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Integrating e-bikes and bikesharing with public transport: Impacts on job accessibility and equity

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A R T I C L E I N F O

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Transport equity

A B S T R A C T

Despite their potential to address limitations of conventional cycling, the role of e-bikes and bikesharing systems in improving job accessibility and transport equity, particularly when integrated with public transport, remains underexplored. This study addresses this gap by evaluating the impacts of e-bikes and bikesharing on job accessibility and spatial equity in São Paulo, Brazil, through a systematic comparison of access-only, egress-only, and full integration scenarios combining cycling with public transport. Cycling travel times are modeled using GPS data from a large-scale bikesharing system. Results show that, when used to access public transport, e-bikes substantially increase job accessibility relative to access by walking, and also relative to conventional bicycles across all travel-time thresholds, although their relative advantage diminishes as travel times increase. Access-only and egress-only configurations produce comparable gains independently, while full integration scenarios yield the largest improvements. The inclusion of bikesharing at egress further amplifies accessibility gains, particularly at longer thresholds, while substantial accessibility deficits persist in peripheral areas. Equity analyses using the Concentration Index and bivariate Local Moran's I indicate that cycling-based integration with public transport reduces but does not eliminate income-based and spatial inequalities, with bikesharing at egress generating larger equity improvements than cycling at access alone. Job accessibility gains from e-bikes and bikesharing are relatively larger for lower- and middle-income groups at longer travel times, even as absolute accessibility advantages remain concentrated in higher-income, central areas. These results highlight both the potential and the limits of e-bikes and bikesharing as strategies for improving job accessibility and transport equity in large, highly centralized metropolitan regions, particularly given the uneven spatial distribution of Tembici stations and cycling infrastructure.

1. Introduction

From a time-space perspective, the biggest limitation of commuting by bike is its restricted spatial range compared to motorized modes (Pritchard et al., 2019). Numerous studies on bicycle commuting have concluded that the likelihood of cycling decreases as the distance to the destination increases (e.g., Handy et al., 2014). This limitation is particularly noticeable in large cities, where it is not uncommon for people to commute for long hours to reach their desired destinations. This limitation can be overcome by integrating cycling and public transportation, referred to as bike-and-ride. Kager et al., 2016 argue that the combination of cycling and public transport can work both ways. The bicycle can soften the rigid nature of public transport, while public transport can dramatically extend cycling's speed and spatial reach. One of the most successful cases of this combination is the Netherlands, where the bicycle is used by 40% of the passengers as first or last mile on home-based trips (de Haas and Kolkowski, 2023).

Several studies have examined how combining cycling with high-capacity public transport impacts accessibility and equity. Kosmidis et al., 2025 showed that integrating bicycles as access and egress options improved job accessibility and reduced inequality, though accessibility levels remained below those achieved by car travel. Lopes et al., 2025 observed that combining bike-sharing and public transport increased accessibility, especially in peripheral areas near docking

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stations, but equity effects varied by opportunity type. Liu et al., 2024 found that bike–transit integration expanded accessible opportunities by up to 70%. In addition, Pritchard et al., 2019 found that bike-and-ride systems in São Paulo could substantially enhance job accessibility despite not producing a more equitable spatial distribution. The authors concluded that bicycles alone cannot offset broader structural factors limiting accessibility in certain areas.

Despite growing attention to the integration of cycling and public transport, several gaps remain. In the context of cycling, accessibility depends strongly on travel time, physical effort, and perceived comfort. Electric bicycles are particularly relevant because they reduce physical exertion and increase average speed, which allows riders to travel farther and overcome topographical and endurance constraints (Bourne et al., 2020; Fyhri et al., 2017; MacArthur & Kobel, 2014). This capacity to extend feasible cycling distance positions e-bikes as an important complement to public transport, since they can provide effective first- and last-mile connectivity. However, the impacts of integrating (shared) e-bikes with public transport on accessibility and equity outcomes remain understudied. Second, most bike-and-ride analyses focus exclusively on travel time and overlook spatial equity considerations. Third, bicycles are often included only as access or egress modes in accessibility studies, ignoring their full potential for multimodal integration (Louro et al., 2026a; Pritchard et al., 2019).

This study addresses these gaps by evaluating how e-bikes, as first- and last-mile components of bike-and-ride systems, influence job accessibility and spatial equity in São Paulo, Brazil. Accessibility is estimated using cumulative opportunity measures, using multiple time thresholds, and spatial equity is assessed with the Concentration Index, comparison between decile groups and bivariate Moran's I.

Accordingly, this paper seeks to answer three key research questions: To what extent do e-bikes, when integrated with metro, rail and bus systems, enhance job accessibility compared with conventional bicycle access in São Paulo? How do these accessibility gains vary spatially across neighborhoods with different socioeconomic profiles? Can e-bikes, as part of bike-and-ride systems, contribute to reducing spatial equity gaps in job accessibility?

2. Methodology

2.1. Study area

This study focuses on the urban area of São Paulo, Brazil's most populous city. Table 1 summarizes key urban indicators from the 2022 Census (IBGE, 2022).

With a population of over 11 million inhabitants, and approximately 20 million in its metropolitan region, São Paulo is a highly urbanized and spatially complex metropolis. According to data from IBGE (2022), the city had an average monthly per capita household income of R$ 2713.36 in 2022, corresponding to approximately 2.2 times the national minimum wage in force that year. Fig. 1 illustrates the spatial distribution of income, formal employment, and population across the municipality.

Population density is more dispersed compared with income and jobs, with higher densities occurring in different areas of the city. Higher-income groups are primarily concentrated in the central-western region, while lower-income populations are more prevalent in the far southern and eastern peripheries. Formal employment is heavily concentrated in the central core, where job density overlaps with high-income areas, reinforcing the city's pattern of economic centralization.

Table 1
Key urban indicators of São Paulo.

Population	11.451.999
Population density (inhabitants/km²)	7.528,26
Average monthly wage of formal workers (in minimum wages[1])	4,1
Urban area (km²)	914,56

[1] The national minimum wage in 2022 was R$ 1212.00 (about USD 230), based on the 2022 average exchange rate.

Regarding mobility, São Paulo's travel patterns remain predominantly motorized, as approximately 72% of trips involve motorized modes, according to the Origin–Destination Survey (Metrô, 2023). However, the system is not primarily car-dependent. Public transport accounts for 39.4% of daily trips, led by buses (19.2%), metro (11.5%) and commuter rail (2.7%), while private automobiles represent 26.9% of trips. Active modes also play a substantial role, especially walking, which accounts for 26.2% of the trips, while cycling remains limited at 1.1%. To further contextualize these patterns, Fig. 2 presents the spatial distribution of São Paulo's main transport infrastructures, including metro and commuter rail lines (CPTM), bus terminals, and bike-sharing stations.

The distribution of urban infrastructure shows a strong concentration in certain regions. São Paulo's metro system spans 110.9 km and does not form a dense network, leaving much of the population underserved. According to recent infrastructure reports, the metro system is undergoing a major expansion phase, with nearly 15 km of new track expected to open in 2026 (Companhia do Metropolitano de São Paulo, 2026). For comparison, Mexico City, which has a similar population, has over 220 km of metro lines (Reyna et al., 2021). The commuter rail system currently comprises 142 km of operational lines, serving 12 municipalities within the São Paulo Metropolitan Region (CPTM, 2025). The combination of urban sprawl and a lack of high-capacity public transport results in long commuting times, high levels of car use, and the associated negative consequences.

Regarding bus terminals, some are integrated with metro and rail stations, facilitating multimodal trips. Bike-sharing infrastructure is highly concentrated in higher-income areas and is provided by a private company, Tembici. These stations are often located near metro lines, making them suitable for first- and last-mile trips. For an equity analysis regarding the distribution of bikesharing in São Paulo, see Fortes et al., 2024.

2.2. Data

This study draws on multiple datasets obtained from open and institutional sources. Transportation networks were extracted from OpenStreetMap (OpenStreetMap, 2026) using the BBBike extraction service (BBBike.org, 2025), in formats compatible with the r5r package in R (Pereira et al., 2021) and subsequently used to generate travel time matrices. Cycling infrastructure was obtained from the *Mapa de Infraestrutura Cicloviária*, provided by the *Companhia de Engenharia de Tráfego de São Paulo* (CET, 2025). Bikesharing data were supplied by Tembici, a leading bikesharing operator in Brazil, through an agreement with the University of São Paulo. The dataset includes both conventional bicycles and pedal-assisted e-bikes, the latter capable of reaching speeds of up to 25 km/h. Tembici operates a network of docking stations across the city, allowing users to rent and return bicycles at fixed locations.

Employment data were obtained from the *aopdata* package in R (Pereira et al., 2022), which provides harmonized datasets from the Instituto Brasileiro de Geografia e Estatística (IBGE) and the Ministry of Labor. The employment data correspond to 2019, the most recent year available at the time of the study, and are spatially aggregated using a hexagonal grid at resolution 9, indexed by the H3 geospatial system developed by Uber (Brodsky, 2018). Each hexagonal cell covers approximately 0.11 km^2, thereby enabling high-resolution spatial analysis of urban accessibility patterns. The use of high-resolution grid units also mitigates biases associated with the Modifiable Areal Unit Problem (MAUP), as accessibility measures can be systematically overestimated when larger administrative units are employed, potentially distorting conclusions about equity outcomes (Jasso Chávez and Manaugh, 2025; Pereira et al., 2019).

To complement these sources, socioeconomic data on population and

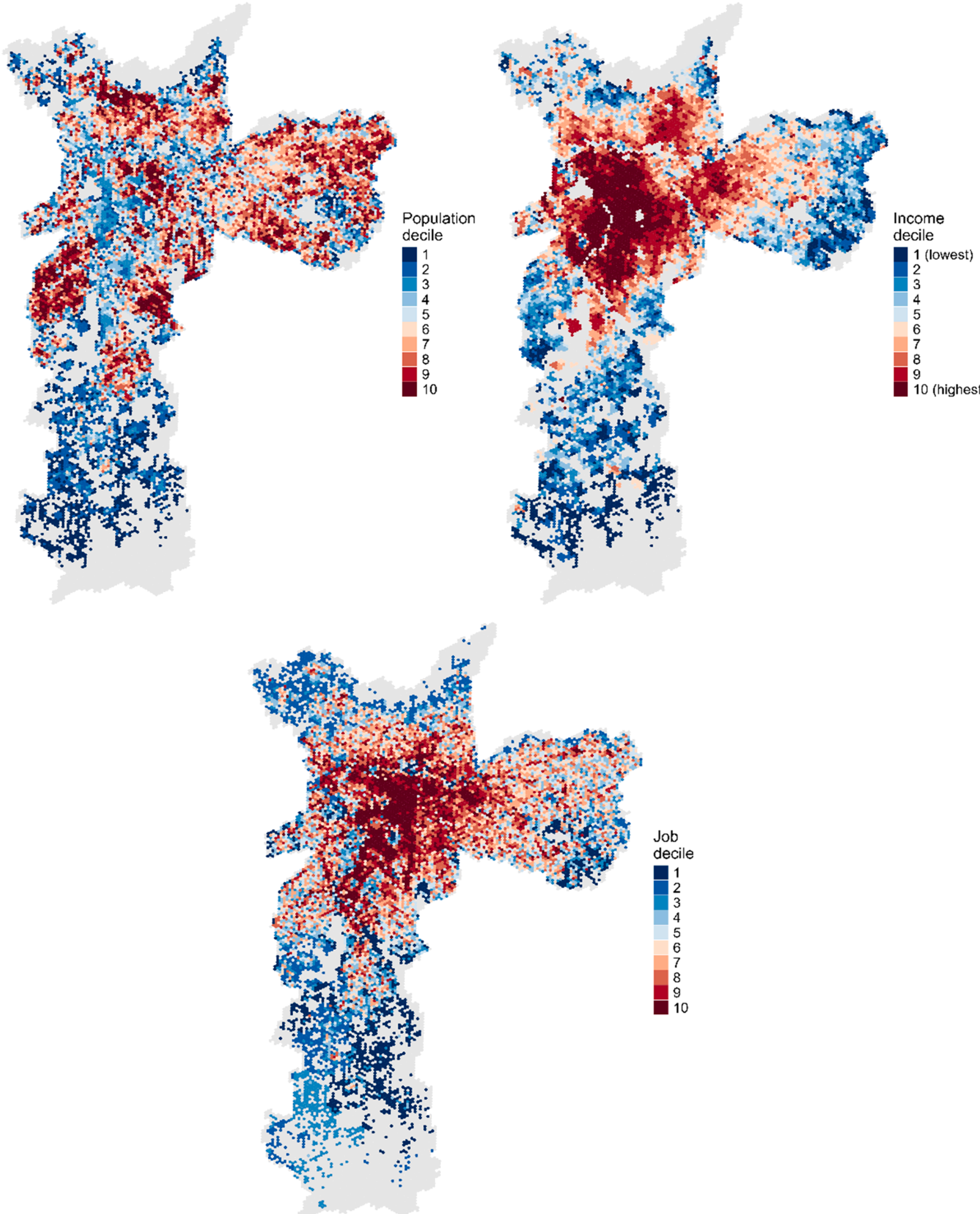

Fig. 1. Distribution of population, income and formal jobs in São Paulo.

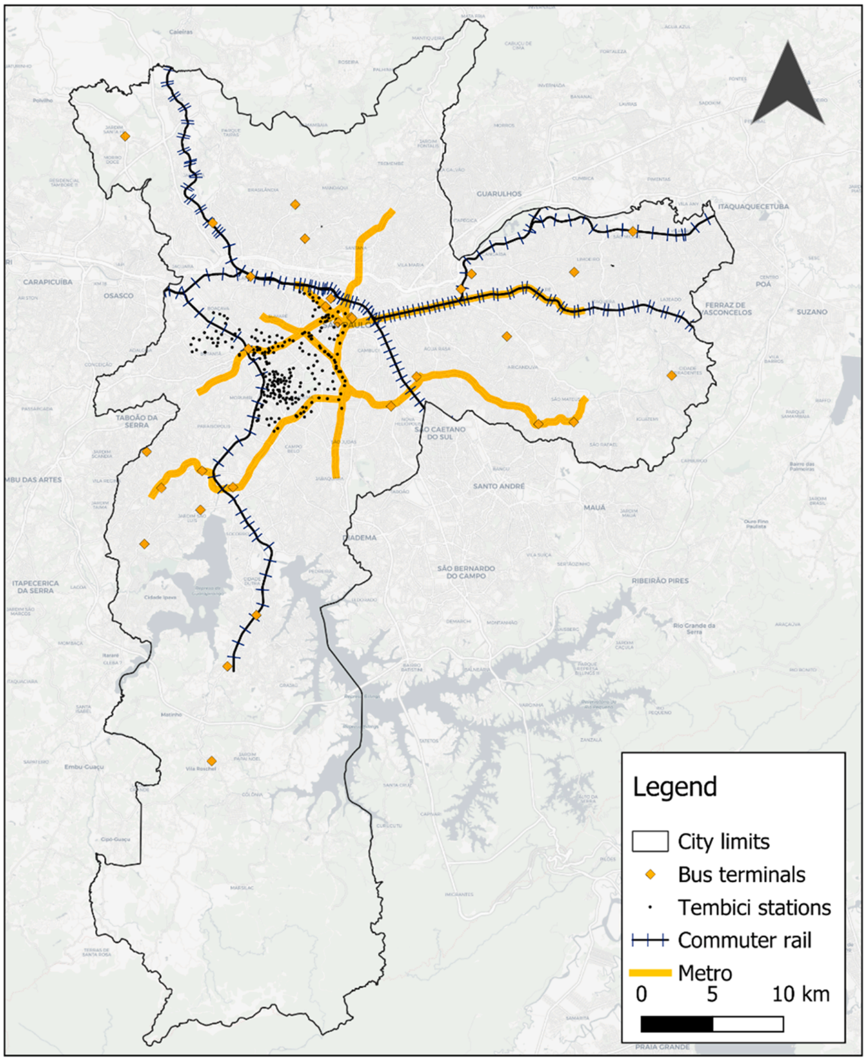

Fig. 2. Public transport infrastructure and bikesharing network in São Paulo.

average income of the household head at the census tract level were obtained from the 2022 IBGE Census through the *cnefetools* package (Pedreira Junior et al., 2026). These data were spatially matched to the same hexagonal grid used for the accessibility metrics, ensuring consistency across datasets. Public transport travel times were estimated using General Transit Feed Specification (GTFS) data provided directly by SPTrans (São Paulo Transporte, 2025).

2.3. Accessibility measurement

Geurs & van Wee (2026) conceptualize accessibility as "the extent to which land use, transport, and digital communication systems enable individuals or groups to participate in activities and reach destinations, physically or virtually, at different times of day". In this context, accessibility patterns emerge from the interaction of social, economic, and spatial factors, including residential and employment locations, network configurations, and differences in individual mobility capacities (Levinson & Wu, 2020; Pereira & Herszenhut, 2023)

Accessibility can be measured through multiple approaches that vary according to data availability, transport mode, and research objectives. These approaches include infrastructure-based, location-based, person-based, and utility-based methods, with some formulations incorporating decay functions or accounting for competition among destinations. In this study, accessibility was calculated using the cumulative opportunity measure, which applies a binary impedance function to count the number of opportunities reachable within a specified travel time, distance, or cost from each origin (Barboza et al., 2021; Geurs & van Wee, 2004). Calculating cumulative accessibility across multiple travel-time thresholds allows for an examination of how access changes as travel time increases, thereby highlighting the incremental gains associated with each additional minute of travel. Levinson (2026) demonstrates that, under certain conditions, different impedance functions, such as cumulative, exponential, or inverse-power, can result in comparable accessibility outcomes.

Common criticisms of cumulative accessibility metrics include their inability to account for competition among opportunities and the potential for misinterpretation when a single threshold is applied (Pereira & Herszenhut, 2023). Nevertheless, the cumulative opportunity measure remains one of the most widely used approaches (Boisjoly & El-Geneidy, 2017; Pereira & Herszenhut, 2023) because of its relatively modest data requirements, ease of computation, and straightforward interpretation. In addition, cumulative measures are often highly correlated with other accessibility metrics (Santana Palacios & El-Geneidy, 2022). The formulation is presented in Equation (1).

$$A_i = \sum O_j \cdot f_t(c_{ij}),\ f_t(c_{ij}) = \begin{cases} 1 \ \text{if} \ c_{ij} \le t \\ 0 \ \text{if} \ c_{ij} > t \end{cases} \tag{1}$$

In which A_i is the accessibility at point i; O_j represents the number of opportunities (like jobs, businesses, services, etc.) at location j; c_{ij} is the travel cost between i and j (time, distance, cost, or a combination of these elements); and the function $f_t(c_{ij})$ returns 1.0 if c_{ij} is less than or equal to a defined cost (t) and zero if it exceeds this threshold. The limiting cost t serves as a calibration parameter and largely depends on users' tolerance for travel costs and the transport mode (Boisjoly & El-Geneidy, 2017; Pereira & Herszenhut, 2023). It is important to note that accessibility calculations in this study focus exclusively on travel time. Monetary costs associated with the use, acquisition, or maintenance of bicycles, e-bikes, bikesharing services, and public transport were considered outside the scope of the analysis.

To address some of the limitations of cumulative accessibility metrics, multiple travel time thresholds were selected: 30, 45, 60, 90, and 120 min. These thresholds represent the total door-to-door travel time, including access, public transport travel, and egress. The selection of these thresholds reflects the distribution of actual commuting times in São Paulo. According to the 2022 IBGE Census, 4% of trips take up to 5 min, 11% between 6 and 15 min, 22% between 15 and 30 min, 32% between 30 and 60 min, 26% between 1 and 2 hours, 3% between 2 and 4 hours, and <1% exceed 4 hours (IBGE, 2022). This distribution shows that while nearly one-third of trips exceed one hour, the majority (69%) are completed within 60 min or less, justifying the range of thresholds selected.

For the cycling component of trips, the typical range of conventional bicycles is commonly considered to be approximately 5 km, with most commuting trips lasting between 15 and 30 min (Mohamed et al., 2024; Pritchard et al., 2019). In São Paulo, the 2023 Origin–Destination survey reported a mean cycling trip duration of 21 min, with the third quartile at 30 min. Accordingly, cycling access and egress legs were constrained to a maximum of 30 min each, while walking access and egress were limited to 20 min. E-bikes have the potential to extend cycling accessibility by mitigating physical constraints, either increasing feasible travel distances or expanding the number of people willing to cycle (Banerjee et al., 2022; de Haas & Kolkowski, 2024; Rybels et al., 2024). By varying travel time thresholds in increments and examining multiple access and egress configurations, this study aims to capture a broad spectrum of travel possibilities across modes and to assess how accessibility outcomes differ under each scenario. All accessibility metrics were calculated using the *accessibility* package in R (Pereira et al., 2024).

2.3.1. Travel time estimation

Cycling and public transport travel times were estimated separately using mode-specific data and models, while applying standardized assumptions regarding time of day and operating conditions. Travel times were estimated using a linear mixed-effects speed model developed for São Paulo by Louro et al. (2026b), based on GPS data from the Tembici bike-sharing system. For the accessibility calculations, only the model's fixed effects were applied, accounting for road characteristics such as slope and segment length, time of day, and the presence of cycling infrastructure. A limitation of this approach is that the model is derived from bike-sharing users, who tend to be younger, more technologically oriented, and likely to make shorter trips concentrated in central areas, and may therefore not fully represent the broader population of cyclists. This may lead to overestimation of cycling speeds in peripheral areas and consequently of accessibility and equity gains for those populations, which should be considered when interpreting the spatial equity results.

Public transport travel times were estimated using General Transit Feed Specification (GTFS) data provided by SPTrans, using median travel speeds between stops derived from Automatic Vehicle Location (AVL) data for the week of June 2 to June 6, 2025. By relying on observed operating conditions rather than scheduled timetables, this approach provides a realistic representation of public transport network performance under typical weekday conditions. Travel times were estimated for a representative 07:30 departure time using a 60-minute departure window, with median travel times used to account for short-term service variability.

2.3.2. Bike-and-ride modelling

Job accessibility by public transport combined with cycling was estimated by integrating multiple travel-time models representing different access and egress configurations. Seven scenarios were specified (Table 2): (i) a walk–public transport–walk baseline; (ii) private bicycle access with walking egress; (iii) private e-bike access with walking egress; (iv) walking access with shared bicycle egress; (v) walking access with shared e-bike egress; (vi) private bicycle access combined with shared bicycle egress; and (vii) private e-bike access combined with shared e-bike egress. This design specification enables the identification of marginal accessibility gains associated with introducing cycling in the access and/or egress legs relative to the walk–-public transport baseline, while also distinguishing the incremental contribution of e-bikes compared to conventional bicycles.

The walk→PT→walk configuration served as the baseline, representing conventional public transport trips with pedestrian access and egress. Walking speed was fixed at 3.6 km/h (the default in *r5r*), access and egress walking times were limited to 20 min each, and total trip duration was capped at 120 min. All cycling-based alternatives were evaluated relative to this reference.

Cycling was first introduced as an access mode only. In these scenarios, travelers could reach metro, commuter rail (CPTM), and major bus terminals by private bicycle or private e-bike, while the egress leg from the final public transport station to the final destination was completed on foot. Access cycling trips were limited to 30 min, and the model differentiated between conventional bicycles and e-bikes. Public transport travel times between stations were computed using the *r5r* package (Pereira et al., 2021), explicitly accounting for waiting times and transfers.

Next, cycling was introduced as an egress mode only through bike sharing. Travelers could access public transport on foot and, after arriving at the final station, complete the final leg using bikesharing. In these scenarios, we used the existing bikesharing stations in São Paulo and assumed that bikes and e-bikes were always available at the stations. Travelers could walk up to 5 min to reach a nearby bike-sharing station and, after returning the bicycle, could walk up to 5 min to the final destination. The total bikesharing segment was limited to 30 min.

Finally, two complete bike-and-ride scenarios were developed, combining cycling in both trip legs by using private bicycles or e-bikes for access and shared bicycles or shared e-bikes for egress.

For each scenario, travel-time matrices were constructed by combining the relevant access, in-vehicle, transfer, and egress components. In addition, unimodal trips by bike and e-bike were estimated separately, with a maximum duration of 30 min. Following a rule-based selection algorithm adapted from Pritchard et al., 2019, the baseline transit option, the corresponding multimodal alternative, and unimodal cycling were compared for each origin–destination pair, and the minimum travel time was retained, as shown in Fig. 3. This procedure was applied independently to each of the six scenarios with cycling at some point, resulting in one final travel-time matrix per scenario.

The resulting bike-and-ride model represents a best-case integration of cycling and public transport. For each origin–destination pair, travelers may complete the trip entirely by bicycle or combine transit with either walking or cycling for the access and/or egress legs. The walk→PT→walk configuration serves as the default reference.

Table 2
Travel-time scenarios combining public transport, cycling, and bike sharing.

Scenario	Access mode	Egress Mode
Walk→PT→Walk (baseline)	Walking	Walking
Private bike→PT→Walk	Private bike	Walking
Private E-bike→PT→Walk	Private E-bike	Walking
Walk→PT→Shared bike	Walking	Shared bike
Walk→PT→Shared E-bike	Walking	Shared E-bike
Private bike→PT→Shared bike	Private bike	Shared bike
Private E-bike→PT→Shared E-bike	Private E-bike	Shared E-bike

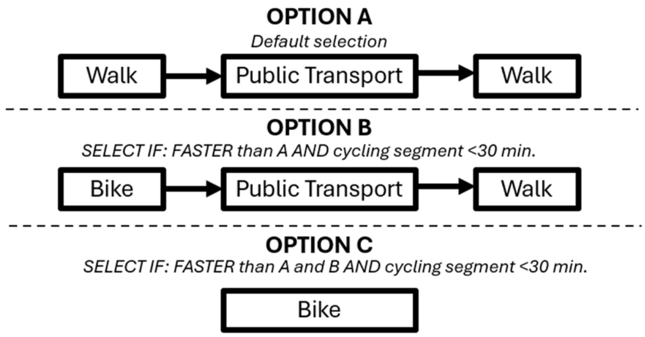

Fig. 3. Rule-based selection algorithm for bike-and-ride travel time estimation.

Multimodal bike–PT alternatives are retained only when they provide shorter travel times than the walk-based transit option, while unimodal cycling is selected only when it is faster than both transit-based alternatives. Fig. 3 illustrates this rule-based selection procedure for one scenario as an example; the same algorithm was applied independently to all six scenarios that incorporate cycling.

2.4. Equity methodology

To assess the spatial equity of accessibility outcomes, three complementary approaches were employed: the Concentration Index (CI), the bivariate Local Moran's I, and an income-decile analysis of accessibility outcomes. Together, these methods provide a comprehensive understanding of equity in accessibility outcomes (Karner et al., 2025).

The CI quantifies the extent to which accessibility disparities are systematically associated with income by comparing the cumulative distribution of accessibility with the income-ordered population distribution (Karner et al., 2025; Shen et al., 2020). CI values range from −1 to +1, where negative values indicate a pro-poor distribution (greater accessibility among lower-income populations) and positive values reflect a pro-rich distribution. All computations were performed in R using the *accessibility* package (Pereira et al., 2024).

To capture the spatial dimension of inequality, spatial associations between income and accessibility were further analyzed using the bivariate Local Moran's I (Anselin et al., 2002; Lee, 2001). This statistic identifies significant spatial clusters where income and accessibility jointly exhibit high or low values, classified as High–High (H–H), Low–Low (L–L), High–Low (H–L), or Low–High (L–H). The analysis was implemented in the *spdep* package (Bivand & Wong, 2018), which operationalizes the bivariate Local Moran's I.

Finally, to provide an intuitive portrayal of the socioeconomic gradient of accessibility, outcomes were also analyzed by income decile. For each travel-time threshold and across all scenarios, the population-weighted distribution of accessible jobs was examined.

3. Results

3.1. Accessibility

As an initial exploratory analysis, Table 3 presents the population-weighted percentage of jobs accessible across all scenarios and travel-time thresholds in São Paulo. The values represent the share of total jobs accessible within each time threshold, calculated using a population-weighted average as described in Equation 2:

$$\textit{Population Weighted Accessibility } (\%) = \left(\frac{\sum_i (AccessibleJobs_i \ x \ Population_i)}{\sum_i Population_i \ x \ Total \ Jobs}\right) x100 \quad (2)$$

Where i denotes each spatial unit.

The results show that integrating cycling with public transport substantially increases job accessibility across all travel-time thresholds. At 30 min, the walk→PT→walk baseline provides access to only 1.5% of jobs, while cycling-based scenarios reach between 9.0% and 12.3% depending on configuration. At 120 min, baseline accessibility increases to 66.2%, compared with 73.2% to 87.1% for scenarios incorporating cycling.

Table 3
Average accessibility to jobs by scenario and travel time threshold (% of total jobs).

Scenario	30 min	45 min	60 min	90 min	120 min
Walk→PT→Walk (baseline)	1.5%	6.1%	15.0%	42.2%	66.2%
Private bike→PT→Walk	9.3%	15.3%	27.4%	54.8%	73.2%
Private E-bike→PT→Walk	11.7%	17.8%	30.3%	57.5%	74.8%
Walk→PT→Shared bike	9.0%	12.8%	23.6%	55.4%	76.9%
Walk→PT→Shared E-bike	11.4%	14.8%	25.6%	57.9%	79.1%
Private bike→PT→Shared bike	9.9%	20.1%	36.1%	67.9%	84.4%
Private E-bike→PT→Shared E-bike	12.3%	24.4%	42.0%	72.9%	87.1%

Access-only and egress-only scenarios demonstrate comparable gains when introduced independently. Private bicycle access (Private bike→PT→Walk) reaches 9.3% of jobs at 30 min, while bikesharing at egress (Walk→PT→Shared bike) achieves 9.0%, indicating that cycling at either trip end can substantially expand accessibility. E-bike variants performed consistently better, with Private E-bike→PT→Walk reaching 11.7% and Walk→PT→Shared E-bike 11.4%. Although the absolute increase was approximately 2.4 percentage points, in a labor market the size of São Paulo this represents thousands of additional accessible jobs. These results suggest that electrification generates meaningful accessibility gains regardless of whether it is applied to the access or egress leg.

Full integration scenarios, combining private bicycle or e-bike access with shared bicycle or e-bike egress, generated the highest accessibility levels. The Private bike→PT→Shared bike scenario reaches 36.1% of jobs at 60 min and 84.4% at 120 min, while the equivalent e-bike scenario reaches 42.0% and 87.1%, respectively.

E-bikes consistently provided higher accessibility than conventional bicycles, although their relative advantage diminished as travel time increased. At 30 min, e-bikes increased accessibility by approximately 24–26% relative to conventional bicycles, whereas at 120 min the gains fell to around 2–3%. This pattern reflects the diminishing share of cycling in total travel time: as overall trip duration increases, the marginal impact of higher cycling speeds on accessibility declines.

Next, Fig. 4 presents the proportion of São Paulo's population that can access different shares of employment opportunities under all seven scenarios and travel-time thresholds.

Fig. 4 illustrates how these accessibility gains translate into population coverage across job-share thresholds. At 30 min, the baseline allows only 3% of the population to access 10% of jobs, with no residents reaching 25% or more. Private bicycle access raises these figures to 28% and 11%, respectively, while e-bikes increase them further to 36% and 15%. Under full integration with e-bikes (EB+PT+EBS), 37% of the population can access 10% of jobs, 17% can reach 25%, and 0.3% can access 50% of total employment. At 60 min, the baseline enables 45% of the population to access 10% of jobs and 6% to reach 50%. Cycling scenarios expand these shares considerably: under B+PT+W, 65% can reach 10% and 22% can reach 50%, rising to 70% and 26% with e-bikes. Full integration (EB+PT+EBS) enables 79% of the population to access 10% of jobs and 45% to reach 50%, an eightfold improvement over the baseline at this threshold.

At longer thresholds, the gaps narrow but do not disappear. At 90 and 120 min, most residents can access a large share of jobs regardless of scenario, so differences at lower job-share thresholds become small. However, gaps remain meaningful at higher thresholds. At 90 min, the baseline enables 40% of the population to reach 50% of jobs, compared

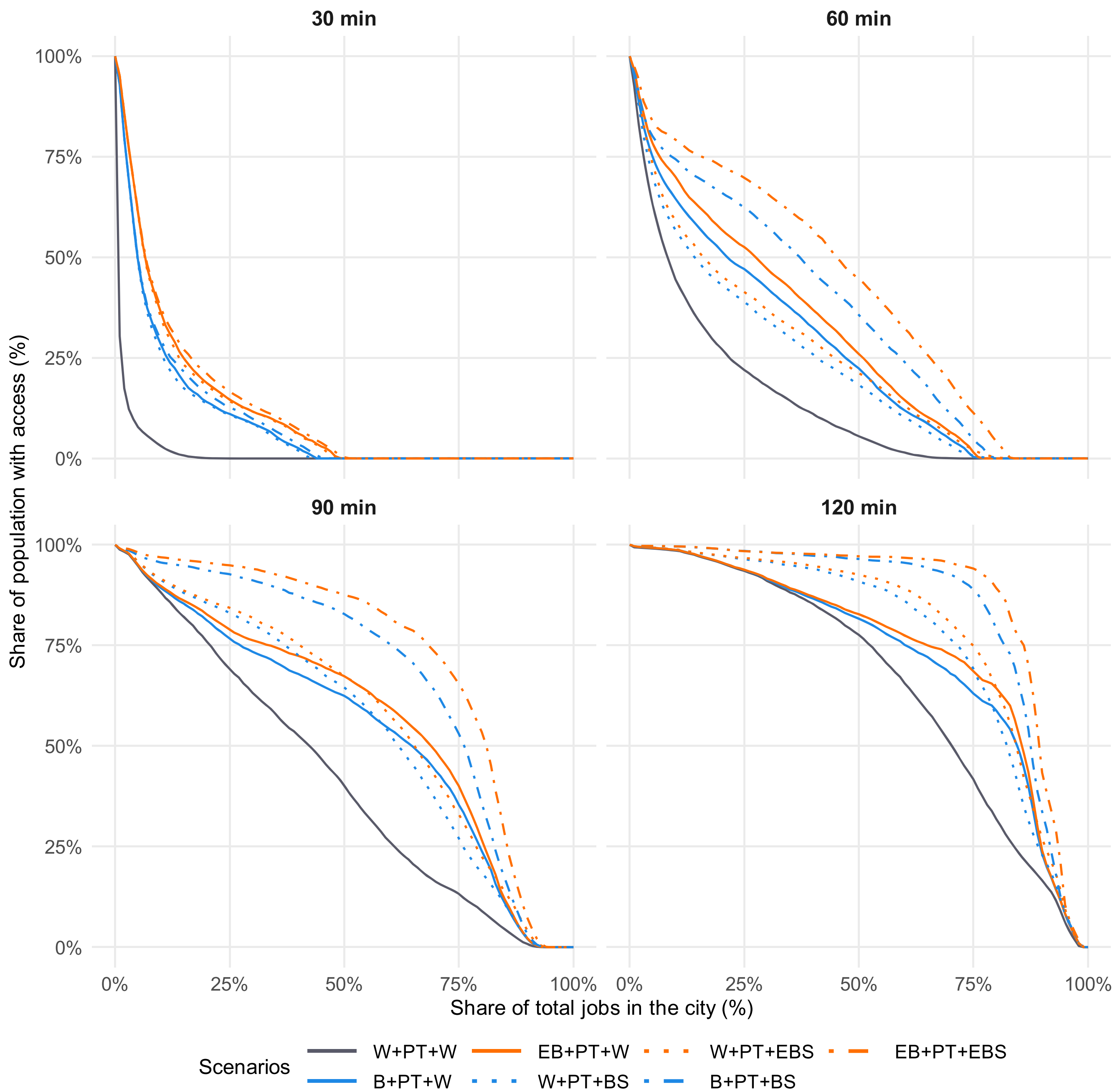

Fig. 4. Percentage of population with access to jobs by walk-and-ride, bike-and-ride and e-bike-and-ride in São Paulo across different travel time thresholds.

with 88% under EB+PT+EBS. At 120 min, this gap narrows but persists: 97% of residents can access 50% of jobs under full integration with e-bikes, against 78% under the baseline.

To examine spatial patterns, Figures 5 and 6 present the share of total citywide jobs accessible from each hexagonal cell under different scenarios and travel-time thresholds. Fig. 5 displays access-only and egress-only configurations, showing absolute accessibility for walk→PT→walk, private bike→PT→walk, and walk→PT→shared bike, along with the percentage increase from e-bikes relative to conventional bicycles for both access (EB+PT+W) and egress (W+PT+EBS). Fig. 6 presents full integration scenarios, where cycling is available at both trip ends (B+PT+BS and EB+PT+EBS), compared against the walk→PT→walk baseline.

Across all scenarios, job accessibility is concentrated in central São Paulo, reflecting the city's monocentric employment structure. Under the baseline and for smaller thresholds, accessibility is largely confined to areas near metro and rail corridors, with limited reach into peripheral neighborhoods.

Private bicycle and e-bike access expand the catchment area of transit stations, producing a more spatially homogeneous accessibility pattern along major corridors and adjacent neighborhoods, while bike-sharing at egress produces a different spatial pattern, one more closely tied to the metro network. Despite these differences, both access-only and egress-only cycling substantially increase accessibility relative to the baseline.

The e-bike gain maps show largest relative gains at shorter thresholds and at the edges of the central region, where conventional cycling already provides moderate accessibility but e-bikes extend feasible

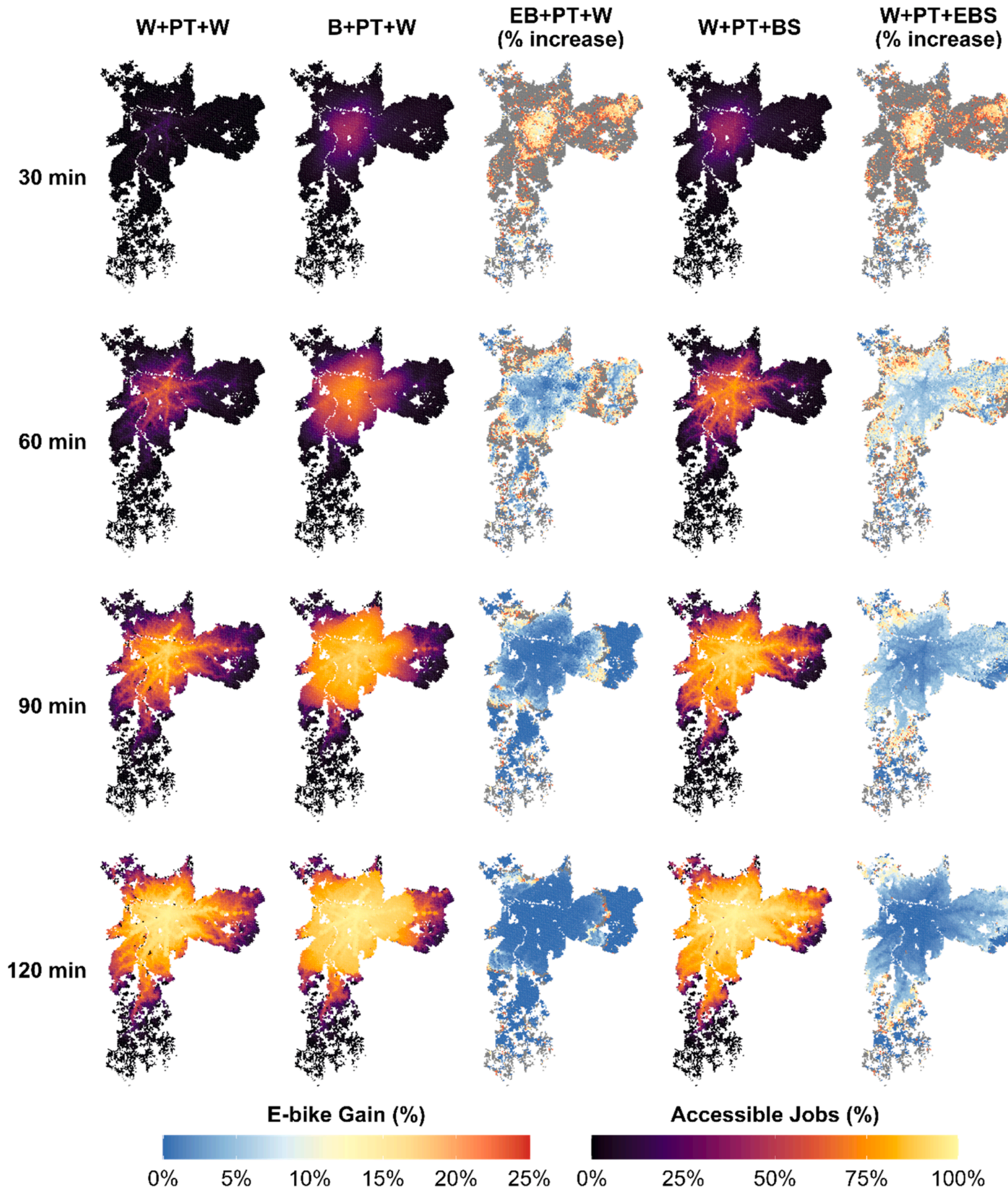

Fig. 5. Spatial distribution of job accessibility by walk-and-ride, bike-and-ride, and e-bike-and-ride across travel time thresholds.

reach. At 30 and 60 min, gains reach up to 25% in these intermediate zones. At 90 and 120 min, e-bike advantages diminish as public transport travel time dominates total trip duration, reducing the marginal contribution of the cycling legs.

At longer thresholds, accessibility spreads across most of the city, but the eastern and southern peripheries continue to show lower accessibility even at 120 min, indicating that even extended travel-times are not enough to integrate these regions to the full labor market.

Under full e-bike integration (EB+PT+EBS), accessibility increases across the entire city, with near-universal coverage in central areas and meaningful gains in intermediate zones. Peripheral areas remain comparatively less accessible, indicating that spatial inequality persists even under the most favorable scenario.

3.2. *Equity*

To assess equity outcomes across the different access and egress scenarios, we analyze the Concentration Index across all travel-time thresholds in São Paulo. The results are presented in Table 4.

The Concentration Index remains positive across all scenarios and thresholds, confirming that job accessibility consistently favors higher-income groups. However, the degree of inequality varies substantially across scenarios and decreases as travel-time increases.

Table 4 shows that the degree of inequality varies substantially across scenarios and decreases as travel time increases. At 30 min, the baseline shows the highest concentration (CI = 0.53). Introducing cycling at either trip end reduces this to 0.42–0.44, a relative reduction of 17–21%, with e-bikes producing marginally lower values than conventional bicycles. At 60 min, the baseline CI falls to 0.43, while cycling-based scenarios range from 0.26 to 0.40. Full integration scenarios

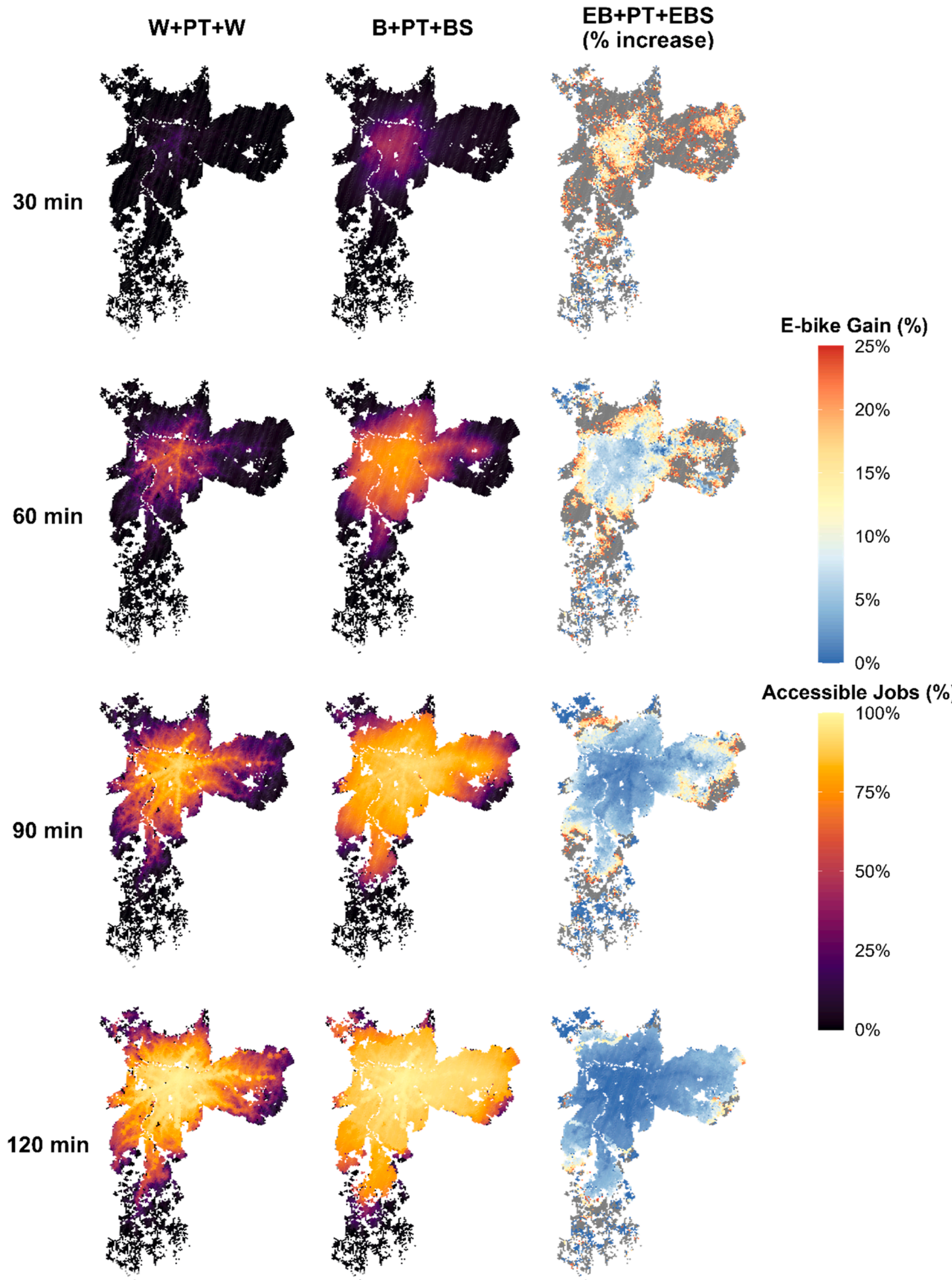

Fig. 6. Spatial distribution of job accessibility gains from e-bikes and the impact of bikesharing at egress in São Paulo.

reduce concentration by 30–40% relative to the baseline, with the full integration scenario with e-bikes reaching 0.26 compared with 0.30 for the conventional bicycle equivalent.

At longer thresholds, cycling integration produces increasingly equitable distributions. At 90 and 120 min, concentration declines substantially across all scenarios. At 120 min, the baseline reaches 0.14, while the full integration scenario with e-bikes achieves 0.03, a 79% reduction. These patterns indicate that extended travel-time budgets combined with cycling at both trip ends produce increasingly equitable accessibility distributions.

The relative contribution of access and egress cycling also shifts with travel time. At shorter thresholds, access-only and egress-only cycling produce similar CI values, with access-only scenarios performing slightly better at 45 and 60 min. At longer thresholds (90 and 120 min), egress-only bikesharing generates somewhat greater equity improvements, suggesting that last-mile connectivity becomes relatively more important as travel-time budgets increase.

To further examine distributional patterns, we analyzed job

Table 4
Concentration Index for all scenarios.

Scenario	30 min	45 min	60 min	90 min	120 min
Walk→PT→Walk (baseline)	0.53	0.5	0.43	0.25	0.14
Private bike→PT→Walk	0.44	0.43	0.37	0.21	0.12
Private E-bike→PT→Walk	0.42	0.41	0.34	0.19	0.11
Walk→PT→Shared bike	0.44	0.47	0.4	0.19	0.09
Walk→PT→Shared E-bike	0.42	0.45	0.39	0.18	0.08
Private bike→PT→Shared bike	0.44	0.42	0.3	0.11	0.05
Private e-bike→PT→Shared E-bike	0.42	0.38	0.26	0.09	0.03

accessibility across income deciles for all scenarios and travel-time thresholds. Figures 7 and 8 present accessibility levels by income group for access/egress-only scenarios and full integration scenarios, respectively.

Across all scenarios, accessibility exhibits a clear socioeconomic gradient, with higher-income deciles consistently accessing a larger share of employment opportunities. In access/egress-only scenarios (Fig. 7), cycling increases accessibility for all income groups, with lower- and middle-income deciles experiencing relatively larger gains at longer travel-time thresholds. E-bikes provide higher accessibility than conventional bicycles across all deciles, with more pronounced advantages for lower-income groups at medium thresholds.

In full integration scenarios (Fig. 8), accessibility increases substantially across all income groups, particularly at 90 and 120 min, when the combination of private cycling for access and bikesharing for egress enables most residents to reach the majority of employment opportunities. The full integration scenario with e-bikes produces the highest accessibility levels overall and the most compressed distributional spread, indicating reduced inequality. Despite these improvements, absolute accessibility advantages remain concentrated among higher-income deciles across all configurations, consistent with the positive Concentration Index values observed at shorter thresholds.

To assess spatial equity patterns, we examined the joint spatial distribution of income and job accessibility using a bivariate Local Moran's I. Figures 9 and 10 present the resulting spatial clusters for five access/egress-only scenarios and three full integration scenarios, respectively.

Under the baseline scenario, High-High clusters concentrate in central São Paulo along metro and rail corridors, while Low-Low clusters dominate the southern and eastern peripheries and Low-High clusters appear near central areas at shorter thresholds.

In access/egress-only scenarios (Fig. 9), cycling integration shifts the spatial distribution of clusters in two ways. First, High-High clusters expand outward from the center as cycling extends the reach of transit stations into surrounding neighborhoods. Second, Low-High clusters increase in areas adjacent to the center, meaning that low-income

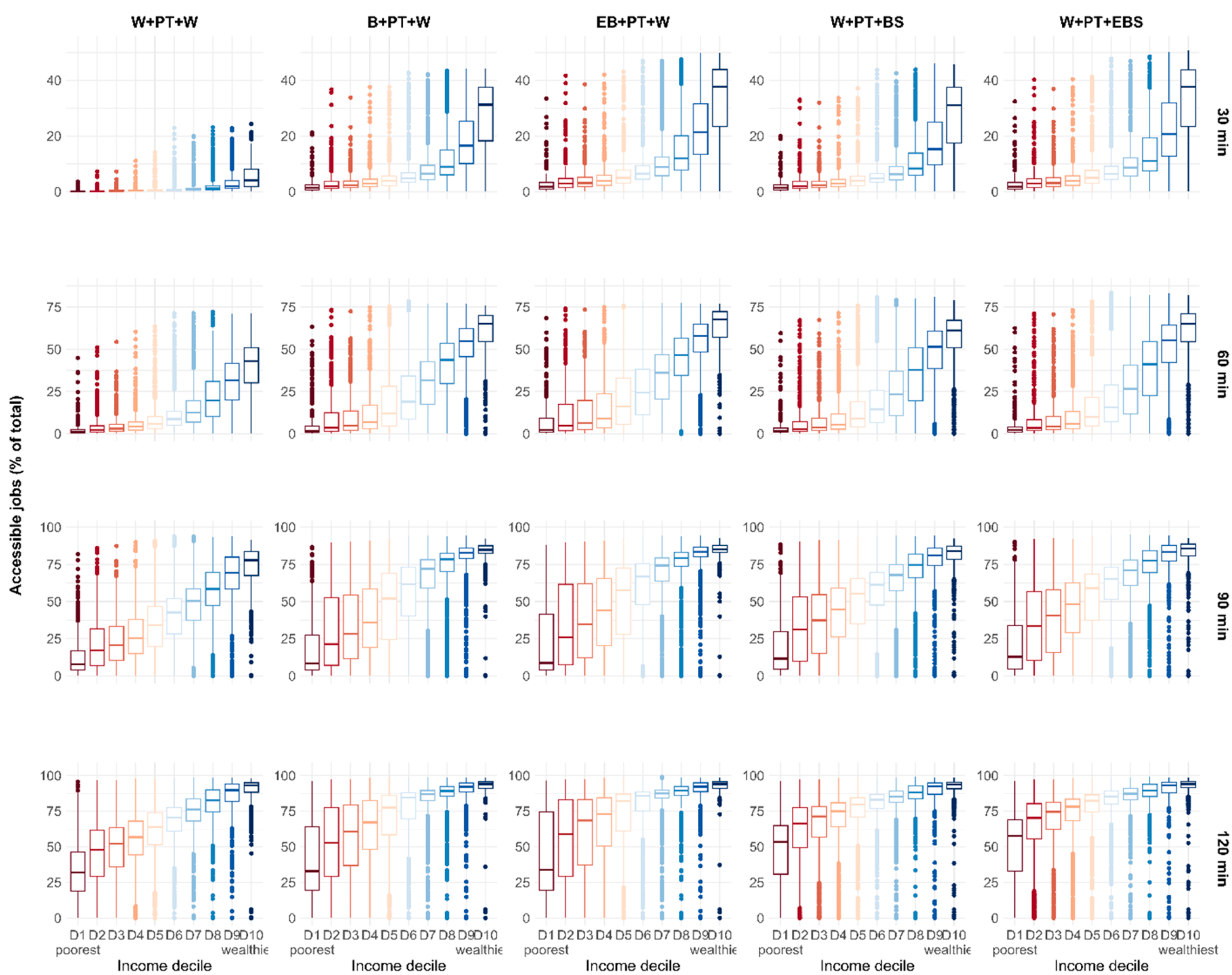

Fig. 7. Distribution of job accessibility across income deciles in São Paulo for walk-and-ride, bike-and-ride, and e-bike-and-ride scenarios across travel-time thresholds.

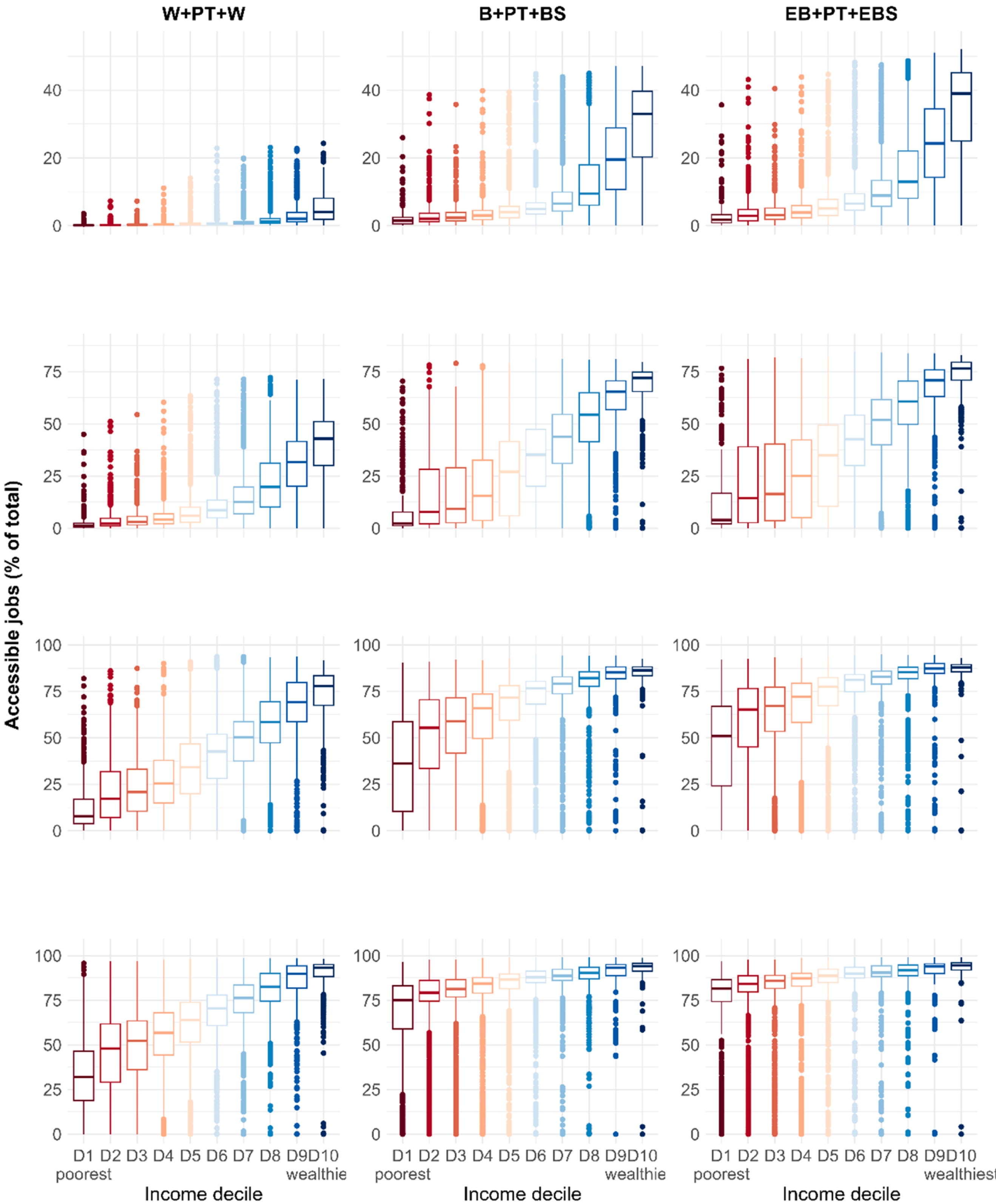

Fig. 8. Distribution of job accessibility across income deciles in São Paulo for walk-and-ride, bike-and-ride, and e-bike-and-ride scenarios with bikesharing available at egress across travel-time thresholds.

neighborhoods near transit corridors gain access to high-accessibility zones through cycling. At longer thresholds (90 and 120 min), a distinct Low-High cluster emerges in the eastern zone along the metro line, reflecting the growing role of transit reach as travel-time budgets increase.

The spatial extent of these changes differs between access and egress configurations. Private bicycle and e-bike access produce a broader spatial pattern because cyclists can reach transit stations from a wider catchment area. Bikesharing at egress produces a more spatially concentrated pattern, closely following the location of bikesharing

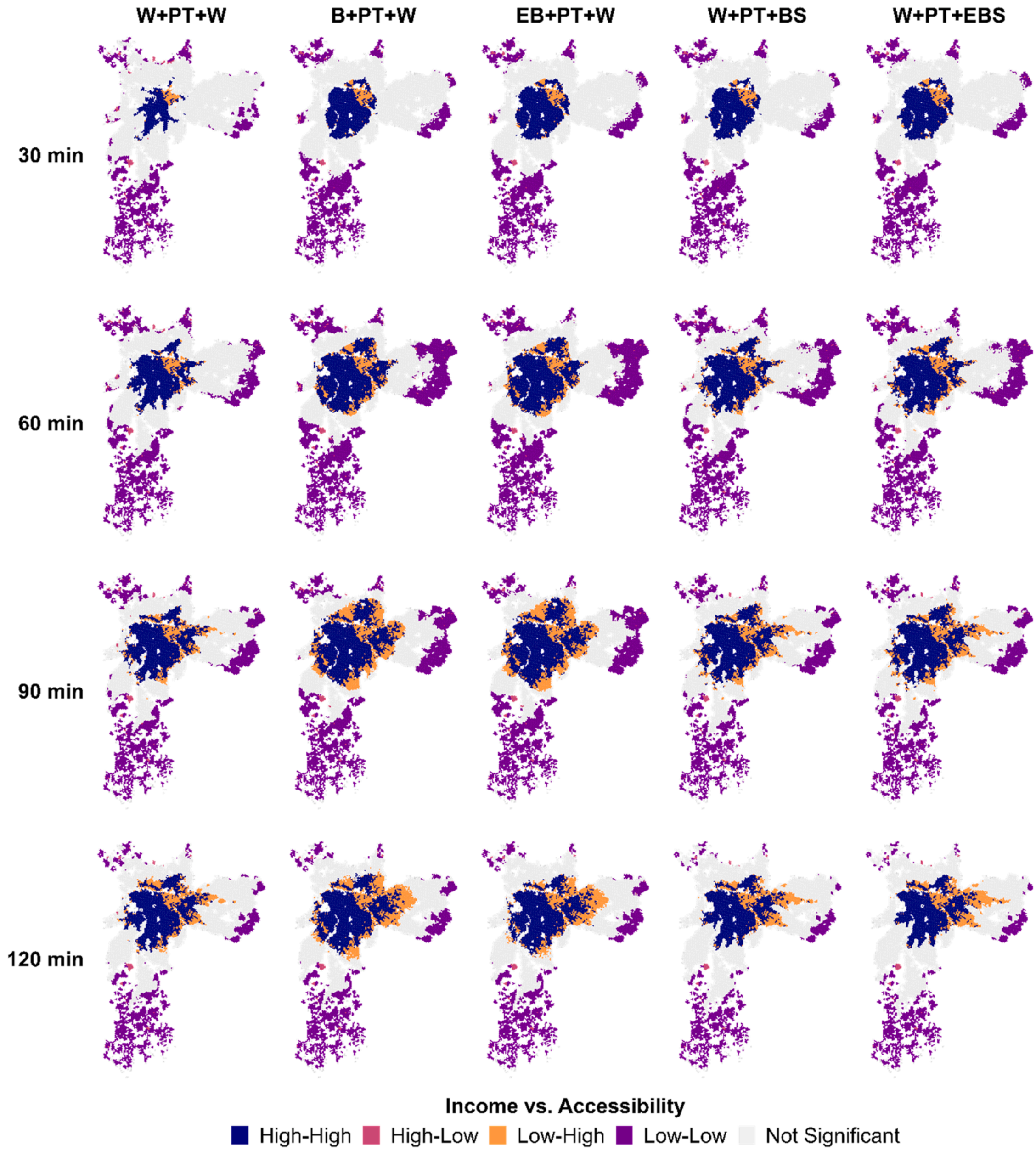

Fig. 9. Spatial clusters of income and job accessibility in São Paulo for walk-and-ride, bike-and-ride, and e-bike-and-ride scenarios across travel-time thresholds.

stations near metro stops.

In full integration scenarios (Fig. 10), Low-High clustering expands substantially. At longer thresholds, a large Low-High cluster extends across much of the eastern zone, particularly under full e-bike integration (EB+PT+EBS), indicating that lower-income areas along transit corridors achieve high accessibility through comprehensive cycling integration. Despite these improvements, persistent Low-Low clusters remain in the far south and east across all scenarios.

Overall, cycling integration improves accessibility in lower-income areas near transit corridors, as shown by the expansion of Low-High clusters. However, Low-Low clusters persist in the far south and east across all scenarios and thresholds, indicating that cycling-based first- and last-mile improvements alone are insufficient to overcome the accessibility disadvantage of areas far from the transit network.

4. Discussion

4.1. Accessibility

The observed accessibility gains are consistent with a growing body of evidence demonstrating the benefits of integrating cycling with public transport. In São Paulo, Pritchard et al., 2019 found that first-mile bicycle access increased average job accessibility by 24% during the morning peak. Comparable effects have been found in Nord-Jæren, Norway, where cycling integration increased accessibility by about 15% (Kosmidis et al., 2025), and Lisbon (Lopes et al., 2025), where accessibility almost doubled. Despite differences in urban form and cycling cultures, these studies consistently show that cycling substantially extends the effective reach of public transport.

Our study extends this evidence in three main ways. First, by systematically comparing access-only, egress-only, and full-integration configurations, we show that access and egress had almost the same impact on accessibility to jobs, and that improvements at both ends

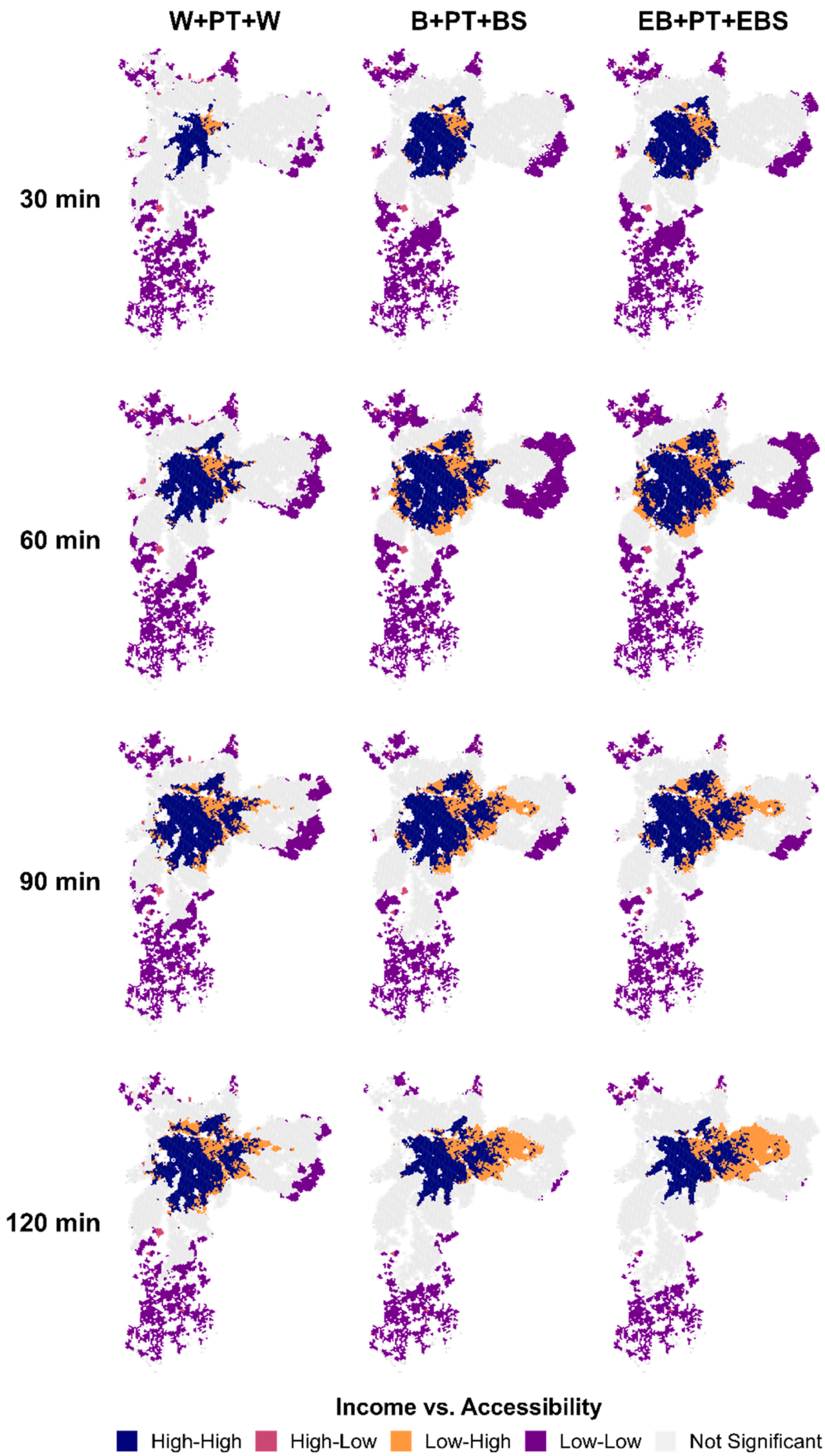

Fig. 10. Spatial clusters of income and job accessibility in São Paulo for walk-and-ride, bike-and-ride, and e-bike-and-ride scenarios with bikesharing available at egress across travel-time thresholds.

generate cumulative benefits that exceed those of any single-leg intervention. Second, we demonstrate that e-bikes provide additional accessibility gains, particularly at shorter time thresholds, where cycling constitutes a larger share of total travel time. Third, by incorporating bikesharing availability at the egress stage, we illustrate how shared mobility can extend transit coverage into areas beyond walking distance. These results underscore the importance of distributing bikesharing stations broadly across the city. At the access leg, stations located in residential neighborhoods would allow people to pick up a bicycle close to home and cycle to a public transport station, effectively enlarging the catchment area from the origin side. At the egress leg, stations near transit stops and across employment areas would allow travelers to pick up a bicycle upon arrival and cycle to their final destination, extending the reach of the network from the destination side.

However, because this analysis relies exclusively on travel time as the impedance measure, the estimated differences between conventional bicycles and e-bikes primarily reflect differences in operating speeds. In relative terms, the accessibility gains from walking to cycling are larger than those from conventional bicycles to e-bikes, as the introduction of any bicycle substantially expands the reachable area. The additional gains from e-bikes are more modest in percentage terms. This should not be interpreted as evidence that e-bikes are of limited importance. Their principal advantage lies not only in marginal speed increases but in reduced physical effort, lower perceived exertion, and the ability to overcome longer distances and topographical barriers (Louro et al., 2025). These characteristics expand cycling opportunities to individuals who might otherwise be unwilling or unable to cycle, including older adults, less physically fit users, and those living in hilly areas. The accessibility improvements reported here therefore likely represent conservative estimates of the broader behavioral and equity impacts of e-bike adoption.

In this context, both the integration of e-bikes into bikesharing systems and policies that facilitate private e-bike ownership may contribute to broadening participation in cycling-based first- and last-mile integration. These findings reinforce the view of bikesharing as a complementary component of public transport rather than a standalone mode (Mbugua et al., 2025; Saidla et al., 2025). Bikesharing and transit are most effective when planned as an integrated system, with coordinated station locations, pricing, and service coverage. This approach is already used in several European cities: Paris integrates Vélib' with the Navigo card, Lisbon links GIRA to the Navegante card with free trips of up to 45 min, and Munich's MyRadl offers public transport season ticket holders 30 free minutes per rental (Île-de-France Mobilités, 2026; Gira, 2026; MyRadl, 2026).

Evidence also indicates that bicycle parking at metro stops and cycle lanes linking these stops to dense and peripheral neighborhoods produce the largest accessibility gains, suggesting that investments should prioritize high-frequency transit stations (Spierenburg et al., 2024). In São Paulo, this highlights the eastern metro corridor as a priority, especially under full e-bike integration. Low-High clusters in this area indicate places where transit infrastructure exists but bikesharing coverage remains limited, making metro and CPTM corridors high-return zones for new stations and cycling infrastructure.

Realizing these gains, however, also depends on enabling conditions at the infrastructure level, including cycling network quality, bicycle parking at stations, perceived safety, and individual socioeconomic characteristics (Siqueira et al., 2024). Without complementary investments in these areas, accessibility benefits are unlikely to be realized uniformly across populations.

At the same time, the persistence of lower accessibility in peripheral neighborhoods highlights structural constraints that cycling alone cannot overcome. São Paulo's highly centralized employment structure means that first- and last-mile improvements enhance access within the existing spatial structure but cannot fully offset the concentration of opportunities in central areas. Addressing these fundamental accessibility deficits ultimately requires the expansion of high-capacity public transport. Express metro systems with more widely spaced stations, such as Guangzhou Metro Line 18 in China (Metro Report International, 2021), illustrate how high-speed urban rail can reduce travel times across metropolitan areas, while cycling-based first- and last-mile connectivity can support such designs by enlarging station catchment areas.

Beyond mobility outcomes, these accessibility improvements also carry important implications for labor markets. Greater job accessibility expands the set of employment opportunities that workers can realistically consider, which increases the probability of finding a job that matches their skills and improves worker-job matching. This has been associated with higher employment probabilities and labor force participation, particularly among women, low-income, and car-constrained populations (Bastiaanssen et al., 2020; Duarte et al., 2023), as well as productivity and wage gains (De Borger et al., 2025; Melo et al., 2017). In Brazilian cities, where congestion disproportionately reduces accessibility for low-income populations (Tomasiello et al., 2025), integrating cycling and bikesharing with public transport may help mitigate these losses while enabling agglomeration benefits without exacerbating congestion.

Taken together, these findings position cycling, particularly when supported by e-bikes and bikesharing, as a strategic complement to public transport. Realizing these benefits at scale, however, requires supportive infrastructure, an equitable spatial distribution of services, and policies that address safety and affordability barriers.

4.2. Equity

The equity analysis indicates that integrating cycling with public transport can improve the distribution of job accessibility across income groups in São Paulo. Rather than simply increasing overall accessibility, first- and last-mile cycling appears to redistribute opportunities more evenly, reducing the relative advantage of higher-income groups. This finding suggests that cycling integration influences not only how much access the transport system provides, but also who benefits from it.

How cycling is incorporated into the trip chain matters for distributional outcomes. At shorter thresholds, access-only and egress-only cycling produce similar equity improvements, with access-only scenarios performing marginally better at 45 and 60 min. At longer thresholds, bikesharing at egress generates somewhat greater equity gains, suggesting that last-mile connectivity becomes relatively more important as travel-time budgets increase, likely because it disperses travelers from transit stations into surrounding employment areas beyond walking distance. Addressing both trip ends is nonetheless critical: combining private cycling at access with shared cycling at egress consistently produces the lowest CI values across all thresholds. It should be noted that the egress-based gains reported here reflect the existing Tembici station network, which is heavily concentrated in central, higher-income areas. A more equitable spatial distribution of stations into peripheral neighborhoods would likely generate substantially larger equity improvements than those reported here.

Electrification amplifies these equity effects by reducing physical effort and extending feasible cycling distances. This makes longer access and egress legs viable for a broader range of users, including older adults, less physically fit individuals, and those living farther from transit stations, thereby expanding station catchment areas and reducing the disadvantage faced by residents who are not able to use conventional bicycles (Louro et al., 2025).

The strengthening of equity effects at longer thresholds reflects the structure of São Paulo's labor market. Because employment is highly concentrated in central areas, low-income residents in peripheral neighborhoods face long travel times regardless of mode. Cycling integration is particularly effective in these contexts because it extends the reach of public transport at both ends of the trip, partially compensating for the distance between peripheral residential areas and central job concentrations.

This is particularly relevant when considering commute preferences. In São Paulo, the ideal commute time is around 20 min, with a maximum willingness to commute of 120 min (Pritchard et al., 2021). To reach a comparable, and equitable, number of job opportunities, low-income residents may therefore need to travel well beyond what they consider desirable, raising questions about whether accessibility gains at longer thresholds represent genuinely equitable outcomes.

Nevertheless, persistent inequalities at shorter and intermediate thresholds point to structural limitations that cycling alone cannot overcome. Although improved first- and last-mile connections increase station catchment areas and job accessibility, substantial peripheral areas with low income and low accessibility remain. These patterns underscore that cycling and transit integration should be viewed as one component of a broader urban strategy, complementing investments in high-capacity public transport that can connect peripheral populations more directly to job centers, as well as land-use policies promoting mixed-use development and densification in areas with high employment concentration.

These findings are broadly consistent with prior work but also reveal some contrasts. In São Paulo, Pritchard et al., 2019 reported that first-mile bike-and-ride increased inequality relative to walking, with gains concentrated near central metro corridors. The more progressive effects observed here may reflect methodological differences, including finer spatial resolution and the use of a locally calibrated cycling speed model that better captures benefits in peripheral areas. Evidence from other contexts aligns with this interpretation. Kosmidis et al., 2025 find that bicycle and transit integration reduced the Gini index in Nord-Jæren, particularly in peri-urban zones, and Lopes et al., 2025 show that bikesharing and public transport integration in Lisbon reduced inequality for most activity types.

Finally, it is important to note that this analysis evaluates accessibility exclusively in terms of travel time. Differences in the economic accessibility of first- and last-mile modes therefore remain central to interpreting equity outcomes. In 2026, the Brazilian federal minimum wage is R$ 1621 per month. In São Paulo, access to the Bike Itaú (Tembici) bikesharing system costs R$ 43.90 per month or R$ 281.90 per year, equivalent to approximately 2.7% and 1.4% of monthly minimum-wage income, respectively (Bike Itaú, 2025). By contrast, shared e-bikes are priced per ride, with additional charges of R$ 9.90 for subscribers and R$ 16.90 for single trips, resulting in substantially higher costs for frequent users.

However, this pricing structure is not universal. In Fortaleza, in the northeast of Brazil, bikesharing costs R$ 20 per month or R$ 80 per year and is free for users of the integrated public transport fare card, with electric bicycles available at no additional charge (Bicicletar, 2025). In Belo Horizonte, in the southeast of Brazil, the system operates exclusively with e-bikes offered through subscription plans costing R$ 32.90 per month or R$ 281.90 per year (Tembici, 2025). At these price levels, e-bike sharing can function as an affordable and broadly accessible complement to public transport, or as a standalone mode, suggesting that the accessibility gains associated with bike-and-ride and bikesharing scenarios are economically attainable for much of the population, including lower-income groups.

Private e-bike ownership, however, presents a more substantial barrier. Entry-level pedal-assist bicycles cost approximately R$ 4300 to R$ 5000, equivalent to roughly 2.7 to 3.1 months of minimum-wage income. Consequently, the gains from scenarios requiring private e-bike access (e.g., Private E-bike → PT → Walk) represent an upper bound contingent on overcoming this ownership barrier, whereas shared e-bike scenarios (e.g., Walk → PT → Shared E-bike) entail a far lower barrier and are more immediately actionable for equity-focused policy. Taken together, these cost differences indicate that, although electrified first- and last-mile integration generates larger time-based accessibility gains, the ability to realize these benefits remains uneven across income groups. Policy measures such as purchase subsidies, income-based rebates, or the expansion of subsidized or fare-integrated bikesharing programs, similar to Fortaleza's model, could help lower these barriers and broaden access to the equity benefits of electrified first- and last-mile connectivity.

Overall, these findings position bicycle and public transport integration as a potentially effective tool for reducing income-based disparities in job accessibility in large, centralized metropolitan contexts. However, maximizing these benefits requires not only infrastructure provision but also supportive pricing policies and broader interventions that address the persistent spatial concentration of employment.

5. Conclusions

This study examined how different cycling-based access and egress strategies influence job accessibility and spatial equity in São Paulo, with a focus on their integration with public transport. By comparing a walk→PT→walk baseline against six cycling-based scenarios, private bicycle and e-bike access with walking egress, walking access with shared bicycle and shared e-bike egress, and full integration scenarios combining private cycling for access with bikesharing for egress, the analysis provides a comprehensive assessment of how each configuration contributes to accessibility and equity outcomes.

The results show that integrating cycling with public transport substantially increases job accessibility across all travel-time thresholds, with the largest gains arising from the shift from walking to any form of cycling. Access-only and egress-only configurations produce comparable improvements when introduced independently, indicating that both first-mile and last-mile cycling can effectively expand the catchment areas of public transport stations. E-bikes consistently outperform conventional bicycles, particularly at shorter thresholds where the cycling leg constitutes a larger share of total travel time, although their relative advantage diminishes as travel-time budgets increase. Full integration scenarios, which combine private cycling or e-bike access with bikesharing or shared e-bike egress, produce the largest accessibility gains across all thresholds, confirming that addressing both ends of the trip produces cumulative benefits that exceed those of any single-leg intervention.

Accessibility outcomes are strongly conditioned by São Paulo's monocentric urban structure. Across all scenarios, accessibility remains concentrated in central areas with high employment density, while peripheral areas, especially in the eastern and southern zones, experience markedly lower levels of access. Private cycling for access expands accessibility more evenly across areas surrounding transit corridors, while bikesharing at egress generates a spatial pattern more closely aligned with the metro network and existing station locations. Despite these differences in spatial configuration, neither approach fundamentally alters the city's central–peripheral accessibility gradient.

From an equity perspective, improved access and egress options reduce, but do not eliminate, income-based and spatial disparities in job accessibility. The Concentration Index decreases consistently as cycling is introduced at access, egress, or both, with full integration scenarios achieving the lowest values across all thresholds. Bikesharing at egress generates larger equity improvements than cycling at access alone, suggesting that last-mile connectivity plays a particularly important role in redistributing accessibility benefits across income groups. Income-decile analyses indicate relatively larger gains for lower- and middle-income groups at longer travel times, while absolute accessibility advantages remain concentrated among higher-income deciles at shorter thresholds. Spatial clustering analyses further confirm persistent polarization, with high-income–high-accessibility clusters concentrated in the central core and low-income–low-accessibility clusters dominating much of the periphery, even as low-income–high-accessibility clusters expand along transit corridors under cycling-based integration.

Overall, the findings suggest that integrating cycling, e-bikes, and bikesharing with public transport can meaningfully improve job accessibility and reduce measured inequalities, with the greatest benefits arising from full integration configurations that address both access and egress. However, these measures alone are insufficient to overcome the structural effects of employment concentration, residential segregation, and the uneven spatial distribution of cycling and bikesharing infrastructure in large, highly centralized metropolitan regions. Maximizing these benefits therefore requires that bikesharing systems be broadly distributed across both residential and employment areas, include e-bikes to extend feasible travel distances, and remain affordable and well integrated with public transport, reinforcing cycling as a complement to, rather than a substitute for, high-capacity transit investment.

These conclusions should be interpreted considering some methodological limitations. The model represents a best-case integration scenario, assuming perfect bike availability at all stations, no time penalty for docking or unlocking bicycles, and a willingness and ability to cycle among all residents. In practice, station imbalances, peak-hour unavailability, and docking delays of two to five minutes would reduce realized accessibility gains, particularly at shorter thresholds where time budgets are tightest. The 20-minute walking cap and 30-minute cycling cap also represent upper bounds, selected for consistency with observed travel behaviour in São Paulo, but a more conservative specification would reduce absolute accessibility levels while leaving the relative ranking of scenarios unchanged. Safety perceptions and physical ability also constrain cycling adoption in ways not captured by travel time models, especially in peripheral areas with limited cycling infrastructure. Additionally, the cycling speed model is calibrated on bikesharing users in central São Paulo, who are not representative of all potential cyclists, which may lead to overestimation of speeds in peripheral areas and consequently of equity gains in those zones. Finally, the analysis measures accessibility exclusively in terms of travel time, excluding monetary costs, which remain a significant barrier for lower-income populations seeking to access the electrified scenarios that generate the largest accessibility and equity improvements.

CRediT authorship contribution statement

Thiago Vinicius Louro: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Diego Bogado Tomasiello:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Anna Beatriz Grigolon:** Writing – review & editing, Supervision, Methodology, Conceptualization. **André Luiz Cunha:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Karst T. Geurs:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The author declares no competing interests.

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