_{u,a}-\bar{x}_a\bigr)\bigl(y_{u,p}-\bar{y}_p\bigr)}{\sqrt{\sum_{u=1}^{U}\bigl(x_{u,a}-\bar{x}_a\bigr)^2}\,\sqrt{\sum_{u=1}^{U}\bigl(y_{u,p}-\bar{y}_p\bigr)^2}}\,, \tag{3.17}$$

where $x_{u,a}$ is Proximity Time (minutes) for unit u in category a, $y_{u,p}$ is the electoral metric for unit u and outcome p, and bars denote unit means. Negative $r_{a,\text{turnout}}$ indicates civic disengagement as accessibility worsens; positive $r_{a,\text{volatility}}$ indicates spatially concentrated discontent.

Simple Pearson correlations are retained as the primary diagnostic for shifts in electoral behavior (Pedersen, 1979), supported by evidence on access costs and participation (de Kadt, 2017) and by spatial analyses highlighting informative pairwise structure (Bourdin & Tai, 2022). A multivariable regression was tested and discarded due to multicollinearity danger among accessibility indicators. Unsupervised PCA would mitigate collinearity but would mix state-provided and privately provided services into latent factors, undermining the hypothesis verification that requires the separation of these domains.

3.4. Interpretation Guide for Results

This section provides the interpretation schemes used throughout the empirical analysis. The tables summarize how to interpret the sign and magnitude of correlations between accessibility variables and electoral outcomes, distinguishing between state-provided and private-provided services. These schemes serve as a reference to understand the city-specific results presented below.

3.4.1. Correlation interpretation guide

To make sign evaluation explicit, Table 3.3 clarifies which sign of $r_{a,p}$ confirms the institutional-presence hypothesis and which sign contradicts it.

Outcome p	**Supports hypothesis**	**Contradicts hypothesis**	**Rationale**
Turnout	$r_{a,\text{turnout}} < 0$	$r_{a,\text{turnout}} > 0$	(H1) Longer PT (worse access) should increase political disengagement and reduce participation.
Volatility	$r_{a,\text{volatility}} > 0$	$r_{a,\text{volatility}} < 0$	(H2) Longer PT (worse access) should raise dissatisfaction and change electoral preferences.

Table 3.3: Sign conventions for $r_{a,p}$ under the institutional-presence hypothesis.

3.4.2. Interpretation Tables for Turnout

Table 3.5 provides a reading guide for the correlations $r_{a,\text{turnout}}$ between walking Proximity Time (PT, minutes) and turnout across geographical units. “High $|r|$” denotes a strong linear association in magnitude. The expected sign is negative: longer PT (worse access) aligns with lower participation under the institutional-presence interpretation. All variables are walking-only (`_f`); lower PT means higher accessibility. Entries provide qualitative interpretations, not causal claims.

3.4.3. Interpretation Tables for EV

Table 3.7 guides the interpretation of $r_{a,\text{volatility}}$ between walking PT and electoral volatility (Pedersen index). “High $|r|$” denotes a strong linear association in magnitude. The expected sign is positive: longer PT (worse access) aligns with greater electoral instability and protest-driven switching. Variables are walking-only (`_f`); lower PT means higher accessibility. Interpretations are associative and should be read alongside robustness checks.

Variable	Meaning	Turnout (high $|r|$)
`b_f`	Accessibility to cultural services (museums, cultural centers)	Poor cultural access corresponds to lower turnout, as citizens feel detached from institutions.
`c_f`	Accessibility to educational services (schools, universities)	Long distances to education reduce turnout, weakening civic inclusion.
`d_f`	Accessibility to healthcare facilities (hospitals, clinics)	Poor healthcare access is linked with lower turnout due to distrust in institutions.
`e_f`	Accessibility to outdoor spaces (parks, recreational areas)	Districts far from parks show weaker turnout, as green spaces foster community cohesion.
`f_f`	Accessibility to physical exercise facilities (gyms, sports centers)	Long distances to gyms or sports centers reduce participation, especially in areas with fewer leisure options.
`g_f`	Accessibility to eating services (restaurants, cafes)	Where restaurants are distant, turnout decreases; closer amenities correlate with higher participation.
`h_f`	Accessibility to general services (urban amenities)	Long distances to essential services correspond to low turnout, as citizens feel institutionally abandoned.
`i_f`	Accessibility to supply services (shops, retail)	Poor access to shops coincides with lower turnout, while better-served areas vote more.
`l_f`	Accessibility to public transport	Poor transport access reduces turnout, especially in peripheral areas cut off from political life.

Table 3.5: Interpretation of high absolute correlations between accessibility variables and turnout (expected negative sign).

Variable	Meaning	Electoral Volatility (high $\lvert r \rvert$)
b_f	Accessibility to cultural services (museums, cultural centers)	Poor cultural access corresponds to higher volatility, reflecting protest and discontent.
c_f	Accessibility to educational services (schools, universities)	Limited access to education increases volatility, as citizens perceive institutional neglect.
d_f	Accessibility to healthcare facilities (hospitals, clinics)	Distant healthcare facilities are associated with higher volatility, expressing anger and protest voting.
e_f	Accessibility to outdoor spaces (parks, recreational areas)	Poor access to outdoor spaces is linked with higher volatility, reinforcing urban dissatisfaction.
f_f	Accessibility to physical exercise facilities (gyms, sports centers)	Poor access to sport facilities increases volatility, as residents feel excluded from urban opportunities.
g_f	Accessibility to eating services (restaurants, cafes)	Poor access to restaurants is linked with higher volatility, reflecting dissatisfaction in less central zones.
h_f	Accessibility to general services (urban amenities)	Poor access to services leads to higher volatility, confirming strong discontent.
i_f	Accessibility to supply services (shops, retail)	Distant shops are associated with higher volatility, showing protest voting in peripheral zones.
l_f	Accessibility to public transport	Long travel times to transport nodes increase volatility, as citizens express frustration with exclusion.

Table 3.7: Interpretation of high absolute correlations between accessibility variables and electoral volatility (expected positive sign).

4 Results

This chapter presents the main empirical results of the study and links the analytical framework developed in Chapter 3 to the three city cases. The focus is on how accessibility, income, voter turnout, and EV co-vary within Paris, Berlin, and Rome once data are aggregated on the relevant spatial supports (hexagonal grid for accessibility and EV, precincts for turnout). Throughout the chapter, the results are interpreted in light of the institutional-presence hypothesis, while remaining explicitly descriptive and non-causal.

The chapter is organised as follows. The section *Income: Rental Cost* documents the construction and spatial distribution of the income proxies used to control for socio-economic composition in each city, clarifying their origin, limitations, and the way they enter the subsequent analysis. The section *Accessibility (a_f) by City* provides a comparative overview of the general accessibility index, describing how average walking PT to services is distributed across the hexagonal grid in Paris, Berlin, and Rome and how these patterns reflect different urban morphologies. More detailed accessibility maps and category-specific results are provided in Appendix D, *Accessibility in Paris, Berlin, and Rome*. The section *Turnout Analysis* then examines the relationship between PT and voter turnout, using time series of correlations by service domain and election type and discussing how these patterns differ across the three cities. Finally, the section *Electoral Volatility Analysis* analyses EV on the hexagonal grid, combining maps of EV for 2014–2019 and 2019–2024 with correlation matrices that report both unweighted coefficients and coefficients weighted by the number of registered voters in each hexagon. Taken together, these components provide a city-by-city picture of how accessibility and institutional presence relate to democratic engagement in the three metropolitan contexts across the EU.

4.1. European Benchmark: Abstention and Foot Accessibility

Before turning to the within-city analyses, it is useful to situate the three case studies in a broader European context. Figure 4.1 reports the relationship between a city-level foot accessibility index (horizontal axis) and the abstention rate in the 2024 European elections (vertical axis) for a set of European capitals. Each point corresponds to a city, the dashed line shows the linear fit, the shaded band represents its confidence interval, and the red label in the top-left corner indicates the Pearson correlation coefficient ($r = 0.39$).

The positive slope of the regression line and the moderate correlation ($r = 0.39$) suggest that, at this aggregate city scale, higher levels of foot accessibility are associated with higher abstention rates rather than with increased participation. The positions of Paris, Berlin, and Rome in Figure 4.1 already anticipate the heterogeneity analyzed in the remainder of this chapter. Berlin combines relatively low foot accessibility with one of the lowest abstention rates in the sample, while Paris appears in the low-to-medium accessibility range with moderate abstention. Rome, by contrast, occupies the upper-right quadrant, with comparatively high accessibility and high abstention. Taken together, these patterns underscore two key points that guide the subsequent analysis: (i) city-level averages are insufficient to capture the micro-territorial inequalities that matter for democratic engagement, and (ii) the sign and

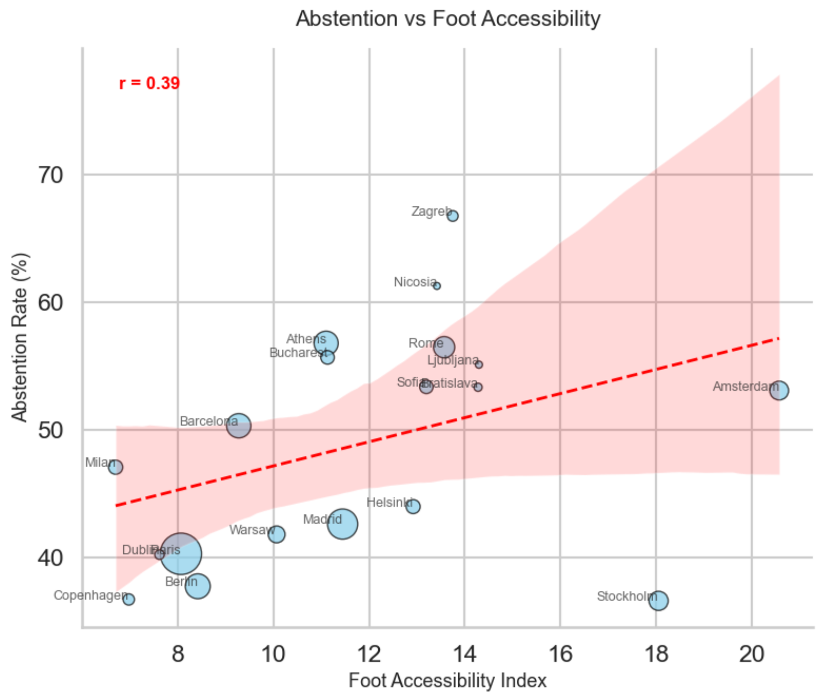


Figure 4.1: City-level relationship between abstention rate in the 2024 European elections and a synthetic foot accessibility index for a selection of European capitals. The dashed line shows the linear fit, with $r = 0.39$, and the shaded band its confidence interval.

strength of the accessibility–abstention relationship are likely to be context-dependent.

For these reasons, the rest of the chapter moves from this coarse, cross-city benchmark to a fine-grained, within-city perspective, examining how accessibility, income, turnout, and EV co-vary across neighborhoods in Paris, Berlin, and Rome once data are disaggregated on the hexagonal grid and at the precinct level.

4.2. Income : Rental Cost

This section documents the spatial distribution of income proxies and explains how they are integrated into the empirical analysis as controls for socio-economic composition. The proxy differs by city due to data availability: Paris uses regulated rent per square metre in 2024; Berlin uses the weighted mean Airbnb price for 2-person private rooms based on the 10 nearest listings; and Rome uses the weighted mean rent per square metre derived from the 10 nearest long-term rental advertisements. Values are aggregated at the hexagon level using distance weights to smooth sparse areas and ensure spatial continuity.

Although all three datasets share the same nominal unit of measurement (€/m²), they are inherently heterogeneous in origin and meaning. In Paris, the data come from a state-provided rent reference system that defines official ceilings by zone. While this provides a coherent and spatially exhaustive source, it may diverge from real market dynamics, particularly in high-demand central districts. Rome's dataset, on the other hand, is based on scraped listings from public rental platforms that include both agency and private offers. This source captures actual market conditions more accurately, reflecting real price variability across neighbourhoods. Berlin's data, by contrast, are drawn from Airbnb listings, which primarily represent short-term tourist rentals rather than the long-term residential market. As a result, they tend to overemphasize areas of high visitor demand and underrepresent local housing costs, making them an imperfect proxy for residents' income but still indicative of spatial desirability and centrality.

Despite these differences in data sources and market representativeness, all three proxies serve a common analytical purpose: to provide an understanding about local variations in socio-economic status and to examine whether accessibility with income as proxied by rental costs within each city. Given this shared conceptual role and the fact that each dataset is internally consistent and spatially comparable within its urban system, it is therefore appropriate to proceed with a city-by-city description of rental cost distributions, interpreting each map relative to its specific data source and urban context.

4.2.1. Paris

Figure 4.2 shows a clear west–east gradient. Higher rents concentrate in the western and south-western arrondissements and in the inner core, while lower values cluster in the north-east. The pattern aligns with well-known residential stratification (Korsu & Wenglenski, 2010) and provides a stable baseline for interpreting accessibility–outcome relations.

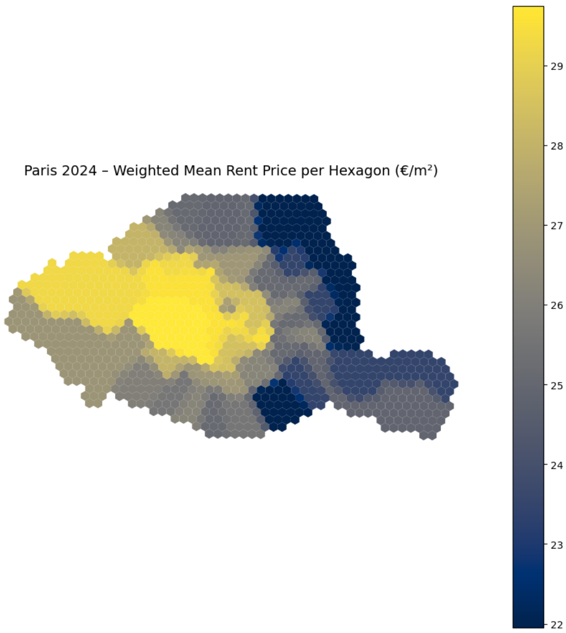


Figure 4.2: Weighted mean rent price per hexagon in Paris (reference year 2024), computed from arrondissement level reference rents. Higher values concentrate in the western and south western arrondissements and in the inner core, while lower rents cluster in the north eastern sectors. This west to east gradient reflects well known residential stratification and provides a stable baseline for separating accessibility effects from socio economic composition in the empirical analysis.

The gradient implies that accessibility disadvantages and lower rents co-locate in the northeast more often than in the west. In the correlation tables, the income proxy is included to separate accessibility effects from socio-economic composition.

4.2.2. Berlin

Figure 4.3 indicates multiple high-price clusters in the inner city and around secondary hubs, with lower values in the outer belt. The Airbnb proxy captures short-term accommodation prices and is sensitive to tourism corridors and transit access.

Because the Berlin proxy reflects both residential desirability and visitor demand, it may overstate central premiums relative to long-term rents. The control still improves comparability across hexagons within Berlin, but coefficients should be interpreted as conditional on a market signal that mixes residential and visitor economies.

The uniform color bands visible in the south-western part of the map are algorithmic artefacts resulting from the interpolation method used to assign a rental value to each hexagon. Each hexagon's value is computed as the weighted average of the ten nearest Airbnb listings. In areas where listings are sparse—particularly in peripheral or low-tourism zones—the same limited set of nearby points is used repeatedly across adjacent hexagons, producing uniform color strips. These artefacts thus reflect data scarcity rather than real price homogeneity and should not be interpreted as meaningful spatial patterns

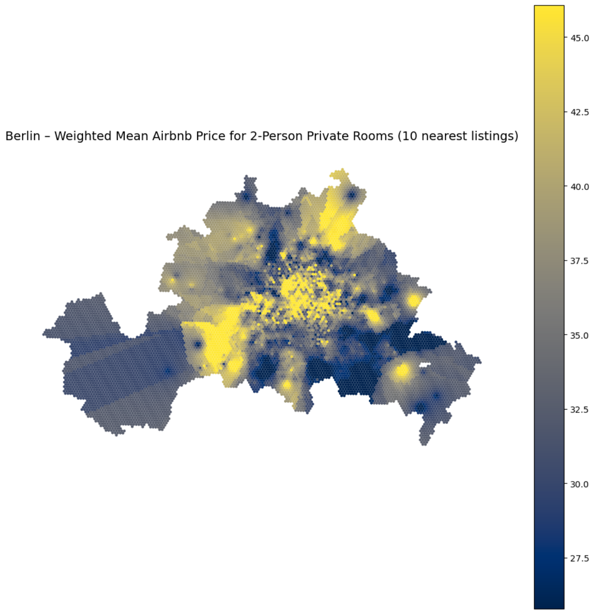


Figure 4.3: Weighted mean Airbnb price for 2-person private rooms based on the 10 nearest listings. The map highlights multiple high-price clusters in central and semi-central areas, with lower values toward the outer belt. Because the proxy is derived from short-term tourist accommodation, it captures both residential desirability and visitor demand. Uniform colour bands in the southwestern sector are artifacts generated by sparse listing density, where the same small set of points is used repeatedly in distance-weighted averaging. These artifacts reflect data scarcity rather than real price uniformity.

in rental costs.

4.2.3. Rome

Figure 4.4 shows a clear core–periphery contrast. Higher rents concentrate in the historic core and selected eastern corridors, while lower values extend across the peripheral quadrants. The pattern is less radial than in Paris, with several medium-value pockets distributed along major transport axes.

The pronounced rent gap between the central districts and the periphery implies that accessibility disadvantages and lower rents often coincide in outer belts. Including the rent proxy in the models helps reduce the risk of confounding when estimating the relationship between accessibility and turnout or EV.

The faint linear patterns visible in the northwestern periphery are artefacts generated by the spatial interpolation algorithm used to assign a value to each hexagon. Each cell's rent is calculated as the weighted mean of the ten nearest listings, but in areas with few available rental points—typical of low-density or peripheral zones—the same limited set of listings is used repeatedly across adjacent cells. This results in uniform color bands that do not represent actual market regularities but rather reflect the scarcity of underlying observations in those parts of the city.

4.3. Accessibility to Services by City

This section provides a comparative overview of the general accessibility index (`a_f`) across Paris, Berlin, and Rome. The variable aggregates all service categories described in Chapter 3 into a single proximity measure, representing the average walking time (*Proximity Time, PT*) to reach essential amenities from each hexagonal cell. Lower values (blue) indicate areas where daily urban functions are easily reachable, while higher values (red) correspond to locations with limited access and longer travel times. For detailed accessibility maps by service category and methodological reference to the SonyCSL dataset, see Appendix D.

Paris (Fig. 4.5) displays a markedly monocentric pattern. Accessibility is highest in the central arrondissements and gradually declines toward the periphery, with sharp contrasts across the Boulevard

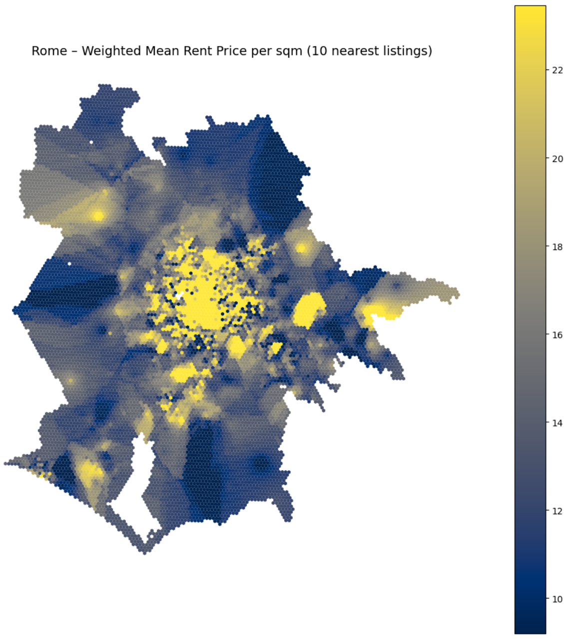


Figure 4.4: Weighted mean rent price per square metre for Rome, computed from the 10 nearest rental listings. The map shows a strong core-periphery contrast, with high rents in the historic centre and selected eastern corridors and lower values in the outer districts. Linear strips in the north-west are artefacts created by limited data availability in peripheral areas, where repeated use of the same rental points produces uniform colour bands. These patterns should not be interpreted as real market structures.

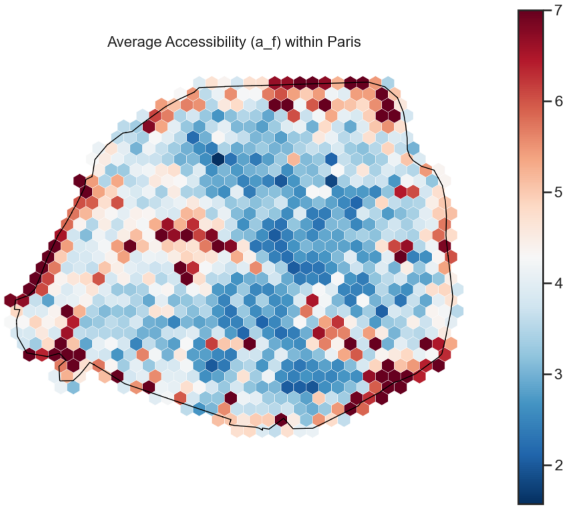


Figure 4.5: Average accessibility (a_f) expressed as walking PT from each hexagon to essential services. Paris shows a clear monocentric structure, with short PT values concentrated in the central arrondissements and longer PT values in the peripheral sectors. Although the municipal boundaries of Paris are relatively small and coincide with the Boulevard Peripherique, a clear internal division between the core and the peripheral edge remains visible. This pattern reflects the compact urban morphology of the city and the concentration of amenities in the historical core.

Périphérique. The hexagonal structure reveals strong clustering of high-accessibility cells within the historical core, consistent with the dense spatial concentration of amenities and the compact morphology of the city. Peripheral areas, particularly in the north and southeast, exhibit longer PT values, confirming the persistence of accessibility inequalities despite the city's compact scale.

In Berlin (Fig. 4.6), the accessibility surface exhibits a polycentric structure with several contiguous clusters of high accessibility. The core area within the S-Bahn ring is broadly uniform, showing low PT values and dense service coverage. Secondary concentrations appear toward the east and south-east,

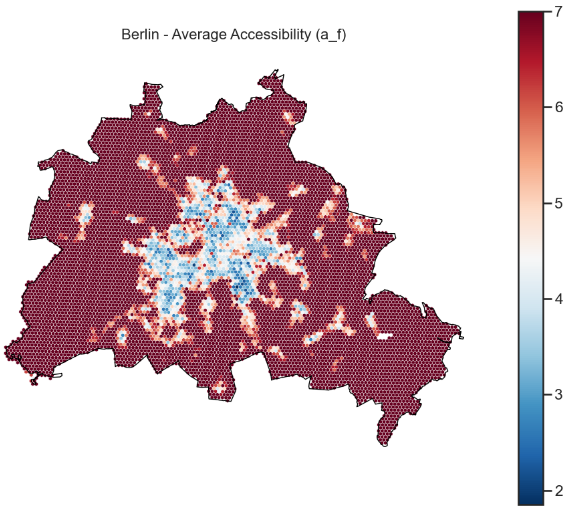


Figure 4.6: Average accessibility (a_f) measured as walking PT. Berlin displays a polycentric structure where several clusters inside and outside the inner ring show short PT values. Peripheral areas have longer PT but remain connected through a distributed service network that reflects Berlin's decentralised spatial organisation.

suggesting a well-distributed urban fabric where essential services extend beyond the traditional core. Peripheral zones remain less accessible but still relatively integrated through the transport network, reflecting Berlin's post-reunification decentralization strategy and balanced urban topology.

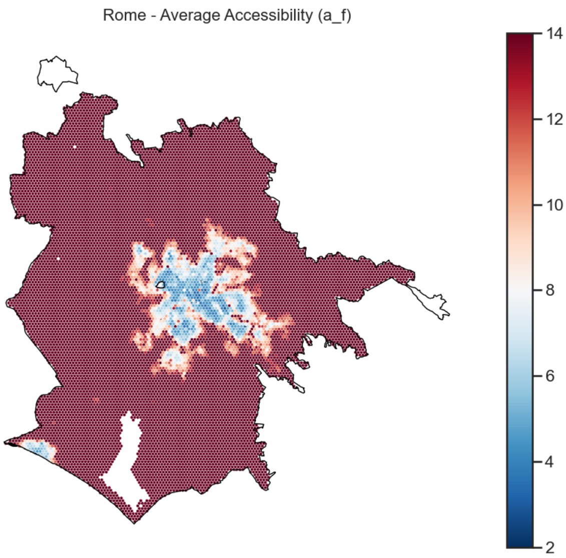


Figure 4.7: Average accessibility (a_f) measured as walking PT. Rome displays a fragmented accessibility landscape, with very short PT values in the historical centre and much longer PT in peripheral districts. Discontinuous urban development and the city's scale produce isolated high-accessibility pockets along major corridors such as EUR and Tiburtina.

Rome (Fig. 4.7) presents a fragmented and uneven accessibility surface. The concentration of low PT values around the historical center stands in sharp contrast with the extensive low-accessibility zones that dominate the city's periphery. Topographical constraints and discontinuous urban development create isolated clusters of accessibility, especially along the main transport corridors and near secondary hubs such as EUR and Tiburtina. The city's vast territorial scale magnifies these contrasts, emphasizing the structural dependence of peripheral districts on car mobility for everyday functions.

Accessibility and Income: Cross-City Comparison

Across all three cities, accessibility gradients align with urban morphology and governance models, but the OLS results in Table 4.1 show that these patterns cannot be reduced to income differences alone. Paris, with its compact and monocentric structure, exhibits only a weak and domain-specific association between rent and accessibility. The average index (`avg_f`) is essentially unrelated to rent (very small coefficient, non-significant p-value, and $R^2 \approx 0$), and most state-provided domains (education, healthcare, outdoor spaces, services, supplies, transport) display negligible explanatory power. Only culture and physical activity stand out: cultural services become more accessible in higher-rent areas (negative slope, $R^2 \simeq 0.05$), while physical activity facilities are more accessible in relatively cheaper zones (positive slope, $R^2 \simeq 0.09$). Even in these cases, however, rent explains only a small fraction of the spatial variation in PT, consistent with a dense city where service provision is relatively widespread and not strictly stratified by income.

Table 4.1: OLS between income proxy (rent) and accessibility categories

City	Accessibility	Coef. mean_rent	Intercept	R^2	p-value
Paris	avg_f	-0.0344	6.1654	0.0008	0.3468
Paris	culture_f	-0.2850	13.5925	0.0477	0.0000
Paris	education_f	0.0454	6.2277	0.0006	0.4204
Paris	healthcare_f	-0.0425	8.2375	0.0005	0.4567
Paris	outdoor_f	-0.0362	4.5426	0.0020	0.1344
Paris	physical_f	0.3010	-1.7029	0.0858	0.0000
Paris	eating_f	-0.1542	8.6070	0.0088	0.0018
Paris	services_f	-0.0044	3.8877	0.0000	0.9126
Paris	supplies_f	-0.0803	6.9689	0.0019	0.1492
Paris	transport_f	-0.0538	5.1320	0.0032	0.0611
Berlin	avg_f	-0.2172	24.7176	0.0082	0.0000
Berlin	culture_f	-0.1154	23.7184	0.0021	0.0000
Berlin	education_f	-0.3982	37.2816	0.0139	0.0000
Berlin	healthcare_f	-0.4273	41.5616	0.0105	0.0000
Berlin	outdoor_f	-0.2021	16.8945	0.0138	0.0000
Berlin	physical_f	-0.1779	22.0761	0.0059	0.0000
Berlin	eating_f	-0.2024	24.9393	0.0066	0.0000
Berlin	services_f	-0.1197	17.8978	0.0025	0.0000
Berlin	supplies_f	-0.1979	23.8292	0.0046	0.0000
Berlin	transport_f	-0.1135	14.2588	0.0037	0.0000
Rome	avg_f	-0.2377	52.7143	0.0136	0.0000
Rome	culture_f	-0.3071	68.1906	0.0157	0.0000
Rome	education_f	-0.3048	68.3731	0.0126	0.0000
Rome	healthcare_f	-0.3670	80.3419	0.0154	0.0000
Rome	outdoor_f	-0.1956	40.0052	0.0089	0.0000
Rome	physical_f	-0.1311	31.2158	0.0061	0.0000
Rome	eating_f	-0.2340	51.5183	0.0114	0.0000
Rome	services_f	-0.2683	60.6397	0.0108	0.0000
Rome	supplies_f	-0.1889	44.6069	0.0091	0.0000
Rome	transport_f	-0.1421	29.5371	0.0064	0.0000

In Berlin and Rome, the association between rent and accessibility is more systematic but remains modest in strength. In both cities, slopes are consistently negative across all domains, indicating that higher-rent hexagons tend to enjoy shorter Proximity Times and therefore better access to services. This pattern matches the core–periphery structures seen in the maps: central or semi-central neighbourhoods combine higher rents with denser service networks, while peripheral belts are both cheaper and less accessible. Yet, even where coefficients are highly significant, the R^2 values remain low (typically around 0.01–0.02), implying that rent accounts for only 1–2% of the observed variance in each accessibility indicator. Income proxies thus track the broad direction of accessibility inequalities—especially in Rome's strongly polarised urban fabric—but they do not organise the accessibility landscape in a deterministic way.

Taken together, the cartographic evidence and the regressions in Table 4.1 indicate that accessibility captures more than a simple economic gradient. Paris shows that a compact monocentric city can sustain relatively high accessibility across income levels, with only selected domains clearly stratified, but this interpretation could be biased by the tight municipal boundaries. Berlin's polycentric layout and Rome's fragmented, corridor-based morphology reinforce the tendency for better-off areas to be better served, but the low explanatory power of rent suggests that planning legacies, transport infrastructure, zoning, and historical development trajectories are at least as important in shaping who lives close to what. For the purposes of this thesis, this implies that the rental-cost proxies are necessary controls for socio-economic composition, yet income alone does not explain differences in service accessibility. The `a_f` index and its components retain independent substantive meaning as indicators of the spatial organisation of services and, by extension, of institutional presence across the three metropolitan systems.

4.4. Turnout Analysis

4.4.1. Paris

In order to explore the relationship between accessibility and electoral turnout in Paris, Figure 4.8 reports the evolution of correlation coefficients between 2014 and 2024. The figure distinguishes between state-provided services (such as education, healthcare, culture, outdoor spaces, and public transport) and private-provided services (including eating facilities, supply shops, and leisure-related amenities). Markers indicate the type of election (municipal, European, and legislative), while lines track the temporal evolution of each accessibility variable.

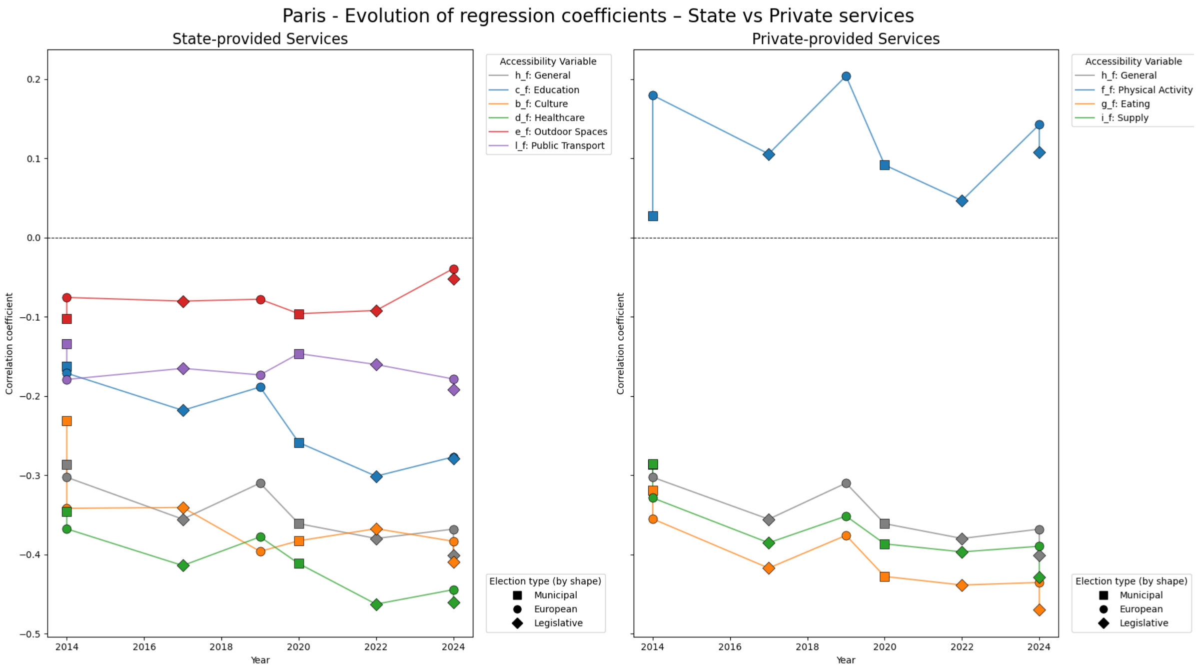


Figure 4.8: Evolution of correlations between PT and voter turnout in Paris between 2014 and 2024. The figure compares state-provided and private-provided services across municipal, European, and legislative elections. State domains show consistent negative coefficients, especially education and healthcare, indicating reduced participation in areas with higher PT.

The results show a systematic and moderate negative association between turnout and poor accessibility to state-provided services. In particular, education and healthcare exhibit the strongest coefficients: areas further from schools or hospitals tend to record lower participation rates across all elections. Public transport accessibility also plays a notable role, confirming the central importance of mobility and institutional presence for civic engagement.

Among private-provided services, most relationships are weak or inconsistent, with one main exception: physical activity facilities display a clear positive and time-variable correlation. This reflects their peripheral distribution and the concentration of low-turnout areas outside the compact urban core. Hence, while private amenities generally play a secondary role, the accessibility of leisure and physical activity services appears to interact more strongly with civic participation than other private domains.

Overall, the Paris case supports the working hypothesis despite the tight municipal boundaries of the study area : the longer the travel timesto essential public services, the lower the electoral participation.

4.4.2. Berlin

In order to explore the relationship between accessibility and electoral turnout in Berlin, Figure 4.9 reports the evolution of correlation coefficients between 2014 and 2024. The figure distinguishes between state-provided services (such as education, healthcare, culture, outdoor spaces, and public transport) and private-provided services (including eating facilities, supply shops, and leisure-related amenities). Markers indicate the type of election (municipal, European, and legislative), while lines track the temporal evolution of each accessibility variable.

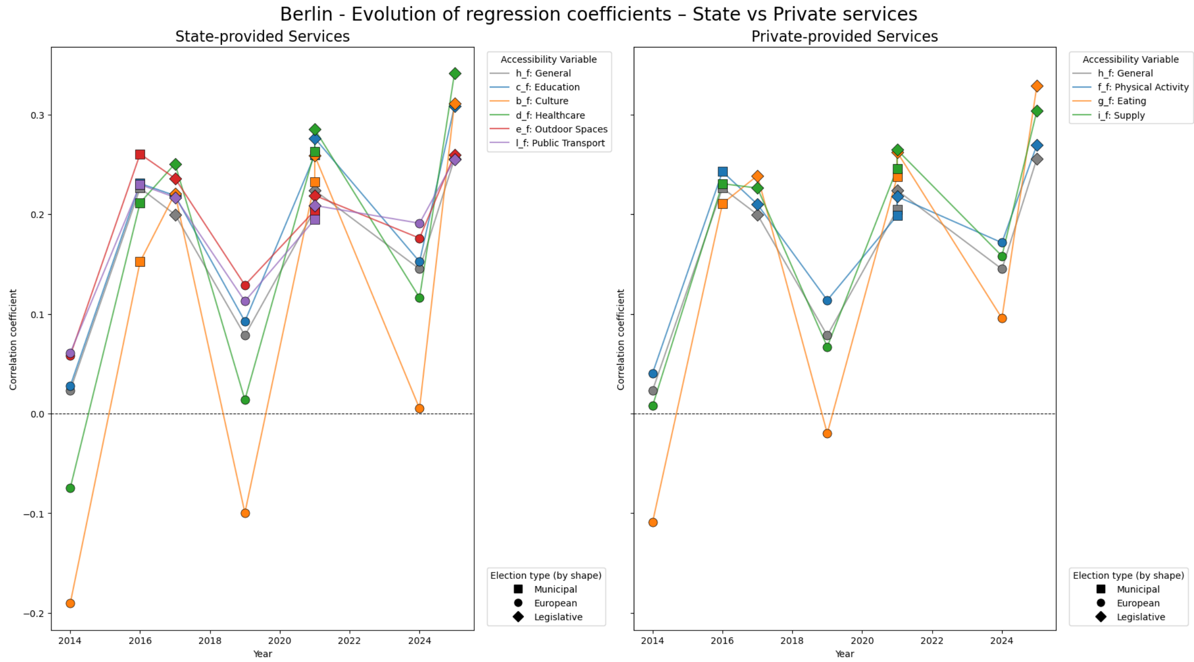


Figure 4.9: Evolution of correlations between PT and turnout in Berlin between 2014 and 2024. Most coefficients are positive, indicating slightly higher participation in areas farther from services. This pattern reflects Berlin's polycentric structure and the stronger residential stability of less accessible neighbourhoods.

The results for Berlin stand out for their unexpected direction. Contrary to the working hypothesis—which anticipates a negative sign between turnout and longer travel times— the coefficients for both state- and private-provided services are predominantly *positive*. This means that areas located further from amenities tend to display slightly higher turnout levels, a finding that diverges from the pattern observed in Paris and Rome.

Among state-provided services, education, healthcare, and culture show consistently positive and moderate coefficients. Public transport and outdoor spaces follow a similar trajectory, with all domains converging toward positive values in the most recent elections. The general accessibility indicator (`h_f`) also aligns with this trend, reinforcing the idea that the relationship between access and participation in Berlin operates under a different territorial logic. Rather than penalising distant zones, distance here may coincide with greater residential stability, stronger local identity, or socio-economic profiles more prone to civic participation.

Several contextual factors may help explain this inversion. Berlin's polycentric urban form distributes services across multiple hubs, which may reduce the perception of disadvantage even in areas with higher PT values. Peripheral or less accessible neighbourhoods often host long-term residents and established communities, while inner districts, despite higher accessibility, experience greater demographic mobility and lower electoral participation. In this sense, the positive coefficients could reflect the stabilising role of residential permanence rather than direct spatial accessibility effects.

Private-provided services also show small but consistently positive coefficients, suggesting that the relationship between turnout and everyday amenities is not driven by proximity alone. The urban layout and socio-demographic mix of Berlin appear to mitigate accessibility inequalities, transforming them into dimensions of territorial differentiation rather than exclusion.

Overall, the Berlin case offers an intriguing exception to the expected pattern. While accessibility remains an important structural dimension, its political meaning reverses: longer travel times do not necessarily imply disengagement but may correspond to more cohesive, established neighbourhoods with strong local attachment. This distinctive outcome highlights how spatial accessibility interacts with broader social dynamics and cautions against universalising the sign and strength of the accessibility–turnout relationship across cities.

4.4.3. Rome

In order to explore the relationship between accessibility and electoral turnout in Rome, Figure 4.10 shows the evolution of correlation coefficients between 2014 and 2024. The figure distinguishes between state-provided services (such as education, healthcare, culture, outdoor spaces, and public transport) and private-provided services (including eating facilities, supply shops, and leisure-related amenities). Markers indicate the type of election (municipal, European, and legislative), while lines track the temporal evolution of each accessibility variable.

Figure 4.10: Evolution of correlations between PT and turnout in Rome between 2014 and 2024. The coefficients are consistently negative and stronger in magnitude than in Paris, with both state-provided and private-provided domains showing reduced turnout at higher PT levels.

The results for Rome show a clear negative association between turnout and poor accessibility to both state-provided and private-provided services. Compared to Paris, the magnitude of the coefficients is generally larger in absolute value, indicating a stronger link between distance to services and electoral participation. Education, healthcare, and culture are particularly salient, with turnout decreasing more sharply in areas located further away from these state-provided services. Public transport also plays a notable role, but the coefficients suggest a more gradual effect over time.

For private-provided services, the association with turnout is more evident in Rome than in Paris. Distance to eating facilities, retail shops, and general amenities correlates consistently with lower participation rates, suggesting that the availability of everyday services has a stronger impact on civic engagement in Rome's urban context.

Overall, the Rome case provides a promising evidence in support of the working hypothesis of causal plausibility: longer travel times to both public and private services are increasingly linked with lower electoral participation. This pattern reinforces overt time the interpretation of accessibility as a factor of institutional presence and as a determinant of the health of democratic participation in metropolitan areas.

4.5. Electoral Volatility Analysis

This section examines how EV varies within each city and how it relates to accessibility measured as walking PT. The reading proceeds in two steps. First, the maps describe where EV concentrates in each couple of consequent European elections elections (2014–2019 and 2019–2024), highlighting shifts in the spatial structure of competition. Second, correlation matrices quantify the association between EV and each accessibility domain. A positive coefficient indicates that longer PT is associated with higher EV, which is the sign expected under the institutional-presence hypothesis in Table 3.3. Weighted results give more influence to hexagons with more registered voters. All results are descriptive and do not imply causality.

4.5.1. Paris

Figure 4.11 shows a clear reconfiguration of EV between the two periods. In 2014–2019 higher EV is more frequent in the western and south-western sectors, while the central arrondissements are comparatively stable. In 2019–2024 the pattern rotates toward the north-east and the eastern rim, with several contiguous clusters of higher EV and a more homogeneous core. This shift signals that the geography of electoral change in Paris is episodic and localized rather than a monotone citywide drift.

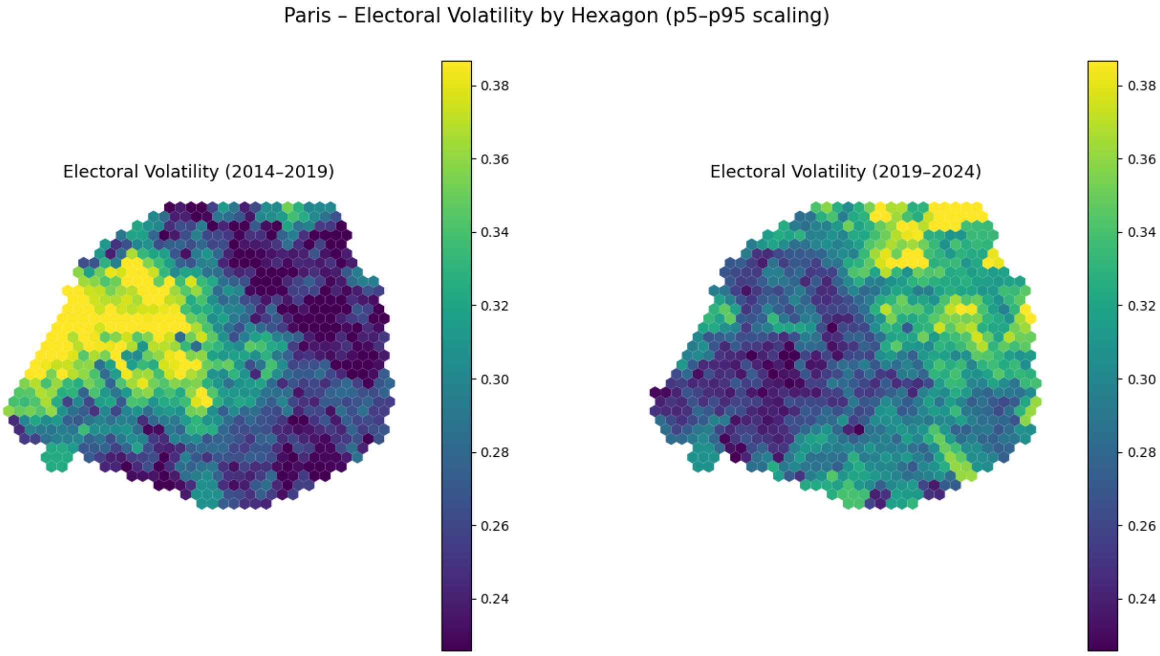


Figure 4.11: EV for Paris by hexagon, scaled between the 5th and 95th percentiles. EV shifts from being higher in the west and south-west in 2014-2019 to higher in the north-east and eastern rim in 2019-2024. This rotating geography indicates that electoral change in Paris occurs in localised cycles rather than following a persistent gradient.

Figure 4.12 mirrors the spatial reshuffling with heterogeneous coefficients across periods. In 2014–2019, once weighting is applied, EV aligns positively with several domains, with a pronounced association for `f_f` (physical activity) and smaller positives for education and general access. In 2019–2024 the structure changes: healthcare and eating retain small positive coefficients, public transport turns weakly positive, while `f_f` becomes negative and culture hovers around zero. Overall, Paris provides limited and period-specific support to the hypothesis. The direction of effects is not stable across domains, which is consistent with the rotating hotspots observed on the maps.

Figure 4.13 indicates a transition from a diffuse EV pattern in 2014–2019 to a sharper east and south-east concentration in 2019–2024. Central and south-western sectors display comparatively lower EV in the second period, suggesting a strengthening of the east–west contrast in electoral change. Over time, this territorial divide appears to become more pronounced: the high-EV belts in 2019–2024 closely follow the classic separation between East and West Berlin inherited from the period of the Wall, with higher volatility concentrated in the structurally weaker eastern districts (Burda & Hunt, 2001).

Figure 4.14 shows small to moderate positive associations that become stronger when weighting by registered voters. Culture, healthcare, eating, and the composite `a_f` increase from roughly 0.12–0.14 in 2014–2019 to about 0.14–0.22 in 2019–2024. Public transport remains positive and small, while outdoor spaces weaken slightly. Taken together, Berlin offers consistent support to the hypothesis and the increase in magnitude matches the clearer spatial concentration of EV in the east, which aligns

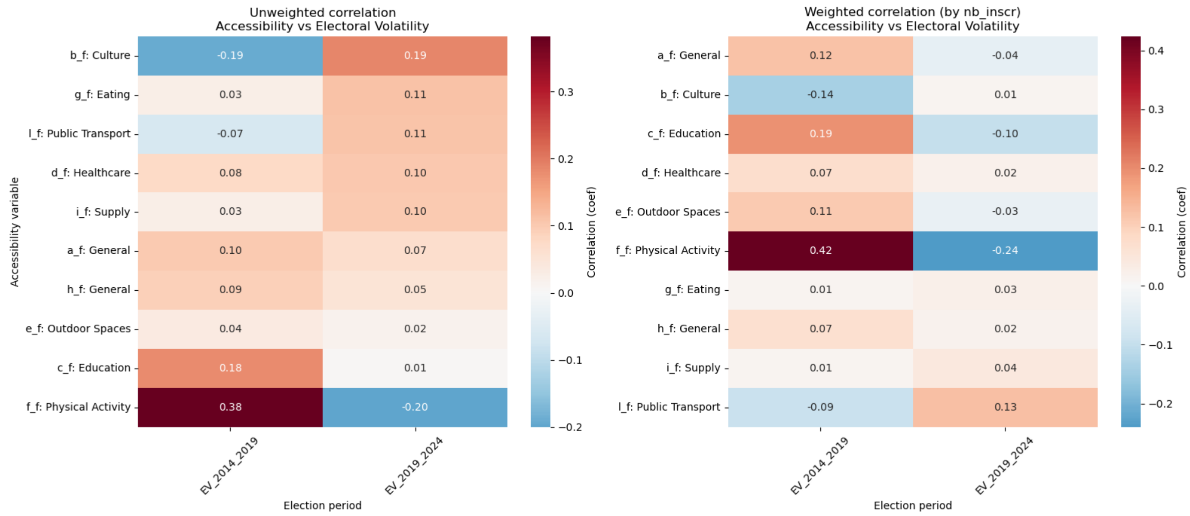


Figure 4.12: Correlations between walking PT and EV in Paris. The left panel reports unweighted correlations where all hexagons contribute equally. The right panel reports weighted correlations where each hexagon is weighted by the number of registered voters to reflect the local size of the electorate. The results vary across periods and domains. Some domains show small positive correlations in 2014 to 2019, while signs become weaker or inconsistent in 2019 to 2024. This instability matches the rotating spatial hotspots seen in the EV maps.

with the historical socio-economic divide between the formerly socialist East and the more affluent West (Burda & Hunt, 2001).

4.5.2. Rome

Figure 4.15 displays a stable core–periphery structure across both periods. Higher EV forms wide belts along the outer eastern and south-eastern sectors, with consistently lower values in the inner city. The persistence of this pattern suggests that the drivers of electoral change in Rome have a strong territorial component that does not invert between periods.

Figure 4.16 reports uniformly high positive coefficients. Unweighted correlations range from about 0.34 to 0.60 in 2014–2019 and remain large in 2019–2024. Weighted correlations are slightly lower, as expected, but still strong at roughly 0.25–0.54. Education and healthcare lead the state-provided domains, culture and eating are close behind, and general service aggregates retain high values. Rome therefore provides robust and stable support to the hypothesis across periods and domains, in line with the persistent peripheral hotspots shown on the maps.

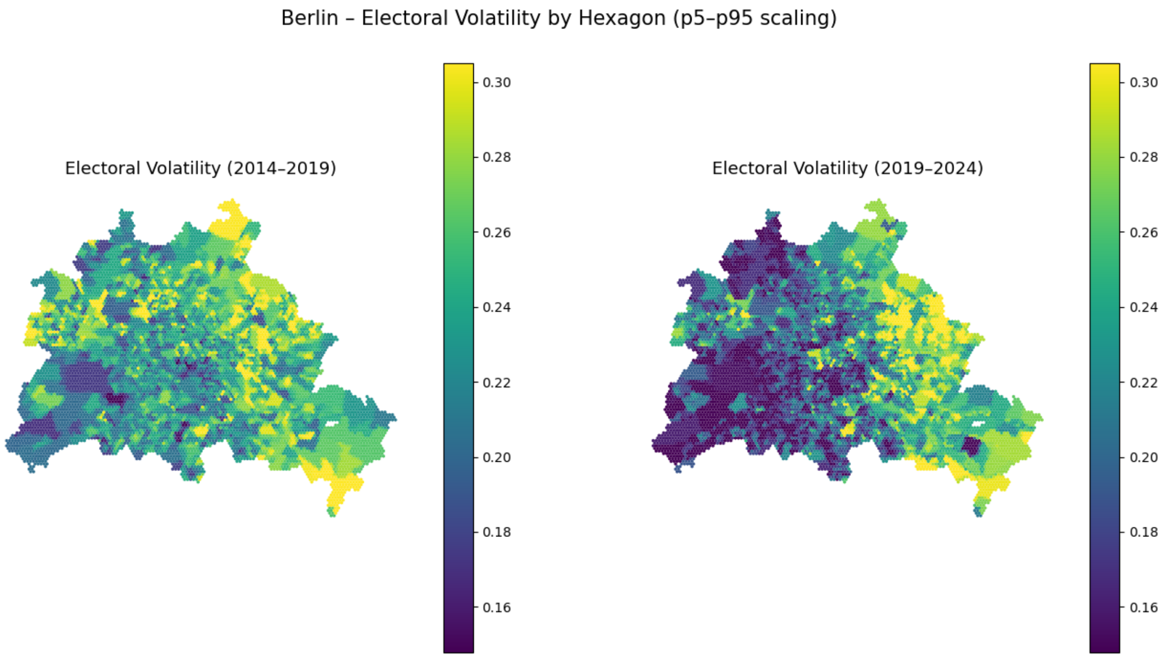


Figure 4.13: EV for Berlin by hexagon, scaled between the 5th and 95th percentiles. The left map shows EV for 2014 to 2019 and the right map shows EV for 2019 to 2024. The earlier period displays a diffuse pattern, while the second period shows a clearer concentration of high EV in the eastern and south-eastern sectors. This shift reinforces the long-standing territorial contrasts in Berlin and indicates an increasing spatial clustering of electoral instability.

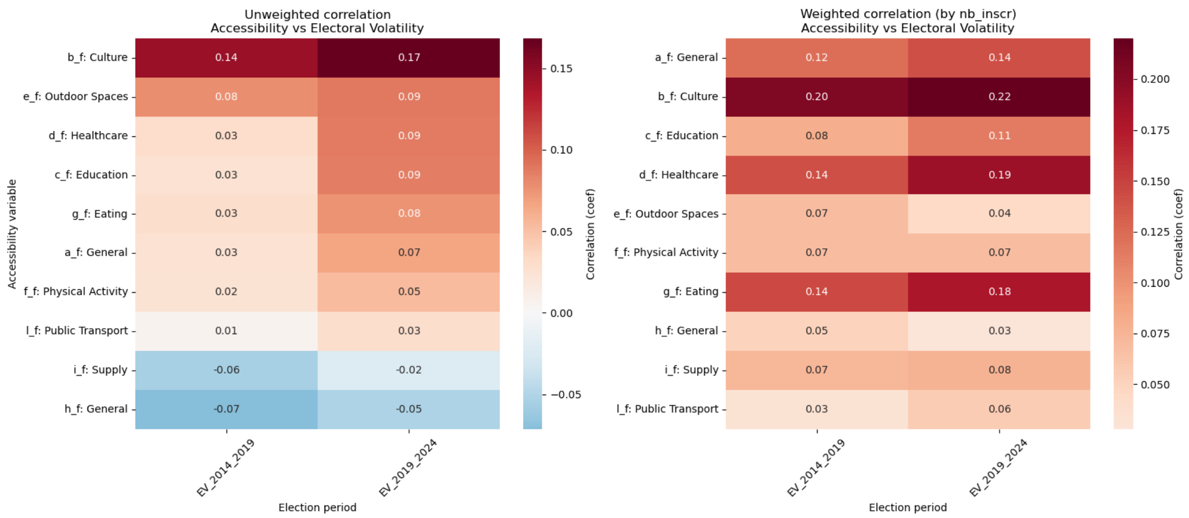


Figure 4.14: Correlations between walking PT and EV in Berlin. The left panel shows unweighted correlations and the right panel shows weighted correlations that attribute more importance to hexagons with higher numbers of registered voters. Positive coefficients increase between the two periods across several domains, including culture, healthcare, eating, and the aggregate a_f measure. This rise in magnitude is consistent with the growing spatial concentration of EV observed in the eastern districts.

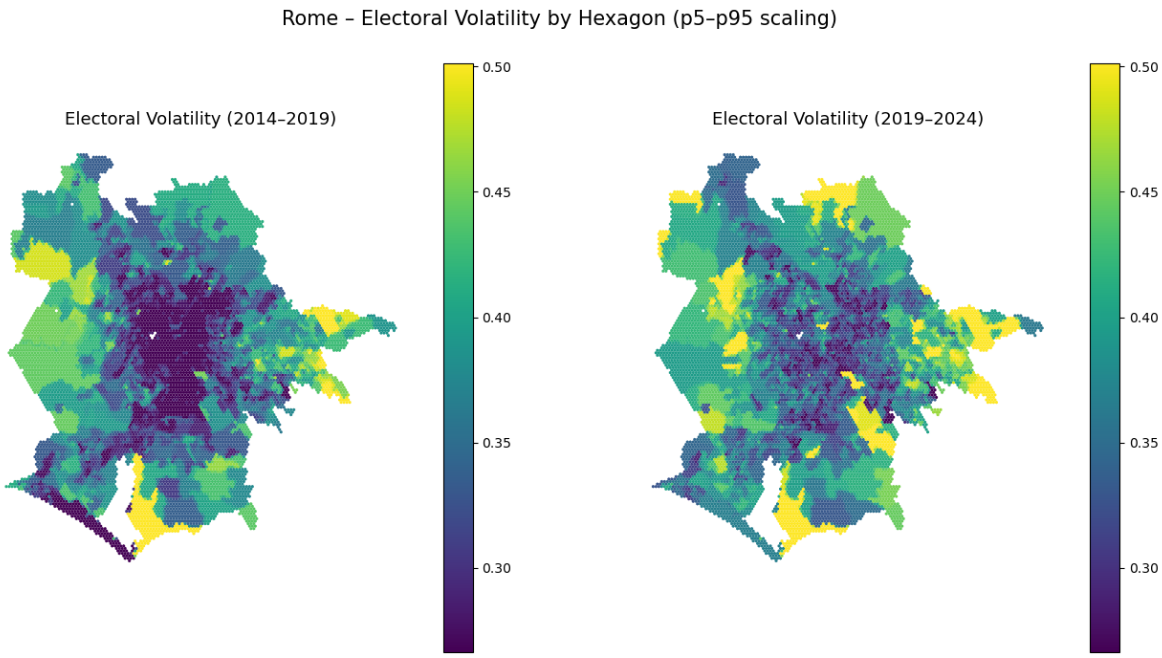


Figure 4.15: EV for Rome by hexagon, scaled between the 5th and 95th percentiles. The left map shows EV for 2014 to 2019 and the right map shows EV for 2019 to 2024. Both periods show persistent high EV in wide belts along the eastern and south-eastern periphery, while the historic core remains stable. This persistence indicates structural and long-lasting territorial drivers of electoral change in Rome.

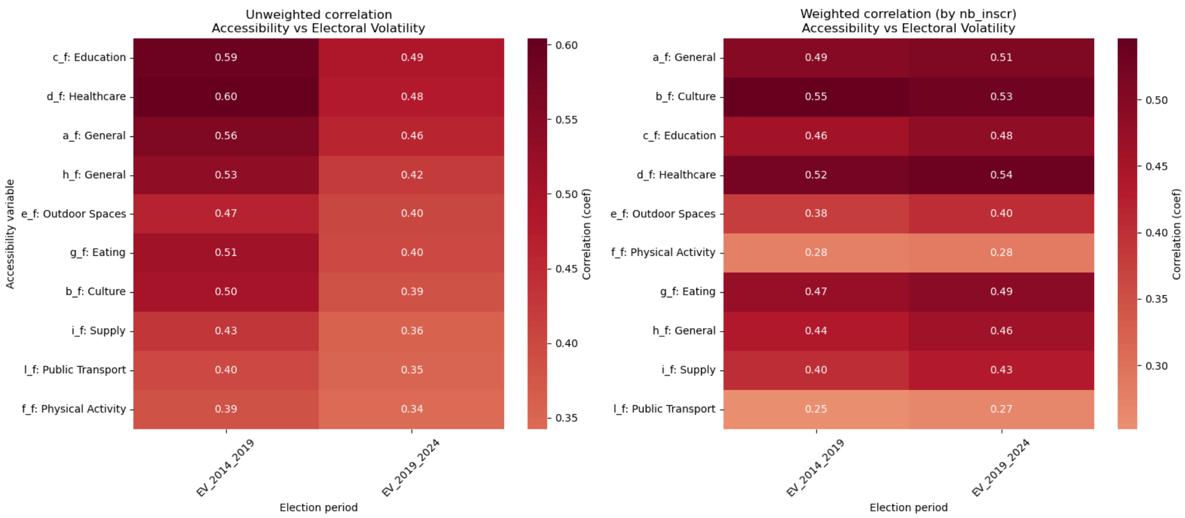


Figure 4.16: Correlations between walking PT and EV in Rome. The left panel reports unweighted correlations and the right panel reports correlations weighted by the number of registered voters to reflect the relative size of each hexagon's electorate. Coefficients are large and positive across both periods, with values typically between 0.25 and 0.60 depending on the domain and weighting scheme. These results provide strong, stable support for the expected relationship between longer PT and higher EV, in line with the persistent peripheral hotspots observed in the maps.

5 Discussion

5.1. Main findings

Accessibility emerges as a plausible, context-dependent correlate of democratic behavior rather than a causal driver. Patterns observed across Paris, Berlin, and Rome indicate that the spatial distribution of public and private services co-varies with participation and electoral dynamics, with directions and magnitudes that differ by city and reflect interacting historical trajectories, welfare, socio-demographic composition, urban morphology and core–periphery structure, network connectivity and travel frictions, at which outcomes are measured. Although the statistical sample is too limited to assert generalizable trends, the localized associations identified here provide valuable insights for future comparative analyses and for refining hypotheses on the territorial mechanisms linking accessibility and civic engagement.

Paris shows a distinct socio-spatial structure marked by a clear west–east income divide and dense service concentration within the municipal boundaries. The poorest districts, notably the 19th and 20th arrondissements, cluster around the Périphérique, where accessibility values are lowest and abstention rates highest. Low accessibility to public services correlates consistently with low turnout, particularly for education, culture, and healthcare, confirming that civic engagement weakens where institutional presence is harder to reach. Physical activity facilities display the only positive correlation, reflecting their peripheral distribution and the concentration of low-turnout areas outside the urban core. In contrast, accessibility and EV show moderate and unstable relationships. No consistent spatial pattern persists across electoral periods; hotspots shift across domains and time. Physical activity again provides the strongest but most variable signal, with alternating signs. These fluctuations indicate that political instability is not confined to specific territories but diffuses across changing social groups. Income further nuances this reading: abstention is spatially concentrated in poorer eastern districts, while volatility patterns suggest that during 2014–2019, wealthier voters shifted preferences, whereas in 2019–2024, instability rose among low-income populations. Accessibility in Paris thus interacts with economic inequality and temporal change, amplifying existing divides without establishing a single, enduring spatial pattern.

The findings of this thesis align with several core insights of Bourdin and Tai (2022) while diverging in scope and spatial resolution (Bourdin & Tai, 2022). Their study, which encompassed the entire Paris metropolitan area, demonstrated that electoral abstention follows a dual logic: disenchantment in socially marginalized neighborhoods and protest in zones where public services and local commerce have receded. They emphasized the territorial roots of abstention, showing how accessibility to institutional and everyday services acts as a mediator of civic inclusion. The present analysis, focused exclusively on the municipal boundaries within the Boulevard Périphérique, corroborates this relationship but reveals a more compact and internally differentiated picture. Even within central Paris, accessibility inequalities are narrower in absolute terms yet remain sufficient to reproduce the east–west and core-periphery socio-economic divide identified by Bourdin. The consistent negative correlations between public service accessibility and turnout confirm that even inside the city's administrative perimeter, institutional presence remains unevenly perceived and spatially patterned. However, unlike Bourdin's broader metropolitan results, this study finds that volatility lacks a stable territorial anchor: fluctuations in electoral behavior appear more dispersed and temporally variable, reflecting shifting social compositions rather than fixed zones of discontent. In this sense, the two studies converge on the centrality of service access as a determinant of civic engagement but diverge on scale and temporal stability—Bourdin's metropolitan lens captures structural patterns of exclusion at the urban fringe, while this municipal-scale analysis highlights how, even within a dense and well-serviced core, proximity remains an essential yet dynamic dimension of democratic participation.

Berlin combines strong central accessibility and high housing prices with a polycentric structure that mitigates, though does not remove, spatial inequality. Central districts enjoy short proximity times and high costs, while outer areas face longer access times to services. This distributed organization reduces sharp contrasts in accessibility and helps sustain relatively homogeneous participation patterns. Turnout shows weak and inconsistent correlations with accessibility, with coefficients fluctuating around zero and revealing stable engagement citywide. The limited spatial inequality in turnout likely reflects the resilience of Berlin's decentralized service network. Accessibility and EV, however, display a weak but positive relationship: volatility concentrates mainly in the eastern parts of the city, historically poorer and politically less stable, and this divide grows more visible over time. The persistence of this east–west contrast—still echoing the former Berlin Wall—illustrates how historical and socio-spatial legacies shape democratic behavior. While income data may be biased by tourism effects, both turnout and volatility remain influenced more by structural and historical boundaries than by contemporary accessibility alone. Berlin therefore exemplifies how polycentric organization and social stability can offset the political consequences of spatial distance.

The results for Berlin also align with recent findings from the Monitoring Soziale Stadtentwicklung reports, which highlight the city's persistent but moderate socio-spatial inequalities and the gradual reconfiguration of the historical east–west divide (Senatsverwaltung für Stadtentwicklung, Bauen und Wohnen Berlin, 2023). Within polycentric urban environments, local participation patterns tend to reflect community stability more than proximity to services. In this sense, the weak correlation between accessibility and turnout observed here confirms that physical access plays a limited role in shaping civic engagement in Berlin's decentralized structure. Volatility patterns, however, mirror the insights of the Gesundheits- und Sozialstrukturatlas Berlin, which documents structural disadvantage and lower institutional trust persisting in several eastern districts (Burda & Hunt, 2001; Gesundheits- und Sozialstrukturatlas Berlin, 2022). The slight increase in volatility over time, particularly east of the former Wall, thus resonates with the long-term social memory of division and uneven redevelopment. This study therefore refines previous urban analyses by emphasizing how the city's polycentric design buffers against accessibility-driven exclusion, while confirming that historical trajectories continue to influence where democratic instability concentrates.

Rome exhibits the strongest and most enduring core–periphery divide. The historic center concentrates high rents and the best accessibility, while peripheral zones combine lower income with longer travel times to essential services. This pattern magnifies socio-economic inequalities and entrenches spatial exclusion. Over time, correlations between accessibility and turnout intensify: both public and private services increasingly influence participation, signaling that accessibility has become a structural determinant of civic inclusion. Peripheral districts experience a cumulative disadvantage—low access, low income, and low turnout—revealing how spatial marginality aligns with democratic disengagement. Accessibility also shows the clearest connection with EV. Weighted correlations strengthen across electoral cycles, indicating growing spatial polarization. Education and healthcare drive the highest volatility, while eating and supply services display inverse trends, suggesting greater political stability in the service-rich city center. When adjusted for population, these effects moderate slightly, implying that urban sprawl and uneven service reach contribute to political fragmentation. Although turnout appears relatively uniform within municipal boundaries, volatility accentuates the core–periphery divide, widening over time. Rome thus offers the clearest evidence that spatial disadvantage—through both accessibility and income—can evolve into enduring democratic disaffection.

The patterns identified for Rome reinforce but also extend, the findings of recent spatial analyses on urban inequality and civic participation. The Mapparoma project consistently reports that income, education, and service accessibility form a clear concentric gradient, with inner districts benefiting from dense infrastructures and higher turnout, and peripheral areas marked by cumulative socio-economic and civic disadvantage (De Bonis et al., 2024). The correlations detected in this thesis between poor accessibility, low turnout, and high volatility are therefore coherent with these earlier studies but add a temporal dimension showing how polarization intensifies across electoral cycles. Statistical data from Roma Capitale confirm that municipal-level disparities in income and service coverage persist despite ongoing investment in transport and housing (Roma Capitale, 2023). Moreover, the Istituto Cattaneo's electoral analyses suggest that volatility has grown most visibly in the socially and spatially peripheral municipalities, particularly between 2019 and 2024 (Istituto Cattaneo, 2024). The present findings thus align closely with this cumulative evidence: accessibility is not an isolated driver but a territorial amplifier that interacts with economic inequality and institutional presence, gradually transforming spatial marginality into electoral instability.

Taken together, these findings suggest that accessibility can operate as more than a technical or spatial feature of urban systems—it can carry political and social significance that shapes how citizens experience and relate to public institutions. In specific contexts between the selected case studies, the associations observed between proximity to services, turnout, and volatility indicate that accessibility interacts with broader historical, social, and morphological contexts rather than determining outcomes on its own. In Paris and Rome, where urban form and income distribution reinforce a central–peripheral structure, limited accessibility often coincides with weaker civic participation and more fluid electoral behavior, pointing to areas where institutional presence may be perceived as less tangible. In Berlin, by contrast, the city's polycentric structure and social cohesion appear to buffer these dynamics, suggesting that distance does not necessarily equate to disconnection but can coexist with stable civic engagement. Overall, accessibility emerges as a plausible lens through which to interpret how urban inequalities intertwine with democratic behavior—its effects vary across contexts but consistently highlight the importance of proximity, perception, and spatial structure in sustaining civic inclusion.

5.2. Limitations

This section clarifies what the analysis can and cannot establish and explains how design choices shape interpretation. The results are read as descriptive signals that motivate but do not prove causal mechanisms.

Correlation does not mean causality. Associations between accessibility and civic outcomes may arise from omitted variables, reverse causality, or policy endogeneity. Several unobserved or only partially controlled factors could shape both accessibility and participation simultaneously. Socioeconomic characteristics such as income, education, and employment stability strongly influence turnout and may also determine residential location, producing spurious spatial correlations. Demographic composition—especially the share of residents with migrant backgrounds, age structure, or tenure status—can further affect both access to services and political engagement (Bourdin & Torre, 2025). Local factors such as neighborhood cohesion, civic organizations, or historical legacies of trust in institutions may similarly mediate the observed relationships. Even political variables—like campaign advertising intensity, targeted mobilization, or local party networks—can vary spatially and interact with accessibility. In this setting, the bivariate patterns identified here should therefore be interpreted as preliminary evidence that a mechanism could exist rather than as measured effects (Angrist & Pischke, 2009; Hernán & Robins, 2020; Pearl, 2009). Establishing causality would require follow-up designs and mixed methods. Targeted surveys and semi-structured interviews could explore how day-to-day access frictions shape perceptions of institutional presence and civic inclusion, while quasi-experimental settings—such as service openings, transport expansions, or localized policy shocks—could help isolate causal effects and adjudicate among competing explanations suggested by the maps and correlations.

The spatial frame follows administrative city boundaries rather than functional urban areas. In Paris, for example, the perimeter stops at the Boulevard Périphérique, while everyday urban life extends into adjacent banlieues with autonomous municipalities. This choice can mute or distort core-periphery gradients and constitutes a specific instance of the modifiable areal unit problem (MAUP), whereby results depend on both the scale and the zoning used to aggregate data (Andresen, 2021).

The accessibility layers used in this study are a 2024 snapshot, without a historical time series. As a result, correlations match contemporaneous PT in 2024 with electoral outcomes drawn from earlier and later elections across 2014–2024. This temporal mismatch limits longitudinal interpretation: if accessibility changed meaningfully before a given election, the 2024 PT may measure past access with error, attenuating effects toward zero and, where policy targeted low-participation areas, potentially introducing endogeneity. Read findings as cross-sectional associations relative to current spatial structure rather than as evidence about changes over time.

Using accessibility as a proxy for "institutional presence" is informative but imperfect. The healthcare domain is classified as state-provided, yet the PT metric is computed from the 20 nearest points of interest and may include private clinics; the resulting signal can therefore blend public and market footprints. More broadly, accessibility does not equal quality. Proximity measures capture distance or travel time but not capacity, affordability, acceptability, opening hours, or process standards. Classic frameworks on access and quality emphasize that structure and process mediate outcomes, so interpreting PT as institutional presence must acknowledge these dimensions (Gulliford et al., 2002).

The party mapping used to compute the Pedersen volatility index is conservative and minimizes assumptions, but some bias remains possible. Mergers, splits, rebranding, and local coalitions complicate cross-year harmonization; aggregating non-recurring lists into `Others` and aligning labels across elections can marginally affect volatility levels and their spatial distribution. These limitations point to clear extensions: sensitivity to alternative city footprints, stricter provider filters in the POI set, complementary quality or capacity indicators, and counterfactual party mappings to bound measurement error.

A further limitation concerns the proxy used for income, which in this study is based on rental costs. While rent levels provide a reasonable spatial approximation of local socio-economic conditions, they only indirectly capture household income and may not fully represent residents' purchasing power or long-term wealth. Rental markets are influenced by short-term fluctuations, regulatory ceilings, and the presence of non-resident groups such as students or tourists, all of which can distort the relationship between rent and actual income. Future work could replace or complement this proxy with geolocated income data drawn from tax records, census microdata, or administrative registries that link household income to place of residence or domicile. Such data would enable a more accurate assessment of how material living conditions interact with accessibility and would help disentangle the economic and territorial dimensions of civic engagement.

5.3. Directions for future research

A broader comparative scope can test whether the patterns observed here are city-specific or general. Extending the analysis to a larger set of European cities and to at least one non-European region with different governance, welfare, and land-use regimes would help separate institutional features from urban-form regularities. A wider sample would reveal which relationships between accessibility, institutional presence, and civic behavior travel across contexts and which depend on electoral rules or service governance.

Temporal depth can turn descriptive regularities into credible estimates of change. Building a historical series of Proximity Time (PT) aligned with election dates would allow event studies and difference-in-differences around policy shocks (e.g., new transit lines, school or clinic openings) and support spatial models with spillovers and heterogeneous effects along core–periphery gradients. Where direct archives are missing, historical PT could be reconstructed from timetables, land-use records, and address-level service registries, with uncertainty propagated through inference.

Neighborhood change is a key mediator that deserves explicit measurement. Gentrification dynamics can be proxied by the volatility of rental prices over time using rolling-window dispersion or hedonic indices, then linked to abstention and EV to distinguish behavioral change of incumbents from compositional turnover. Interactions between PT and rent volatility can identify whether accessibility upgrades that coincide with rapid tenure churn carry different democratic footprints than more inclusive improvements.

Future analyses should also incorporate multivariate regression frameworks that jointly account for the socioeconomic and contextual factors discussed earlier. Including covariates such as income, education levels, age structure, migration background, and employment stability would help disentangle the direct effect of accessibility from broader socio-demographic drivers of civic engagement. Extending the dataset with contextual variables—such as neighborhood cohesion indices, political advertising intensity, or historical voting patterns—would strengthen the explanatory power of the models and help evaluate how spatial accessibility interacts with structural inequality and political mobilization. Such models could also test moderation effects, for instance, whether accessibility matters more in low-income areas or where education levels are lower, thereby clarifying the social conditions under which proximity translates into participation.

Text-grounded party mapping should move volatility measurement from labels to ideology. Build a pipeline in which a language model ingests party manifestos, aligns them in a multilingual space, and locates each party as a vector of positions on a stable set of issues (for example, redistribution, migration, climate, and Europe). Calibrate axes across every election, represent the electorate as a distribution over these party vectors weighted by vote shares, then compute ideological volatility as the displacement of this distribution between elections. Decompose results into within-family drift and cross-family jumps, and quantify uncertainty with bootstrap over precincts and over manifesto passages. Keep a human in the loop to validate topic extraction, handle splits and mergers, and maintain a versioned taxonomy. This approach yields reproducible party positions and a volatility metric that captures not only changes in preference but also changes in ideology and opinion.

Together, these extensions would test external validity across institutional settings, strengthen causal leverage with longitudinal designs, and refine accessibility, neighborhood change, party mapping so that the democratic effects of proximity can be measured with greater precision and used more directly for policy design.

6 Conclusion

This study has taken a first step toward assessing whether urban accessibility, a core dimension of the "15-minute city" framework, may play a causal role in shaping democratic engagement. Using accessibility metrics from the Sony CSL dataset combined with electoral outcomes in Paris, Berlin, and Rome, the analysis has examined how spatial proximity to services relates to voter turnout and electoral volatility. The empirical patterns are locally meaningful but remain strictly correlational and do not establish causality.

Across the three cities, accessibility does not always appear as an important or coherent correlate of democratic behavior. In Paris and Rome, poorer accessibility to public services is generally associated with lower turnout and higher instability, suggesting that physical distance from institutions may both signal and reinforce political detachment. Berlin, by contrast, exhibits the opposite configuration: areas located farther from services tend to show slightly higher participation, indicating that in polycentric urban systems with relatively stable communities the meaning and implications of "distance" can differ substantially. Taken together, these findings show that the democratic significance of accessibility is context dependent and mediated by urban morphology.

Within this framework, the evidence speaks unevenly to the two guiding hypotheses (H1 and H2). Given the limited three-city sample, the results cannot be generalized and are interpreted on a case-by-case basis. Urban form emerges as a central factor. Berlin's polycentric structure does not replicate the relationships observed in Paris and Rome and, in several instances, reverses the expected sign between PT and turnout. Rome, with its pronounced core–periphery divide, provides the strongest support for H2: democratic discontent and electoral instability are most visible in the least accessible peripheral belts, where longer travel times to services coincide with higher volatility and lower participation. Paris presents a more mixed configuration. EV appears to follow income- or political system-driven dynamics more than accessibility alone, while turnout still mirrors the distribution of service proximity despite the tight municipal boundaries of the study area. Overall, these city-specific results suggest that accessibility interacts with local socio-spatial structures rather than exerting a uniform effect across European capitals.

At the same time, the evidence remains correlational. The analysis identifies spatial associations, not causal effects. Accessibility and political engagement may both be shaped by deeper, unobserved variables such as socio-economic structure, population stability, or local policy history. To test whether accessibility can truly be considered a causal factor in shaping participation and satisfaction, future work will need to rely on longitudinal or quasi-experimental approaches. Panel data covering multiple electoral cycles would make it possible to track how changes in service provision affect participation over time. Similarly, natural experiments, such as the opening or closure of schools, healthcare centers, or transport nodes, could provide exogenous shifts in accessibility and help identify their political consequences.

Expanding and diversifying the empirical base is also essential. A larger sample of cities, combined with harmonized socio-demographic controls, would clarify whether the relationships observed here are general features of European urban systems or context-specific outcomes. Integrating accessibility with other spatial dimensions, such as segregation, inequality, and mobility patterns, could further illuminate the mechanisms through which urban form mediates democratic behavior and institutional trust.

In conclusion, this research suggests that accessibility matters for democracy, but the mechanisms through which it operates remain to be empirically demonstrated. This thesis has provided an initial comparative framework and a set of empirical benchmarks for future work that will test, using stronger causal designs and a broader case sample, whether bringing citizens closer to essential services, as envisioned by the 15-minute city, can genuinely strengthen civic engagement and the perceived legitimacy of democratic institutions.

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A

Stakeholder Analysis

This appendix identifies the main institutional and political actors interested in the outputs of this research and clarifies how each of them can use the results within its own scope of action. The thesis assess who holds power to make or implement decisions, but rather who stands to benefit from, or find relevance in, the empirical evidence generated by the analysis.

The audiences of interest operate at three main territorial levels: supranational, national, and local. Each of these levels connects to the topic of accessibility and democratic participation in different ways.

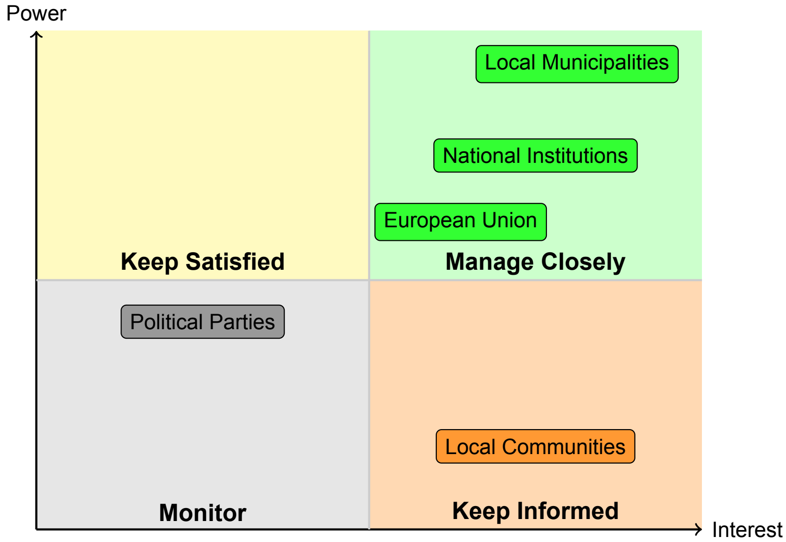

Figure A.1: Power–Interest matrix illustrating the positioning of stakeholders relative to the research outputs. Each quadrant corresponds to a recommended engagement strategy: Monitor (low power, low interest), Keep Satisfied (high power, low interest), Keep Informed (low power, high interest), and Manage Closely (high power, high interest).

At the supranational level, the `European Union (EU)` represents a key stakeholder. It faces the dual challenge of maintaining democratic legitimacy and territorial cohesion across member states while managing high-impact decisions concerning resource allocation, cohesion funding, and regulatory standards. The EU's coordination role relies on comparable, standardized indicators that enable cross-country benchmarking and guide funding priorities under the Cohesion Policy and related frameworks.

Because of its supranational nature, the Union can appear distant from citizens' everyday experiences. Understanding how inequalities in accessibility and service provision shape civic disengagement therefore aligns with the EU's current research and policy agenda. In particular, the objectives of the *Horizon Europe Work Program, Cluster 2 — Culture, Creativity and Inclusive Society*, and its topic on *Economic* *inequalities and their impact on democracy*, emphasize the need to understand the links between inequality and participation, to identify drivers of political disengagement, and to support inclusive and resilient governance models.

The findings of this research contribute directly to that mission. By identifying where institutional presence is spatially weakest and by quantifying how such disparities relate to democratic participation, the study provides empirical tools that can inform EU cohesion policies, guide resource allocation, and strengthen communication and funding strategies aimed at restoring citizen trust and reinforcing democratic legitimacy across diverse territories.

National governments and institutions—including ministries, planning authorities, and statistical agencies—are directly interested in spatial diagnostics that reveal where accessibility and democratic participation diverge. The integration of spatial accessibility indicators with turnout and volatility measures helps identify territorial disparities that may signal weak institutional embeddedness or public dissatisfaction. These insights can guide the development of equity-oriented social and territorial policies and improve coordination between national and regional programs.

By linking accessibility to civic engagement, the research provides a quantitative foundation for evaluating whether governance and service delivery efforts reach citizens evenly or whether certain areas experience cumulative neglect that translates into discontent or instability.

At the local scale, **municipal governments** are responsible for much of the service provision directly measured in this study—such as schools, healthcare facilities, parks, cultural venues, and public transport infrastructure. For them, the spatial analysis of accessibility and participation provides a concrete diagnostic tool for identifying neighborhoods where the distance to public services is systematically higher and where civic engagement tends to be lower.

Municipalities can use these results to prioritize interventions that combine social equity with democratic vitality, designing proximity-based urban policies that address both functional and civic dimensions of accessibility.

Finally, **national political parties** represent an important audience interested in understanding the territorial distribution of civic participation and trust. The association between accessibility, institutional presence, and engagement provides actionable information on where and why abstention or electoral volatility are spatially concentrated. Beyond electoral strategy, these findings can inform broader efforts to rebuild connections between citizens and political organizations, reinforcing representativeness and responsiveness across different territories.

Table A.2 summarizes the level of interest of each stakeholder in the research outputs, distinguishing their scale of action and the potential use of the findings.

Stakeholder	Scale	Main Interest in Research Outputs
European Union	Supranational	Understanding how spatial inequalities in accessibility relate to civic disengagement and democratic legitimacy; guiding cohesion funding and cross-country policy evaluation.
National Institutions	National	Detecting territorial disparities in accessibility and participation; integrating spatial diagnostics into social, territorial, and equity policies.
Local Municipalities	Local	Identifying neighborhoods with poor service accessibility and low engagement; supporting evidence-based urban planning and prioritization of investments.
National Political Parties	National	Analyzing territorial patterns of abstention and volatility; informing strategies for political representation and citizen outreach.

Table A.2: Stakeholders interested in the research outputs and their respective areas of application.

In summary, these stakeholders represent the institutional and political audiences that can benefit most from the findings of this thesis. Each, at its respective level, faces the challenge of maintaining democratic participation and institutional trust in a context of spatial inequality. The empirical results and indicators developed here provide them with concrete evidence to better understand, monitor, and address the territorial dimensions of civic engagement in European cities.

B

Turnout Maps by City

This appendix reports the complete set of turnout maps used for descriptive context. Each figure shows three elections of the same type for a given city with a common colorscale, but not identical geographic units as voting precints' shapes can differ between different rounds of elections. Values are turnout ratios. Maps are for visual comparison only and do not imply causal relations. Data souces are specified in chapter 03. Methodology. For Paris, the third oldest municipal election could not be included because the record is not available on the Paris Open Data platform.

B.1. Paris

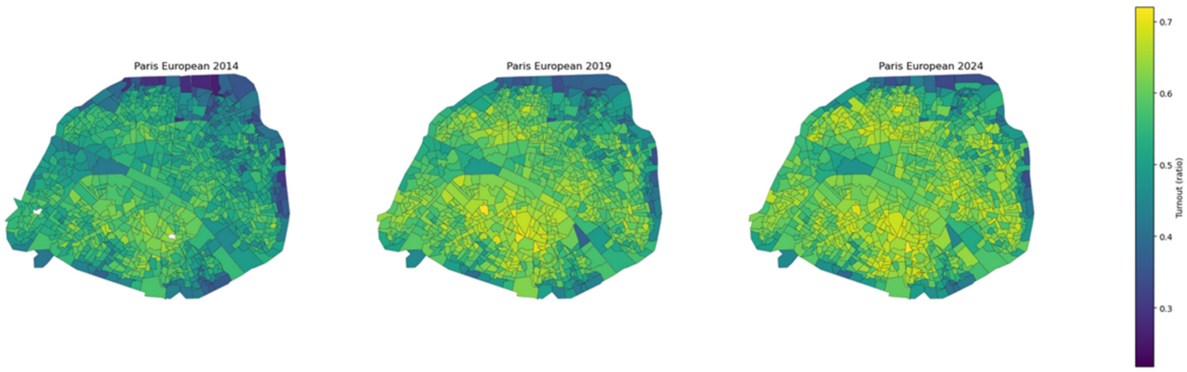

Figure B.1: Paris — European elections turnout (2014, 2019, 2024).

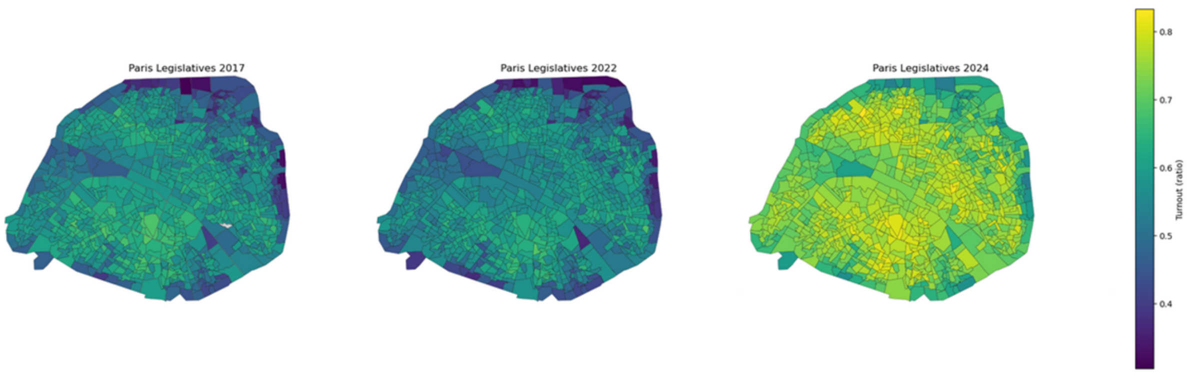

Figure B.2: Paris — Legislative elections turnout (2012, 2017, 2022).

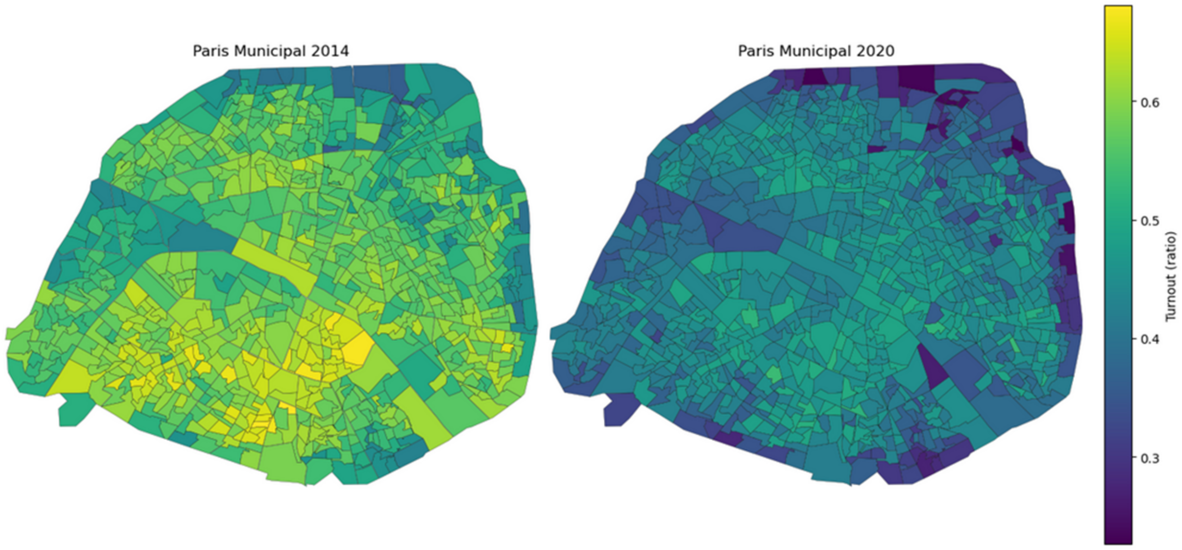

Figure B.3: Paris — Municipal elections turnout (2014, 2020, 2024).

B.2. Berlin

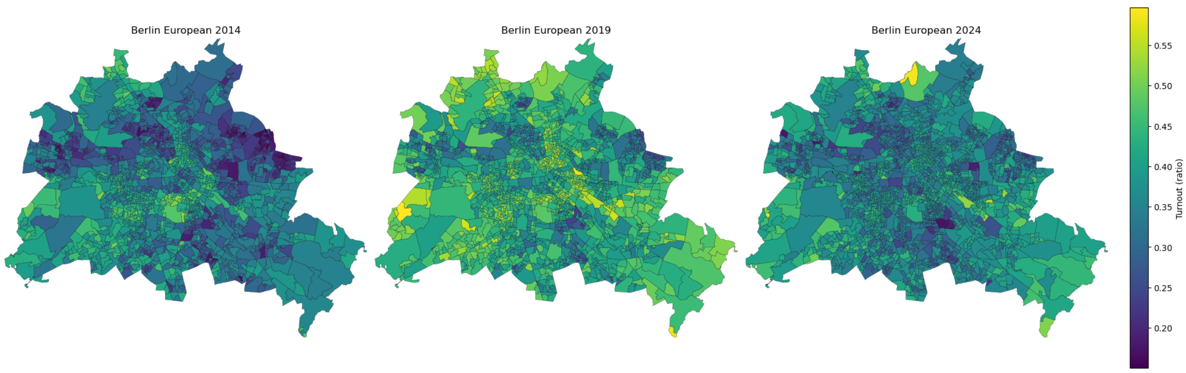

Figure B.4: Berlin — European elections turnout (2014, 2019, 2024).

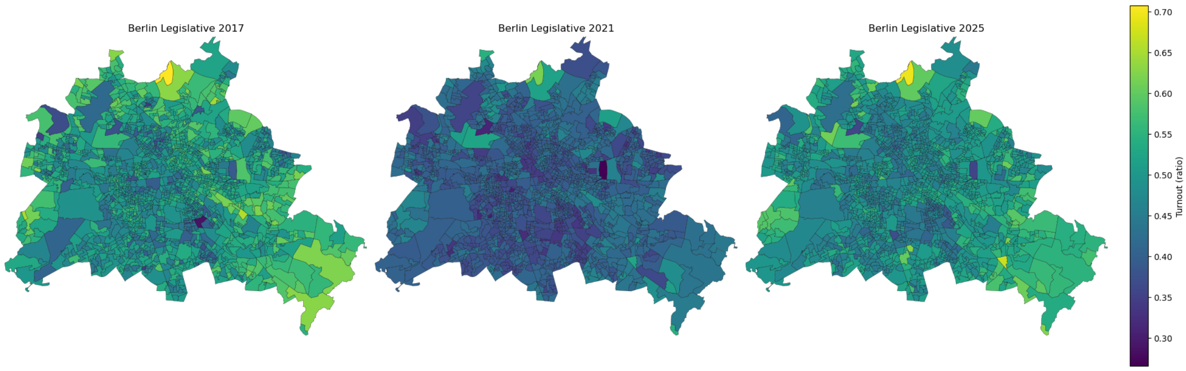

Figure B.5: Berlin — Legislative elections turnout (2017, 2021).

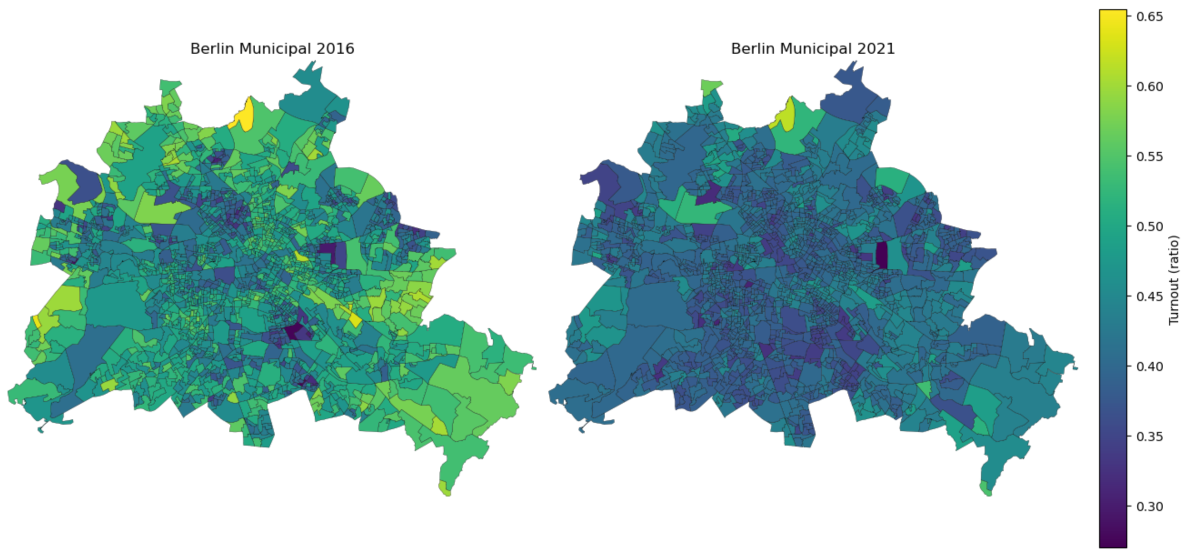

Figure B.6: Berlin — Municipal elections turnout (2016, 2021, 2025).

B.3. Rome

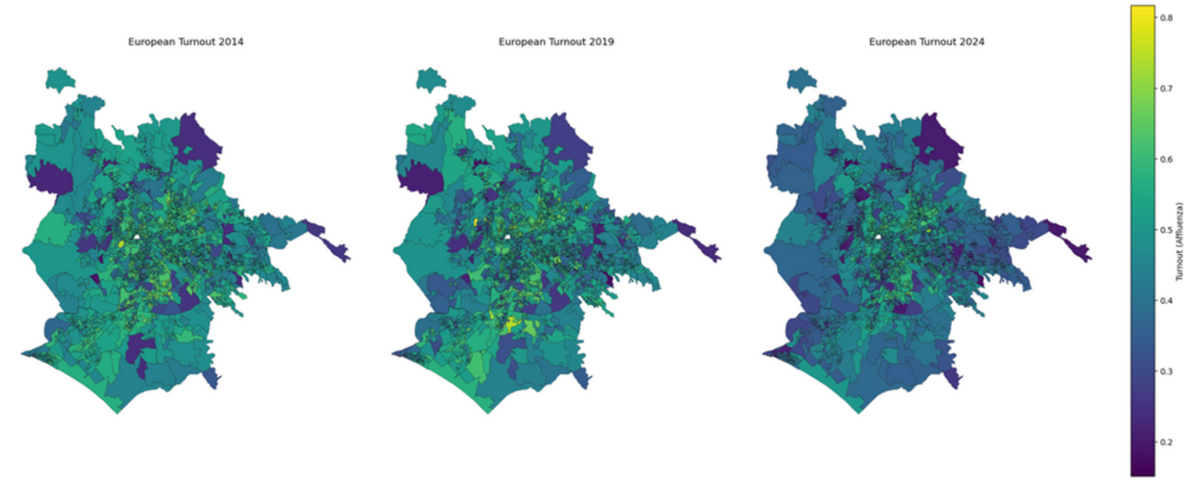

Figure B.7: Rome — European elections turnout (2014, 2019, 2024).

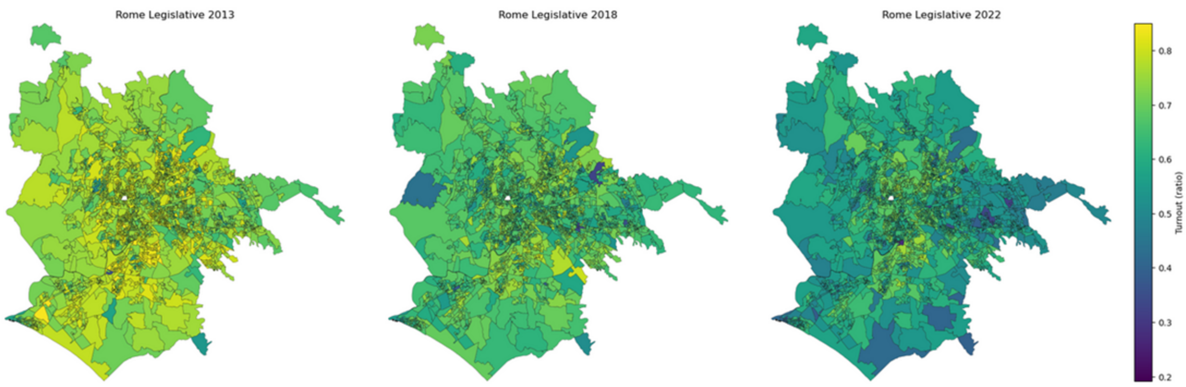

Figure B.8: Rome — Legislative elections turnout (2013, 2018, 2022).

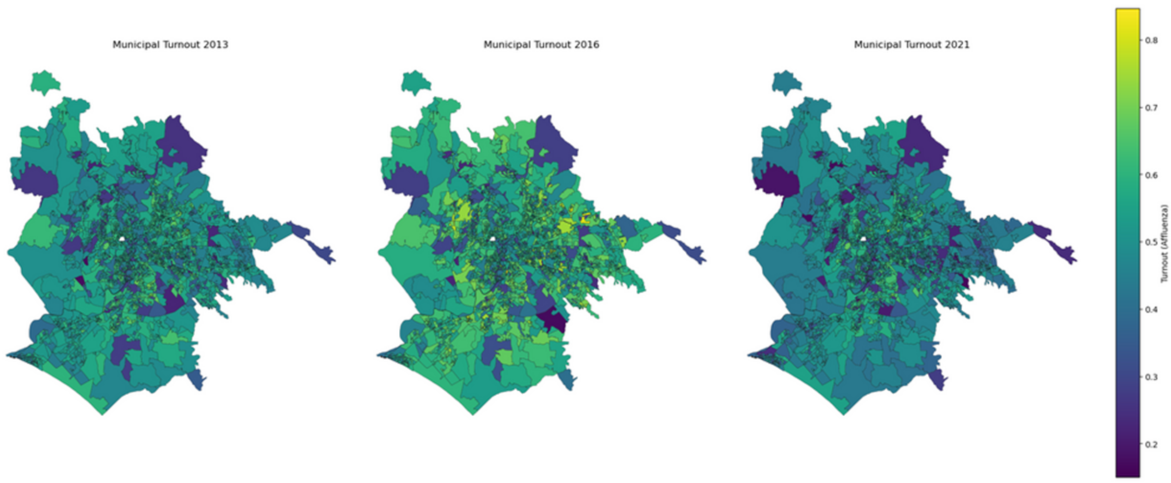

Figure B.9: Rome — Municipal elections turnout (2013, 2016, 2021).

C

EV Calculation

C.1. Why and how we measure volatility?

We consider EV as a measure to capture how far voters move between successive elections, treating change as a signal of civic (dis)content. We adopt Pedersen's formulation, which quantifies the net shift in vote *shares* across the party system:

$$\mathrm{EV}_{t,t-1} = \frac{1}{2}\sum_{i\in\mathcal{P}}\left|\, p_{i,t} - p_{i,t-1} \,\right|, \tag{C.1}$$

where $p_{i,t}$ denotes the share of *valid* votes for party i at time t, and $\mathcal{P}$ is the reference set of parties compared across the two elections. Pedersen's index is powerful but fragile with respect to party engineering: splits, mergers, rebrandings, and coalitions alter labels (Pedersen, 1979) while the electorate behind them may remain similar. If handled naively, these transformations preclude EV calculation as it is impossible to keep track of the exact A second source of fragility lies in institutional heterogeneity: different tiers of election follow different rules and electoral laws, so comparing a municipal cycle in one country with a national or European cycle in another folds rule changes into the volatility measure.

To make electoral volatility comparable across cities and countries while avoiding political interpretation, we fix the scope to the last three European Parliament elections (2014, 2019, 2024). Holding the election tier constant limits noise from heterogeneous electoral rules and keeps party competition on a common footing. We then standardize party labels with minimal intervention. Within each dataset, lead candidate, list name, and party are reconciled to a single canonical label, and obvious spelling or orthographic variants are harmonized across years. With a common vocabulary established, only parties that recur in all three contests are kept as named series, since these are the most reliable anchors for tracking voter reallocation through time. All remaining lists, including breakaways, micro-parties, and one-off coalitions, are pooled into the residual category `Others`. This pooling avoids making judgments about organizational continuity and protects the signal of interest, namely shifts among enduring poles of competition, from being diluted by ephemeral labels. For comparability across places and years, the share of `Others` is capped at 15% of total valid votes so that residual variation cannot dominate the volatility metric or the graphical summaries.

C.2. Party Mapping and Votes by Party Evolution

This section presents the process of harmonising electoral data across time and cities to allow a coherent comparison of party dynamics in Paris, Berlin, and Rome. The objective is twofold: first, to illustrate how the mapping of electoral lists and parties was constructed for each city, ensuring consistency across the 2014, 2019, and 2024 European elections; second, to visualise the evolution of vote shares by party over the same period. These mappings form the foundation for the calculation of EV in the following sections, ensuring that observed changes capture voter reallocation rather than artefacts of rebranding or coalition shifts.

C.2.1. Paris

Party mapping

In the French case, the European elections are contested by national lists, each led by a principal candidate rather than by explicitly named parties. The raw data used for this analysis were downloaded from the *Paris Data* portal Paris Data, 2025, which reports election results by lead candidate (*tête de liste*) for each voting section. To connect these records to their corresponding lists and parties, an additional step of reconciliation was required. Each lead candidate was matched to their official electoral list using the national candidate dataset published by the Ministry of the Interior Ministère de l'Intérieur et des Outre-Mer, 2024. The list was then linked to its corresponding political party or European parliamentary group following the official classification issued by the European Parliament European Parliament, 2024. This two-step mapping ensured full consistency between local results, national records, and European-level affiliations.

The French political scene between 2014 and 2024 underwent a major realignment. The historical bipolar structure opposing the Socialist Party (PS) and the Gaullist Right (Les Républicains) weakened as centrist movements (MoDem–Renaissance) emerged, reshaping the traditional left–right balance. At the same time, the National Rally (RN) consolidated its leadership on the far right, La France insoumise (LFI) grew on the radical left, and the Ecologists (EÉLV) experienced temporary surges, most notably in 2019.

Because several major parties changed names or merged into broader alliances during this period, and new movements gained national relevance, it was necessary to adopt a political family mapping. This approach groups parties and lists according to their enduring ideological orientation, ensuring continuity in cases where nominal labels changed while the underlying political identity remained consistent. Such grouping preserves the analytical meaning of volatility by capturing shifts between broad ideological poles rather than transient branding effects.

The tables below show the mapping between electoral lists, their lead candidates, and the corresponding parties with parliamentary representation across the three rounds of European elections.

Family / Party	**Associated list (2014)**	**Lead candidate**
Nationalist Right (FN–RN)	Liste bleu marine – Non à Bruxelles, oui à la France	Aymeric Chauprade
Gaullist Right (Les Républicains)	Pour la France, agir en Europe	Alain Lamassoure
Pro-European Centre (MoDem–Renaissance)	UDI–MoDem les Européens	Marielle de Sarnez
Reformist Left (PS)	Choisir notre Europe	Pervenche Berès
Radical Left (LFI / former FG)	L'humain d'abord ! Front de Gauche	Patrick Le Hyaric
Ecologists (EÉLV)	Europe Écologie	Pascal Durand

Table C.2: Paris 2014: lists with representation and lead candidates.

Party evolution

Figure C.1 illustrates the evolution of party support across the three most recent European elections in Paris, providing an overview of how the local electorate has redistributed its preferences among the main political families. The data clearly show that the 2019 election represented a pivotal moment in the reconfiguration of the French political spectrum. The centrist bloc (*Renaissance*) achieved a pronounced surge, largely at the expense of the traditional parties on both sides of the spectrum: the Socialist Party (PS) suffered a historic decline, while the Gaullist Right (*Les Républicains*) continued its gradual erosion. At the same time, the Greens (*EÉLV*) reached their highest share of the decade, reflecting the temporary prominence of environmental issues and the mobilization of urban, younger voters.

Family / Party	**Associated list (2019)**	**Lead candidate**
Nationalist Right (FN–RN)	Prenez le pouvoir	Jordan Bardella
Gaullist Right (Les Républicains)	Union de la droite et du centre	François-Xavier Bellamy
Pro-European Centre (MoDem–Renaissance)	Renaissance (LREM–MoDem & partners)	Nathalie Loiseau
Reformist Left (PS)	Envie d'Europe écologique et sociale	Raphaël Glucksmann
Radical Left (LFI)	La France insoumise	Manon Aubry
Ecologists (EÉLV)	Europe Écologie	Yannick Jadot

Table C.4: Paris 2019: lists with representation and lead candidates.

Family / Party	**Associated list (2024)**	**Lead candidate**
Nationalist Right (FN–RN)	La France revient !	Jordan Bardella
Gaullist Right (Les Républicains)	La droite pour faire entendre la voix de la France	François-Xavier Bellamy
Pro-European Centre (MoDem–Renaissance)	Besoin d'Europe	Valérie Hayer
Reformist Left (PS)	Gauche unie pour le monde du travail	Raphaël Glucksmann
Radical Left (LFI)	Union populaire	Manon Aubry
Ecologists (EÉLV)	Europe Écologie	Marie Toussaint
Far Right (Reconquête)	La France fière	Marion Maréchal

Table C.6: Paris 2024: lists with representation and lead candidates.

By 2024, however, this configuration shifted again. The Socialist Party partially regained ground, capitalizing on a re-consolidation of the centre-left electorate and the declining momentum of the environmentalist movement. The far-right, represented by the National Rally (RN), consolidated its base, benefiting from the growing national normalization of its discourse. The centrist bloc contracted, showing signs of electoral fatigue after its initial success, while the Greens lost much of the extraordinary gains achieved in 2019. These oscillations confirm the high volatility of the French electorate in urban contexts such as Paris, where partisan loyalties appear weaker and issue-driven dynamics prevail.

A particularly relevant aspect of this evolution concerns the category `Others`, which aggregates all minor lists, ephemeral alliances, and new parties without continuity across the three rounds. Despite the political fragmentation that characterizes France's European elections, the share of `Others` remained consistently below 15% of total valid votes in each round. This limited and stable residual component indicates that most electoral reallocation occurred among the enduring, structured parties rather than within the periphery of the political system. Consequently, the assumptions we adopted in the volatility computation appear robust and empirically justified.

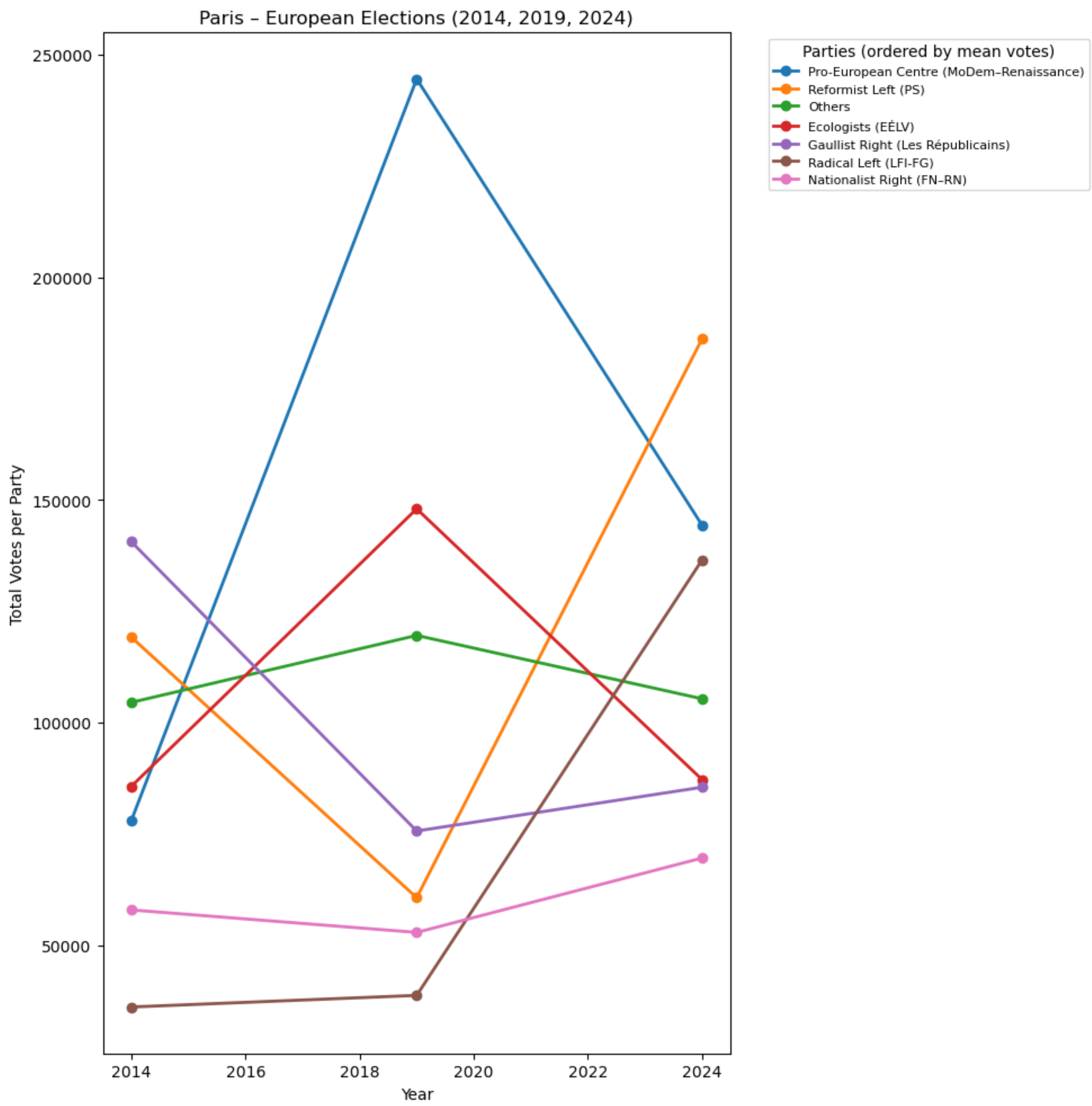

Figure C.1: Paris — total votes by party in the European elections of 2014, 2019, and 2024.

C.2.2. Berlin

Party mapping

For the German case, the European election data were obtained directly from the *Berlin Open Data* portal (Berlin Open Data, 2025), which provides official municipal-level election results already disaggregated by party. Unlike the French dataset, no additional reconciliation across lead candidates or lists was required. However, to ensure cross-year and cross-country comparability, a standardization of party names was conducted, translating each into a single English-language label and aligning spelling conventions across the 2014, 2019, and 2024 datasets. This harmonization was particularly relevant for minor or rebranded formations that appear inconsistently in the source material, ensuring that recurring parties were matched to a stable identifier across all rounds.

Between 2014 and 2024, Berlin's political landscape remained pluralistic but underwent gradual shifts reflecting broader national trends. The dominance of the Social Democratic Party (SPD) weakened steadily, while the Greens (*GRÜNE*) consolidated as the principal urban force, particularly in 2019 when environmental issues gained centrality in German politics. The Christian Democrats (CDU) maintained a resilient but declining base, whereas the Left (*DIE LINKE*) experienced an erosion consistent with its national contraction. The far-right Alternative für Deutschland (AfD), absent in 2014, rose to double-digit shares by 2019 and continued to expand modestly in 2024. Alongside these core actors, the Free Democrats (FDP), the satirical party *Die PARTEI*, and several micro-parties (*Tierschutzpartei*, *FREIE WÄHLER*, *ÖDP*) preserved marginal but persistent support.

Table C.8 and Table C.10 report the standardized mapping for Berlin's European elections (2014–2024), split into *Main Parties* and *Others*. Only parties recurring across the three rounds are kept as distinct entities; all remaining lists are aggregated as `Others`, which stays below 15% of valid votes.

Instance 2014	Instance 2019	Instance 2024	Standardized Party Name	Classification
CDU	CDU	CDU	Christian Democratic Union (CDU)	Main Party
SPD	SPD	SPD	Social Democratic Party (SPD)	Main Party
GRÜNE	GRÜNE	GRÜNE	Alliance 90 / The Greens (GRÜNE)	Main Party
DIE LINKE	DIE LINKE	DIE LINKE	The Left (DIE LINKE)	Main Party
FDP	FDP	FDP	Free Democratic Party (FDP)	Main Party
AfD	AfD	AfD	Alternative for Germany (AfD)	Main Party
Die PARTEI	Die PARTEI	Die PARTEI	Die PARTEI (Satirical Party)	Main Party
PIRATEN	PIRATEN	PIRATEN	Pirate Party Germany (PIRATEN)	Main Party
Tierschutzpartei	Tierschutzpartei	Tierschutzpartei	Animal Protection Party	Main Party
FREIE WÄHLER	FREIE WÄHLER	FREIE WÄHLER	Free Voters	Main Party
ÖDP	ÖDP	ÖDP	Ecological Democratic Party	Main Party
FAMILIE	FAMILIE	FAMILIE	Family Party of Germany	Main Party
DKP	DKP	DKP	German Communist Party	Main Party
MLPD	MLPD	MLPD	Marxist–Leninist Party of Germany	Main Party

Table C.8: Berlin — standardized mapping of *Main Parties* (2014–2024).

Party evolution

Figure C.2 shows the evolution of total votes per party in Berlin across the three most recent European Parliament elections. The data highlight a marked rise of the Greens (*GRÜNE*) in 2019, when they reached nearly 300,000 votes, overtaking both SPD and CDU. This surge mirrors the broader national trend of the environmental vote during that period, driven by the prominence of climate issues and a highly mobilized urban electorate. By 2024, however, their support declined sharply, returning closer to the 2014 levels, suggesting that part of their 2019 momentum was temporary and issue-driven rather than structural.

The SPD continued its gradual erosion, losing voters steadily over the decade, while the CDU maintained relative stability but did not recover its former centrality. The Left (*DIE LINKE*) declined further, whereas the AfD expanded substantially between 2014 and 2024, consolidating as a significant, though still secondary, presence in the city. The FDP and smaller liberal or satirical parties (*Die PARTEI*, *PIRATEN*) exhibited modest fluctuations but remained within a narrow band of support. These movements collectively reflect an increasingly fragmented electorate, where volatility is driven by issue salience rather than enduring partisan identification.

The residual category `Others`, which aggregates all minor and non-recurring lists, displayed moderate growth over time but consistently accounted for less than 15% of total valid votes. This stable and limited share confirms that the observed electoral volatility stems primarily from reallocation among the principal parties rather than from peripheral or short-lived formations. Such consistency strengthens the methodological robustness of the adopted mapping and justifies the decision to treat `Others` as a single residual component in the volatility computation.

Instance 2014	Instance 2019	Instance 2024	Standardized Party Name	Classification
NPD	NPD	–	National Democratic Party (NPD)	Others
REP	–	–	Republicans (REP)	Others
BüSo	–	–	Citizens' Movement Solidarity (BüSo)	Others
BP	BP	–	Bavarian Party (BP)	Others
PRO NRW	–	–	Pro NRW	Others
Volksabstimmung	Volksabstimmung	–	Party of Referendum	Others
PBC	–	–	Party of Bible-abiding Christians	Others
AUF	–	–	Action for Germany	Others
CM	–	–	Christliche Mitte	Others
PSG	–	–	Socialist Equality Party (PSG)	Others
Volt	Volt	Volt	Volt Europa	Others
TIERSCHUTZ hier!	TIERSCHUTZ hier!	TIERSCHUTZ hier!	Animal Protection Alliance	Others
SGP	SGP	SGP	Socialist Equality Party (SGP)	Others
Bündnis C	Bündnis C	Bündnis C	Christian Values Alliance	Others
BIG	BIG	BIG	Alliance for Innovation and Justice	Others
BGE	BGE	–	Basic Income Alliance	Others
DIE DIREKTE!	–	–	Direct Democracy Party	Others
DiEM25	–	–	Democracy in Europe Movement 2025	Others
III. Weg	–	–	The Third Way	Others
Die Grauen	Die Grauen	–	The Greys	Others
DIE RECHTE	DIE RECHTE	–	The Right	Others
DIE VIOLETTEN	DIE VIOLETTEN	–	The Violets	Others
LIEBE	LIEBE	–	Love Party	Others
DIE FRAUEN	DIE FRAUEN	–	Women's Party	Others
Graue Panther	Graue Panther	–	Grey Panthers	Others
LKR	LKR	–	Liberal Conservative Reformers	Others
MENSCHLICHE WELT	MENSCHLICHE WELT	MENSCHLICHE WELT	Human World Party	Others
NL	NL	–	Neutral Party	Others
ÖkoLinX	ÖkoLinX	–	Ecological Left	Others
Die Humanisten	Die Humanisten	–	The Humanists	Others
PARTEI FÜR DIE TIERE	PARTEI FÜR DIE TIERE	–	Party for the Animals	Others
Gesundheitsforschung	Gesundheitsforschung	–	Health Research Party	Others
Tierschutzallianz	Tierschutzallianz	–	Animal Welfare Alliance	Others
BSW	–	BSW	Alliance Sahra Wagenknecht	Others
dieBasis	–	dieBasis	The Basis	Others
Verjüngungsforschung	–	Verjüngungsforschung	Party for Rejuvenation Research	Others
PdH	–	PdH	Party of Humanists	Others
HEIMAT	–	HEIMAT	Homeland Party	Others
ABG	–	ABG	Alliance for Basic Income	Others
BÜNDNIS DEUTSCHLAND	–	BÜNDNIS DEUTSCHLAND	Alliance Germany	Others
DAVA	–	DAVA	Democratic Alliance for Diversity and Awakening	Others
KLIMALISTE	–	KLIMALISTE	Climate List	Others
LETZTE GENERATION	–	LETZTE GENERATION	Last Generation	Others
PDV	–	PDV	Party of Reason	Others
PdF	–	PdF	Party for Research	Others
V-Partei³	–	V-Partei³	Party for Change, Vegetarians and Vegans	Others
MERA25	–	MERA25	Democracy in Europe Movement	Others

Table C.10: Berlin — standardized mapping of *Others* (2014–2024).

C.2.3. Rome

Party mapping

Italy's political system is renowned for its chronic volatility and continuous party restructuring. The period between 2014 and 2024 was characterized by a profound transformation of both the centre-left

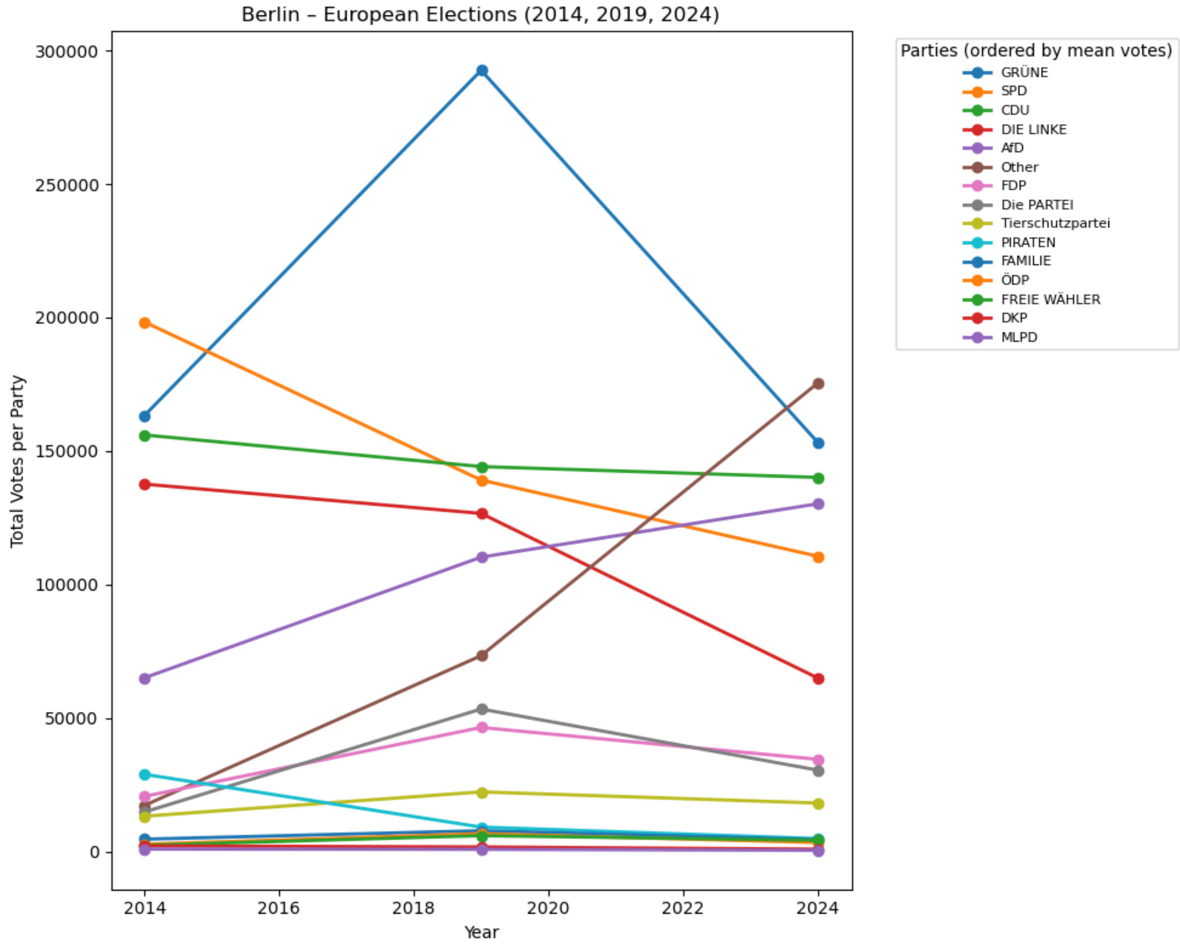

Figure C.2: Berlin — total votes by party in the European elections of 2014, 2019, and 2024.

and the centre-right blocs. The *Partito Democratico (PD)* remained the principal force of the centre-left, but gradually lost ground amid internal fragmentation and competition from new movements. On the opposite side, the conservative and nationalist area consolidated under the dual leadership of *Lega* and *Fratelli d'Italia (FdI)*, while *Forza Italia (FI)* progressively declined as its traditional electorate realigned. At the same time, the populist *Movimento 5 Stelle (M5S)* emerged as a major disruptive actor in 2014, peaking shortly thereafter before entering a phase of erosion.

The datasets used for Rome were obtained from the official archives of the *Ministero dell'Interno*, which already report results at the party level. Consequently, the main task consisted in harmonizing the numerous naming variants of political formations and consolidating them into standardized references valid across all three electoral rounds. Particular attention was required for coalitions and alliances that changed composition or branding between elections.

A notable example concerns the Green and leftist area: in 2014, the lists *Federazione dei Verdi–Green Italia* and *L'Altra Europa con Tsipras* were merged into a single standardized category, **SI–Verdi**, to ensure analytical continuity across the subsequent 2019 and 2024 elections, where the same political current reappeared under similar alliances. This type of consolidation was applied sparingly and only when ideological consistency was clearly established, preserving comparability while minimizing subjective interpretation.

Instance 2014	Instance 2019	Instance 2024	Standardized Party Name	Classification
PARTITO DEMOCRATICO	PARTITO DEMOCRATICO	partito democratico	Partito Democratico (PD)	Main Party
MOVIMENTO 5 STELLE	MOVIMENTO 5 STELLE	m5s	Movimento 5 Stelle (M5S)	Main Party
FRATELLI D'ITALIA–ALLEANZA NAZIONALE	FRATELLI D'ITALIA	fdi	Fratelli d'Italia (FdI)	Main Party
LEGA NORD PER L'INDIPENDENZA DELLA PADANIA	LEGA SALVINI PREMIER	lega	Lega	Main Party
FORZA ITALIA	FORZA ITALIA	forza italia	Forza Italia (FI)	Main Party
FEDERAZIONE DEI VERDI–GREEN ITALIA / L'ALTRA EUROPA CON TSIPRAS	SINISTRA EUROPEA, SINISTRA ITALIANA / FEDERAZIONE DEI VERDI	si-verdi	SI–Verdi	Main Party
SCELTA EUROPEA CON GUY VERHOFSTADT	–	–	Scelta Europea	Others
N. CENTRO DESTRA (NCD) – UN. DEI DEMOCRATICI (UDC)	–	–	NCD–UDC	Others
PARTITO COMUNISTA	PARTITO COMUNISTA	–	Partito Comunista	Others
ALTERNATIVA POPOLARE	ALTERNATIVA POPOLARE	altern_popol	Alternativa Popolare	Others
AZIONE	–	azione	Azione	Others
SUE	–	sue	SUE	Others
PACETERRA	–	paceterra	Paceterra	Others
LIBERTÀ	–	liberta	Libertà	Others
DEMOCRAZIA SOVRANA POPOLARE	DEMOCRAZIA SOVRANA POPOLARE	democrazia sovrana popolare	Democrazia Sovrana Popolare	Others
IO CAMBIO–MAIE	–	–	Io Cambio–MAIE	Others
ITALIA DEI VALORI (IDV)	–	–	Italia dei Valori (IDV)	Others
DESTRE UNITE–CASAPOUND AEMN	DESTRE UNITE–CASAPOUND	–	Destre Unite–CasaPound	Others
PARTITO ANIMALISTA ITALIANO	PARTITO ANIMALISTA ITALIANO	–	Partito Animalista	Others
POPOLARI PER L'ITALIA	POPOLARI PER L'ITALIA	–	Popolari per l'Italia	Others
PARTITO DEMOCRATICO EUROPEO PDE ITALIA	PDE ITALIA	pde italia	PDE Italia	Others
FORZA NUOVA	FORZA NUOVA	–	Forza Nuova	Others

Table C.12: Rome — standardized cross-year mapping of parties (2014–2024) with classification between Main Parties and Others.

Party evolution

The evolution of party support in Rome reveals a pattern of rapid and recurrent realignment. The *Partito Democratico (PD)* experienced a progressive erosion of its electorate, reflecting both national fatigue and the fragmentation of the centre-left. Conversely, *Fratelli d'Italia (FdI)* and *Lega* expanded dramatically between 2014 and 2019, becoming the dominant bloc by 2024 as conservative and nationalist narratives gained traction. *Forza Italia (FI)*, once hegemonic within the centre-right, steadily declined across all three rounds.

The *Movimento 5 Stelle (M5S)* — the principal anti-establishment force in 2014 — suffered a marked loss of support after its initial surge, unable to sustain a coherent base by 2024. Meanwhile, smaller actors like *SI–Verdi*, *Azione*, and *PDE Italia* remained relatively marginal but offered ideological continuity across elections, contributing to the system's pluralism.

Despite the proliferation of lists, the share of `Others` — which aggregates ephemeral or non-recurring formations — consistently remained below 15% of total valid votes. This stability indicates that most electoral reallocation in Rome occurred among the enduring political poles rather than through the emergence of entirely new forces. Consequently, the mapping approach adopted here appears both empirically justified and analytically robust, enabling a faithful estimation of electoral volatility within a complex and fluid political environment.

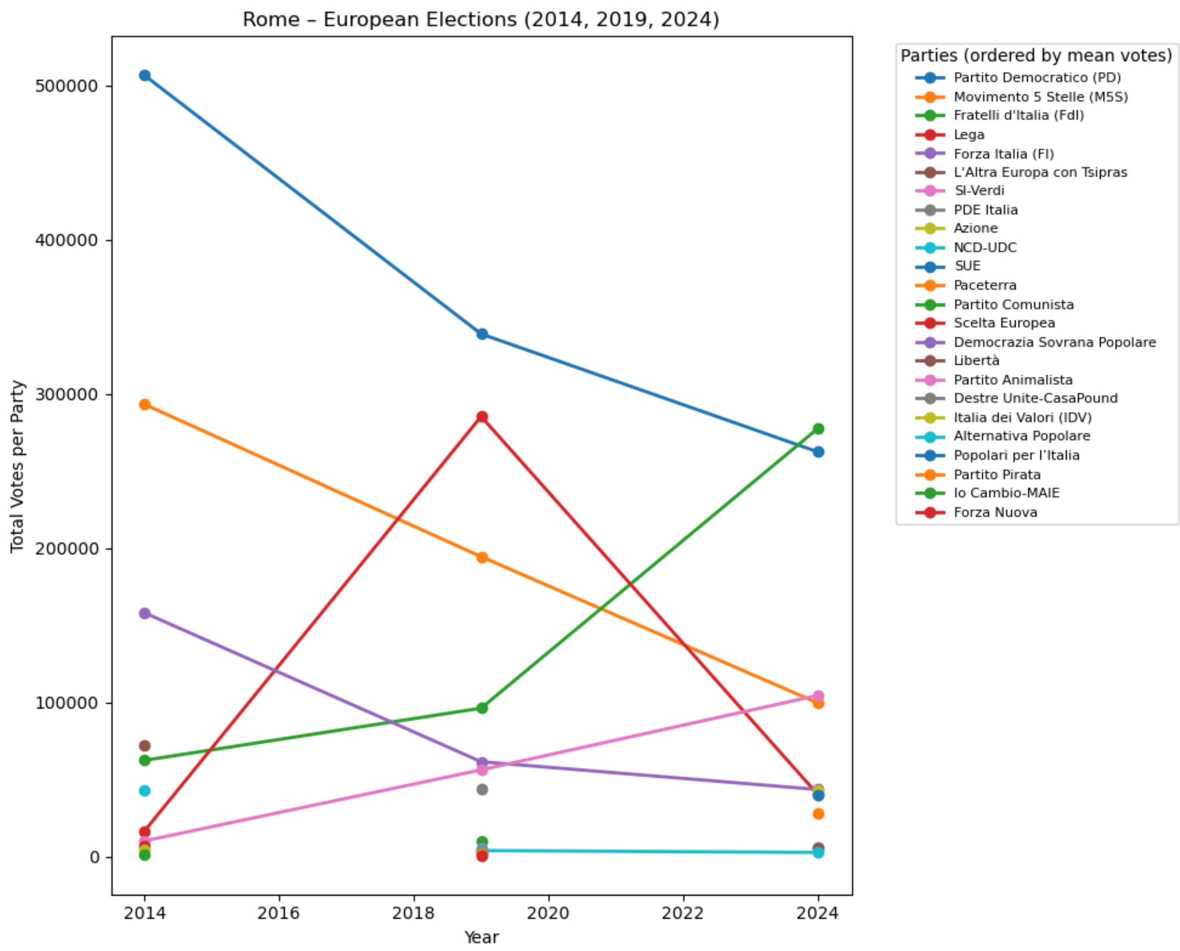

Figure C.3: Rome — total votes by party in the European elections of 2014, 2019, and 2024.

C.3. Conclusion on Method and Assumptions

This appendix set out a conservative path to measuring electoral volatility as civic reallocation rather than artefact. We fixed the scope to the last three European Parliament elections (2014, 2019, 2024) so that rules and tiers are constant, and we standardized labels with minimal intervention: candidate, list, and party were reconciled where needed; only parties recurring in all three rounds were kept as named series; every other list was pooled into `Others`, capped at 15% of valid votes. Row-level checks ensured party totals matched the `Valid` count within tolerance. Under these controls, Pedersen's index captures genuine movement in vote shares.

The city evidence aligns with this design. In Paris, the centrist bloc surged in 2019, the Greens peaked the same year, the Socialist Party recovered in 2024, and the National Rally consolidated. In Berlin, the Greens spiked in 2019 then fell back in 2024, the SPD eroded, the CDU stayed resilient but limited, and AfD expanded. In Rome, the PD declined across the decade, Fratelli d'Italia and Lega became dominant, the M5S lost momentum, and FI continued to contract; the green–left current was tracked consistently via the SI–Verdi consolidation. Across all three cities the `Others` bucket remained small and stable, indicating that most change occurred among enduring poles of competition.

Taken together, the uniform election tier, transparent mappings, and bounded residual category reduce the two main fragilities of volatility measurement: party engineering and institutional heterogeneity. The resulting EV estimates therefore reflect substantive shifts in voter preferences across places and time, not noise from label harmonisation or data aggregation.

D

Accessibility in Paris, Berlin, and Rome

This appendix presents the accessibility maps used in the spatial analysis of proximity and civic engagement. All data were provided by *Sony Computer Science Laboratories (SonyCSL)* and computed using the methodological framework developed by Bruno et al. (2024), which introduces a universal, data-driven approach to the measurement of 15-Minute City accessibility.

D.1. Methodological reference

Following Bruno et al. (2024), accessibility is expressed as the *Proximity Time* (*PT*), defined as the average walking time—measured along the street network—from the centroid of each hexagonal cell to the nearest facility of a given category. This measure integrates spatial coverage, population distribution, and network-based distances to evaluate how easily residents can reach essential services. All results were obtained from the open-access SonyCSL platform for proximity-based cities (https://whatif.sonycsl.it/15mincity).

The spatial unit is a regular hexagonal grid (side length ≈ 400 m), ensuring comparability across cities of different sizes and densities. Lower *PT* values (blue) indicate higher accessibility, while higher *PT* values (red) denote longer walking times to reach equivalent services.

D.2. Service categories

The maps are organized into nine accessibility dimensions corresponding to the functional categories defined in the Bruno et al. (2024) framework:

- **Culture** – museums, theatres, and cultural venues.
- **Education** – schools and universities.
- **Healthcare** – hospitals, clinics, and pharmacies.
- **Outdoor spaces** – parks and public green areas.
- **Physical activity** – gyms and sports facilities.
- **Eating** – restaurants, cafés, and bars.
- **General services** – postal offices and administrative facilities.
- **Supply** – grocery stores and essential retail.
- **Public transport** – metro, bus, and tram stops.

D.3. Maps and Descriptions by City

Figures D.2–D.3 display the estimated accessibility by foot for Berlin, Paris, and Rome. Each map uses a continuous red–blue color scale normalized to the *PT* distribution within each city, highlighting spatial contrasts between highly accessible areas and peripheral zones.

D.3.1. Paris

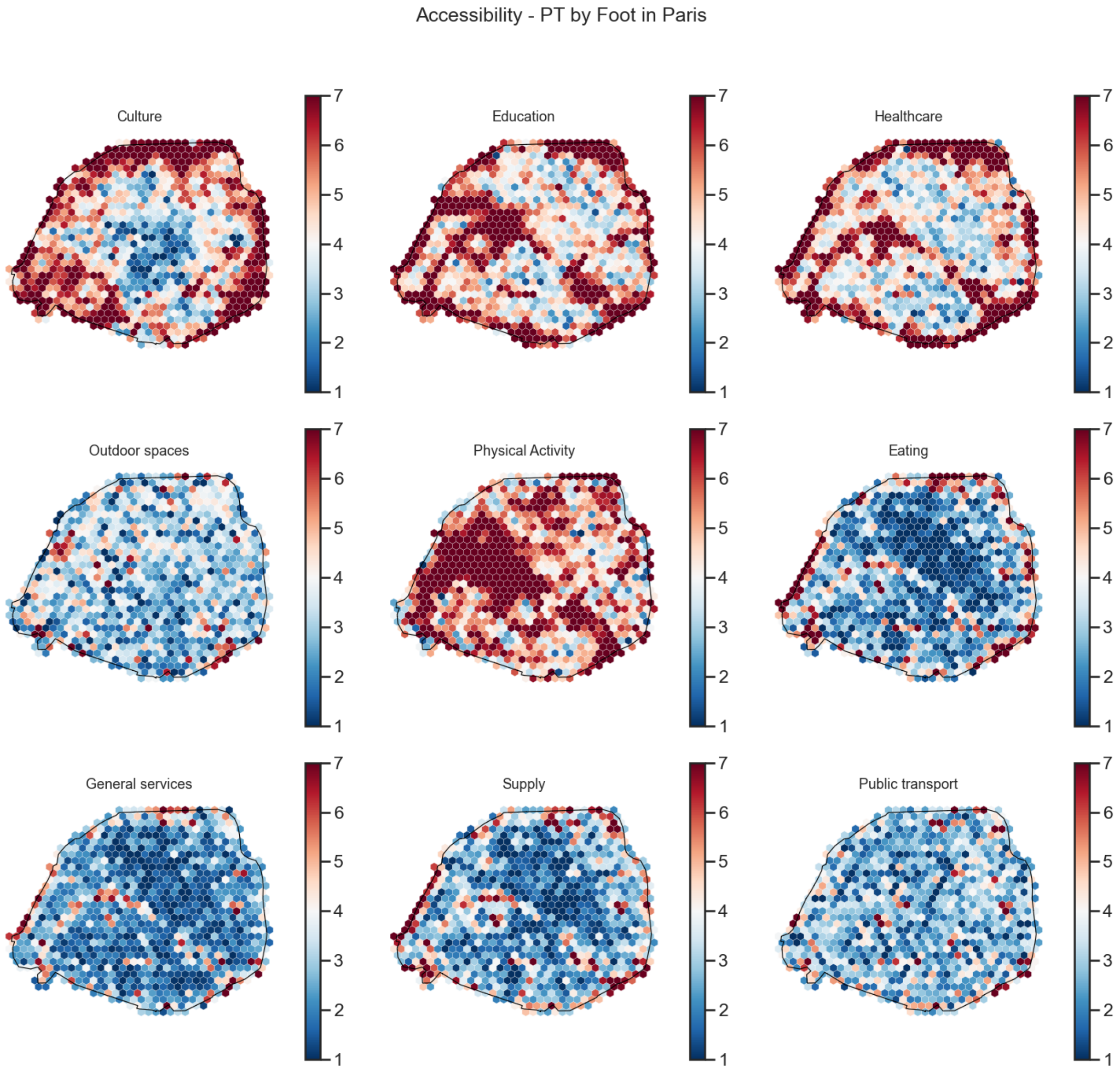

Figure D.1: Accessibility in Paris - PT by foot. Blue areas represent shorter proximity times. Central arrondissements show the highest accessibility levels.

Paris reveals a strong core-periphery structure with a high concentration of services within the inner arrondissements. Low *PT* values cluster tightly around the historical core, where population and amenities overlap spatially. Peripheral zones, particularly beyond the Boulevard Périphérique, show higher *PT* values due to fragmented service distribution and physical discontinuities. This topology reflects a monocentric urban form, where accessibility is strongly dependent on central proximity and limited by urban density gradients.

D.3.2. Berlin

Berlin exhibits a relatively polycentric spatial organization. The accessibility patterns extend beyond the historical core, forming several secondary hubs distributed along major radial axes. The spatial extent

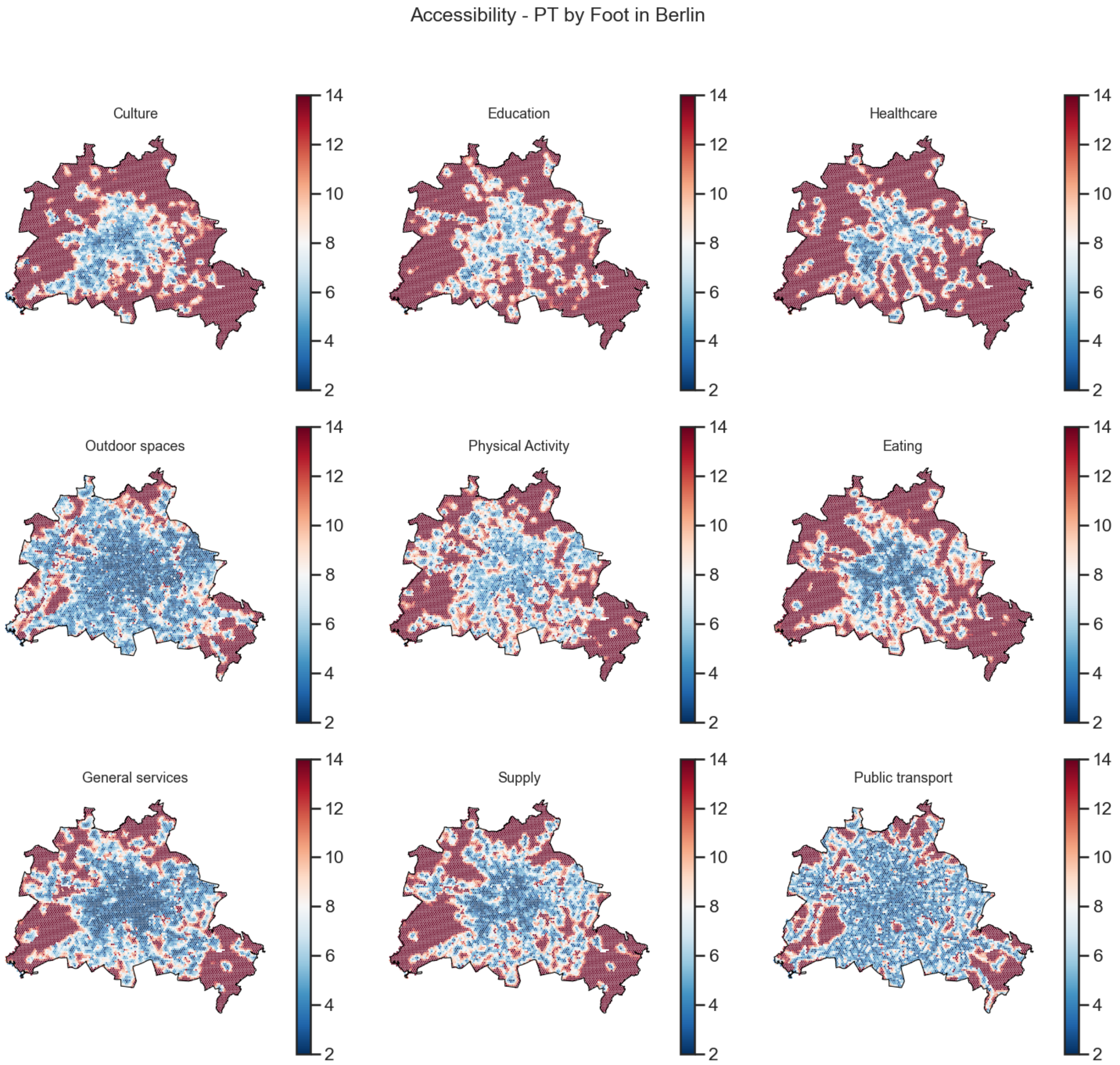

Figure D.2: Accessibility in Berlin - PT by foot. Blue areas represent shorter proximity times.

of low *PT* values suggests an even distribution of urban services, particularly in central and eastern districts, consistent with the city's balanced topology and post-reunification development. Peripheral areas, especially in the southern and western sectors, remain less connected, reflecting lower service density rather than physical distance constraints.

D.3.3. Rome

Rome displays a markedly uneven accessibility structure. The concentration of low *PT* values within the central area contrasts with the sparse and discontinuous distribution of services in peripheral neighborhoods. The large territorial scale and topographic constraints—particularly the river Tiber and surrounding hills—further accentuate spatial disparities. The city's poly-nucleated morphology, with few localized hubs such as EUR and Tiburtina, does not fully compensate for the central dominance in service provision, reinforcing the dependence on motorized mobility.

Figure D.3: Accessibility in Rome - PT by foot. Blue areas represent shorter proximity times. Accessibility is concentrated around the historical core.