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Commuting Burden Distribution: The Equity Effects of the New Work Dynamics on the Lisbon Metropolitan Area

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Abstract

Transport-related equity is gaining increasing attention, highlighting the need for a system that is equitable, accessible, and affordable for all. From a spatial perspective, the spatial distribution of transport infrastructure plays a key role in mitigating socio-spatial inequalities. Since Covid-19, teleworking has become more prominent across sectors, raising questions about the equity implications of remote work. This study examines the spatial distribution of commuting burden (CB), as the ratio of travel costs to wages, across the Lisbon Metropolitan Area and tests the hypothesis that telework increases inequality in CB distribution rather than alleviating it. We analyse CB before and after increased telework adoption, integrating occupational typologies, wage levels, and telework potential at the civil parish level. Generalised commuting costs are estimated using travel time and distance by mode, fare structure, and value of time. An adapted Palma index assesses the equity impact of telework on CB distribution, identifying areas of compound burden or benefit. The findings confirm that despite a general decline in average CB under the telework scenario, inequality increases, as measured by the Palma index. High-wage workers in skilled occupations, predominantly located in more central or well-connected areas which already have a lower CB, gain disproportionate advantages from telework. Conversely, low-wage workers in peripheral areas face both higher CB and limited telework capacity. This suggests telework, in its current distribution logic, exacerbates rather than mitigates socio-spatial disparities. The study underscores the need to embed telework within equitable urban planning frameworks that address the structural causes of socio-territorial fragmentation.

Keywords

commuting burden; equity; telework; transport justice

1. Introduction

The transport justice approach advocates that all members of society should have equitable access to safe and affordable transport options (Gössling, 2016; Pereira et al., 2017). From a spatial perspective, transportation resources and infrastructure distribution should address and alleviate spatial inequalities (Haxhija et al., 2024; Wu & Liu, 2022), since spatial and social inequalities mutually influence each other, and the transportation system can potentially impact this dynamic (Preston & Rajé, 2007). Equity in transportation typically refers to the fair distribution of transportation outcomes, materialised through accessibility levels (Amorim & de Abreu e Silva, 2024). Consequently, transport policies have increasingly focused on equity issues, aiming to ensure that the transportation system is accessible to all individuals, regardless of socioeconomic characteristics (Martens, 2017). Therefore, transport equity could be explored through distributive justice principles, identifying disparities in accessibility, or through restorative justice, redressing marginalisation through recognition processes.

Commuting can substantially impact individuals' quality of life, productivity, and well-being. Thus, commuting plays a central role in discussions about equity in transportation, particularly regarding time and monetary costs (Maheshwari et al., 2024). In metropolitan areas, urban sprawl and congestion impose a substantial commuting burden (CB), due to increased travel times and monetary costs (Schleith & Horner, 2014; Zhao, 2015). For instance, public transit (PT) commuters often face overcrowding, delays, and limited connectivity and coverage, while private car users encounter fuel and toll expenses. CB reflects these challenges through the travel cost-to-income ratio, in other words, the relationship between the cost incurred by workers to access their jobs and the income they generate (T. Li et al., 2021). Strategies to reduce CB may include improving PT infrastructure, fostering mixed land use, or promoting telework to reduce the need for commuting, especially for long-distance commuters.

Since the Covid-19 pandemic, new work dynamics and, in particular, teleworking have gained importance across both private and public sectors (Sostero et al., 2020). Telework has become increasingly relevant for certain professional sectors, offering flexibility and potentially reducing commuting expenses. As those living farther from work are more likely to telework due to higher commuting costs, this shift may impact CB distribution (de Abreu e Silva & Melo, 2018). However, CB is not evenly distributed among socioeconomic groups and neighbourhoods, raising concerns about transport equity. Disadvantaged groups and low-income areas are more likely to face higher levels of transport burden, limiting their access to employment opportunities and essential services (Zhang et al., 2018). Meanwhile, wealthier populations, often located in central and/or well-connected areas, benefit from better transit supply. Additionally, these groups also frequently own private vehicles and enjoy more flexible work schedules or remote work opportunities. This disparity exacerbates existing social and economic inequalities, making equitable transportation policies critical to ensure fair and efficient commuting for all workers. Therefore, analysing CB distribution by considering telework adoption helps identify overlapping disadvantages or benefits—an equity dimension often overlooked in studies focused on productivity, mental health, and environmental effects.

This study examines the distribution of CB across the Lisbon Metropolitan Area (LMA) and how increased telework adoption could affect this distribution, with particular attention to equity implications. Given that existing inequalities in commuting costs, travel time, and transport supply are deeply embedded in the socio-spatial urban structure, often reflecting wage disparities and social segregation, we investigate whether telework adoption exacerbates or alleviates CB disparities.

Because teleworking propensity varies across occupations and socioeconomic groups that are unevenly distributed throughout the LMA, its adoption is expected to imply changes in the spatial distribution of CB. We compare the CB distribution before and after teleworking became widespread, calculating it by civil parish based on the proportion of different professional occupations, which determines average wages and teleworking potential. We employ the concept of generalised commuting costs (GCC), combining financial and time factors into a unified measurement parameter estimated using travel time by mode, PT fares, road travel costs, and the value of time (VoT) from existing literature. Through an equity index, the Palma Index (PI), we assess whether telework adoption increases or decreases CB disparities, mapping its spatial impact and revealing whether individuals with lower CB are more likely to telework while those unable to telework face higher CB.

2. Literature Review

2.1. Transport Equity

Transport equity and justice are concepts commonly found in policy documents. However, both concepts can be relatively vague and subject to different interpretations. Policies and interventions in the transportation system inevitably impact population groups and areas differently, creating a relationship between social and spatial inequalities and the transportation system (Preston & Rajé, 2007). This results from the unequal distribution of resources and infrastructures, leading to different levels of access to employment opportunities. Inadequate transport services can directly affect community livelihoods and contribute to social exclusion (Lucas, 2012).

Equity refers to the fairness in how benefits and costs are distributed (Litman, 2022) and can also be understood as treating disadvantaged groups advantageously and fairly (Romero-Lankao & Nobler, 2021; Silva, 2016). The operationalisation of the concept typically includes three components: the distribution of costs and benefits, the population groups involved (those favoured and those harmed), and the distributive principle used to justify and assess the intervention (Di Ciommo & Shiftan, 2017). Transport equity mainly concerns the fair distribution of transportation outcomes across spatial or sociodemographic groups (Di Ciommo & Shiftan, 2017; Martens, 2017; Pereira & Karner, 2021; Pereira et al., 2017), typically approached through vertical equity from the perspective of distributive justice, comparing basic access, affordability, travel time, distance, or the job–housing mismatch.

Distributive justice is the most used framework in transport equity analysis, stressing the need for all individuals, regardless of socioeconomic status, to access employment opportunities. Whether viewed from a spatial justice perspective, which focuses on the distribution of resources in space (Madanipour et al., 2022), or from an equity perspective, which emphasises individuals' ability to access opportunities (Romero-Lankao & Nobler, 2021), both perspectives underscore the centrality of distributive justice in transport equity analysis. The job–housing mismatch amplifies CB inequalities, disproportionately affecting low-wage workers who face poor PT, long travel distances, and limited affordable housing near employment hubs (Schleith & Horner, 2014; Zhao, 2015).

In today's urban context, employment and other opportunities remain highly concentrated in the central areas of large cities and metropolitan regions. Thus, ensuring an equitable transportation system, particularly PT networks, is crucial for individual well-being (Guzman & Oviedo, 2018). In peripheral areas, residents without access to private vehicles face isolation or limited access to services, goods, and employment opportunities (Rodrigue et al., 2017). A fair transport system should ensure a sufficient level of basic access for everyone in most situations (Martens, 2017), especially for socioeconomic groups that rely on PT.

2.2. CB

Commuting significantly impacts well-being, as the time spent represents a substantial part of the daily routine (Maheshwari et al., 2024). CB refers to the cumulative costs individuals incur while travelling between home and work (Zhao, 2015), including travel time, distance, psychological stress, financial costs, and effort (C. Liu et al., 2022; Zhao & Cao, 2020). It can also be perceived as the ratio between commuting costs and income (T. Li et al., 2021). In metropolitan areas, high CBs affect quality of life and may contribute to the social exclusion of disadvantaged groups. From a transport equity perspective, identifying areas or groups with high CB levels is essential to understanding distributive inequalities.

Socioeconomic groups experience these burdens differently (Zhao & Li, 2016). The unfair CB distribution particularly impacts disadvantaged groups through longer travel times resulting from heightened job–housing spatial mismatches (Zhou et al., 2013). For low-wage workers, the absence of a private vehicle or a poor job–housing match is the main factor influencing CB (Zhang et al., 2018; Zhao & Li, 2016; Zhou et al., 2013). High CB can limit participation in various daily activities, particularly for disadvantaged groups (Zhang et al., 2018).

From a metropolitan perspective, commuting time has emerged as a key indicator of CB, given that origin–destination pairs can yield significantly different durations depending on the transport mode (Zhao & Cao, 2020). However, time alone is insufficient to capture CB's full extent. Financial costs associated with commuting (e.g., transit fares, fuel, tolls) must also be considered (C. Liu et al., 2022; Zhao & Cao, 2020). In the absence of car ownership and given dependence on PT, travel distance has less impact on CB than travel time. Commute duration and GCC are the primary variables used to measure CB levels (Tong et al., 2022). Because travel times for the same distance vary drastically across transport modes (Zhao & Cao, 2020), the VoT (Choudhury et al., 2018) is incorporated into CB to represent the monetary equivalent of travel time.

2.3. Telework

Telework as a concept emerged during the first oil crisis and the rise of mobile digital technologies in the 1970s, primarily linked to issues related to commuting and its connections to traffic problems and fuel consumption (Allen et al., 2015; Nilles, 1975). Telework can be defined as work carried out partially or totally away from a workplace, often from home, using information and communication technologies (ICTs; Allen et al., 2015). The EU defines telework as a form of organising and/or performing work using ICTs, in the context of an employment contract, where work that could be performed at the employer's premises is carried out away from those premises on a regular basis (Eurofound, 2020).

Improvements in ICTs have made telework a viable alternative for several jobs, serving as a mechanism for controlling or reducing commuting expenses (Kazekami, 2020). One of teleworking's main advantages is the time savings from reduced or eliminated commuting (Nagler et al., 2024). There is a potential two-way relationship between telework and travel distance: Teleworkers tend to live farther away from the workplace (Zhu, 2013), and those who live farther away are more likely to telework (de Abreu e Silva & Melo, 2018).

Recently, the widespread adoption of hybrid and remote work has transformed commuting patterns in metropolitan areas, challenging long-established assumptions about commuting and infrastructure needs. For instance, Dingel and Neiman (2020) estimated that around 37% of US jobs could be performed entirely remotely, mostly in white-collar sectors associated with higher wages and predominantly white workers. In the EU, Sostero et al. (2020) found a similar proportion (37%) concentrated in high-paid jobs.

However, whilst this flexibility benefits knowledge-based professionals, it does not extend to lower-wage manual and frontline occupations, which require physical presence (Florida et al., 2023). The adoption of teleworking has not only altered commuting patterns but also deepened socio-spatial inequalities, offering flexibility mainly to already privileged workers (Gokan et al., 2022). Therefore, the uneven distribution of CB across wage-related social groups is a key layer of transport inequality, as these studies collectively illustrate that this disparity contributes to a cycle where CB reinforces economic inequality, with CB being deeply intertwined with wage inequalities and spatial mismatch, which in turn contribute to the urban socioeconomic divide.

2.4. Measuring Transport Equity

Mapping high-burden commuters is the starting point for exploring transport equity issues (Tong et al., 2022). Equity indicators can be used to evaluate the distribution effects of attributes (mostly income) and access to opportunities (goods and services) within a population. These metrics reveal spatial and modal disparities in resource allocation. However, there is no consensus on the ideal equity measurement (Amorim & de Abreu e Silva, 2024; Di Ciommo & Shiftan, 2017; Karner et al., 2024; Pereira & Karner, 2021; Pereira et al., 2017).

The Gini index and Lorenz curve, widely used in economics, are also applied to accessibility inequity analysis (Ben-Elia & Benenson, 2019; Guzman & Oviedo, 2018; Kaplan et al., 2014; Welch & Mishra, 2013). The PI (Palma & Stiglitz, 2016), originally developed to measure income inequality, compares the income share of the top 10% to that of the bottom 40%, where higher values indicate higher inequality. Unlike the Gini index, it is sensitive to changes on the extremes of the distribution, is easier to communicate, and has been used in assessments in different contexts (Guzman & Oviedo, 2018; Herszenhut et al., 2022; W. Li et al., 2023; D. Liu et al., 2022; Oviedo & Guzman, 2020; Pritchard et al., 2019).

3. Methodology

3.1. Case Study

According to the 2021 Census (Instituto Nacional de Estatística [INE], 2022), commuting patterns in the LMA are characterised by a predominance of private transport and a significant disparity in access to PT among different municipalities (Figure 1), despite the fully integrated PT network. Although cars account for 58% of commuting trips and PT (bus, train, subway, and ferry) for only 25%, the LMA has the lowest car-use proportion in the country. This discrepancy is evident in the time spent on daily commutes, with employed residents using cars averaging 18.8 minutes, while those using PT average 43.5 minutes. Moreover, 44% of the LMA population works in a municipality that is different from their place of residence, implying daily commutes that are more costly in terms of time, distance, or money. Lisbon residents have the lowest percentage of commuting outside their municipality, which is due to Lisbon being the central hub of the metropolitan area and having a greater supply of job opportunities, associated with higher levels of accessibility and PT availability.

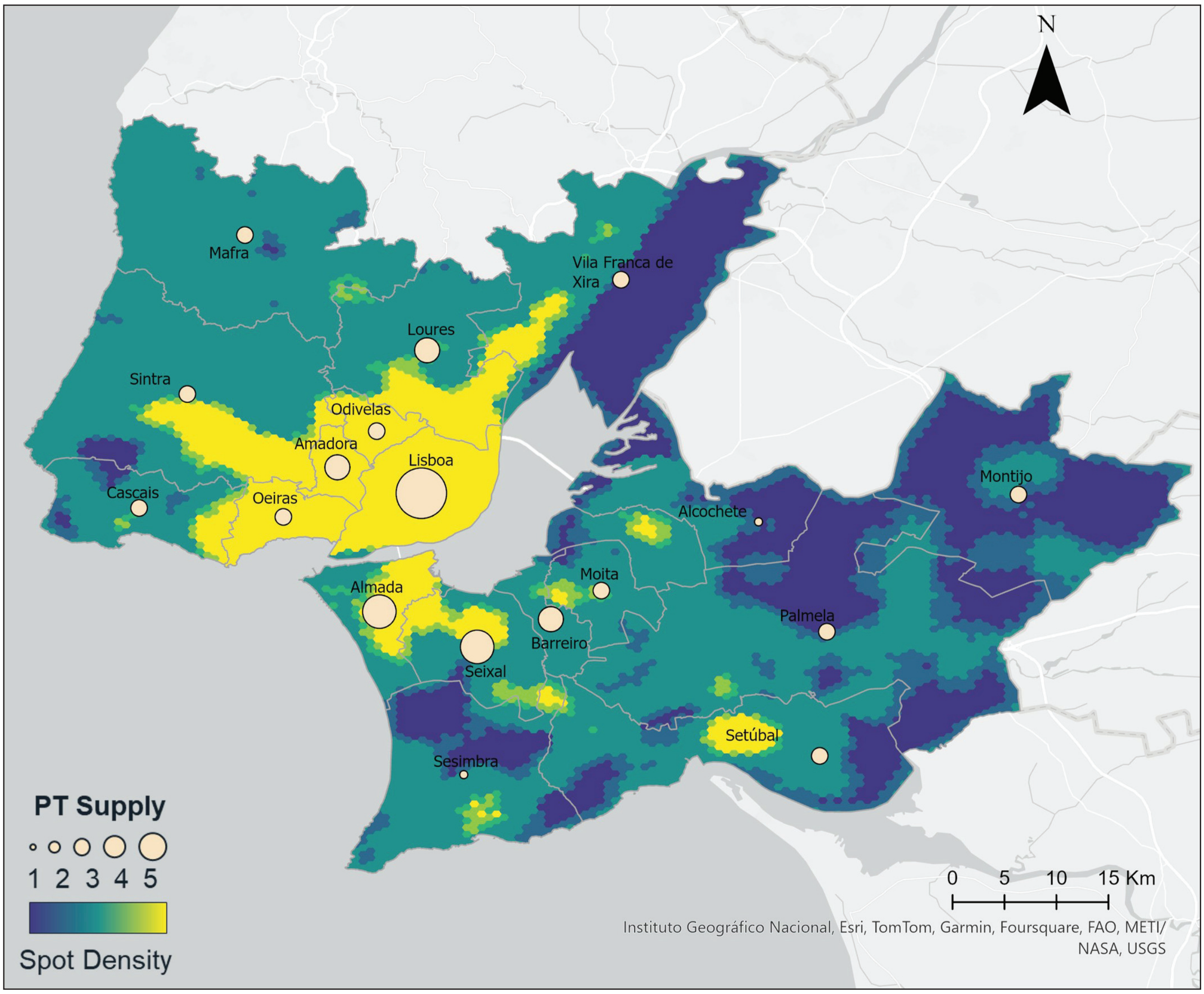


Figure 1. PT supply and access points density by municipality in the LMA. Source: Map created using ArcGIS Pro (Esri, 2023), using data provided by the authors.

CB is not experienced uniformly; rather, it is stratified by income level, occupation, and consequently by the possibility of teleworking. According to the latest Labour Force Survey (LFS; INE, 2024), Portugal had 21.5% of the population employed in full or partial telework. The LMA presents the highest values when compared with the national average, accounting for approximately 31%. Within the Portuguese classification of occupations (CPP; INE, 2010), telework can be effectively adopted by a range of professionals, particularly workers in the ICT and knowledge-intensive sectors, whose tasks can be performed digitally (Table 1). The CPP system uses a 5-digit code corresponding to five levels. In our case study, we use the first level of disaggregation, resulting in 10 major occupational groups (INE, 2010).

Table 1. CPP, percentage of telework adoption, and average weekly number of telework days.

Code	CPP	Telework Adoption	Telework Days
0	Armed forces occupations	20.0%	0.46
1	Representatives of the legislative and executive bodies, directors, officers, and executive managers	34.5%	0.78
2	Specialists in intellectual and scientific activities	50.0%	1.44
3	Intermediate-level technicians and professions	25.8%	0.70
4	Administrative staff	14.4%	0.41
5	Personal service, security, and safety workers and salespeople	4.1%	0.11
6	Farmers and skilled workers in agriculture, fisheries, and forestry	5.0%	0.11
7	Skilled workers in industry, construction, and crafts	4.6%	0.12
8	Plant and machine operators and assembly workers	1.5%	0.05
9	Unskilled workers	0.9%	0.01

Source: INE (2024).

3.2. Conceptual Framework

Our main objective is to evaluate the equity of CB distribution across workers in the LMA and assess the role of telework adoption on that distribution. The conceptual framework presented in Figure 2 describes our multidimensional construct of CB, integrating economic capacity (commuting costs and wage), mobility patterns, and employment structures. CB is an individual-level measure shaped by GCC and worker wage. GCC consists of two principal components: monetary costs (encompassing fuel, tolls, and transit fares) and the monetary equivalent of travel time (VoT). These costs are contextualised relative to worker wages to understand the unequal impact of commuting costs across different populations. Additionally, different employment types are associated with different telework potentials and wages, introducing variability into individual CB values (acting as moderating variables), either exacerbating or mitigating them. Finally, the PI (Palma & Stiglitz, 2016) is used for assessing inequality in the distribution of CB values between employment and wage groups across the LMA.

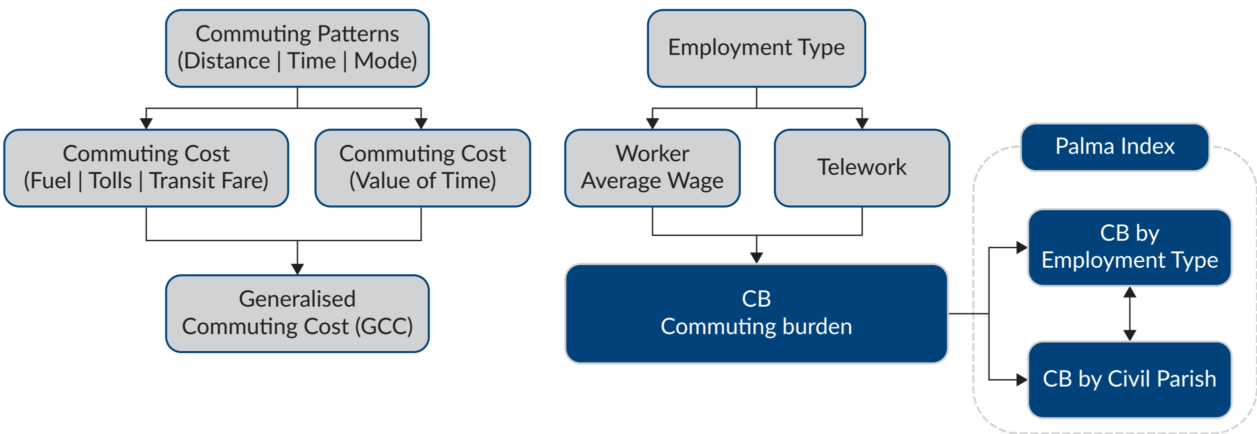


Figure 2. Framework of data analysis.

3.3. CB

The CB is estimated as the ratio between GCC and average wage (equation 1). GCC is a composite measure that estimates the monetary costs of commuting by transport mode, calculated for working days only to capture the influence of teleworking. CB is calculated for each transport mode and the average wage for each CPP, with civil parishes as the spatial unit of analysis. Since CB relates to monthly wages, it's calculated on a full-month basis, while GCC considers only actual working days:

$$\mathrm{CB}_y^{nx} = \frac{\mathrm{GCC}_y^x}{\mathrm{AvgWage}_x^n} \tag{1}$$

Where GCC is the generalised commuting cost, n is the occupation, x is the spatial unit, and y is the transport mode.

Thus, the daily commuting cost (two-way) for private transport (car) is calculated based on commute distance, fuel price, and toll values, plus the monetary cost of travel time (MCTT), then multiplied by the number of working days. For PT, the commuting cost includes the monthly transit pass plus MCTT. For active modes, the GCC consists solely of MCTT. The MCTT for all modes is calculated using the VoT based on Choudhury et al. (2018) multiplied by travel time. The GCC is presented in equations 2–4:

$$\mathrm{GCC}_{\mathrm{car}}^x = Wd[(\mathrm{Dist} \cdot \mathrm{Fuel})_x + \mathrm{Tolls}_x + (\mathrm{VoT}_x \cdot Tt)] \tag{2}$$

$$\mathrm{GCC}_{\mathrm{PT}}^x = \mathrm{TransitFare}_x + Wd(\mathrm{VoT}_x \cdot Tt) \tag{3}$$

$$\mathrm{GCC}_{\mathrm{Soft}}^x = Wd(\mathrm{VoT}_x \cdot Tt) \tag{4}$$

Where Wd is the number of working days, VoT is the MCTT, and Tt is the travel time.

3.4. Equity Index: PI

In transport-related equity evaluations, the PI is a valuable tool for measuring distributional disparities by isolating extremes of the distribution through the ratio of the top 10% to the bottom 40% of earners (Palma & Stiglitz, 2016). However, this study adapts the PI to reflect the characteristics of our variable by inverting its logic. Since higher CB values indicate a greater disadvantage level (unlike income, where higher values indicate an advantage), we redefined the PI as the mean CB of the 40% of most burdened individuals divided by the mean of the 10% least burdened individuals. Because CB represents an individual-level cost or constraint rather than a share of total resources, we use average CB levels for the top and bottom. This inversion preserves the original index's interpretative integrity, where higher values represent greater inequality between privileged and disadvantaged groups. The interpretation of the adapted index follows the logic: A value of 1 indicates no inequality between the two groups, meaning that the average CB is the same for both, while values above 1 indicate that the most burdened face disproportionately higher CB than the least burdened, implying greater inequality. In this CB context, higher PI values indicate more severe distributional inequalities. The adapted PI is thus formulated as presented in equations 5–7:

$$P_{\mathrm{index}} = \frac{\mathrm{CB}_{\mathrm{bottom40\%}}}{\mathrm{CB}_{\mathrm{top10\%}}} \tag{5}$$

$$\mathrm{CB}_{\mathrm{top10\%}} = \frac{1}{\left| I_{\mathrm{top10\%}} \right|} \sum_{i \in I_{\mathrm{top10\%}}} \mathrm{CB}_i \tag{6}$$

$$\mathrm{CB}_{\mathrm{bottom40\%}} = \frac{1}{\left| I_{\mathrm{bottom40\%}} \right|} \sum_{i \in I_{\mathrm{bottom40\%}}} \mathrm{CB}_i \tag{7}$$

Where P_{ratio} is the adapted PI, $\mathrm{CB}_{\mathrm{bottom40\%}}$ is the average CB of the 40% most overburdened ($I_{\mathrm{bottom40\%}}$ is the subset of individuals with the highest values), and $\mathrm{CB}_{\mathrm{top10\%}}$ is the average CB of the 10% least overburdened ($I_{\mathrm{top10\%}}$ is the subset of individuals with the lowest values).

4. Data Collection

4.1. Travel Time and Distance

To calculate the distances and travel times between the different civil parishes of the metropolitan area, we build origin–destination (O/D) cost and travel time matrices for each mode (car and PT). We use General Transit Feed Specification (GTFS) in a geographic information system (GIS) environment to generate optimised routes for each O/D pair, estimating travel time from average travel speeds and distances (Farber & Grandez, 2017; Farber et al., 2014; Fransen et al., 2015). The values were estimated for a Monday during the morning peak hour. In the O/D matrices, the centroids of each civil parish were used as origin and destination points. The LMA road network is used for the time and distance estimation by car, while for the PT measures, the PT network (ferry, bus, subway, train, and tram) was used. The average travel time in active modes was obtained from the LFS and the 2021 Census (INE, 2022, 2024).

4.2. Commuting Costs

The commuting costs were calculated for each transport mode: private transport (cars), PT (ferry, train, bus, subway, and tram), and active modes (walking and cycling). In addition, for the GCC, the VoT for each mode of transport was established based on the work of Choudhury et al. (2018) for the LMA (PT 2€/h; car 5€/h; and active modes 2€/h) and multiplied by the commuting duration. The GCC considers the average number of working days (21 working days in a month; D. Liu et al., 2022) for individuals who do not telework, while for those who do telework, we deduct the telework days from that total (for more details, see Table 1).

The commuting costs using a car were estimated based on distance, fuel price, fuel consumption per km, and toll prices. In the LMA, fuel prices have minimal variations; we adopted 1.707€/L and 1.586€/L for regular gasoline and diesel, respectively, based on the values presented by the Direção-Geral de Energia e Geologia (2025). Additionally, we use the average fuel consumption of a standard car (0.06 L/km; Dodson et al., 2020; International Energy Agency, 2021). The fuel price is multiplied by the average consumption of a standard vehicle to generate the monetary cost of each trip based on the distance travelled, and toll prices were incorporated into the trip cost when applicable. The GCC for cars is obtained through the sum of the commuting out-of-pocket cost (fuel and tolls) and the VoT for private transport.

The commuting costs using PT were estimated based on the PT fare system. In the LMA, there are basically two modalities of monthly PT passes, the first allowing unlimited trips originating and ending within each municipality of the LMA for 30€, and another allowing unlimited trips between all zones of the LMA for 40€.

The VoT for PT and commuting time was incorporated into the calculation of the GCC. The costs for the active modes include only the VoT for active modes multiplied by the commuting duration.

4.3. Wages and Telework

Income distribution directly affects the perception and construction of commuting costs among different socioeconomic groups. Thus, the economic perspective of CB is calculated by the ratio between the GCC and the individual wages. For our case study, we use the average wages for each occupation provided by the LFS (INE, 2022). It is worth noting that these data are only available at the municipal level; therefore, we assume that the average wages for each occupation type are uniform within the same municipality. Finally, CB was calculated for each civil parish in the LMA, in global values and disaggregated by occupation and transport mode. Given that CB is wage-dependent, the analysis accounted for the distribution of the working population across different job categories.

To evaluate the potential impact of telework on CB distribution, two scenarios were considered: (a) a baseline scenario in which no workers engage in telework, and (b) a scenario reflecting the potential prevalence of teleworking within the LMA. Therefore, for our teleworking scenario, the probability of engaging in telework is defined for each type of occupation based on the LFS. The telework adoption (for more details on telework adoption, see Table 1) data are provided by the specific survey (ad hoc "working from home" module) from the LFS (INE, 2024). The telework adoption rate was used to determine the number of individuals in each civil parish who are potential teleworkers.

5. Results

5.1. Spatial Distribution of CB Across the LMA

Figure 3 illustrates the distribution of the CB global values, considering all transport modes and CPPs, across each civil parish. A clear pattern of spatial disparity emerges, where CB is lower in central (Lisbon) civil parishes and increases towards the periphery. In the absence of telework (Figure 3a), Lisbon civil parishes reveal significantly lower CB levels (< 10%). This can be explained by the fact that jobs are more centralised than the population, combined with a denser and more efficient PT network serving the urban core of the LMA.

Conversely, peripheral civil parishes (e.g., civil parishes of Mafra, Montijo, and Sesimbra municipalities) show higher CB levels (> 25%), suggesting structural dependence on long commutes or limited integration into the LMA labour market. Moreover, a relationship can be established between CB (Figure 3) and PT supply (Figure 1); outlying municipalities with lower PT supply are associated with higher GCC, since commuting costs by car are usually higher, especially given the LMA's integrated PT network with a dual multimodal transit pass tariff scheme.

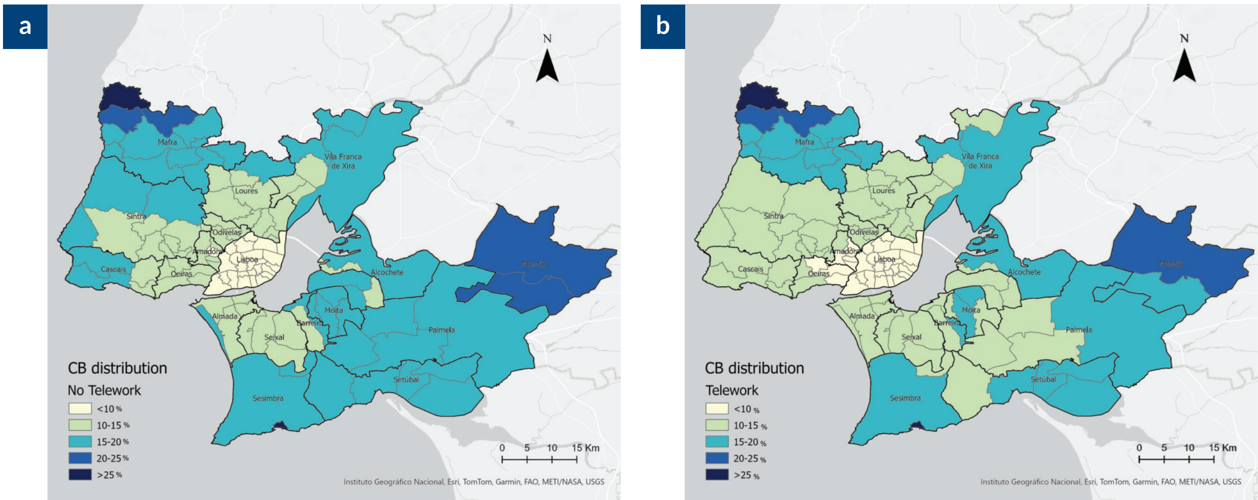


Figure 3. CB distribution across the LMA: (a) no telework; (b) telework. Source: Map created using ArcGIS Pro (Esri, 2023), using data provided by the authors.

5.2. CB and Occupational Characteristics

The distribution of CB levels across CPP categories (Table 2) reveals a pronounced socio-occupation stratification in the LMA. Higher-level professionals (CPP1 and 2) experience significantly lower average CB levels in both scenarios. These results could reflect the association of two factors: first, their greater capacity for telework adoption and spatial flexibility (Eurofound, 2020; Sostero et al., 2020); second, their higher wages compared to other occupations. In contrast, occupations related to services, sales, and manual labour (CPP5, 7, and 9) experience higher CB levels, reflecting both lower telework adaptability and some level of spatial anchoring of these job positions.

Table 2. CPP and the relation with average distance to the central business district (CBD), average wage, and the impact of telework.

	Avg Wage (€)	Avg Distance to CBD (km)[1]	No Telework		Telework		CB Variation (%)	Range Variation (%)
			Avg CB	Range[2]	Avg CB	Range[2]		
CPP0	1,551.0	14.7	15.74	24.95	15.47	25.05	−1.70	0.37
CPP1	3,294.4	12.9	9.64	16.63	9.15	15.78	−5.07	−5.12
CPP2	2,131.8	11.9	12.96	24.44	11.21	21.05	−13.47	−13.89
CPP3	1,835.5	13.5	15.14	30.56	14.66	29.52	−3.20	−3.41
CPP4	1,242.3	14.0	20.07	32.06	19.86	31.70	−1.05	−1.13
CPP5	1,026.5	13.9	21.50	37.92	21.49	37.89	−0.08	−0.09
CPP6	974.2	20.6	21.42	32.37	21.40	32.34	−0.10	−0.10
CPP7	1,133.4	15.4	20.83	35.79	20.81	35.76	−0.10	−0.10
CPP8	1,244.3	15.5	19.84	31.01	19.84	31.00	−0.01	−0.03
CPP9	965.5	14.6	22.54	35.61	22.54	35.61	0.00	0.00
Global	1,574.7	13.67	18.41	42.80	18.08	42.90	−1.81	0.23

Notes: [1] average distance between the civil parishes' centroids and LMA centroid; [2] range is the difference between the maximum and minimum CB values.

It is also possible to identify a clear pattern, where high-wage occupations (particularly CPP1 and CPP2) tend to live closer to the central business district, and lower-wage occupations (CPP6–CPP9) are generally located farther away. The case of CPP6 (on average 20.6 km from the central business district) may reflect the original ruralisation dynamics in the peripheral municipalities of the LMA.

The three scatter plots (Figure 4) illustrate a negative correlation between CB and occupational structure indicators: average wage, percentage of high-wage workers, and telework incidence. Higher CB levels are consistently associated with lower wages or a lower incidence of telework. As CB increases, average monthly earnings decline, with a relatively strong correlation ($r = -0.65$; $R^2 = 0.493$), suggesting a disproportionate burden borne by individuals with lower socioeconomic status who often face greater mobility constraints and longer commutes due to spatial mismatch dynamics. The percentage of high-earning workers drops as CB rises ($r = -0.55$; $R^2 = 0.383$), and telework incidence also declines with increasing CB ($r = -0.56$; $R^2 = 0.387$). These trends indicate that civil parishes with higher CB tend to have their population employed in occupations with lower teleworkability and lower wages, likely reflecting structural inequalities in the labour force distribution.

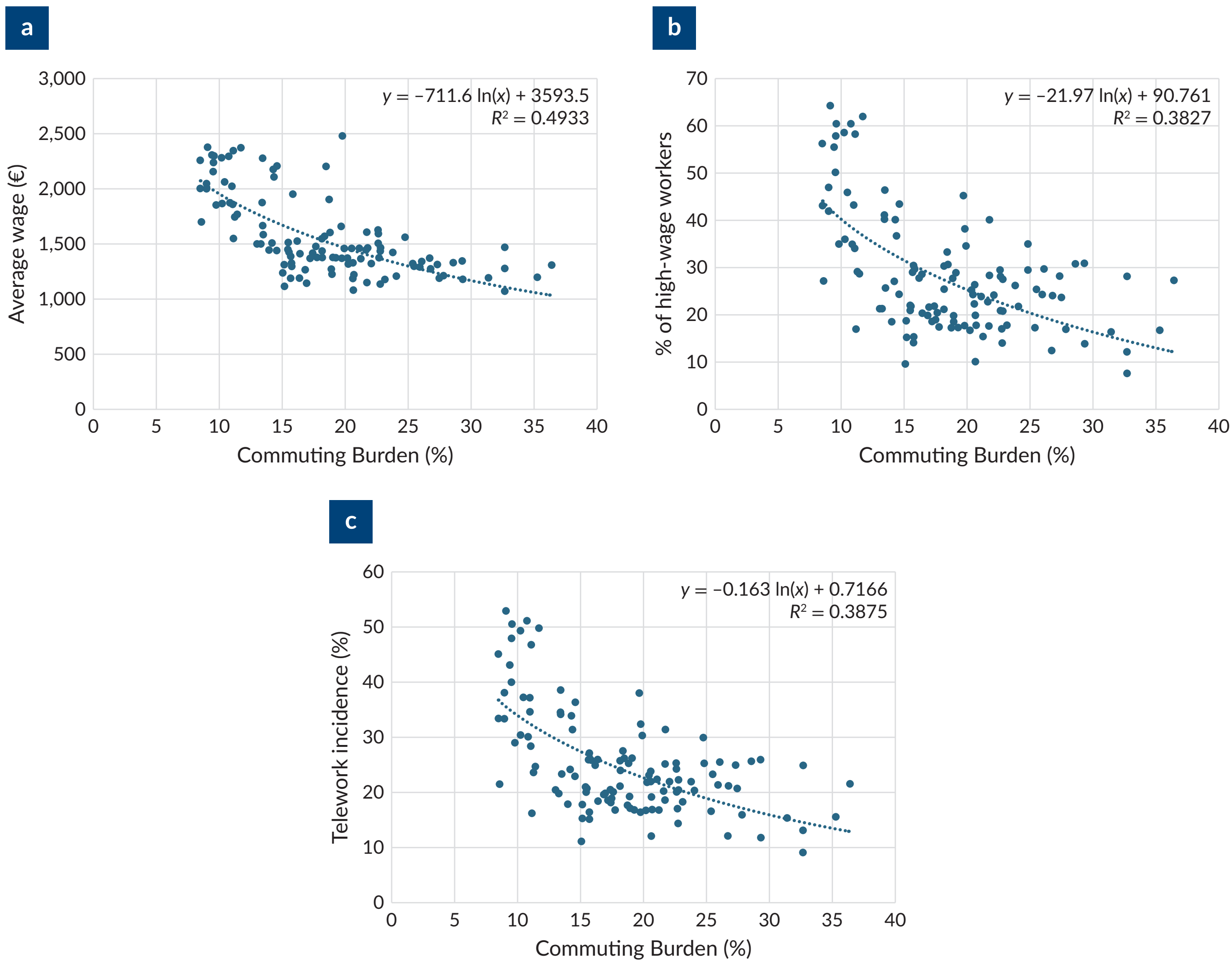


Figure 4. CB's scatterplots: (a) CB and average wage; (b) CB and % high-wage workers; (c) CB and telework incidence.

The high concentration of workers with high-skilled occupations in central civil parishes contrasts with the peripheralization of low-skilled jobs, predominantly located in outlying suburban civil parishes (Figure 5). The CB distribution reflects this pattern: The outlying civil parishes disproportionately concentrate the most burdened commuters, while central civil parishes, often characterised by higher socioeconomic status and proximity to employment hubs, account for significantly lower CB levels. Thus, the spatial distribution of the different CPPs in the LMA reveals some level of socioeconomic segmentation, as reflected in the CB inequalities, which are captured by the adapted PI.

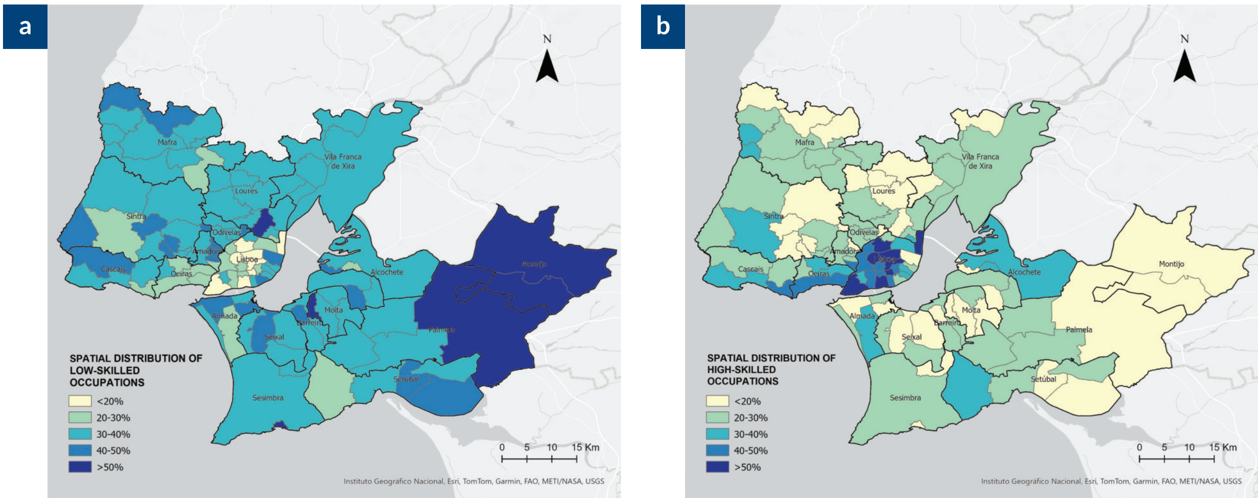


Figure 5. Spatial distribution of (a) low- and (b) high-skilled occupations. Source: Map created using ArcGIS Pro (Esri, 2023) using data provided by the authors.

From an equity perspective, these disparities suggest a spatial mismatch between affordable residential areas and workplaces for lower-wage workers, reinforcing structural labour market segmentation and contributing to the peripheralisation of unskilled or low-wage workers (Zhang et al., 2018; Zhao & Li, 2016; Zhou et al., 2013). In other words, the uneven distribution of transport-related time and financial costs disproportionately affects the more socioeconomically vulnerable worker groups. The elevated CB values among manual and unskilled workers may exacerbate social exclusion risks resulting from the daily commuting implications on household budget and well-being (Lucas, 2012). Such workers are unlikely to be able to reduce their CB by engaging in telework.

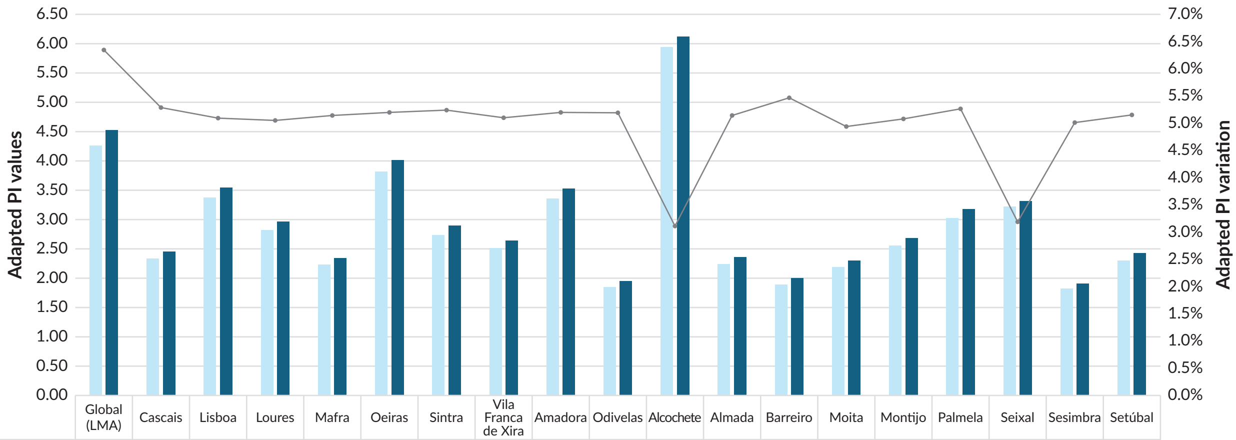
5.3. Impact of Telework on CB Distribution

Table 2 reveals significant disparities in how different CPPs benefit from teleworking. Teleworking appears to disproportionately benefit more highly skilled and higher-wage occupations. Workers with the highest wages show significant CB reduction with telework (CPP1: –5.07%; CPP2: –13.47%), whilst low-wage occupations (CPP5–CPP9) show virtually no reduction (ranging from –0.10% to 0%).

The adoption of telework (Figure 3b) alters this spatial distribution, increasing the number of civil parishes in the two lower CB brackets. However, two patterns remain stable: CB increases towards the periphery, and civil parishes with the highest CB remain almost exactly the same. Thus, fulfilling the potential for telework adoption does not appear to contribute to mitigating spatial differences in CB. The persistence of high CB in LMA borders even under the telework scenario could reflect occupational rigidity due to sectoral occupation group patterns that limit remote work flexibility, as shown in Table 1.

5.4. Equity Assessment

Applying the adapted PI to CB levels across all civil parishes and CPP categories in the LMA offers a critical lens to examine spatial and socio-professional commuting inequalities. Figure 6 presents the values of the adapted PI for the CB in the LMA municipalities, comparing two different scenarios (without telework and with telework), highlighting the disparity levels of CB among different municipalities. The results reveal that, despite the telework effect on average CB levels (Table 2), its implementation tends to increase the PI by 5%, on average, and, consequently, the inequality compared to the no telework scenario. However, the magnitude and spatial distribution of this effect vary considerably across municipalities.



	Global (LMA)	Cascais	Lisboa	Loures	Mafra	Oeiras	Sintra	Vila Franca de Xira	Amadora	Odivelas	Alcochete	Almada	Barreiro	Moita	Montijo	Palmela	Seixal	Sesimbra	Setúbal
No telework	4.26	2.34	3.38	2.82	2.24	3.82	2.75	2.52	3.36	1.86	5.95	2.24	1.89	2.20	2.56	3.02	3.22	1.82	2.31
Telework	4.53	2.46	3.55	2.97	2.35	4.02	2.89	2.64	3.53	1.95	6.13	2.36	2.00	2.30	2.69	3.18	3.32	1.91	2.43
Variation	6.35%	5.28%	5.10%	5.05%	5.14%	5.20%	5.24%	5.11%	5.20%	5.19%	3.12%	5.15%	5.47%	4.94%	5.08%	5.26%	3.18%	5.01%	5.16%

Figure 6. PI for average CB distribution across the LMA municipalities.

Initially, telework was conceived and explored as a commuting equaliser. Contrary to these expectations, Figure 6 reveals that the benefits of telework may be disproportionately accruing to populations already less burdened by commuting, which aligns with our hypothesis that these new work dynamics (teleworking) end up accentuating the inequality in the distribution of CB: In other words, digitalisation exacerbates disparities. Typically, higher-wage, white-collar professionals who are more likely to have telework-compatible positions (Eurofound, 2020; Sostero et al., 2020) also tend to live in central or well-connected areas. In contrast, low-wage workers are often more concentrated in peripheral areas and have low or no telework compatibility, concentrating the burden among the more socioeconomically fragile groups.

This occupational geography directly relates to the adapted PI results shown in Figure 7. Although telework adoption reduces overall commuting times and costs, it disproportionately benefits high-skilled workers in central areas, who can more easily telework, while low-skilled or presential-bound workers, often in peripheral zones, experience relatively fewer or no gains. Consequently, the adapted PI increases, reflecting a widening inequality in CB distribution.

Another analytical perspective examines the relationship between the inequality of CB and the spatial distribution of the CPPs. The adapted PI reveals significant disparities in CB in the LMA, with these levels increasing in the telework adoption scenario. However, high levels of inequality, as captured by the PI, are not necessarily aligned with high average levels of CB.

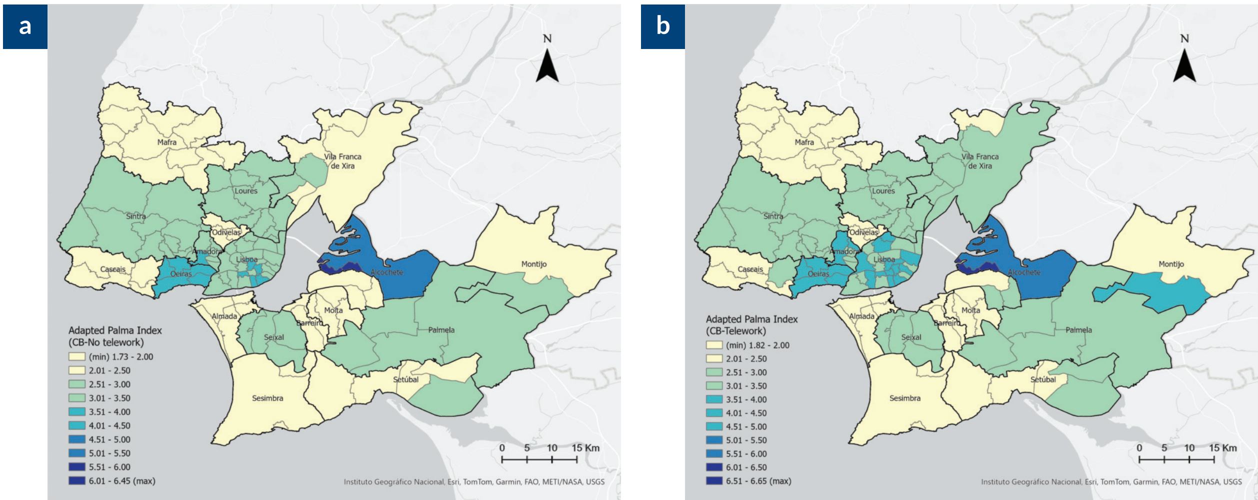


Figure 7. Adapted PI for the CB distribution across the LMA: (a) no telework; (b) telework. Source: Map created using ArcGIS Pro (Esri, 2023), using data provided by the authors.

For example, the municipality of Lisbon, despite having a relatively low average CB, shows PI values among the highest in both scenarios. Similarly, the Alcochete civil parishes, which present only moderate levels of CB, are among those with the highest PI values. These two realities may reflect pronounced inequalities among their residents, possibly due to the urban sprawl in previously rural areas facilitated by the construction of the Vasco da Gama Bridge, which may have attracted wealthier population groups, leading to a change in the socioeconomic characteristics of this municipality.

High-skilled occupations, higher wages, and greater adaptability to telework are closely interrelated and tend to be associated with lower CB levels. These characteristics generally follow a centre–periphery spatial distribution. However, the adapted PI does not always mirror this pattern. Central areas (particularly Lisbon and its surroundings) tend to display higher PI values, a tendency that appears to have been further reinforced by the growth of teleworking. In contrast, peripheral zones with a high concentration of low-skilled workers often register both elevated CB levels and greater inequality in their distribution, as reflected in the PI. The adapted PI captures the extent of the disparity between the opposite extremes of the sample, workers classified by CPP, highlighting how job type, location, and transport infrastructure influence the equity of urban mobility. While telework has the potential to reduce CB, in the absence of inclusive urban planning and mobility policies, it risks reinforcing the existing socio-spatial inequalities within the LMA.

6. Discussion and Conclusion

This study examined the spatial distribution of CB across the LMA and tested the hypothesis that new work dynamics, particularly teleworking, increase inequality in CB distribution. In broader terms, it examined whether digitalisation exacerbates existing socio-spatial disparities. Using integrated geospatial CB indicators, occupational typologies (CPP), and an adapted PI, we assess how teleworking reshapes, but does not necessarily resolve, pre-existing mobility inequalities.

The findings confirm our hypothesis that while telework reduces overall commuting demands, its benefits are unequally distributed. The PI increased by 5% on average under the telework scenario despite reducing average CB levels, indicating that telework exacerbates rather than mitigates CB inequality. This challenges the notion that telework acts as a commuting equaliser and aligns with recent studies exploring how digitalisation can deepen socio-spatial disparities (Florida et al., 2023; Gokan et al., 2022).

This amplification of inequality can be understood through two aspects: First, telework capacity is strongly mediated by occupation and income, where high-skilled and white-collar occupations (CPP1–2) show CB reductions of 5–13%, whilst low-skilled workers (CPP5–9) experienced virtually no change. This aligns with findings from Dingel and Neiman (2020) and Sostero et al. (2020), who identified that around 37% of jobs are teleworkable, concentrated in high-wage sectors. Second, this occupational stratification has a clear spatial expression: High-skilled workers are predominantly located in central, well-connected areas with lower CB, while low-skilled workers are concentrated in peripheral areas with limited PT infrastructure and higher CB. This creates a "double advantage" for privileged workers, as existing spatial advantages are associated with new flexibility advantages, and conversely, a "double burden" for peripheral, low-skilled workers, who are both excluded from telework opportunities and face poor transport access.

The spatial analysis revealed a persistent centre–periphery gradient in CB that telework adoption cannot disrupt. Peripheral civil parishes maintained CB levels exceeding 25% even under the telework scenario, while central Lisbon parishes remained below 10%. This reflects what Preston and Rajé (2007) described as the relationship between social and spatial inequalities in the transportation system, where unequal distribution of resources and infrastructures leads to differential job access opportunities. Interestingly, the analysis also reveals that high levels of inequality in the CB distribution are not necessarily associated with higher CB values. The Lisbon municipality demonstrates low average CB but high PI values, while municipalities like Alcochete present both high CB and high PI values. These contrasting patterns suggest significant intra-municipal disparities, underscoring the importance of disaggregated spatial analysis, as argued by Pereira and Karner (2021).

The job–housing mismatch identified by Zhang et al. (2018) and Zhou et al. (2013) as a key driver of CB inequality remains fundamentally unchanged by telework adoption. The occupational and spatial mismatch observed in the LMA reinforces the centre–periphery divide, where physical distance from economic hubs intersects with structural barriers to telework adoption. The persistence of such patterns likely reflects structural constraints that go beyond individual travel behaviour and enter the domain of systemic spatial injustice.

From a distributive justice perspective, our findings reveal that telework, in its current pattern, while offering new opportunities for reducing commuting-related pressures, risks amplifying existing socio-spatial inequities due to its uneven diffusion across CPPs and the uncritical implementation of policies. To harness telework as a tool for equity, policy efforts should encompass inclusive mobility strategies, such as improving the PT network in peripheral areas to reduce CB for non-teleworkers; developing targeted upskilling programmes to expand access to teleworkable occupations for disadvantaged workers; promoting mixed land-use and affordable housing close to employment centres to address job–housing mismatches; and implementing regulatory frameworks that extend telework options more equitably across occupational categories where feasible.

Several limitations should be acknowledged. First, our CB calculations assume that workers bear the full financial burden of their commute. While Portuguese labour law does not mandate employer reimbursement of regular commuting costs in the private sector, and there is no legal obligation to cover PT passes or fuel expenses, some employers voluntarily provide full or partial transport subsidies. Second, the CB concept focuses solely on out-of-pocket and travel time costs rather than subjective travel experiences. Third, the cross-sectional nature limits causal inference; longitudinal data would strengthen claims about telework's impact.

An important consideration beyond this analysis concerns potential feedback effects between large-scale adoption of telework and PT demand and supply. Most literature focuses on emergency pandemic responses rather than structural adjustments to sustained telework. As such, future research should address these limitations through comparative studies across metropolitan areas, longitudinal CB evolution with sustained telework, and the feedback effect on PT.

In conclusion, this study contributes to transport equity literature by demonstrating how ostensibly progressive innovations can inadvertently deepen inequalities when their diffusion follows existing lines of privilege. Without inclusive urban planning and integrated policy approaches addressing the root causes of socio-territorial fragmentation, telework risks entrenching existing disparities across the metropolitan context rather than mitigating them. The benefits of labour digitalisation must be contextualised within broader planning frameworks to ensure equitable outcomes for workers, regardless of occupation, income, or residential location.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data presented in this study are available upon request.

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