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BICYCLE ACCESSIBILITY PLANNING:

Towards an Equitable Approach

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To my family

"Life is like riding a bicycle.

In order to keep your balance, you must keep moving."

Albert Einstein

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ABSTRACT

Cycling planning has emerged as a paramount approach for developing resilient, sustainable, inclusive, and low-carbon cities. The literature endorses the bicycle as an affordable, healthy, and reliable transport mode which has the potential to democratise mobility, facilitate social cohesion, and ultimately increase access to opportunities for distinct population groups. Nevertheless, previous research indicates that cycling planning tends to prioritise central and wealthy areas disregarding disadvantaged and peripheral neighbourhoods.

Scholars argue that this phenomenon might directly relate to the shortage of equity-oriented metrics for project appraisal in the earlier stages of planning and decision-making processes. Although equity issues have been highlighted in transport literature in recent decades, empirical evidence indicates that this concept is hardly measured and prioritised in cycling planning. Therefore, it remains unclear whether planning practitioners address or prioritise equity throughout the development and implementation of cycling plans.

In response, this thesis employs a mixed-methods approach to examine to what extent planning practitioners from European cities address equity in the planning and decision-making processes. Firstly, drawing on the literature produced over the last decade, this research introduces a planning support tool, TIRE, to measure the equity impact of cycling network allocation. Then, this research quantitatively assesses cycling plans from three different European cities to examine the distribution of cycling accessibility levels across socioeconomically advantaged and disadvantaged groups. Finally, this thesis examines to what extent equity issues are addressed and prioritised through the qualitative analysis of interviews, focus groups, questionnaires and official documents.

From a quantitative perspective, the tool indicates social-spatial asymmetries across the case studies, suggesting that socioeconomically advantaged zones are likely to be better provisioned, with levels of bicycle accessibility above the municipality average. In terms of qualitative analysis, this thesis suggests that vertical equity is not directly assessed and addressed throughout the implementation of the evaluated cycling plans. Conversely, there is a tendency towards the horizontal equity perspective, which expects an equal distribution of investments, resources, and service levels among all social groups, regardless of individual needs and constraints.

Furthermore, this study shows that the involved planning practitioners do not ignore the relevance of equity in planning practice. The participants positively evaluated the tool's user-friendliness and usefulness dimensions, arguing that TIRE has a potential application in planning practice as a data-driven prioritisation tool. Accordingly, the participants believe the tool TIRE could foster the involvement of citizens and other stakeholders in the decision-making process, encouraging the development of equitable cycling plans.

KEYWORDS: Bicycle planning, Equity, Accessibility, Planning support systems, Spatial analysis, GIS, Focus group, Interview.

RESUMO

O planeamento ciclável surgiu como uma crucial abordagem no desenvolvimento de cidades resilientes, sustentáveis, inclusivas e com baixo teor de carbono. A literatura aponta a bicicleta como um modo de transporte acessível, saudável e viável, com potencial para democratizar a mobilidade, facilitar a coesão social e, em última instância, aumentar o acesso à oportunidades para grupos populacionais distintos. Entretanto, pesquisas indicam que planos de infrastrutura ciclável tendem a priorizar as áreas centrais e afluentes, desconsiderando bairros desfavorecidos e periféricos.

Pesquisadores argumentam que este fenómeno pode estar diretamente relacionado à escassez de indicadores para suportar fases iniciais dos processos de planeamento e de tomada de decisão. Embora as questões de equidade tenham sido destacadas na literatura nas últimas décadas, evidências empíricas indicam que este conceito dificilmente é medido e priorizado no planeamento ciclável. Portanto, ainda não está claro em que medida planeadores abordam ou priorizam a eqüidade durante o desenvolvimento e implementação de planos de infraestrutura ciclável.

Em resposta, esta tese emprega uma abordagem de método misto para examinar até que ponto planeadores de cidades européias abordam e priorizam a equidade durante processo de planeamento e tomada de decisão. Primeiramente, esta pesquisa introduz um ferramenta de apoio ao planeamento, TIRE, capaz medir o impacto da alocação da rede de ciclovias em termos de equidade. Em seguida, esta pesquisa mede quantitativamente o impacto da equidade de planos cicláveis de três cidades européias distintas para examinar a distribuição dos níveis de acessibilidade entre grupos socioeconómicos favorecidos e desfavorecidos. Por fim, esta tese examina em que medida as questões de equidade são priorisadas, através da análise do conteúdo de documentos oficiais, bem como a análise dos grupos focais, entrevistas e inquéritos dirigidos aos planeadores locais.

Com base nos resultados quantitativos, a ferramenta indica assimetrias sócio-espaciais nos estudos de caso, sugerindo que as zonas socioeconomicamente favorecidas são provavelmente mais bem providas, com níveis de acessibilidade de bicicletas acima da média do município. Relativamente à análise qualitativa, esta investigação indica que a equidade vertical não é directamente avaliada e abordada durante a implementação dos planos estudados. Em contrapartida, há uma tendência para a perspectiva da equidade horizontal, que pressupõe uma distribuição igualitária de investimentos e serviços dentre todos os grupos sociais, independentemente das necessidades e restrições individuais.

No entanto, os profissionais do planeamento não ignoram a relevância da equidade na prática. Os participantes avaliaram positivamente a ferramenta em suas dimensões de facilidade de uso e utilidade, argumentando que TIRE tem uma aplicação potencial na prática como uma ferramenta de priorização. Assim, os participantes acreditam que a ferramenta TIRE pode promover o envolvimento dos cidadãos e outras partes interessadas no processo de tomada de decisão, encorajando o desenvolvimento de planos cicláveis equitativos.

PALAVRAS-CHAVE: Planeamento ciclável, Equidade, Acessibilidade, Sistemas de Apoio ao Planeamento, Análise espacial, SIG, Grupo focal, Entrevista.

RESUMÉ

Le développement des mobilités douces s'est affirmé comme un moyen incontournable pour développer des villes résilientes, durables, inclusives et à faible émission de carbone. La littérature décrit le vélo comme un mode de transport abordable, écologique et efficace, capable de démocratiser la mobilité, de faciliter la cohésion sociale et, finalement, d'améliorer l'accès aux opportunités pour des populations distinctes. Néanmoins, des études récentes indiquent que l'aménagement cyclable et la distribution des bénéfices liés au vélo tendent à privilégier les zones centrales et favorisées, au détriment des quartiers défavorisés et périphériques.

Les spécialistes estiment que ce phénomène pourrait être directement lié au manque de données sur l'équité pendant les phases d'évaluation des projets de développement des transports. Bien que les questions d'équité aient été mises en évidence dans la littérature sur les transports au cours des dernières décennies, les preuves empiriques indiquent que ce concept est à peine mesuré et priorisé dans la planification cyclable. Par conséquent, il n'est pas certain que les professionnels de la planification prennent en compte ou donnent la priorité à l'équité tout au long de l'élaboration et de la mise en place des plans cyclables.

En réponse, cette thèse utilise une approche méthodologique mixte pour examiner dans quelle mesure les villes européennes abordent l'équité dans le processus de planification et de prise de décision. Dans un premier temps, en s'appuyant sur la littérature produite au cours de la dernière décennie, cette recherche introduit un outil d'aide à la planification, nommé TIRE, pour mesurer l'impact sur l'équité de l'allocation des réseaux cyclables. Par la suite, elle mesure quantitativement l'impact sur l'équité des schémas directeurs cyclables de trois villes européennes distinctes afin d'examiner la répartition des niveaux d'accessibilité entre les groupes socio-économiquement favorisés et défavorisés. Enfin, elle examine dans quelle mesure les questions d'équité sont abordées et priorisées à travers l'analyse qualitative d'entretiens, de groupes de discussion, de questionnaires et de documents officiels.

D'un point de vue quantitatif, l'outil révèle des asymétries socio-spatiales significatives dans les études de cas, suggérant que les zones socio-économiquement favorisées sont susceptibles d'avoir des niveaux d'accessibilité cyclable supérieurs à la moyenne de la ville. En ce qui concerne l'analyse qualitative, cette recherche indique que l'équité verticale n'est pas directement évaluée et traitée tout au long de la mise en œuvre du plan vélo. À l'inverse, la tendance est à l'équité horizontale, qui prévoit une répartition égale des investissements, des ressources et des niveaux de service entre tous les groupes sociaux, quels que soient les besoins et les contraintes de chacun.

Par ailleurs, il ressort que l'outil TIRE apporte aux professionnels, déjà sensibilisés à la pertinence de l'équité dans les transports, une aide à la priorisation lors de la planification des réseaux cyclables. Au-delà de son utilité, la facilité d'usage de TIRE a été reconnue par ces derniers. Ils considèrent également que TIRE pourrait favoriser l'implication des citoyens et des autres parties prenantes dans le processus de prise de décision, encourageant ainsi le développement de plans cyclables équitables.

MOTS-CLÉS: Plan vélo, Équité, Accessibilité, Systèmes d'aide à la Planification, Analyse Spatiale, SIG, Groupe de Discussion, Entretien.

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

BA – Bicycle Accessibility Indicator

BMP – Bicycle Master Plan

BSS – Bicycle-sharing system

CITTA – Research Centre for Territory, Transports and Environment

CBA – Cost-benefit Analysis

CO2 – Carbon dioxide

DEC – Departamento de Engenharia Civil

EU – European Union

GIS – Geographic Information System

HEAT – Health Economic Assessment Tool

MCA – Multicriteria analysis

NGO – Non-governmental organisation

OSM – OpenStreetMap

PCA – Principal Component Analysis

POIs – Points of Interest

PSS – Planning Support System

SE – Socioeconomic Index

TIRE – Tool for assessing the Relative Equity Impacts of Bicycle Plans

USA / US – United States of America / United States

Q&A – Questions and Answers

1
INTRODUCTION

1.1. RESEARCH BACKGROUND

Cities worldwide are under great pressure to reduce their reliance on fossil fuels, regarded as one of the largest contributors to global climate change. Among several drivers, the transport sector accounts for a significant share of global greenhouse gas emissions and all carbon dioxide emissions (Lamb et al., 2021). Therefore, this sector is recognised as crucial in the development of mitigation and adaptation solutions (Banister, 2011; Banister and Hickman, 2013; Hickman et al., 2011).

Nevertheless, the decarbonisation of the transport sector remains challenging due to the growing decentralisation of activities and urban sprawl, which directly affects travel distances and modal choices (Banister, 2008, 1994). Furthermore, empirical evidence suggests that traditional transport planning focused on providing road infrastructure investments to alleviate congestion and facilitate the movement of motorised vehicles through the city (Banister, 2008) heavily influences this vicious cycle. Consequently, cities increasingly depend on motorised modes of transport, struggling to address the generated negative burdens (Lyons, 2018).

Moreover, the decades of car-oriented planning have affected the evolution of urban areas, land use and travel behaviour, cratering a solid symbolic attachment to this mode of transport (Lyons and Davidson, 2016), which has been profoundly path-dependent and increasingly disconnected from broader social and environmental policy goals (Vigar, 2017). Accordingly, studies suggested that in motorised societies, people with no access to the dominant mode of transport are likely to struggle to access opportunities to fulfil basic needs (i.e., employment, education, health assistance), ultimately leading to the phenomenon of transport poverty (Lucas, 2012) and transport-related social exclusion, among socioeconomically disadvantaged people (Martens, 2017; Martens and Golub, 2012; Pereira et al., 2017).

In order to overcome this conundrum, research and policy have sought to explore potential avenues for advancing sustainable transport modes, entailing a balance between economic development, environmental preservation and social equity goals (Lucas et al., 2013; Manaugh et al., 2015), which requires a broad understanding of a myriad of social, technical, cultural and economic factors (Goldman and Gorham, 2006). Accordingly, studies indicate that the bicycle, as a transport mode, has

the potential to tackle the aforementioned issues, carrying significant economic, environmental and social benefits (Banister, 2011; Hickman et al., 2011; Nunen et al., 2011; Temenos et al., 2017).

Scholars argue that the modal shift from motorised vehicles to cycling has the potential to systematically reduce congestion, pollution, and greenhouse emissions and guarantee a better quality of urban spaces (Feitelson, 2002). Thus, reducing the attractiveness of the car and promoting active modes of transport are strategies aimed at addressing environmental issues while promoting economic efficiency and social equity in societies (Golub and Martens, 2014; Marshall and Banister, 2000; Martens et al., 2012; McLeod et al., 2017).

Furthermore, the bicycle is regarded as an affordable, low-carbon and flexible mode of transport, able to increase access to opportunities for the whole community, democratising mobility and ensuring social diversity and inclusion (Golub and Martens, 2014; Karner, 2016; Pereira et al., 2017). More recently, with the pandemic of COVID-19, numerous cities have reallocated public and street space for cyclists and introduced pro-bike interventions such as pop-up bike lanes, e-bike subsidies, free shared bike use, and traffic calming measures. This disruptive outbreak has created an overarching momentum for encouraging potential strategies to support cycling as an accessible, healthy and resilient transport mode (Nikitas et al., 2021; Teixeira and Lopes, 2020).

Nevertheless, among the three sustainability goals mentioned above, previous research has identified that little attention has been paid to the equity dimension in transport planning practice, in contrast to the emphasis on environmental and economic impacts (Martens, 2006). Mainly, transport planners rely on evaluation methods that hardly address equity issues. Likewise, this topic is usually disregarded by local authorities' guidebooks for transport appraisal in Europe (Di Ciommo and Shiftan, 2017). Regarding active transport planning, scholars argue that the cycling benefits are unevenly distributed across distinct societal groups in cities despite the efforts to normalise the bicycle as a fully recognised daily transport mode (Aldred et al., 2016), suggesting that the equity implications are often neglected during the planning and decision-making processes (Manaugh and El-Geneidy, 2011).

In order to examine this phenomenon in-depth, previous studies explored distinct theories of justice and theoretical principles to assess the equity[1] impacts of transport.Within the equity debate, research focuses on the target profiles of cycling projects and the extent to which the needs of minority groups are considered during the planning and decision-making process (Dill and McNeil, 2013; Gatersleben and Appleton, 2007; Hosford and Winters, 2018; Pucher et al., 2010). For instance, previous studies found evidence that cycling planning often targets the creative class in the United States, which may contribute to the maintenance of social injustices, segregating the potential people who do not fit into the privileged groups (Gössling et al., 2018; Hoffmann, 2013; Lubitow et al., 2017; Lubitow and Mahmoudi, 2016). Therefore, scholars defend the importance of changing the status quo of cycling planning and decision-making processes (Deka, 2017; Oosterhuis, 2018).

Concerning cycling equity assessments, the literature emphasises aggregate socioeconomic indicators and spatial analysis. In the latter, studies have employed accessibility measures as an analytical equity parameter, as increased accessibility is considered a generated benefit from transport investments (Bills and Walker, 2017; Geurs and Ritsema van Eck, 2001; Pereira, 2019; Pritchard et al., 2014). In addition, this literature examines how low accessibility can lead to social exclusion, hindering the well-being of disadvantaged individuals and groups or vulnerable communities, by exploring crucial facets of urban structure, such as housing location and employment opportunities (Iacono et al., 2010).

[1] Concept further discussed in subsection 1.6.

Likewise, scholars argue that the lack of accessibility to essential destinations such as jobs, education facilities and recreation can profoundly impact the prospects for communities (Boarnet et al., 2017; Guthrie et al., 2017; Karner and Niemeier, 2013) and individuals (Bills and Walker, 2017; Cui et al., 2019; Guzman et al., 2017; Manaugh and El-Geneidy, 2011; Pereira et al., 2019).

Research intersecting accessibility, equity and bicycle emerged over the last decade, as further discussed in Chapter *3*. This literature examines how bicycle infrastructure, investments and accessibility gains are distributed across minority groups and disadvantaged areas in cities (Braun et al., 2019; Chandra et al., 2017; Clark and Curl, 2016; Houde et al., 2018; Kent and Karner, 2019; Pritchard et al., 2019b; Qian and Niemeier, 2019; Teunissen et al., 2015; Tucker and Manaugh, 2018; Wang and Lindsey, 2017). These studies raise important questions about where and for whom cities plan cycling infrastructure, amenities, and incentive programs. Scholars claim that exclusionary social processes may occur when the investment in bicycle infrastructure emerges as a real-estate development strategy to prioritise areas (Golub et al., 2016; Stehlin, 2015). Accordingly, considerable literature explored the connection of how the cycling infrastructure provision is entangled with capital-intensive real estate redevelopment, highlighting impacts in terms of gentrification or the displacement of poorer households (Flanagan et al., 2016; Golub et al., 2016; Lubitow and Mahmoudi, 2016; Temenos et al., 2017).

The literature review presented in Chapter *3* suggests that equity issues are likely to be disregarded or overlooked in cycling planning across cities in the global north and south since the distribution of bicycle-related benefits often targets socioeconomically advantaged groups, central and denser areas. However, most empirical findings concentrate on infrastructure plans and cycling services implemented in the North and South American contexts. Up to date, there is limited evidence encompassing the equity implications of cycling plans, considering the hints of planning and decision-making process. Likewise, it remains uncertain to what extent planning practitioners address or prioritises equity issues in the European context. This thesis suggests that discussing the equity outcomes of cycling plans in the early stages of planning and decision-making processes could foster the equity outcomes of cycling plans as well as the potential of the bicycle in reducing existing spatial and social inequities in cities.

1.2. RESEARCH SCOPE

This thesis focuses on the equity impacts of cycling planning, framed in the European context, aiming to contribute to the current literature and bridge the gap between research and planning practice.

In contrast to the current approaches to equity assessment in cycling, there is a lack of analytical frameworks oriented to support planning practices considering both ex-ante and ex-post perspectives. The current literature has mainly focused on the equity impacts after the plan implementation or investment allocation, with limited evidence on how planners could delineate cycling-related investments to improve equity outcomes. Although the ex-post analysis of equity gives some directions on managing project investments and revenues (Ramjerdi, 2006), it overlooks how decision-makers, planning practitioners and different stakeholders could address and prioritise equity issues along with parallel planning priorities.

Based on the evidence that the equity dimension has been far less addressed in planning practice (Lucas et al., 2013; Manaugh et al., 2015), this thesis scope focuses on the value of accessibility

planning theory[2] to develop a planning support system tool (PSS) to assess the equity implications of cycling infrastructure allocation and support planning practitioners in the decision-making processes. Scholars suggest that PSS tools can provide better visualisation and spatialisation of transport impacts, allowing planning practitioners to interact with the tool, sketch scenarios, analyse the results and discuss new solutions (te Brömmelstroet and Bertolini, 2008).

Furthermore, scholars argue that accessibility-based PSS tools have the potential to assess the distributive impacts of transport projects, investments or services in the early planning stages, helping to achieve the greatest possible social benefit (Guthrie et al., 2017). Accordingly, there has been increasing research into the development of accessibility tools for active modes of transport (Iacono et al., 2010; Philips et al., 2018; Sagaris and Arora, 2016; Silva et al., 2019, 2014; Tal and Handy, 2012; Vale et al., 2016), despite several challenges to measuring accessibility at the scale of pedestrians and bicycle users. (Iacono et al., 2010; Vale et al., 2016).

Assessing the equity impacts of cycling planning in the European context is complex because the structural and social conditions for cycling vary widely across the continent. On the one hand, some countries have a long cycling tradition, strong commitment, and policies to encourage bicycle use. On the other hand, the importance of cycling for public health, the environment, and the economy is barely recognised in other countries (Lopes et al., 2021; Pucher and Buehler, 2008; Zhao et al., 2018a). Despite significant challenges in the statistics related to cycling, a study estimated that cycling accounts for a modal share ranging from 30% to almost 0% in different countries in the pan-European region (Deffner et al., 2012). Accordingly, cities can be categorised into three categories based on the cycling conditions and bicycle modal share (Dufour, 2010), as illustrated below (Fig. 1).

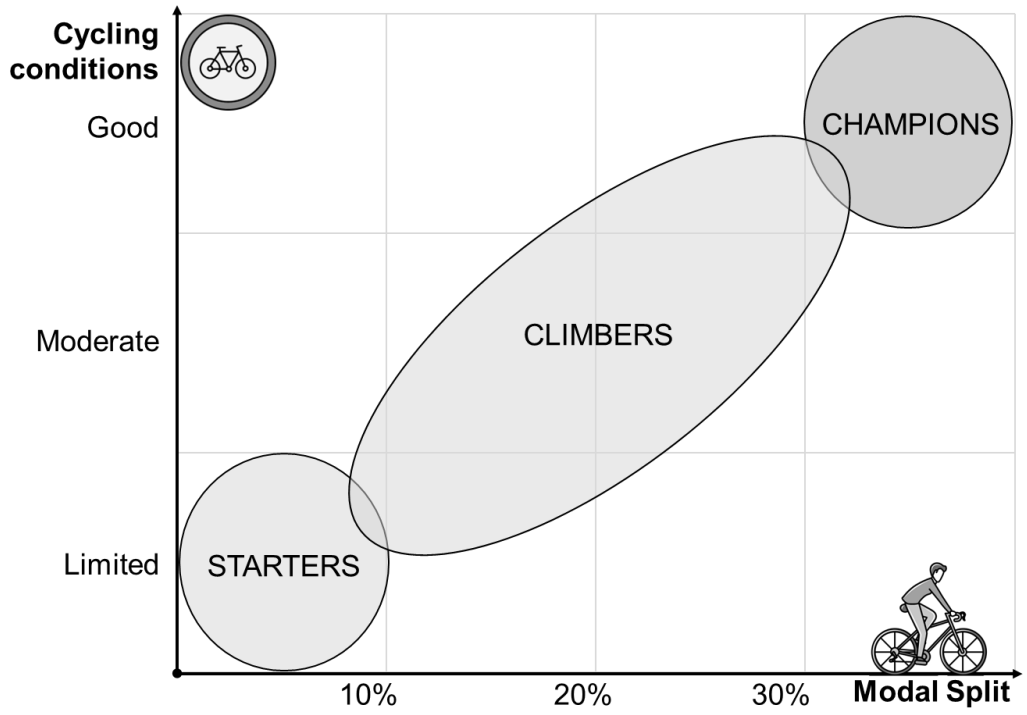


Fig. 1 – Cities categories (starter, climber, and champion). Adapted from Dufour (2010)

[2] Concept further discussed in subsection 1.6.

Respectively, the starter cycling cities present a bicycle modal share below 10% (Urbanczyk, 2010a) and a limited cycling infrastructure. These cities struggle to implement projects to reverse their car-oriented background, recognising the bicycle as a viable transport mode (Silva et al., 2019). Previous research argued that the effectiveness of proposed plans and investments is affected by the current political resistance and lack of cycling commitment (Bicalho et al., 2019). The climber cycling cities depict a higher modal share, between 10% and 30%. These cities have growing cycling levels, increasing infrastructure measures, political commitment, and positive social attitudes toward cycling as a transport mode. Finally, the latter category, the so-called champion cities, has a high bicycle modal split, a strong bicycle culture, and a dedicated, accessible, and well-connected cycling infrastructure (Urbanczyk, 2010a). This thesis focuses on the first two categories as a testbed for the equity-oriented PSS and the further qualitative discussion on the implications for planning practice.

The proposed research scope (Fig. 2) provides the theoretical and empirical support for the proposed research approach and the subsequent research questions. Considering the sustainable mobility goals and challenges, this thesis focuses on developing a useful and user-friendly PSS tool to measure the equity outcomes of cycling plans (see Chapter *3*). Throughout the testbed applications (see Chapter *4*), this thesis seeks an in-depth discussion of how equity is addressed in planning practice, highlighting the measures implemented, the strategies prioritised, and the barriers and potential pathways towards a more equitable approach to cycle planning (see Chapter *5*).

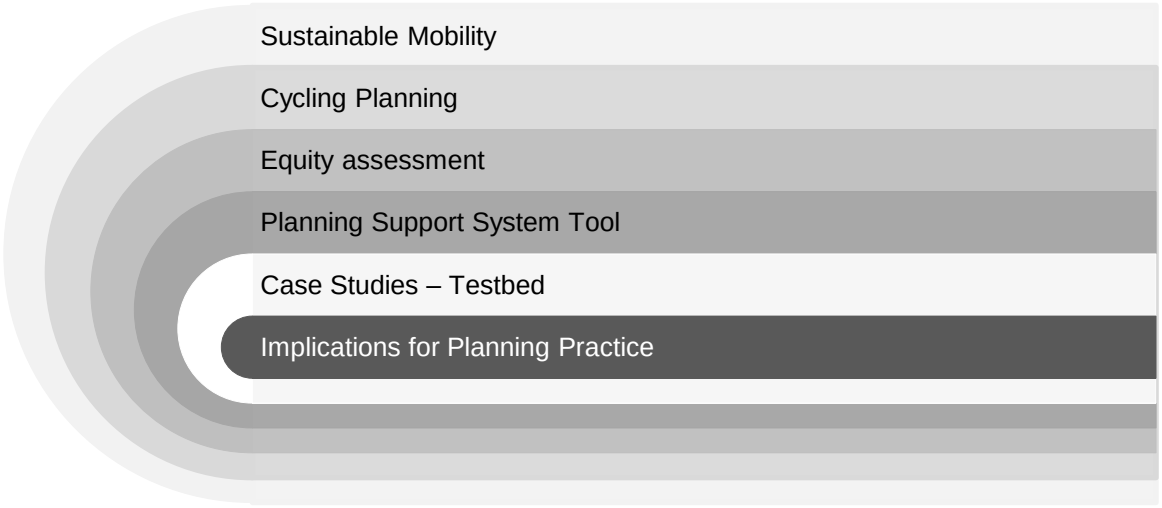


Fig. 2 – Research Scope

1.3. RESEARCH PROPOSAL

1.3.1. RESEARCH OBJECTIVES

This research has three main objectives. Firstly, by building on the literature produced in the last decade, this research seeks to develop a PSS tool, TIRE, to assess the equity impact of cycling plans. Secondly, this research aims to quantitatively measure the equity impact of cycling plans in different European cities, focusing on how the increased cycling accessibility levels benefit different socioeconomic groups. Thirdly, from a qualitative perspective, this research examines whether equity issues are addressed and prioritised in cycling planning and decision-making processes in the European context.

1.3.2. Research Questions

For each research objective, the present study aims to answer the following primary and secondary questions:

1) What would be a useful planning support system tool for assessing the equity impacts of European cycling plans?

> 1.1) What are the most used frameworks, methods, and analysis tools for measuring the equity impact of bicycle planning?
>
> 1.2) Is TIRE user-friendly and useful for supporting equitable planning practices in starter cycling cities?

2) To what extent is the allocation of the cycling infrastructure network equitable, considering the distribution of accessibility levels over socioeconomically disadvantaged and advantaged areas?

> 2.1) How equitable is the distribution of bicycle-related benefits across cities in the global north and south?

3) To what extent do planners address and prioritise equity-oriented strategies within European cycling plans?

> 3.1) To what extent is equity prioritised in cycling planning guidelines?
>
> 3.2) To what extent are equity issues considered compared to competing planning priorities?

1.3.3. Case Study Selection

In recent years, European cities have developed Bicycle Master Plans (BMP) focused on cycling network provision to create favourable cycling conditions and increase the local bicycle mode share. This approach aims to guide the development of projects and strategies at national, regional, and municipal levels, requiring integrated transport and land-use planning, an understanding of the needs of different users, and additional policies towards urban and rural areas (Deffner et al., 2012). This thesis focuses on the municipal scale, representing a crucial sphere of action that materialises the infrastructure planning, investments, and incentives at the local scale, aiming at significantly improving the primary conditions in favour of cycling.

As mentioned above, this research focuses on cities with different cycling statuses, subject to the maturity of the cycling network and bicycle modal split. Thus, the proposed assessment framework concentrates on the starter and climber cycling city contexts. The central planning challenges in the former encompass providing a cycling network to improve cycling safety and directness. In the latter, a basic cycling network infrastructure already exists, and therefore, planning efforts aim to improve network cohesion, linking up cycling areas and expanding the network so bicycle users can ride over longer distances to access opportunities (Dufour, 2010).

This thesis does not assess a champion cycling city since this research aims to assess the equity implications of cycling network allocation and to what extent equity issues are addressed and prioritised in planning and decision-making processes. This latter city category embraces a limited number of northern European cases with a sizeable and maturated network of safe and direct routes implemented. Therefore, such cities do not focus on cycling network provision; instead, they prioritise

the maintenance and upgrading of the established infrastructure to improve cycling flow and speed (Dufour, 2010).

Therefore, in order to develop an equity-oriented PSS tool and evaluate the implications for planning practice, this thesis proposes the assessment of three different case studies, encompassing both ex-post and ex-ante scenarios of starter and climber cycling cities, as depicted in Fig. 3. This case study rationale allows the calibration of the PSS tool based on the available socioeconomic datasets in each city. Moreover, the quantitative testbed of particular cases and the subsequent qualitative analysis of the results with local planning practitioners allows the validation of the PSS tool in different European cities, planning scenarios and socioeconomic contexts.

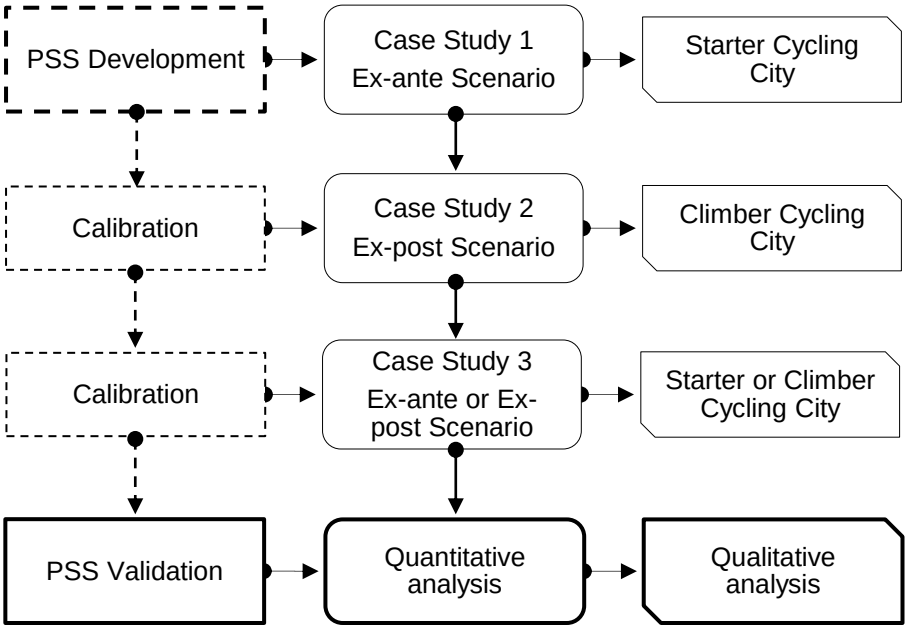


Fig. 3 – Case study rationale

Based on interpersonal relationships, academic and professional networking, as well as the availability of the local research centres to share the required database to conduct the proposed research approach, the cities of Lisbon, the capital of Portugal, Munich, the capital of the State of Bavaria in Germany and Helsinki, the capital of Finland, were selected as case studies (Fig. 4) (further details in Chapter *4* and *5*).

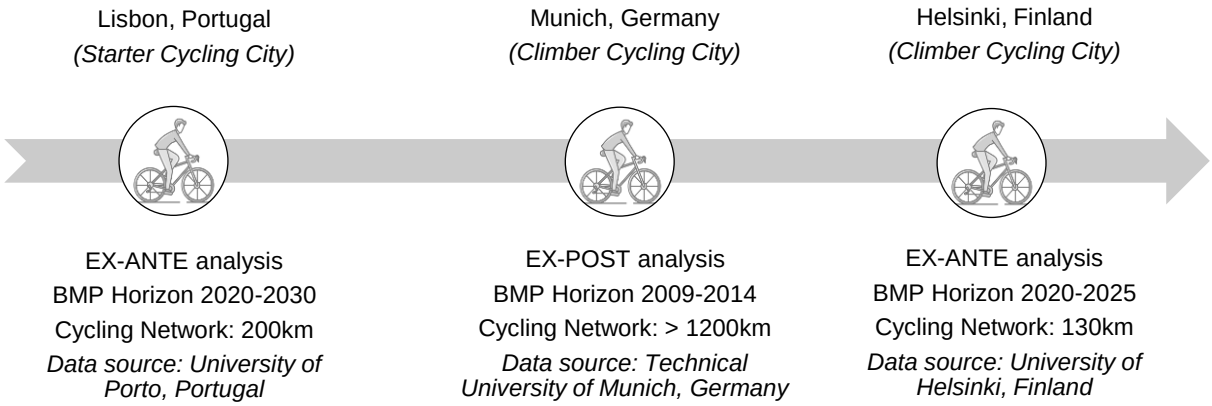


Fig. 4 – Case study selection

1.4. METHODOLOGY

In order to address the research objectives and answer the subsequent research questions, this thesis applies a mixed-method approach encompassing data collection and analysis. Table 1 illustrates the relationship between the proposed methodological approaches, the research questions and the resulting scientific papers.

Table 1 – Methodology Framework

Data Collection	Data Analysis	Purpose	Research Question	Paper (n)
Census Mobility Survey OpenStreetMaps BMP official documents	TIRE	Developing a PSS tool Assessing the distribution of cycling infrastructure and bicycle accessibility levels across distinct socioeconomic groups in distinct European cities	RQ.1 RQ.1.2 RQ. 2	Paper 2 Paper 3
Literature Review	Systematic Analysis	Examining empirical evidence, contemporary methods, and assessment frameworks	RQ.1.1 RQ 2.1	Paper 1
BMP official documents	Content Analysis	Examining to what extent the assessed BMP guidelines approach equity issues	RQ 3 RQ 3.1	Paper 3
Focus Groups	Thematic Analysis	Introducing TIRE and exploring to what extent planning practitioners	RQ 3 RQ 3.2	Paper 4

		address or prioritise equity in practice		
Interviews	Thematic Analysis	Introducing TIRE and exploring to what extent planning practitioners address or prioritise equity in practice	RQ 3 RQ 3.2	Paper 4
Survey	Descriptive analysis	Exploring BMP Priorities and the often-applied assessment methods	RQ 3	Paper 4
Post-Focus Group Survey	Descriptive analysis	Evaluating TIRE's usefulness and user-friendliness	RQ.1 RQ.1.2	Paper 2

The data collection relies on open-source databases, a literature review of peer-reviewed papers, official documents of each BMP under study, focus groups, interviews, and surveys targeting the participants. The analysis tools include the PSS tool TIRE, developed and tested throughout the thesis, the systematic literature analysis, the content analysis of official documents, the descriptive analysis of the surveys, and the thematic analysis of the material collected during the focus groups and interviews involving cycling planning practitioners.

1.4.1. TIRE: DEVELOPMENT AND ASSESSMENT

This research conceives a planning support tool for assessing the relative equity impact of bicycle planning – TIRE, to measure the equity impact of distinct European BMP (further details in *Chapters 3* and *4*).

As illustrated in Fig. 5, the operationalisation of the tool TIRE encompasses both spatial and social dimensions of analysis. The spatial analysis measures the cycling accessibility conditions in the municipality aggregated into a single bicycle accessibility indicator (BA). This contour measure incorporates the land-use component, including several points of interest (POIs) collected from the OpenStreetMap (OSM) database, and the transport component with the cycling network data obtained from the mobility department of each municipality under study. The main output of the social dimension analysis is a socioeconomic index (SE), which aggregates several socioeconomic variables collected from local mobility surveys and census databases. Subsequently, the BA indicator and the SE index are represented as a bi-dimensional hexagonal grip map (2D areal aggregation) using Geographic Information Systems (GIS), in which the data classification is based on a two-colour scale. Such a product is commonly perceived as easier to understand and to communicate for a broad range of people with different levels of expertise (Bertolini et al., 2019).

Afterwards, the intersection of both indicators into a bivariate analysis illustrates the equity impacts of cycling infrastructure and accessibility levels distribution over areas, which are classified and grouped according to their socioeconomic status (i.e., advantage or disadvantage). Finally, TIRE illustrates the equity analysis in a single map, depicting four distributive clusters (further details in *Chapters 3* and *4*).

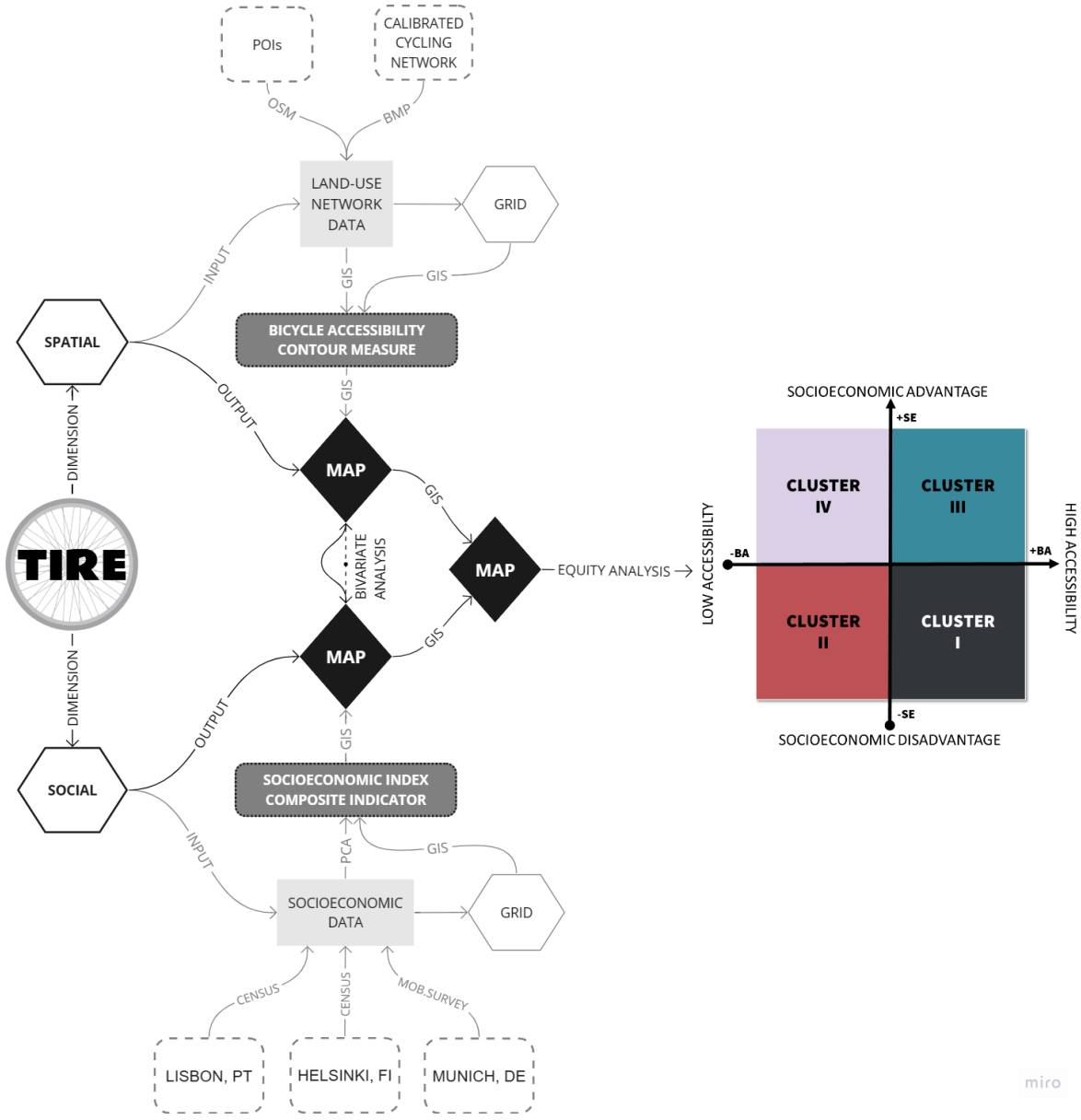


Fig. 5 – TIRE conceptualisation

1.4.2. LITERATURE REVIEW: A SYSTEMATIC ANALYSIS

This thesis systematically reviews the literature produced in the last decade to gather empirical evidence encompassing the distributive impacts of bicycle-related benefits across the global north and south contexts to answer the research question 2.1 and to critically appraise relevant theoretical and methodological approaches to identify knowledge gaps within the current literature, elucidating the research question 1.1 (further details in *Chapter 2*). Literature reviews are commonly conducted to explore a field of research, identify the empirical evidence that fits a particular research question (Snyder, 2019), identify gaps, build knowledge, and draw out concepts to frame a research field (Zunder, 2021).

1.4.3. BICYCLE PLAN OFFICIAL DOCUMENTS: CONTENT ANALYSIS

The selected cities were subject to a more in-depth evaluation to understand if and how equity issues are addressed and prioritised in planning practice. Based on previous research (Doran et al., 2021), this thesis conducts a content analysis of each official document identifying overarching planning goals and the often-applied monitoring techniques to measure several plan impacts. Afterwards, this thesis explores how the selected bicycle plans incorporate equity in planning guidelines by evaluating planning priorities, defined strategies, and expected outcomes (further details in *Chapter 4*).

1.4.4. FOCUS GROUPS AND INTERVIEWS: THEMATIC ANALYSIS

This thesis conducts a focus group to examine the nuances of the decision-making process and explore to what extent planning practitioners address and prioritise equity-oriented strategies in cycling planning, elucidating research questions 3 and 3.2. Scholars defend the focus group as a robust qualitative methodology, offering rich contextual data for understanding the depth and dynamics of decision-making, considering many perspectives (Brotherson, 1994).

This thesis followed the six components of interactive focus group interviewing (Brotherson, 1994), which encompass the formulation of research questions, the selection of participants, developing the protocol and analytical tools, conducting the focus group, data analysis, and reporting the findings. According to previous research, focus group generally last 1.5 to 2 hours and commonly involves six to eleven participants (Brotherson, 1994; Powell and Single, 1996). Nevertheless, when the focus group involves participants with specialised knowledge, scholars have endorsed using the so-called min focus groups, including three (Morgan, 2012) or four participants (Krueger, 1994). Researchers argue that the group size can impact the qualitative analysis. For instance, a low number of participants may foster the feeling of exposure and less interaction. On the other hand, a large focus group can become disorderly and fragmented (Rabiee, 2004).

Concerning the sampling, some authors often recommend that participants should not know each other, thus encouraging more honest and spontaneous expressions (Brotherson, 1994). Nevertheless, homogeneity is desirable and particularly important when the topic under investigation is profile specific. Therefore, Kitzinger (1994) defends that using pre-existing groups with acquaintances is advantageous since there is already a degree of trust and confidence among the group members (Kitzinger, 1994). Therefore, this thesis uses a purposive sample, focusing on planning practitioners involved in cycling planning the selected case studies. Purposive sampling implies that the participants were selected according to predetermined criteria relevant to the research objective and questions (Guest et al., 2017), which is particularly common in applied research.

Hence, this research conducts two focus groups of 1.5 hours to engage planning practitioners involved in European cycling planning. The focus group followed the workshop format aimed at capturing the uniqueness of each case study based on the synergy of the group interaction and the narratives generated by professionals working in cycling in distinct social and geographical contexts.

To select the participants, the focus group moderator contacted the mobility department in each city council between May 2022 and February 2023. Upon agreement on the consent term (Annex C2), invitations were sent to potential participants to create groups with an optimum number of participants to participate in the workshop (further details in *Chapter 5*). Participants who could not attend the workshop on the scheduled day were contacted for a one-to-one expert interview, which followed the same interview protocol defined for the focus group.

The focus groups were conducted in online workshops, using the ZOOM platform, following a threefold structure to encourage the identification of strategic concerns and opportunities among planning practitioners. First, the workshop roadmap encompasses three sections (i.e., Introduction, Interaction, and Interview), designed to be fairly light in terms of facilitation, placing participants as active players in the discussion (further details in *Chapter 5*).

In the first part of the workshop, the workshop facilitator applied a survey to assess the BMP priorities (*Annex A1: Pre-workshop Survey*). After, the facilitator presented the PSS tool TIRE and the conceptual framework, measures, and assessment process encompassing the operationalisation of the tool. At the end of this section, the participants had the opportunity to clarify their queries. In the second section of the workshop, the participants worked together to define new strategies or measures based on TIRE outputs, identifying planning priorities and an intervention plan to increase the equity impact of the local BMP. Finally, the participants had the opportunity to list and prioritise a set of equity-oriented strategies using online tools (i.e., Miro board, Drive PowerPoint). The last section of the workshop followed a semi-structured group interview guide (*Annex B1*). At the end of the workshop, a survey was applied to explore the usefulness and the user-friendliness of the tool for planning practice in the starter cycling city context (*Annex A2: Post-workshop Survey*).

In order to gain a depth understanding of the third research question and increase the sample, this thesis conducts semi-structured interviews with the available planning practitioners who could not attend the workshop on the scheduled day to triangulate the collected qualitative data. The triangulation of the qualitative data represents the act of bringing more than one source of data to bear on an understanding of the phenomenon under study (Brotherson, 1994). Indeed, although the focus group is designed to elicit and examine multiple perspectives, there are barriers related to the adequate attendance and engagement of the participants. For instance, while some group members can feel comfortable with each other and engage in discussion, self-disclosure for others requires deep trust and effort (Rabiee, 2004).

This thesis addresses this issue through semi-structured interviews following the same interview protocol defined for the focus group. This data collection procedure has proved versatile and flexible enough to be combined with individual and group interview methods (Rabiee, 2004). The development of the semi-structured guide followed the five phases framework described elsewhere (Kallio et al., 2016). The proposed interview guide consists of two levels of questions, encompassing primary and follow-up questions. The former covered the main content of the research subject, following a progressive and logical order. In other words, from lighter to more in-depth questions. The latter questions addressed emerging topics spontaneously based on the answers of the participants. Accordingly, the interviewer asks participants to expand on some particular issues during the interview.

The complete semi-structured interview guide offers a logical guide for data collection based on several questions related to the cycling planning and decision-making process (*Annex B1*). The interview guide comprises questions about the overarching planning priorities, network design, how planners perceive the BMP benefits, and how they seize the equity concept in the decision-making and planning processes.

Regarding data saturation, in other words, the point at which no new information or themes are observed in the data, previous research recommended running at least three different workshops (Krueger, 1994; Morgan, 2012) or six to twelve interviews, considering respectively homogeneous and heterogenous samples (Guest et al., 2006). Therefore, this thesis examines a total sample of 21 planning practitioners distributed in two focus groups, with 8 and 3 participants, respectively, and ten

individual interviews, as depicted in Table 2. The Focus group and interviews were conducted in English and Portuguese, according to the case study under analysis, and recorded in video and audio format. The transcription of verbatim dialogues and responses follows a commonly applied and standardised protocol (McLellan et al., 2003). In addition, this thesis conducts a manual transcription of the collected data to avoid recurrent grammatical and cohesions errors from automated transcription tools.

Then, this study runs a thematic analysis and the 6-step approach to arrange and interpret the data obtained from the focus groups and the individual interviews. Thematic analysis is one of the most commonly applied qualitative method to trace patterns in the collected data, the so-called themes (Braun et al., 2017; Braun and Clarke, 2012). This research systematically analyses the whole dataset, grouping the data's recurring characteristics into codes. Afterwards, the generated cores are grouped into themes, which are reviewed according to their consistency, representativeness and relevance to the research goals and questions. Lastly, the final themes were illustrated and further discussed following the focus group and interview excerpts for each theme (further details in *Chapter 5*).

Table 2 – Qualitative analysis sample

Case Study	Focus group*	Individual Interviews*	Total Sample
Lisbon	8	3	11
Munich	3	3	6
Helsinki	-	4	4
TOTAL	11	10	21
*Number of participants			

1.4.5. SURVEYS: DESCRIPTIVE ANALYSIS

Prior to the focus groups, this thesis applies a survey to the participants of the selected cities to assess their considerations on a number of planning priorities. This survey aims to contribute to research question 3.

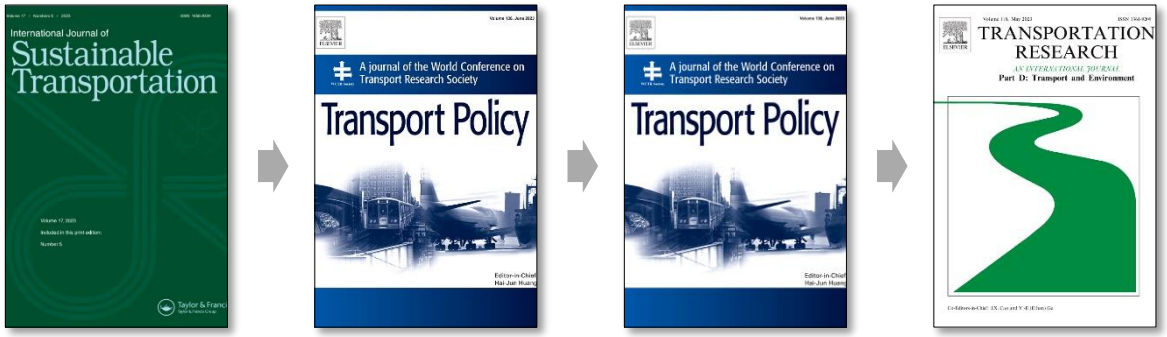
The first section of the survey questions how participants consider the importance given to a range of twenty-two planning priorities (see *Chapter 5* and *Annex A1*). The second section of the survey examined how local planning practitioners prioritise nine distinct population groups, which include minorities, vulnerable representatives, and socioeconomically disadvantaged people, and six target areas (i.e., inner city, periphery, rural areas). Both survey sections used a 5-point Likert scale (1- "Not at all important", 2- "Low importance", 3- "Neutral", 4- "Important", 5- "Very important"). This section ends with an open question, asking what analysis tools are commonly applied to assess the performance or impact of the cycling network implemented or under implementation. Finally, the last section of the survey collected sociodemographic data from the participants, including their years of working experience and professional roles (further details in *Chapter 5*).

Building on previous research (te Brömmelstroet, 2017), this thesis surveys local planning practitioners from the starter cycling city context after the focus group. The survey comprised 18 statements to assess several dimensions of a PSS tool's usefulness and user-friendliness. In this survey,

a 5-point Likert scale measures the agreement of the planners on a series of statements (1- "Strongly disagree", 2- "Disagree", 3- "Neither agree nor disagree", 4- "Agree", 5- "Strongly agree"). Finally, the survey ends with an open question, asking for further feedback or observations about the PSS tool (further details in *Chapter 3* and Annex *A2*). This qualitative approach addresses research questions 1 and 1.2.

1.5. STRUCTURE OF THE THESIS

This thesis is paper-based and organised into six chapters, of which four are papers (two published and two submitted and under review by the time of thesis submission) (Fig. 6 and Fig. 7).



Paper 1
- RQ 1.1
- RQ 2.1

Paper 2
- RQ 1
- RQ 2
- RQ 1.2

Paper 3
- RQ 2
- RQ 3
- RQ 3.1

Paper 4
- RQ 3
- RQ 3.2

Fig. 6 – Papers developed during the thesis

Following this introduction, the second chapter presents the literature review published in the International Journal of Sustainable Transportation[3] in 2022 (*Equity impacts of cycling: examining the spatial-social distribution of bicycle-related benefits).* This paper reports a cohesive and complete analysis of the distributive impacts of bicycle-related benefits, such as infrastructure coverage, mobility, and accessibility gains, in several global north and south cities. Moreover, this investigation critically reviews methodological and empirical insights considering social and spatial analysis perspectives. Concerned with how the bicycle, as a transport mode, can contribute to the development of more equitable cities and societies, the present research revealed that social equity issues have been far less addressed in cycling planning. This paper addresses the thesis research sub-questions 1.1 and 2.1.

The third chapter presents the paper published in Transport Policy [4] in 2023 (*Assessing the equity impact of cycling infrastructure allocation: Implications for planning practice*). This chapter presents the conceptual framework and the planning support tool – TIRE. From an ex-ante perspective, this paper examines the distribution of increased bicycle accessibility levels vis-à-vis the relative concentration of socioeconomic advantaged and disadvantaged shares in Lisbon. Moreover, the tool identifies hotspots in the city for future equity-oriented interventions. Finally, the results were presented to planning practitioners in an experiential workshop, enabling participants to evaluate its

[3] SJR 2022: 1.15, Scopus CiteScore 2021: 7.6, Q1 Best quartile
[4] SJR 2022: 1.95, Scopus CiteScore 2021: 9.0, Q1 Best quartile

user-friendliness and usefulness for planning practice. This paper addresses the main research questions 1 and 2 and the sub-question 1.2.

The fourth chapter (*Pursuing cycling equity? A mixed-methods analysis of cycling plans in European cities*) is under review in Transport Policy. This manuscript explores the equity implications of bicycle master plans from three European cities with distinct cycling cultures and policies. By applying the planning support tool TIRE, this chapter quantitively assesses to what extent the allocation of the cycling network is equitable, highlighting potential zones for future equity-oriented interventions. Additionally, this research performs a content analysis of each BMP official document examining how the planning guidelines address equity issues across different geographic and political contexts. Finally, this paper elucidates the main research questions 2 and 3 and the sub-question 3.1.

The fifth chapter (*Planners' perspectives on cycling equity: bridging the gap between planning priorities*) is under review in the Journal Transportation Research Part D: Transport and Environment[5]. From a qualitative perspective, this manuscript examines to what extent cycling planning practitioners address and prioritise equity issues. This chapter involves local planning practitioners from three European cities in focus groups and semi-structured interviews. Accordingly, the presentation of the planning support system tool TIRE and the generated results for each city provides the theoretical grounds for debate and reflection on crucial challenges encompassing the prioritisation of equity in planning practice. This paper elucidates the main research question 3 and the sub-question 3.2.

The sixth chapter (*Conclusion*) presents the main findings of the thesis, providing the answers to the research questions. In addition, this chapter compiles the main research contributions, limitations, and pathways for future research.

[5] SJR 2022: 2.02, Scopus CiteScore 2021: 10.5, Q1 Best quartile

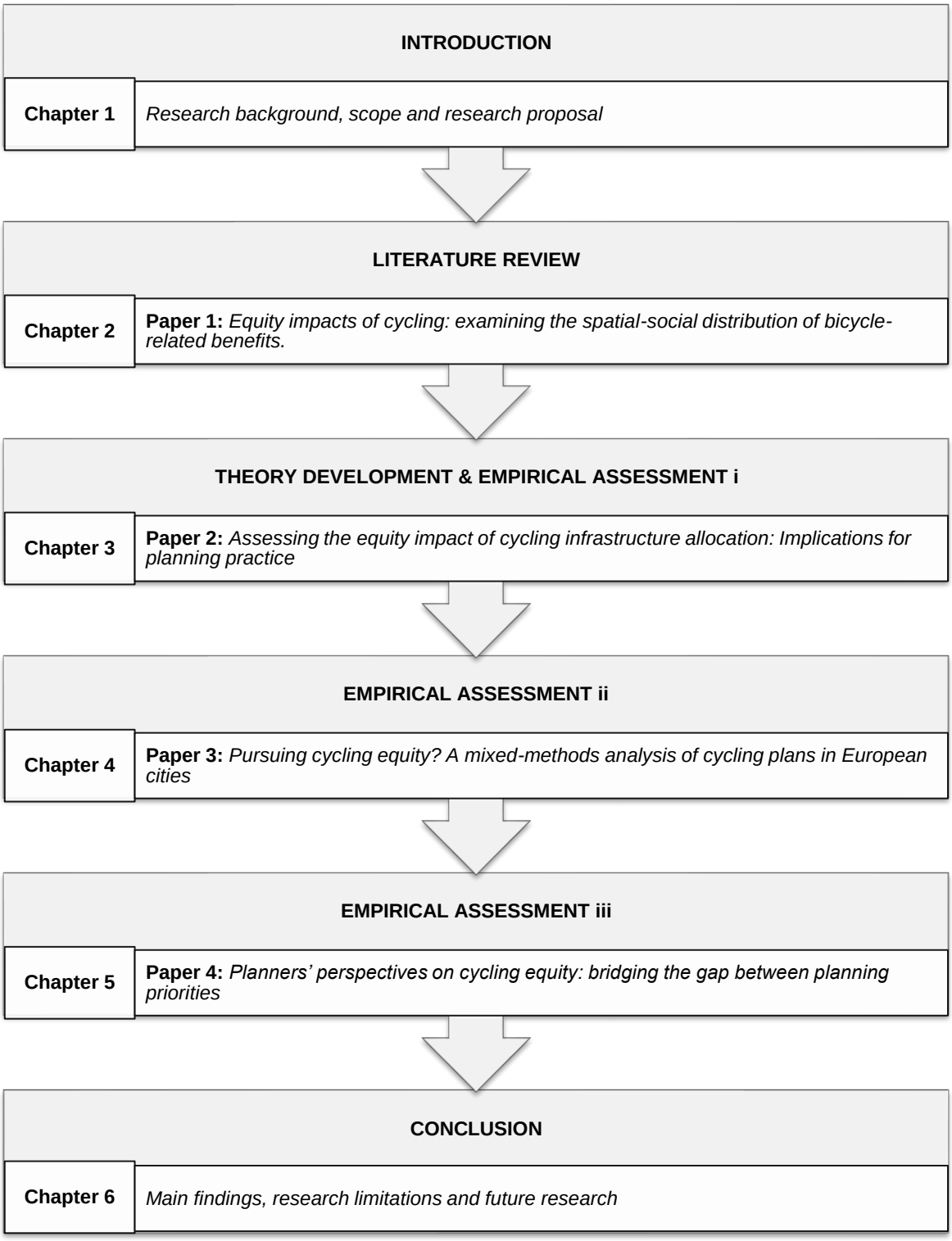


Fig. 7 – Thesis structure

1.6. CONCEPTUAL DISCUSSION

1.6.1. EQUITY IN TRANSPORT

Emerging research has explored the political philosophy literature to incorporate theories of justice into spatial (Fainstein, 2014; Lake, 2016; Rigolon and Németh, 2018; Uitermark and Nicholls, 2017) and transport planning (Jones and Lucas, 2012; Manaugh et al., 2015; Martens et al., 2014a; Pereira et al., 2017). One of the earlier conceptualisations of justice within transport planning dates to the '70s when Harvey (1973) explored the relationship between social processes and cities' spatial transformations (Harvey, 1973). Afterwards, research has gradually focused on the influence of different theories of justice on transport planning and project appraisals (Cui et al., 2019; Golub and Martens, 2014; Gössling et al., 2018; Nahmias-Biran et al., 2017; Pereira et al., 2017).

In this scientific domain, questions of social justice relate to ethical issues and a range of moral principles determined by the scope of the community's values regarding the treatment given to people in society (Deutsch, 1975). Within the social justice debate, scholars often explore questions related to the distribution of material and non-material goods in society (distributive justice), the procedures and processes that determine rules and planning practices (procedural justice), and how to recognise and enhance civil participation in the decision-making process (participatory justice) (Pereira et al., 2017).

Mostly, transport-related studies explore the distributive dimension of justice (Beyazit, 2011; Martens and Golub, 2012; Pereira et al., 2017) since the transport systems play an essential role in distributing 'benefits' and 'costs' created by different modes (Fig. 8). Amongst numerous values that may underly a given justice system, the equity principle is often explored within the distributive justice approach (Deutsch, 1975).

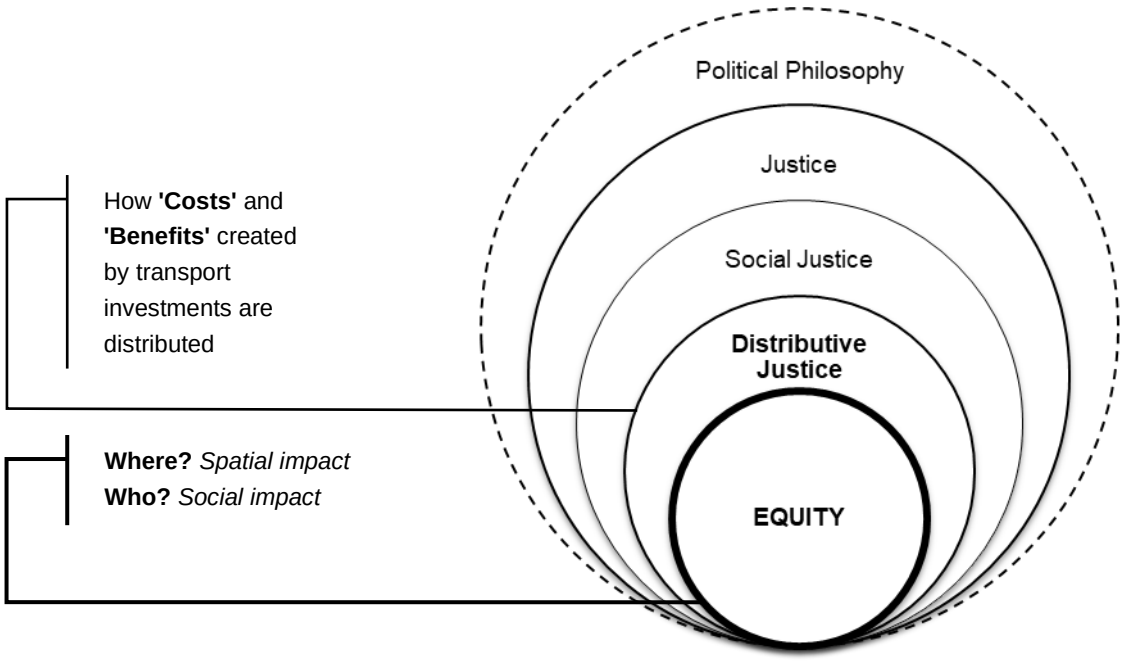


Fig. 8 – Distributive framework focused on the equity principle

Scholars argue that incorporating and assessing transport equity may offer an additional output towards developing a comprehensive and inclusive planning process (Thomopoulos et al., 2009) since this approach assesses the distributional effects of transport investments and their impacts within both spatial and social dimensions. Therefore, in recent years, transport equity has been increasingly recognised as a crucial component of the sustainable development paradigm (Carleton and Porter, 2018).

According to the literature, equity assessments can occur along two primary dimensions, the so-called horizontal and vertical equity (Bills and Walker, 2017; Litman, 2005; Martens et al., 2012; Martens and Golub, 2018).

Horizontal equity or equality tackles the distribution of 'benefits' and 'costs' over areas where individuals are considered equal in ability and need. This approach has its theoretical basis in the egalitarian theory, stating that transport policies should avoid favouring one individual or group over others (Litman, 2005). The horizontal perspective assesses the distributional effect of transport outcomes and determines where inequities occur since public policy outcomes tend to cluster around specific physical locations. Essentially, this analysis stratifies geographic areas based on demographic characteristics. (Lee et al., 2017). Egalitarianism, conceived within Rawls' theory of justice (Rawls, 1971), supports the horizontal equity approach, expecting equal treatment to people regardless of factors such as race, gender or income (Pyrialakou et al., 2016). Therefore, this theory focuses on how institutions and policies deal with inequalities to minimise the overall inequality of opportunities (Pereira et al., 2017).

The vertical equity approach concerns the distribution of impacts between individuals and groups that differ in socioeconomic conditions, ability and needs, exploring who benefits from a specific transport policy or project. Thus, transport investments should address economically and socially disadvantaged groups to mitigate overall inequities. The vertical equity approach aims to encourage affordable modes, accessible and inclusive transport design, and assist disadvantaged and vulnerable groups. (Litman, 2005). The literature highlights that the theories of Sufficientarianism (Lucas et al., 2016b), Walzer's spheres (Nahmias-Biran et al., 2017) and the Capability Approach (Pereira et al., 2017; Sen, 1989) offer the philosophical foundation and theoretical basis for the vertical equity analysis.

Concerning the different theories of justice underlying the distributive approach, the literature criticises the following caveats:

- Egalitarianism offers a reasonable basis for assessing horizontal equity. However, it disregards the social dimension (Pereira et al., 2017);
- Sufficientarianism fails to provide the practical basis for establishing a minimum threshold for analysis (Lucas et al., 2016b);
- The complete application of Walzer's theory might reflect the perspective of the dominant categories rather than disadvantaged groups (Nahmias-Biran et al., 2017);
- Applying the Capability approach requires an in-depth understanding of the individual dimension (Boarnet et al., 2017; Nahmias-Biran et al., 2017; Pereira et al., 2017).

According to the literature, there is no standardised set of indicators or principles to evaluate the equity impacts of transport since this knowledge base is currently influenced by diverse disciplines, including spatial planning, human geography, social policy and sociology, public health, engineering and transport (Markovich and Lucas, 2011). Furthermore, within the transport sector, translating theoretical concepts from social and economic sciences to measurable indicators and empirical evidence remains a significant challenge (Geurs et al., 2009).

For instance, most of the horizontal equity methods rely on statistical measures that originally quantify income inequalities, such as the Gini index with the Lorenz curve (Delbosc and Currie, 2011; Lucas et al., 2016b; Peréz et al., 2014; Pritchard et al., 2019a; Tahmasbi et al., 2019) and, less frequently, through the use of the Theil's entropy index (Hamidi et al., 2019).

The Gini coefficient[6] is a measure of statistical dispersion that represents the income or wealth distribution of a nation's residents, commonly used to measure inequality (Delbosc and Currie, 2011). According to previous research, this measure combines the use of underlying ethical principles, more specifically, the theory of egalitarianism (Lucas et al., 2016b). The Gini index ranges between 0 and 1, with higher coefficients representing higher levels of inequality.

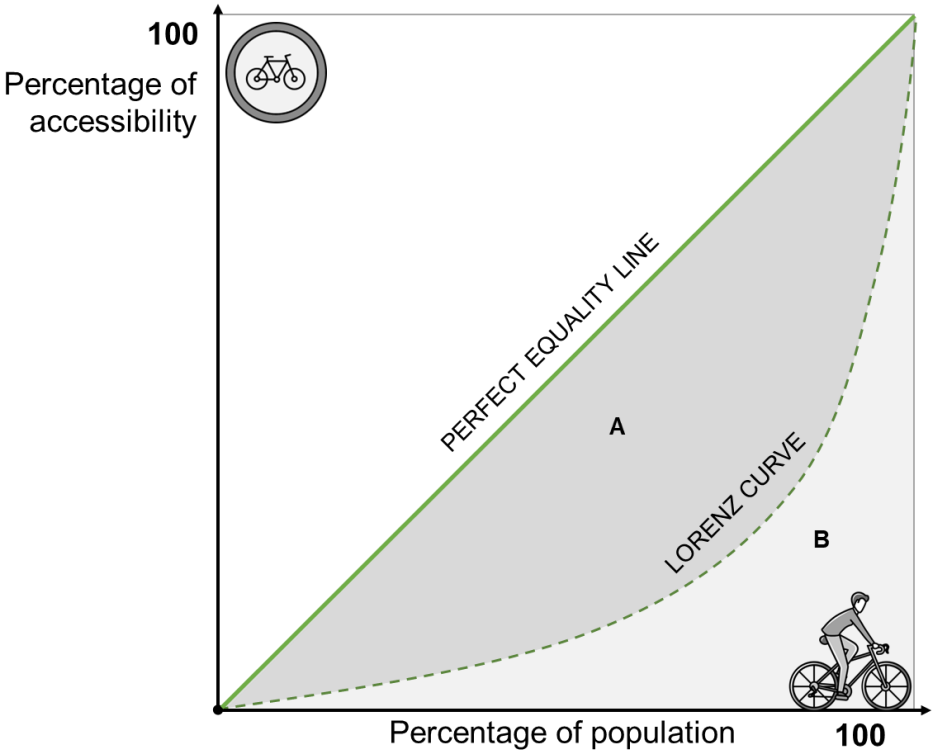


Fig. 9 – Gini Index and the Lorenz curve. Adapted from: (Camporeale et al., 2017)

As illustrated in Fig. 9, whilst the Gini coefficient provides a quantitative index of inequality, the Lorenz curve offers a visual way of assessing accessibility inequality in a population group. The Lorenz curve is a graphical representation of the distribution or proportion of overall income or wealth. Research often applies this method to represent income distribution (from 0 to 100%), with the x-axis showing the percentage of households and the y-axis showing income (Camporeale et al., 2017; Geurs and Van Wee, 2011). Thus, the greater the separation between the diagonal and Lorenz curve, the more unequal the distribution. By comparing the Lorenz curves of two different groups, it is possible to define which group has greater inherent inequality:

$$GINI = \frac{A}{A + B}$$

[6] Also known as the Gini index or Gini ratio

Concerning another economic-related index, the literature proposes adapting Theil's entropy index, a statistic primarily used to measure income inequality (Theil, 1967), revealing an entropic "distance" the population is from the egalitarian state of everyone having the same income. The Theil coefficient of income inequality can be formulated as follows (Hamidi et al., 2019; Novotný, 2007):

$$T = \frac{1}{Pt} \sum_{j=1}^{n} \frac{yj}{\hat{y}} \ln \left(\frac{yj}{\hat{y}} \right)$$

Where T denotes the overall inequality, Pt is the total population made by n individuals *j*; *yj* is the income of each individual *j*, $\hat{y}$ is the average per capita income in the study area. A high Theil index indicates that the total income is not distributed evenly among individuals in the same way. Through this formulation, it is also possible to identify income variability within and between groups. A recent study adapted the formulation of the Theil Index by replacing income with a composite accessibility indicator to assess transportation inequalities (Hamidi et al., 2019).

The literature highlights several methodological approaches regarding the vertical equity dimension of analysis. For example, accessibility measures are often applied in vertical equity assessments, revealing how transport planning affects accessibility levels between disadvantaged communities and essential destinations. Therefore, previous studies adapted economic measures such as the Gini index with the Lorenz curve to measure the distribution of accessibility (Lucas et al., 2016b; Tahmasbi et al., 2019) and the distribution of public transport supply (Camporeale et al., 2017; Delbosc and Currie, 2011; Peréz et al., 2014) over specific vulnerable populations. Scholars also applied the Palma Ratio to compare the accessibility of the wealthiest decile to the four poorest deciles (Guzman and Oviedo, 2018; Pritchard et al., 2019a). The Palma ratio reflects more accurately the impacts experienced by the extremities of the population sample (Guzman and Oviedo, 2018).

1.6.2. ACCESSIBILITY AS AN EQUITY METRIC

Based on the literature review, accessibility measures emerge as a methodological approach within transport equity assessments. One of the earliest definitions of accessibility appeared in the late '50s (Hansen, 1959), offering the conceptual basis for developing this research field. At that time, Hansen (1959) defined accessibility as the ease of access to a desirable set of destinations, arguing that the accessibility level experienced depends on the city context and personal conditions. Thus, this concept apprehends both the spatial distribution of activities and the available transport systems, outlining the maximum set of opportunities or the maximum level of accessibility that people can achieve.

In general, Hansen's method sums potential destinations divided by the travel impedance between the origin and destination. Thus, the intensity of a destination is the magnitude of its attractiveness, while the impedance is a function of travel cost (e.g., distance or travel time). Therefore, according to Hansen's formula, the accessibility (*A*) for a region (*i*) is given by summing the opportunities (*w*) available at each region (*j*) divided by the impedance (*d*) between (*i*) and (*j*):

$$Ai = \sum_{j=1}^{n} \frac{wj}{dij}$$

The accessibility concept evolved, and today it represents a wide field of research with several frameworks of analysis (Geurs and van Wee, 2004). Generally, measures of accessibility consist of transport and land use components (Halden et al., 2000). Whereas the former relates to the available infrastructure, which enables the movement of people, also affecting timetables, prices, perceived barriers, safety, and security, the latter refers to the available opportunities at the destination and the demand at the origin location. Moreover, scholars propose another two components of accessibility that are useful to assess the causes of social exclusion (Geurs and van Wee, 2004), namely the temporal and individual components. The third one considers the time constraining the availability of opportunities (e.g., time available for individuals to participate in certain activities), including accessible options provided by the land use and transport system. Finally, the fourth component includes demographic, socioeconomic, needs and abilities factors that directly affect the individual level of access to transport modes and spatially distributed opportunities.

Comprehensive reviews of accessibility components are reported elsewhere (Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004; Halden, 2002; Halden et al., 2000; Handy, 1996; Lättman et al., 2018; Silva, 2008). However, despite the importance of each component, scholars recognise that the operationalisation of all four accessibility components in planning practice is demanding and very complex.

Researchers often develop accessibility measures to assess the accessibility levels for private-motorised modes and public transport towards a range of opportunities in a given territory (Hine et al., 2009; McLeod et al., 2017; Saghapour et al., 2016; Silva and Pinho, 2010). Regarding active modes of transport, several studies have developed accessibility measures for walking and cycling (Iacono et al., 2010; Philips et al., 2018; Sagaris and Arora, 2016; Silva et al., 2019, 2014; Tal and Handy, 2012; Vale et al., 2016). However, besides the progress, scholars argue that active accessibility has been inconsistently measured (Iacono et al., 2010; Vale et al., 2016). Some of the reasons refer to the lack of high-resolution data and the use of arbitrary impedance functions for walking and cycling (Iacono et al., 2010).

Studies focused on bicycle accessibility measures commonly consider characteristics of the built and natural environments as crucial factors affecting cycling trips, their duration and distances (Wahlgren and Schantz, 2014). However, scholars also argue that cycling is sensitive to land use, level of service, individual perceptions and social norms, which may affect cycling accessibility (Kent and Karner, 2019).

For assessing cycling equity using accessibility analysis, scholars often applied activity-based measures, especially contour measures. Indeed, academia and transport agencies commonly use this approach to examine the accessibility and social impacts of transport investments (Geurs and Van Wee, 2011). Commonly, the explored attractive points are job locations and essential services the city provides, such as education, healthcare, and shopping opportunities. In such frameworks, the often-assessed origins are disadvantaged neighbourhoods, with higher indices of low-incomers, non-car users, young people, elderly, and non-employed populations.

2

Equity impacts of cycling: examining the spatial-social distribution of bicycle-related benefits

This chapter presents an integral reproduction of: "Cunha, I. and Silva, C. (2022) 'Equity impacts of cycling: examining the spatial-social distribution of bicycle-related benefits', International Journal of Sustainable Transportation. Taylor & Francis. Pp. 1 – 19. DOI:10.1080/15568318.2022.2082343."

ABSTRACT

Cities worldwide are developing and implementing strategies to promote the bicycle as a viable and competitive mobility option, to foster the development of resilient, liveable, accessible, inclusive, and low-carbon societies. Nevertheless, empirical evidence has shown that equity issues have been far less addressed during bicycle planning and decision-making processes, regardless of the importance of the social dimension within the sustainable mobility policy.

Therefore, to explore the distributional impacts of bicycle-related benefits in cities around the globe, this paper delves into the current literature encompassing distributive justice frameworks and equity-oriented assessments. Our review revealed that often the distributional effects of bicycle planning are context-dependent, with projects and investments targeting central, advantaged, and wealthy areas of cities. Quantitative assessments identified that bicycle benefits such as infrastructure coverage, cycling trips, accessibility, and health gains are unevenly distributed in cities, not addressing the needs of disadvantaged and vulnerable population groups.

Moreover, despite the current predominance of quantitative frameworks to examine the equity impacts of cycling, a considerable increase in qualitative and alternative approaches has been observed, including the role of bicycle advocacy, individual characteristics, and institutional perspectives in the distributive process.

Whereas empirical evidence suggests that bicycle planning and decision-making processes often overlook equity issues, this paper discusses methodological strengths and limitations and future research pathways to support planners, politicians, and practitioners toward more equitable approaches.

KEYWORDS: Bicycle planning; Equity; Spatial analysis; Social impacts; Sustainable mobility.

2.1. INTRODUCTION

Promoting the bicycle as a viable and accessible transport mode can play a crucial role in fostering low-carbon and equitable transport systems. Bicycle advocates and scholars endorse such alternative mode of transport as an affordable, healthy, and reliable option, which can democratise mobility, improve the overall quality of life in cities, facilitate social cohesion, and ultimately increase access to opportunities for distinct population groups (Karner, 2016). Therefore, cycling emerges as a strategy to change the current mobility paradigm that focuses on providing road infrastructure investments and supplies to facilitate the movement of motorised modes of transport through the city (Banister, 2008).

The emergence of cycling as an alternative mobility option raises environmental and ethical questions about the equity impacts of bicycle infrastructure in the production of urban space (Barajas, 2017; Karner et al., 2020; Lee et al., 2017). Accordingly, researchers have been focusing on the role of cycling activism, social movements, and collectives in fostering an equitable and inclusive bicycle planning and policy across the global north (Candipan, 2019; Lugo, 2013; Stehlin, 2014) and south (Castañeda, 2020; Sagaris et al., 2020; Saud and Thomopoulos, 2021). Based on Lefebvre's theoretical approach, scholars conceptualised the influence of different actors, sectors, politics, and discourses involved in the right to the cyclable city (Castañeda, 2020).

Nevertheless, despite the growing evidence linking the provision of cycling infrastructure to increased bicycle uptake and use (Buehler, 2012; Nielsen and Skov-Petersen, 2018; Xie and Wang, 2018), recent studies demonstrate a mismatch between equity issues and bicycle planning and policy in cities. Scholars explore this phenomenon within a distributive justice framework, which investigates how cities distribute the costs and benefits created by urban transport systems, how fair this distribution is, and whether particular segments of society are systematically disadvantaged and socially jeopardised.

The present paper focuses on the distributive impacts of bicycle-related benefits, recognising the importance of the costs, which have already been explored and reviewed elsewhere (Gelb and Apparicio, 2021). On the one hand, the often explored bicycle-related benefits are network coverage (Ji et al., 2017; Pritchard et al., 2019b), accessibility (de Alba-Martínez et al., 2021; Rosas-Satizábal et al., 2020; Winters et al., 2018), cycling uptake (Barajas, 2019; Cusack, 2021; Lovelace et al., 2020), health gains (Barajas and Braun, 2021; Grimes and Smirnova, 2020), and safety levels (Ravensbergen et al., 2020a; Rebentisch et al., 2019). On the other hand, the bicycle-related costs refer to the cyclists' exposure to burdens and externalities, such as pollution levels (Targino et al., 2018), accidents (Macmillan et al., 2014), as well as taxes and monetary constraints (Barajas, 2021).

Previous frameworks examined vulnerable bicycle users (i.e., children, elderly, immigrants, homeless, physically disabled) (Goodman and Aldred, 2018; Parker, 2019; Qian and Jaller, 2020) and socioeconomically disadvantaged representatives (i.e., low-incomers, illiterates, unemployed, no car owners) (Barajas and Braun, 2021; Mora et al., 2021; Saud and Thomopoulos, 2021), aiming at understanding the equity impacts of such distributive process. Likewise, researchers focused on specific bicycle users based on their mobility behaviour and attitudes (Braun et al., 2016; Félix et al., 2017; Frater and Kingham, 2018; Heinen et al., 2011; Waintrub et al., 2016), elucidating the main barriers and motivators to cycling (Félix et al., 2019; Manaugh et al., 2017).

Accordingly, empirical evidence revealed that the distribution of bicycle-related benefits is often uneven, mostly favouring advantaged and wealthy areas of cities. However, there is little evidence about the needs and constraints of representatives in a situation of transport disadvantage and social exclusion regarding urban cycling. Moreover, another critical question that remains overlooked is whether such groups are keen to change their current mobility patterns toward cycling. Thus, how

planners and policymakers can make cycling attractive to such target groups remains an open question.

To address this problem, scholars argue that the preferences and perceptions of disadvantaged representatives should be included as a paramount element of universal cycling design to normalise bicycle use in cities (Aldred et al., 2016). However, the underlying challenges to fostering an incremental equity approach in bicycle planning are context-dependent, varying widely across global north and south cities. For example, scholars claim that strategies promoted by northern European countries, which have a larger share of bicycle users, are arduous to transfer to cities where the society does not recognize the bicycle as a viable mode of transport (Dias et al., 2021).

There are increasing examples of cities around the globe trying to bridge a political and social commitment toward cycling. Nonetheless, low-cycling cities (Aldred et al., 2016) or the so-called starter cycling cities (Silva et al., 2019) struggle to define and implement bicycle projects to reverse their car-oriented background. Regardless of their low bicycle mode share and residual cycling infrastructure, starter cycling cities need specific measures and strategies to change the current car-oriented mindset and built environment, overcoming the dominant political-technical scepticism towards the bicycle as a transport mode (Dias et al., 2021; Urbanczyk, 2010a). In starter cycling cities, the political resistance and cycling commitment shortage represent significant challenges to overcome within the decision-making process (Bicalho et al., 2019). With the increasing gap between planners, decision-makers, and citizens, the extent to which the bicycle as a transport mode, particularly the bicycle planning and policy, can contribute to the development of more equitable cities and societies remains unclear.

Thus, by building on the literature produced in the last decade, this paper presents a bibliometric review and systematic analysis of the distributive impacts of bicycle-related benefits in cities from both global north and south, aiming to answer the following research questions:

1) How equitable is the distribution of bicycle-related benefits across cities in the global north and south?
2) What are the most used frameworks, methods, and analysis tools for measuring the equity impacts of bicycle planning?

The paper follows a twofold framework, encompassing both empirical and methodological components, to build a critical understanding of the interaction between the bicycle benefits and population segments that are prioritized and disregarded during the distributive process.

After this introduction, the second section brings forward the theoretical background encompassing the equity issues and transportation systems. The third section describes the methodology applied to select and review the core literature. The fourth section is composed of three subsections: firstly, it presents the theoretical reasoning behind the often-assessed bicycle-related benefits and groups of concern in the literature; then, the second subsection presents the empirical evidence of such distributive impacts across cities in the global north and south, and the last subsection explores the methods and frameworks conceived to measure the distributive and equity impacts of bicycle-related benefits. Finally, the fifth section of the paper critically summarizes the main findings and discusses the identified research gaps, pointing out some implications for future research, policy, and practice.

2.2. THEORETICAL BACKGROUND

Scholars scrutinised the spatial and social impacts of transportation systems over the last years, outlining their theoretical grounds from the political philosophy literature and diverse theories of justice (Jones and Lucas, 2012; Martens et al., 2014b; Pereira et al., 2017). Conceptually, social justice refers to a range of moral and ethical principles determined by the scope of the community's values regarding the treatment given to people in society (Deutsch, 1975).

Within the transportation sector, scholars often investigate the distribution of transport benefits and costs in society (i.e., Distributive Justice), the procedures and processes encompassing rules and planning practices (i.e., Procedural Justice), and how to recognize and enhance civil participation in the decision-making process (i.e., Participatory Justice) (Pereira et al., 2017).

Procedural justice deals with the idea of fairness in the process encompassing the allocation of resources, expecting transparent reasoning, trustworthiness, and respect between all involved in the process. Participatory justice refers to the immediate participation of those affected most by a particular decision itself. Finally, the dimension of Distributive justice comprises theories that specify the extent to which society acknowledges distributions of resources, rights, costs, and burdens as just or fair (Cook and Hegtvedt, 1983).

Central to the distributive justice debate, the transportation literature often proposes assessment models based on distinct rules or principles, such as equality, equity, and efficiency (Cook and Hegtvedt, 1983; Di Ciommo and Shiftan, 2017; Duran-Rodas et al., 2020; Lee et al., 2017; Litman, 2005).

In transportation, the equality approach, conceived within the egalitarian theory (Rawls, 1971), expects the distribution of transportation benefits and costs should be equal regardless of an individual's abilities and needs. The equity approach is concerned with the distribution of impacts among population groups distinguished according to their abilities, social-economic conditions, and opportunities, therefore targeting those disadvantaged groups in a situation of social exclusion (Lee et al., 2017). Finally, the efficiency approach expects a distribution of resources according to people's contributions, utility, usage level, and willingness and ability to pay. In this case, the demand guides the allocation of transportation costs and benefits (Duran-Rodas et al., 2020). Amongst numerous principles or rules which may underly a given system of justice, the distributive approach commonly assesses equity as a value (Deutsch, 1975).

Broadly, exploring the equity impacts of transportation systems often considers both spatial and social dimensions of analysis. While the former approach explores the spatial distributional effects and identifies where inequities occur, the latter targets vulnerable or disadvantaged populations (Lee et al., 2017).

Scholars argue that accessibility planning theory offers a valuable framework for examining the equity impact of transportation systems, encompassing transport, land-use, temporal, and individual components (Geurs and van Wee, 2004; Halden et al., 2000). Accessibility refers to the precondition to a person fully participating in society and opportunities, which might require traveling to the places where these opportunities are located (Handy, 1996).

Nevertheless, there is no standardized set of methods, principles, and indicators for assessing equity in transportation since diverse disciplines, including spatial planning, human geography, social policy and sociology, public health, and engineering, influence this knowledge base. In addition, within the

transportation sector, there is the challenge of translating theoretical concepts from social and economic sciences to measurable indicators and empirical evidence (Geurs et al., 2009).

2.3. METHODOLOGY

This paper conducted a bibliometric search and systematic literature review of peer-reviewed articles published between 2010 and 2021 to explore the equity impacts of cycling worldwide. Overall, the review provides a twofold contribution to the bicycle equity debate.

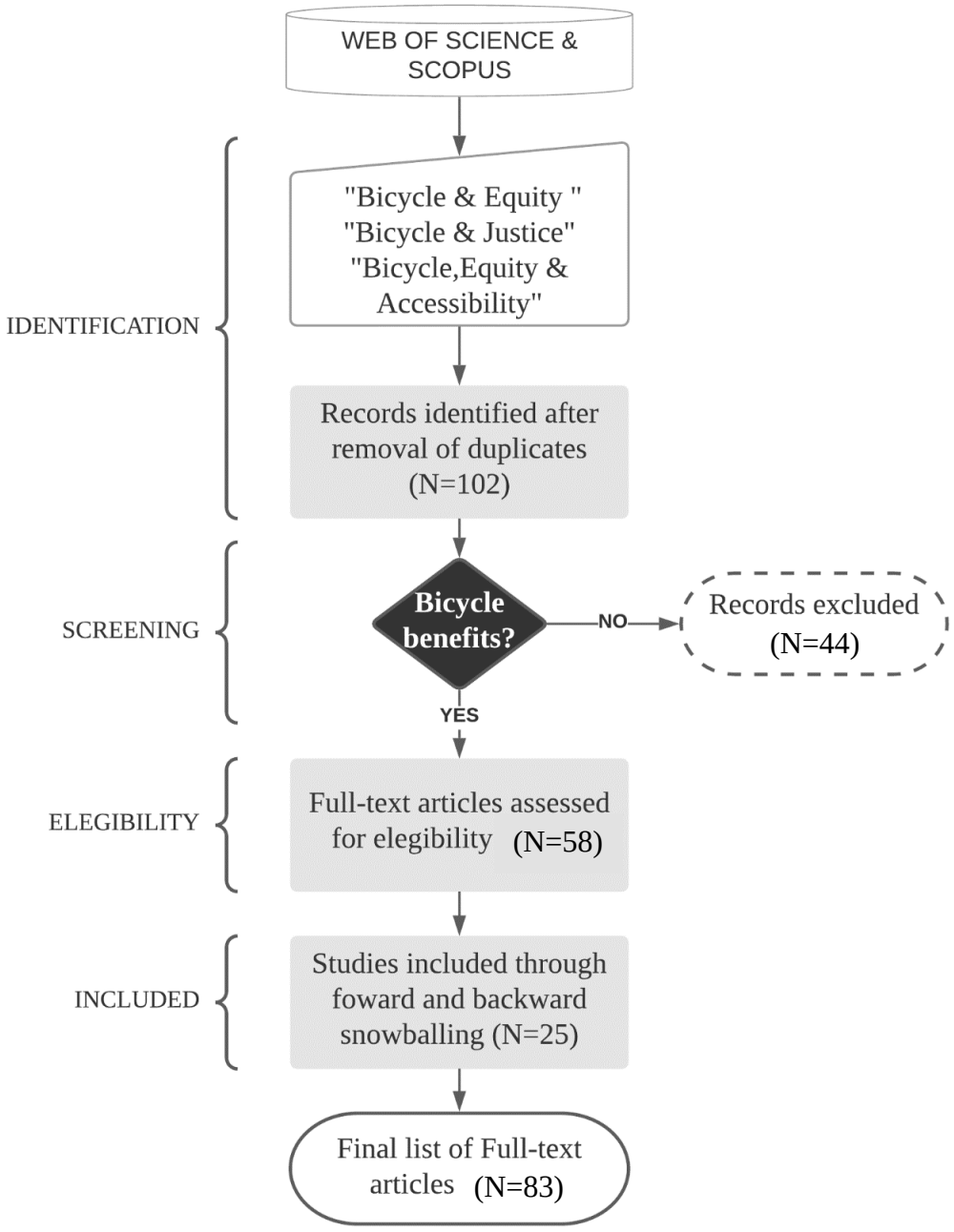


Fig. 10 – Literature Review flow chart

Firstly, it examines the empirical evidence collected in both global north and south, highlighting to what extent bicycle planning and policy consider equity issues during the distributive process. Secondly, it systematizes contemporary frameworks and methodological approaches encompassing the equity impacts of cycling.

Web of Science and Scopus served as research tools to collect studies by using search word combinations of "bicycle", "equity", "justice," and "accessibility". However, this study did not include the term "equality" in the final list of keywords since an egalitarian approach conceptually disregards the individual characteristics, limitations, and needs in the distributional process. Moreover, we did not review studies focused on cycling costs, which have already been explored and reviewed elsewhere (Gelb and Apparicio, 2021).

After identifying and screening papers that explicitly focused on the distributive impacts of bicycle benefits, 58 articles were considered eligible for review. Since the present article focuses on the distributive dimension of justice, the process excluded documents focused on participatory and procedural dimensions of justice and bicycle-related costs. The forward and backward snowballing of the eligible articles identified 25 new documents for further assessment. Hence, the final list of the selected literature comprised a list of 83 publications (see Fig. 11).

2.4. BICYCLE EQUITY

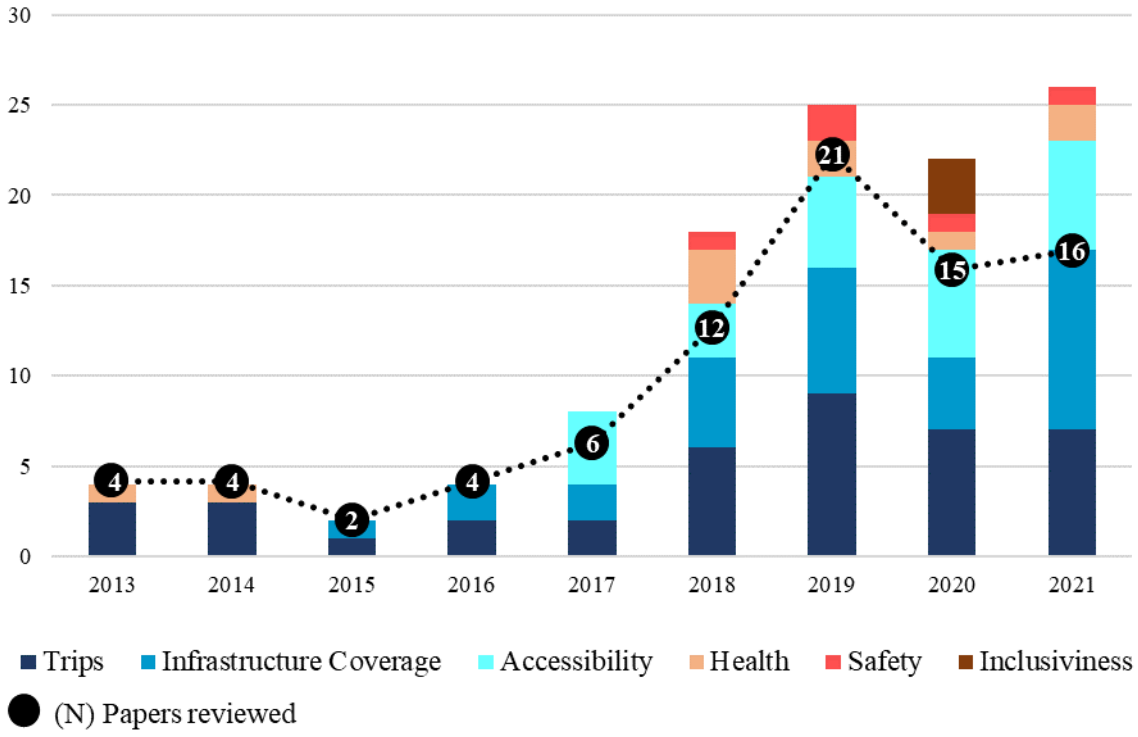


Fig. 11 – Studies on Bicycle Equity per year

The last decade observed a growing body of evidence encompassing the social and spatial impacts of bicycle planning, respectively exploring the distributive implications of bicycle benefits across segments of society deemed to be in a situation of disadvantage living in peripheral neighbourhoods

with low accessibility conditions (Conrow et al., 2018; Goodman et al., 2013; Grisé and El-Geneidy, 2018; Lovelace et al., 2017).

The first published papers back in 2013 had significant concerns about the distribution of cycling trips (Davison et al., 2013; Torres et al., 2013), including effects on utilitarian and recreational trips, as well as the uptake of cycling (Goodman et al., 2013). Over the last five years, research attention drifted towards the equity impacts of the distribution of accessibility to opportunities (Houde et al., 2018; Pritchard et al., 2019b; Tucker and Manaugh, 2018), health gains (Babagoli et al., 2019; Frater and Kingham, 2018) and safety levels (Ravensbergen et al., 2020a; Rebentisch et al., 2019). Often the proposed frameworks explored the distributive impacts of more than one benefit by combining, for instance, the effects of infrastructure provision on the improvement of mobility and accessibility levels in cities (Fig. 11).

To better understand the distributive impacts of such benefits on specific population segments, research produced in the last decade primarily defined groups of concern based on demographic and socio-economic variables, representing respectively 44% and 40% of the explored factors, as illustrated in Fig. 12. All in all, such assessment frameworks interchangeably examined the distribution of bicycle benefits across population profiles regarded as “minorities”, in a situation of social “disadvantage” or “vulnerability”, not drawing a clear distinction between the meaning of these terminologies.

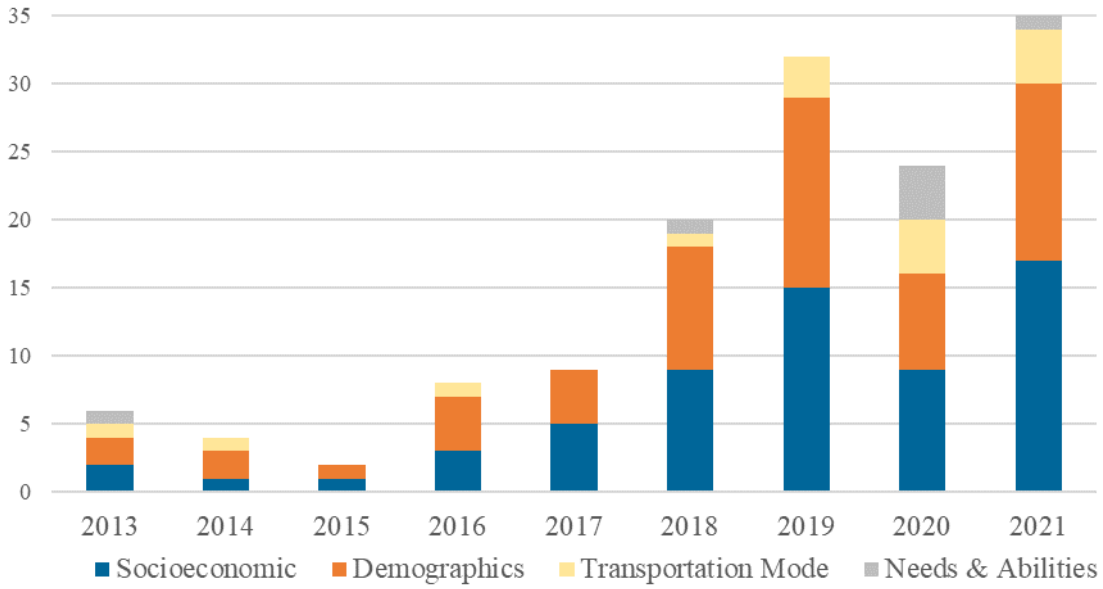
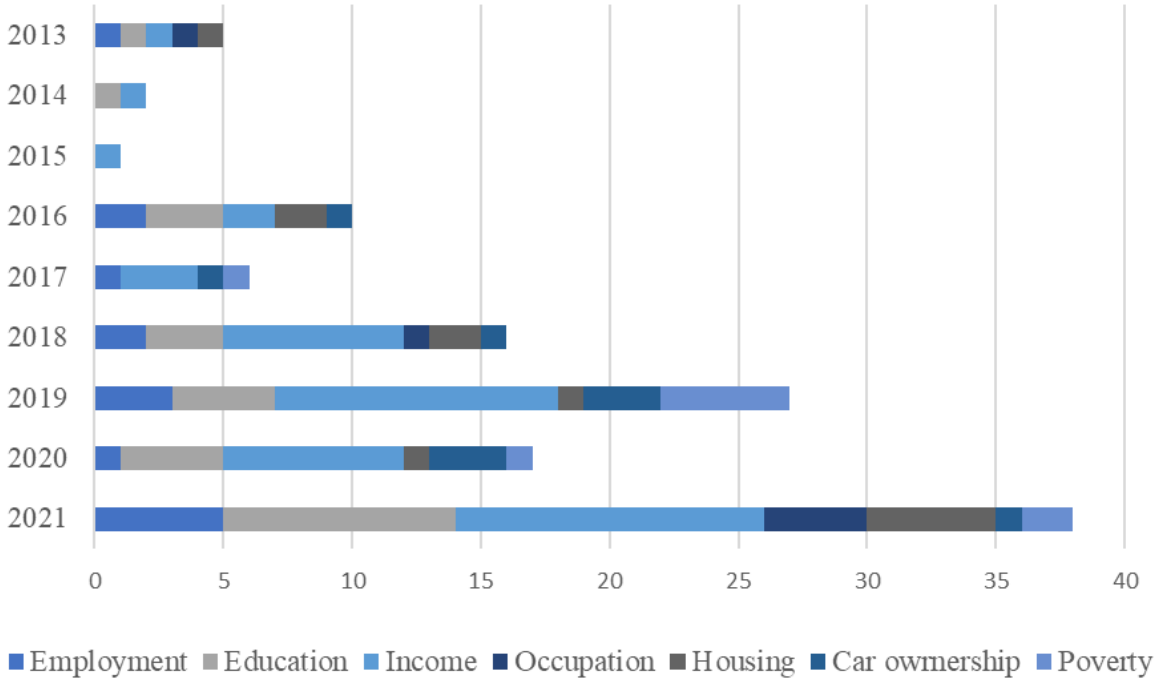


Fig. 12 – Variables applied within the segmentation process (n) per year

As depicted in Fig. 12, previous frameworks segmented population groups according to socio-economic factors (i.e., income, education, employment status, housing dimension or tenure), demographic characteristics (i.e., age, race, ethnicity, and gender), and travel mode (i.e., car, bicycle, and transit users). However, when authors focus on individuals’ needs and abilities, often the segmentation process considers variables related to physical and cognitive disabilities. Overall, frameworks combine variables, mixing socio-economic and demographic characteristics (Fig. 13 and Fig. 14), to systematically compare the distributive shares between concern groups. Accordingly,

income, education, age, race, and ethnicity factors appear as significant determinants within the bicycle equity analysis (Cervero et al., 2009; Lusk et al., 2017; Wahlgren and Schantz, 2014).



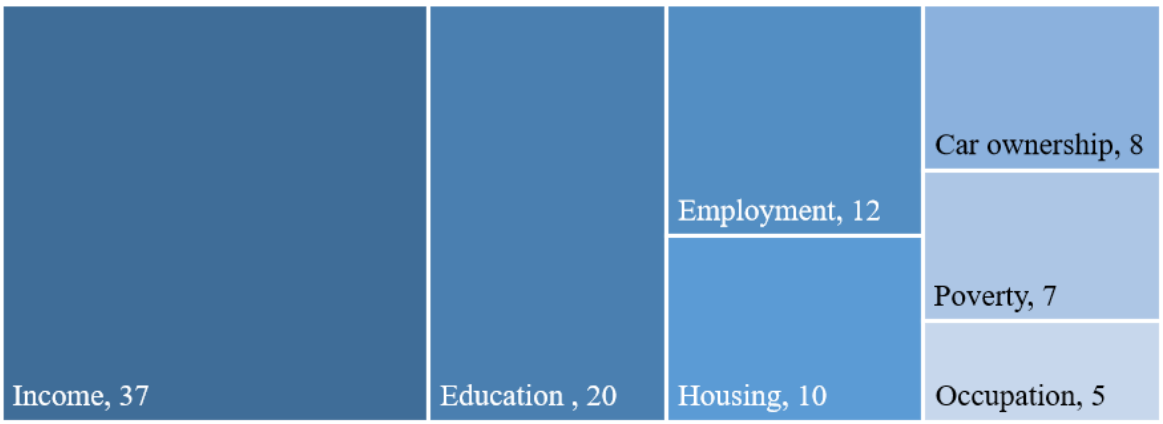


Fig. 13 – Socio-economic variables (n) explored per year and total variables (%) examined through the literature

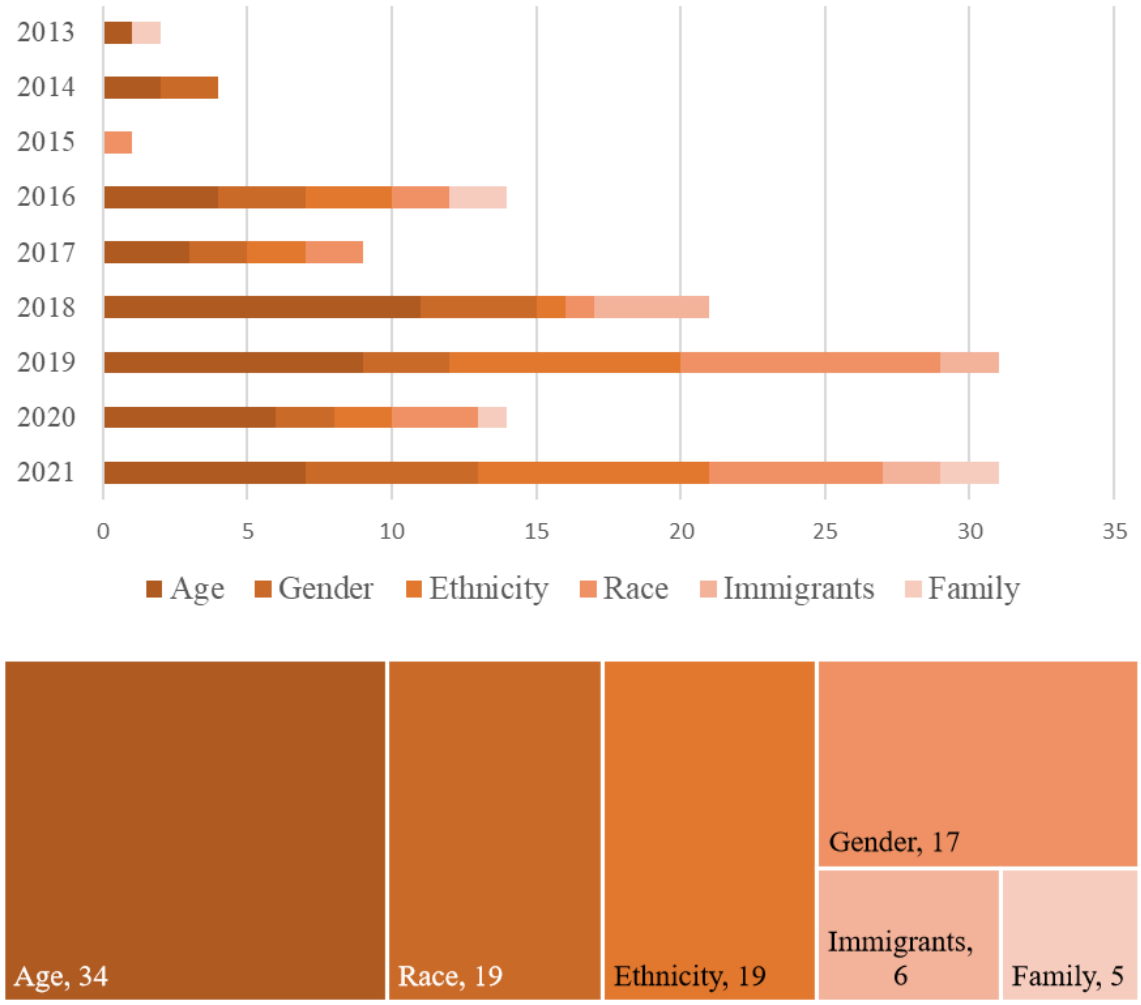


Fig. 14 – Demographic variables explored per year (n) and total variables (%) examined through the literature

2.4.1. Distributive Framework: Cycling Benefits

The present paper further explored four main categories of bicycle-related benefits, highlighted by the available empirical evidence as follows:

- Infrastructure coverage (i.e., cycle paths, bicycle share stations, bike parking);
- Trips (i.e., commuting or recreational bike trips);
- Accessibility (i.e., bicycle accessibility to opportunities);
- Health (i.e., health gains associated with bicycle use in cities).

2.4.1.1. Infrastructure Coverage

According to the present review, the evaluation of the distributional impacts of cycling infrastructure seeks to elucidate whether the location of the cycling network or bicycle-share scheme (BSS) stations is considered fair, meeting the needs of socially excluded and disadvantaged groups. In addition, scholars acknowledge that the infrastructure proximity and the interaction between individuals and

points of interest in the urban landscape are crucial factors to increment bicycle mobility and accessibility, fostering cyclists' health and sense of security and safety (Houde et al., 2018).

Nevertheless, from the global north to the south, the geographic distribution of cycling infrastructure is often biased, targeting privileged neighbourhoods with existing and increasing socio-economic wealth. In contrast, areas with a high concentration of socio-economic disadvantage and transport poverty remain systematically excluded. Consequently, the debate around the equity impacts of bicycle infrastructure often approaches the acute side-effects of urban regeneration developments as the gentrification process (Mora et al., 2021). Scholars claim that the cycling boom and infrastructure provision are entangled with capital-intensive real estate redevelopment with implications in terms of gentrification, which lead to the marginalisation of deprived communities and the displacement of poorer households (Flanagan et al., 2016).

In line with such a phenomenon, Flanagan et al. (2016) suggested that the active transportation projects often create an environment attractive to the creative class, so forth, marginalised communities are unlikely to attract as much cycling infrastructure investment without the presence of a privileged population (Flanagan et al., 2016). Likewise, in the global south, a study revealed that regardless of the continuous growth of the cycling network in Santiago de Chile, equity issues remain overlooked during planning and decision-making processes since central zones, where middle and upper-income groups live, concentrate most of the bicycle lanes (Mora et al., 2021).

To address issues of unequal distribution of transportation infrastructure, planners, scholars, and mobility justice advocates have sought to put into practice the concept of complete streets, aiming to support the fundamental right of circulation and safe access for all users, including pedestrians, bicyclists, motorists (Hui et al., 2018). This concept was embraced by the bicycle advocacy coalition in the USA, based on the argument that streets are ultimately public spaces, and everyone in the community, from pedestrians to bicyclists, should have equal rights to access and circulate within. Thus, bicycle advocates hope to democratize the streets by redistributing the public space, guaranteeing space for cyclists (Furness, 2007).

Nevertheless, while mobility justice movements successfully elevated transportation as a civil rights issue, including bicycles in this framework remains a challenge (Gössling et al., 2016).

2.4.1.2. Trips

Over the last decade, the literature widely examined the equity implications of cycling uptake, utility and leisure trips, supported by 36 reviewed papers. Scholars acknowledge that cycling travel behaviour can vary drastically across socio-economic groups, mainly due to spatial form (i.e., topography, urban sprawl, location of points of interest), infrastructure, and individual attitudes (Barajas, 2019). In other words, the extent to which distinct groups of society use the bicycle as a transport mode for daily activities is likely to be context-dependent (Tortosa et al., 2021).

Since external and individual factors influence the transport mode choice, it is not always straightforward clarifying how much inequality in travel behaviour arises from individuals' tastes and preferences. For instance, a growing evidence base indicates that low-income groups in cities in the global south mainly cycle for utility reasons. However, bicycle planning often prioritizes wealthier neighbourhoods with a significant share of car ownership to receive cycling infrastructure investments (Iglesias et al., 2019). Furthermore, in the global north, the likelihood of cycling uptake is lower

among people living in deprived areas with no cycle paths and home bike parking than among people living in non-deprived areas (Barajas, 2021; Tortosa et al., 2021).

Accordingly, In the United States, low-income populations, people of colour, and transit-dependent households are not often cycling representatives, and residents in disadvantaged communities tend to make longer trips, particularly for utility cycling (Qian and Jaller, 2020). Contrastingly, in England, despite the increasing level of cycling infrastructure in deprived areas than in non-deprived, the mobility levels remained low in such sites, suggesting that providing only infrastructure is not enough to increase bicycle levels among disadvantaged populations (Tortosa et al., 2021). In Northern Europe, especially in cities across the Netherlands (Harms et al., 2014), Sweden (Hamidi et al., 2019), and Denmark, cycling levels are relatively constant between socio-economic groups.

Lovelace et al. (2017) argue that providing high-quality infrastructure alone is insufficient to promote cycling uptake and boost local cycling rates. Instead, planners should define synergistic parallel measures, considering the desired lines of the latent demand. Supporting such an argument, researchers developed the Propensity to Cycle Tool (PCT) as a planning support system tool that estimates cycling rate under different scenarios, including an equity-oriented perspective focused on gender issues. For example, this scenario would simulate the increase of cycling levels if women were as likely as men to cycle a given trip, highlighting areas where the cycling rate is highly gender-unequal. Moreover, the PCT tool also illustrates the proportion of expected new bicycle commuters if England had the same bicycle infrastructure and cycling culture as the Netherlands. Such a perspective aims to identify and prioritize areas to receive new pro-cycling investments and interventions (Lovelace et al., 2017).

Most research on the equity effects of BSS uptake and increased sustainable mobility are centred in the global north, especially in the United States and Canada. However, despite the rising adoption of BSS, it remains unclear whether societies distribute fairly such benefits (Hosford and Winters, 2018), especially in cities in the global south. To bridge this gap, Saud et al. (2021) proposed a multi-level perspective framework to assess the equity impacts of BSS across the Metropolitan Region of Santiago de Chile. Such an approach ascertains that urban transport inequalities require explicit and well-framed analytical tools, encompassing both institutional and operational levels, to address specific challenges found in the global south (Saud and Thomopoulos, 2021).

Concerning the equity performance of BSS and its effects on cycling uptake, previous research examined registered users according to their socio-economic and demographic profiles, considering the spatial comparison of geographic units where BSS infrastructure is located (Chen et al., 2019). Accordingly, the scholars acknowledge key barriers constraining the use of BSS among disadvantaged segments of society, which are the location of the BSS dock station itself, the subscription costs and pricing structure, as well as individual constraints such as the limited access to credit cards, computers, and smartphones (Hosford and Winters, 2018).

2.4.1.3. Accessibility

The accessibility planning theory has offered a solid basis for assessing the distributional equity impacts of cycling, encompassing 20 of the reviewed papers. Accessibility, earliest defined as the ease of access to a desirable set of destinations (Hansen, 1959), refers to the precondition to a person fully participating in society and opportunities, which might require traveling to the places which allocate those opportunities (Halden et al., 2000; Handy, 1993). The level of accessibility is dependent on resources like time, costs, and cognitive skills, which can increase or limit the ability to overcome

distance and space. Any person experiencing some resource limitation may experience a lower level of accessibility. Therefore, scholars argue that stimulating a virtuous cycle of enhanced accessibility and social and economic engagement can promote social inclusion within the transportation sector.

Over the last decade, scholars have been developing accessibility indicators to identify bicycle-friendly areas in cities. Therefore, the accessibility conditions for cycling are sensitive to land use, built environment, level of service, and individual and social factors that may affect bicycle users' ability to reach destinations in cities (Kent and Karner, 2019).

Nevertheless, cycling accessibility assessments often applied arbitrary impedance functions (Iacono et al., 2010; Vale et al., 2016), limited to the census data units represented by census groups in the neighbourhood, disregarding the smaller scale defined by the cyclists. Moreover, in such measures, factors related to cycling network connectivity, parking availability, and topographical effects are often overlooked.

2.4.1.4. Health

Cycling for commuting, leisure, and exercise purposes brings tangible benefits to physical health, such as weight reduction and prevention of chronic health conditions, which includes obesity, diabetes, and cardiovascular diseases (Barajas and Braun, 2021; Grimes and Smirnova, 2020; Standen et al., 2021). Furthermore, scholars argue that the bicycle plays an essential role in improving an individual's independence and self-sufficiency regarding mental and cognitive health.

For instance, cycling to job opportunities can improve the physical health, emotional independence, and self-esteem of men who experience homelessness and unemployment (Grimes and Smirnova, 2020). Regarding gender equity in health, a previous study held focus groups with adolescent girls to assess the primary motivators and barriers affecting their decision to cycle to school. Indeed, empirical evidence demonstrated that cycling to school could be an important source of physical activity, fostering children's autonomy and confidence (Davison et al., 2013; Goodman et al., 2016). However, girls' propensity to use the bicycle as a transport mode is affected by intrapersonal factors encompassing their relationship with parents and friends and concerns about their image, being feminine, and social values. Such gender attribution, summed with personal security concerns, directly affects cycling confidence and uptake, consequently limiting the health benefits associated with the bicycle among women (Frater and Kingham, 2018; Prati, 2018).

Recently, the COVID-19 pandemic called for a holistic understanding of cycling's effects on public health and social and spatial equity (Cusack, 2021). Accordingly, a previous study focused on ethnic and racial minority groups who have experienced high rates of death associated with the pandemic outbreak. Such an approach revealed that often minority groups who work or reside in areas with low accessibility conditions for cycling rely on overcrowded public transportation options. Therefore, these groups are more likely to be exposed to the virus and disproportionately suffer from its harmful effects (Cusack, 2021).

In health-equity assessments, communities with sedentary behaviour and obesity at epidemic levels represent a significant concern group. For example, Babagoli et al. (2019) applied the World Health Organization's Health Economic Assessment Tool (HEAT) to estimate the benefit of cycling and its change over time among BSS users in New York for one year. Such assessment disclosed that BSS allocation did not attend communities of colour in higher poverty neighbourhoods, which are less likely to improve their physical health conditions by using the local BSS (Babagoli et al., 2019).

Moreover, such evidence aligns with other studies that revealed minor health benefits from utility cycling among people of colour due to the high exposure to transport externalities (Grimes and Smirnova, 2020) during commuting trips.

Overall, the present review suggests that whether the distribution of such benefits is fair or varies across demographic groups remains an open question. Previous studies usually explored the health benefits of bicycling for transportation at an aggregated scale coupled with walking (Rahman et al., 2018).

2.4.2. EMPIRICAL EVIDENCE

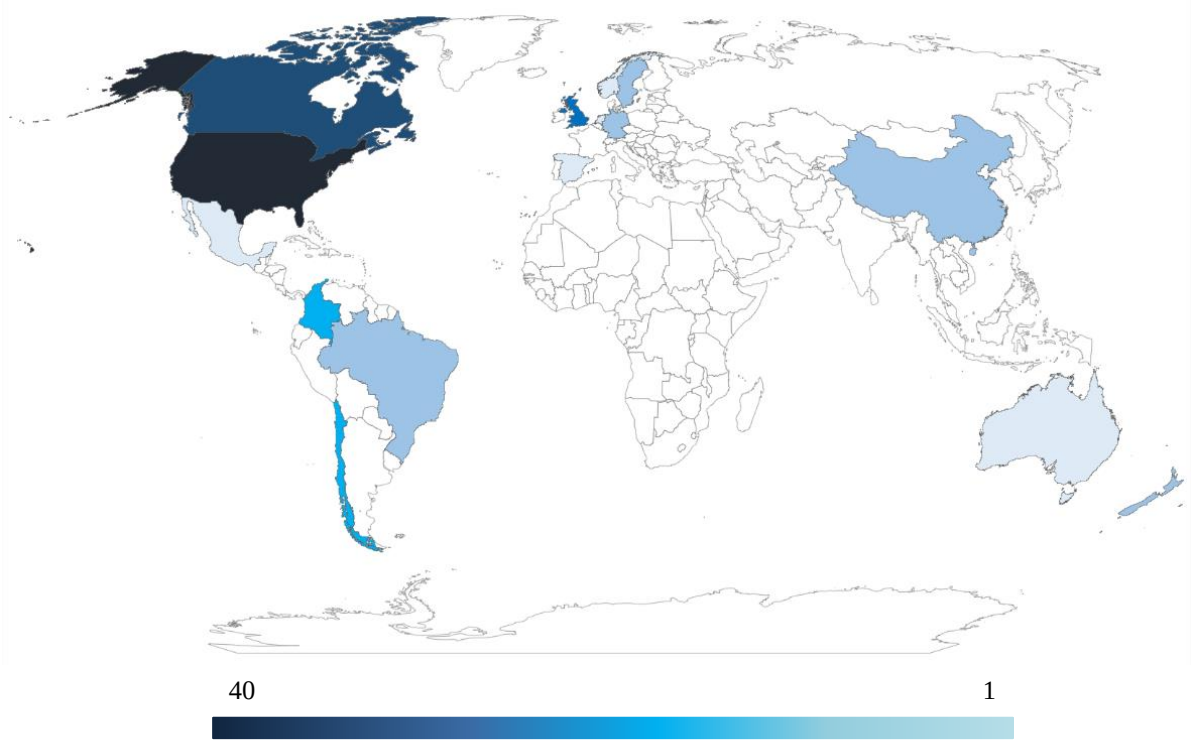


Fig. 15 – Geographical distribution of the Empirical Evidence

As illustrated (Fig. 15), the most significant portion of the empirical evidence comes from the global north, with the United States and Canada concentrating more than half of the literature produced in the last decade. Such a phenomenon may directly relate to the fact that in these countries, bicycle advocacy and critical mass are trying to foster sustainable mobility policies to improve conditions for cycling and walking against the established car-centric infrastructure. Moreover, it may reflect greater availability of resources, including reliable databases and investments for conducting such research in these countries.

In the United Kingdom, the empirical evidence focuses on issues of gender and age, exploring the potential of the bicycle as a transport mode in promoting social inclusion and participation for vulnerable (i.e., women) and minority profiles (i.e., younger, elderly) (Clark and Curl, 2016; Goodman and Aldred, 2018). In Canada, such a distributive framework primarily investigates the distribution impacts across low-incomers and immigrants (Hosford and Winters, 2018; Houde et al., 2018; Winters et al., 2018). In Latin America, the study of transport poverty and distributive inequities has revolved

around the socio-economic aspects, examining the linkages between urban segregation and the location of disadvantaged population segments (Iglesias et al., 2019).

Research conducted in China mainly focused on the equity implications of BSS for socio-economic disadvantaged (i.e., low income, unemployment, and low educational level) and vulnerable groups (i.e., women and elderly) (Ji et al., 2017; Tan et al., 2019). Therefore, scholars argued that combining BSS with the rail system has the potential to address the first and last-mile issue and foster sustainable mobility in Chinese cities (Ji et al., 2017), which are experiencing increasing trip distances and motorisation levels, as well as a gradual deterioration of cycling environment.

Across the Oceania region, studies conducted in Australia and New Zealand assessed the impacts of cycling network provision on gender equity, considering the effects of age and income. Hence, scholars employed mixed-method assessment to evaluate the distribution of accessibility, mobility, and health gains across vulnerable representatives (Frater and Kingham, 2018; Russell et al., 2021; Standen et al., 2021). This review found no empirical evidence in other geographic regions with severe social inequalities and spatial segregation conditions, such as African cities, the Middle East, and India.

In the United States, a recent study explored Bicycle Master Plans implemented in 22 large American cities and suggested that the development of the cycling network disregards areas with lower socio-economic status, lower educational levels, and higher proportions of non-white residents (Braun et al., 2019). For example, in El Paso, bicycle lanes and accessibility improvements are concentrated in the downtown area, poorly connected to public transportation hubs, jobs opportunities, and low-income workers group (Chandra et al., 2017). In Chicago and Philadelphia, the more significant representatives from disadvantaged communities have a low level of bicycle accessibility than areas with more affluent and white populations (Qian and Niemeier, 2019). In Tampa, the accessibility provided by the local bicycle share scheme is more accessible for males, individuals from higher-income households, and people between 18 and 35 years old (Chen et al., 2019).

Previous research conducted in Montreal in Canada revealed that the cycling network provision over the last 25 years improved accessibility for low-incomers, recent immigrants, and seniors. However, the bicycle accessibility for children decreased, mainly due to individuals' perception of insecurity when cycling (Houde et al., 2018). Likewise, the assessment of the distribution of bicycle share level of service in Vancouver, Toronto, Ottawa, and Montreal revealed that advantaged areas, depicting a lower level of deprivation in terms of education, income, and unemployment, have greater access to bicycle share service (Hosford and Winters, 2018).

In the United Kingdom, cycling for commuting and leisure is unequal, considering gender, age, disability, and ethnicity determinants (Goodman and Aldred, 2018). For example, in Glasgow, a low percentage of the population, around 15%, can fully benefit from the accessibility provided by the local system (Clark and Curl, 2016). Although cycling to work has increased relatively equitably between 2001 and 2011, the discrepancy between English towns indicates a crucial challenge regarding future bicycle policies and investments (Goodman et al., 2013).

In Europe, the limited empirical evidence suggests more significant distributional discrepancies across the spatial dimension of analysis. Remarkably, such assessments lack crucial demographic and socio-economic parameters related to income and poverty, whereas these data are not generally available in current open-source European databases at a minor census tract level. To illustrate, previous research conducted in Malmo, Sweden, revealed that the bicycle-sharing station is generally equitably distributed, with more significant differences between people with similar backgrounds living in

different areas than people with diverse backgrounds living in the exact location (Hamidi et al., 2019). In Munich, Germany, the same phenomenon was observed, with the local bicycle-sharing system serving privileged and underprivileged groups (Duran-Rodas et al., 2020).

Results from the South American context also highlight the uneven distribution of bicycle benefits. For instance, in Colombia, the accessibility provided by the cycling network households (Parra et al., 2018; Teunissen et al., 2015; Torres et al., 2013), as well as the local BSS (Cardona et al., 2017) do not attend most of the low socio-economic neighbourhoods. In Brazil, the bicycle network in Rio de Janeiro and Curitiba has proved to benefit the wealthiest communities, favouring the higher income population quintiles (Tucker and Manaugh, 2018). In São Paulo, there is an inequitable distribution of bicycle accessibility to job opportunities, with most improvements centred in the middle to high-income areas. Peripheral regions had the lowest improvement, with higher dependency on public transportation modes and higher poverty levels (Pritchard et al., 2019b).

A study conducted in Chile applied a participatory approach to involve community leaders and researchers in a debate focused on universal access and bicycle inclusion. Results revealed that Chilean transport systems are perceived as unjust, considering age, gender, income, and capability factors (Sagaris et al., 2020). Scholars called for a need to redistribute road space and investments in favour of active transport since the established planning guidelines often benefit high-income households with higher car ownership rates (Iglesias et al., 2019; Mora et al., 2021; Saud and Thomopoulos, 2021).

In China, previous results indicate that vulnerable segments such as females, the elderly, and low-income rail commuters are less likely to make utilitarian trips with bicycles, especially using BSS and rail systems in multimodal journeys. Likewise, people living in socioeconomically disadvantaged neighbourhoods encounter more barriers to access opportunities by bike due to trip distance and cycling frequency (Ji et al., 2017; Tan et al., 2019).

In Australia, the cycling benefits of bicycle infrastructure provision are mainly likely to favour male, high-income, and older-age groups (Standen et al., 2021). Regarding gender equity, studies conducted in New Zealand showed that the negative burdens of the transport system disproportionately affect women and children when cycling for utilitarian reasons due to perceptions of traffic danger, personal safety, and the need to be safety-conscious and take care of others (Russell et al., 2021). Likewise, injunctive and descriptive norms encompassing social relations, concerns about the image, and gender attribution played a vital role in cycling uptake for women (Frater and Kingham, 2018).

Overall, the present review outlines strong evidence that the decision-making and bicycle planning process often targets wealthy areas and privileged population groups in cities, disregarding the equity impacts of bicycle projects and infrastructure provision.

2.4.3. Measuring Bicycle Equity: methods

Most of the previous frameworks employed quantitative assessments to measure the distribution of bicycle-related benefits and their equity impacts. (Fig. 16), despite the increasing interest in qualitative and mixed methods.

Concerning quantitative-oriented approaches, previous studies deployed statistical analysis such as linear and multiple regression models (Houde et al., 2018; Maas et al., 2020; Qian and Jaller, 2020), principal component analysis (Hosford and Winters, 2018), cluster analysis (Pritchard et al., 2019b; Rosas-Satizábal et al., 2020), GIS-based network analysis (Hosford and Winters, 2018; Kent and

Karner, 2019; Tucker and Manaugh, 2018) and descriptive statistics (Barajas, 2020; Flanagan et al., 2016; Hirsch et al., 2019; Reilly et al., 2020).

Descriptive statistics are commonly applied to explore individual characteristics grouped in quartiles (Hamidi et al., 2019; Kent and Karner, 2019; Qian and Niemeier, 2019) or quintiles (Tucker and Manaugh, 2018).

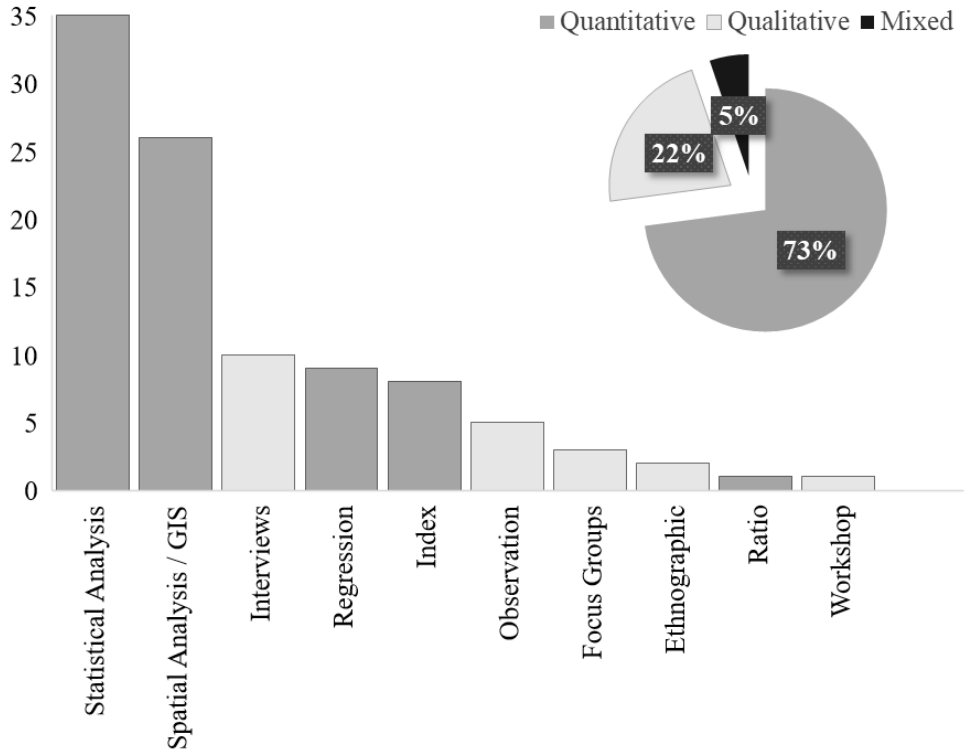


Fig. 16 – Methods for assessing Bicycle Equity

Regarding spatial analysis and bicycle accessibility measurements, most assessment methods are place-based, focusing on local and physical attributes of the built environment and transport system. Hence, these studies shed light on the question of how access-disadvantage can lead to social exclusion, hindering the well-being of vulnerable individuals and disadvantaged groups or communities, linking crucial facets of urban structure, such as the location of dwelling, employment, education, and essential services (Chandra et al., 2017; Chen and Wang, 2020; Qian and Niemeier, 2019; Rosas-Satizábal et al., 2020; Zuo et al., 2020).

Another technique refers to composite indicators or indexes supported by statistical analysis (Braun et al., 2019; Chandra et al., 2017; Houde et al., 2018; Qian and Niemeier, 2019). Hence, a commonly applied method is the Principal Component Analysis, which identifies similar groups with distinct characteristics or factors. In addition, scholars often conduct Pearson correlation matrixes and standardization processes (e.g., Z-score) of the selected indicators to ensure that the proposed equity-oriented indexes identify similar groups (Wang and Lindsey, 2019; Xie and Wang, 2018).

Within regression modelling, censuses and surveys are the leading database source for collecting individual-based factors, offering the baseline to explore interactions between bicycle benefits and specific socio-demographic characteristics. Thus, previous equity assessments employed linear regression models, where the dependent variable is continuous in nature (Barajas, 2021), as well as

logistic regression, where the independent variables can be continuous or binary (Braun, 2021; Cusack, 2021; Ferenchak and Marshall, 2021). For instance, continuous independent variables were changes in income, race, and ethnicity within the period encompassing cycling infrastructure implementation (Ferenchak and Marshall, 2021).

To geographically locate the distributive imbalances of bicycle accessibility, some authors use GIS tools with network analyst extension, mapping the interaction between cycling infrastructure, opportunities, and the location of disadvantaged or vulnerable groups. As a result, bi-dimensional maps (2D areal aggregation) often represent such accessibility indicators, relying on spatial georeferenced variables and data classification based on a colour scale (Bhuyan et al., 2019; Duran-Rodas et al., 2020; Wang and Lindsey, 2017).

Recently, scholars drifted attention towards methods and indicators from economics conceived to measure discrepancies in terms of the distribution of income, such as the Gini index and Lorenz curve (Chen et al., 2019; Duran-Rodas et al., 2020; Pritchard et al., 2019b; Wang and Lindsey, 2017), the Theil Index (Hamidi et al., 2019; Zuo et al., 2020), the Atkinson index (Zuo et al., 2020) and the Palma Ratio (Rosas-Satizábal et al., 2020).

Based on the Gini coefficient and the graphical Lorenz Curve, Pritchard et al. (2019) explored the potential of cycling in reducing spatiotemporal inequalities over trapezoidal urban areas, indicating zonal values of job-accessibility to the population (Pritchard et al., 2019b). Likewise, Wang and Lindsey (2017) applied this method to evaluate the distribution of bicycle accessibility amongst subgroups with potentially more significant transportation needs. Such assessment relied on a composite indicator that aggregates six indicators of a potentially disadvantaged subpopulation (i.e., car ownership, poverty level, ethnicity, race, youth and elderly) developed at the block group level (Wang and Lindsey, 2017).

A recent study readjusted the formulation of the Theil Index by replacing income with a composite bicycle accessibility indicator, assessing the contribution of individual characteristics (e.g., citizenship status) to the total spatial inequality (Hamidi et al., 2019). Initially, the Theil index is a decomposable technique used to measure income inequality, revealing an entropic distance or how far a population is from the egalitarian line. The Atkinson index also has an entropic structure and is sensitive to differences in the distribution scale, especially at the bottom, therefore being valuable to determine which part of the distribution contributes most to the observed inequality (Zuo et al., 2020).

The distributive assessment that makes use of the Palma ratio (Rosas-Satizábal et al., 2020) targets disparities between the bottom of the distribution, represented by 40% of the sample, and those at the top 10% (Pereira et al., 2017), highlighting differences between the richest and poorest, in terms of bicycle accessibility to employment and education opportunities.

Through the literature reviewed, qualitative assessments included ethnographic analysis (Lugo, 2013; Parker, 2019), in-depth and semi-structured interviews (Barajas, 2020; Lubitow et al., 2019; Ravensbergen et al., 2020a), observation studies (Candipan, 2019; Lusk et al., 2017) and focus groups (Frater and Kingham, 2018). In addition, qualitative assessments offered an alternative and anthropological perspective to examine the equity impacts of cycling, looking beyond the infrastructure effects. Hence, researchers often take an active position in observing the urban landscape dynamics encompassing individuals' attitudes, mobility patterns, and the influence of cycling advocacy on planning and policymaking. Such an approach brings fundamental insights for understanding the motivations and barriers of specific groups of concern, sensitive to the individual factors often overlooked in aggregated spatial analysis.

2.5. CONCLUSION

All in all, this review sought to elucidate two main research questions. Firstly, it examined to what extent the distribution of bicycle-related benefits is equitable in cities around the globe. Secondly, it performed a critical collection of the often-applied frameworks, methods, and analysis tools for measuring the equity impacts of bicycle planning.

Over the last decade, researchers developed distributive frameworks for assessing the equity impacts of bicycle-related benefits in cities worldwide. Accordingly, studies have shown that the distributional effects of cycling are context dependent. This review disclosed that the distribution of bicycle benefits is often uneven because projects and investments tend to focus on central areas of cities favouring neighbourhoods with a low share of socio-economic disadvantage or vulnerable representatives.

Amongst diverse methodological approaches for conducting such assessments, most studies have preferred quantitative methods. However, future research could bridge the gap between quantitative and qualitative methods, providing a more holistic perspective to the bicycle-equity debate since measuring the distribution of bicycle-related benefits is challenging due to a lack of clear and suitable indicators for measuring equity progress.

Recent research adapted statistical analysis and distributive measures such as the Gini coefficient & Lorenz Curve, Theil Index, and Palma ratio to address this problem. Such quantitative methods reveal the distributional imbalances in a general framework, such as the city scale, being helpful in discussing the equity impacts of cycling infrastructure allocation. Nonetheless, it remains unclear how such frameworks, which deal with increasing complexities, could guide holistic discussions encompassing mobility justice and social exclusion issues. Indeed, scholars are still establishing databases for measuring bicycle equity since, in some countries, crucial socio-economic data, such as income and poverty level, are not available in open databases, especially at the small scale of the bicycle user.

Likewise, accessibility measures and composite socio-economic indicators have proven helpful for discussing bicycle equity. Nevertheless, the complete integration of the individual component in accessibility measures remains challenging, especially for cycling, due to the general lack of high-resolution data at the personal level. For example, cycling in narrow cycle lanes or on a discontinuous surface could challenge representatives who cannot meet the traffic pace, mainly those relying on specific bikes (i.e., cargo bikes, handcycles, tricycles). In addition, vulnerable segments represented by the elderly, physically disabled, and children may have slower reflex and reaction times to adapt to possible unforeseen events when cycling. Future research could explore perceptions and limitations of vulnerable and socially disadvantaged groups, providing a more equity-oriented output for bicycle accessibility assessments.

Scholars acknowledge that bicycle planning guidelines rely on successful experiences and outcomes experienced in the global north. Nevertheless, the access to a reliable database and available resources to research the equity impacts of bicycle planning varies across distinct geographic regions. Therefore, transferring and adapting cycling policies and strategies from the global north to the global south is not straightforward.

Moreover, the dynamics of urban sprawl, mobility, poverty, socio-spatial inequalities, and political polarization play a different role in such countries. For instance, on the one hand, the strategy developed in the global north revolves around fostering sustainable mobility and economic development by reducing the attractiveness of the car and the carbon footprint by rethinking the road design towards active modes such as walking, cycling, and micro-mobility. On the other hand, in the

global south, bicycle advocacy groups play a crucial role in increasing awareness about the importance of cycling, especially among the poorest representatives, who do not have access to private and motorized vehicles. However, these cities have seen a considerable car use increase and traffic and air pollution in the last decades, whilst the most vulnerable and disadvantaged segments rely on crowded public transport or use alternative modes of transportation to access activities and opportunities. As a result, they are often disproportionately impacted by the burdens and externalities created by the car-oriented transport systems (Stehlin, 2019; Targino et al., 2018).

Most of the current literature examined the ex-post impacts of bicycle-related projects or investments. Although the ex-post analysis of equity gives some directions on managing project investments and revenues (Ramjerdi, 2006), such an approach does not provide directions on how planers could design projects to enhance social inclusion and spatial cohesion. This lack of knowledge may perpetuate or exacerbate inequitable practices within the bicycle planning and decision-making process.

A crucial research pathway in this agenda refers to fostering the knowledge exchange between academia and professionals to enhance political awareness of the social benefits of cycling investments in the initial phases of planning and decision-making processes. For example, the development of methods for evaluating the equity impacts of bicycle plans and projects from an ex-ante perspective could allow comparative assessments, benchmarking different planning scenarios to better reflect the spatial-social context under analysis.

Supported by the present systematic review analysis, this paper demonstrates that the debate encompassing bicycle equity is still in the earlier stages. Hence, the full integration of equity-based assessments within bicycle planning could support future projects and interventions towards more equitable solutions, ensuring social inclusion and spatial cohesion in cities.

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3

Assessing the equity impact of cycling infrastructure allocation: Implications for planning practice

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ABSTRACT

Despite the general political efforts to normalise bicycle use in cities, empirical evidence indicates that cycling investments tend to prioritise central and wealthy neighbourhoods rather than economically disadvantaged and peripheral areas. Among the potential causes, scholars claim that the lack of awareness about the social impacts of cycling and the general absence of equity-oriented appraisal methods during planning and decision-making processes may perpetuate the uneven distribution of bicycle-related investments.

In response, this paper introduces a novel planning support tool for assessing the relative equity impact of bicycle planning (TIRE), which provides a micro-scale spatial assessment of the effects of cycling network allocation on the accessibility levels of distinct socioeconomic groups, allowing a vertical equity assessment with high spatial detail.

In order to apply the tool to a real-case scenario, the cycling strategy under implementation in Lisbon, Portugal, was assessed as a testbed. The results were presented to local planning practitioners in an experiential workshop, enabling participants to define strategies supported by the tool and evaluate its user-friendliness and usefulness for planning practice.

TIRE revealed hotspots in the city where the cycling network distribution is equitable and areas where disadvantaged representatives have levels of accessibility below the municipality average, thus requiring special attention during the bicycle planning process. In addition, the tool supported local planning practitioners in identifying target areas and equity-oriented strategies, increasing awareness about the equity impacts of cycling infrastructure allocation.

KEYWORDS: Bicycle planning; Equity; Accessibility; Planning support systems; Spatial analysis; GIS.

3.1. INTRODUCTION

Promoting cycling as a transport mode has been widely acknowledged as a crucial strategy to foster sustainability and tackle economic, environmental and social goals (Banister, 2011; Sagaris, 2021). The bicycle is regarded as a low-carbon and affordable mobility option, with a considerable potential to reduce inequalities in cities and mitigate the adverse effects of climate change and the misuse of motorised modes of transport (Karner, 2016). Moreover, cycling has the potential to improve health and social well-being (Babagoli et al., 2019; Barajas and Braun, 2021), foster inclusiveness (Böcker and Anderson, 2020), and increase access to opportunities in cities (Mora et al., 2021; Pritchard et al., 2019b).

Nevertheless, a central issue in this research agenda concerns the distributional justice related to the benefits and costs of cycling. Concerning the benefits, empirical evidence indicates that cycling network coverage, accessibility, and health gains often favour privileged representatives of society and wealthier areas of cities, disregarding vulnerable and disadvantaged populations (Cunha and Silva, 2022). Regarding the costs, minority groups and communities of colour are likely to suffer from adverse effects related to urban cycling, including exposure to atmospheric and noise pollution (Gelb and Apparicio, 2021; Targino et al., 2018), bicycle injury, crashes and police citations (Barajas, 2021).

In the transportation sector, prioritising equity, also known as vertical equity, is highlighted as an approach that addresses the needs and barriers of disadvantaged and minority representatives, reducing transport inequalities and promoting social inclusion (Lee et al., 2017; Litman, 2005). Nonetheless, this perspective is frequently overlooked in planning practice due to the shortage of suitable indicators for measuring equity progress in transportation, particularly within bicycle planning, which ultimately induces an inequitable distribution of bicycle-related investments (Lee et al., 2017).

In this respect, scholars advocate that disadvantaged and vulnerable populations should be prioritised in bicycle planning to normalise cycling design and bicycle uptake in cities (Goodman and Aldred, 2018; Russell et al., 2021; Saud and Thomopoulos, 2021). However, few studies attempted to translate such empirical evidence into practical input to support planning practitioners in earlier stages of planning and decision-making, fostering awareness of the equity impact of cycling investments.

Planning practitioners regard the provision of infrastructure as a primary measure to promote the use of the bicycle as a viable transport mode for daily activities (Dias et al., 2021; Tucker and Manaugh, 2018). Nevertheless, cities with a bicycle modal share below 10% and residual infrastructure (Holbrow, 2013; Lopes et al., 2021; Urbanczyk, 2010a), also known as starter cycling cities (Silva et al., 2019), struggle to overcome the general social resistance, as well as the lack of political commitment within planning and decision-making processes (Bicalho et al., 2019). Consequently, these cities may face the most complex challenge of prioritising equity when developing and allocating cycling infrastructure and investments.

In response, this study developed a mixed-method research approach to investigate to what extent a starter cycling city addresses equity issues within the local cycling strategy by introducing the concept of relative bicycle equity and a planning support system (PSS) tool for assessing the Relative Equity Impacts of bicycle planning (TIRE). TIRE is a tool based on Geographic Information System (GIS) that assesses the distribution of cycling infrastructure and accessibility levels across distinct socioeconomic groups, revealing where inequalities are occurring as well as priority zones for future equity-oriented interventions.

PSS instruments generally rely on geo-information technology to support people involved in planning and decision-making processes (Geertman et al., 2015; Pelzer et al., 2014). PSS developers design

such tools as visually attractive platforms to promote the mutual exchange of knowledge and ideas among different actors who come together to learn about a planning issue (te Brömmelstroet, 2017).

Notwithstanding, planning practitioners appear reluctant to apply or implement the increasing number of potentially valuable transport-related PSS instruments (Geertman, 2017). Indeed, modern tools are coping with increasing multidimensional complexities, which may require more time for application, resources, and expertise to conduct specific analyses (Saujot et al., 2016). In response, previous studies conducted workshops with local planning practitioners (Pajares et al., 2022; Silva et al., 2019) to engage users with a PSS tool and address such implementation gaps (Geertman, 2017; te Brömmelstroet, 2012).

Accordingly, this research explored TIRE and its outputs with local planning practitioners in an experiential workshop to evaluate the perceived user-friendliness and usefulness of the tool for planning practice. Overall, this paper addresses the following research questions:

1) To what extent is the allocation of the cycling infrastructure network equitable, considering the distribution of accessibility levels over socioeconomic disadvantaged and advantaged areas?
2) Is TIRE user-friendly and useful for supporting equitable planning practices in starter cycling cities?

This paper is organised into five sections. After this introduction, the second section briefly presents the theoretical background and conceptual framework underlying the proposed planning support tool TIRE. The third section describes the mixed-method research approach applied in this research, including dimensions of analysis, database, and testbed operationalisation. The fourth section focuses on the outcomes of applying TIRE to a real-case scenario, critically discussing the perceived user-friendliness and usefulness for planning practice. Finally, the last section summarises the main findings and limitations of the research, pointing out implications for future research, policy, and practice.

3.2. Relative Equity Impact of bicycle planning

The theoretical foundations encompassing the social impacts of transportation systems entail distinct theories of justice and frameworks (i.e., distributive, procedural, and participatory approaches) (Beyazit, 2011; Martens, 2006; Martens et al., 2012; Vanoutrive and Cooper, 2019). In the transportation sector, equity issues are frequently discussed and assessed within a distributive framework (Pereira et al., 2017), which analyses how benefits and costs created by projects and investments are spatially distributed in cities and how they impact specific segments of society (Litman, 2005).

Accordingly, distinct principles and perspectives have been emphasised in the literature produced in the last decade. For instance, within an egalitarian approach, the horizontal equity perspective expects an equal distribution of investments, resources, and service levels among all social groups, regardless of individual needs and constraints (Litman, 2005). Conversely, vertical equity recognises social heterogeneity, acknowledging that specific groups of society do not have the same opportunities; therefore, they should be provisioned differently to ensure social inclusion (Caggiani et al., 2017; Camporeale et al., 2017). Thus, inequity refers to the lack of fairness, resulting in an uneven distribution of public sources and investments among distinct social groups (Iglesias et al., 2019; Linovski et al., 2018; Talen, 1998).

Regarding cycling equity, previous literature examined the distribution of bicycle-related benefits and costs. Within this framework, examples of cycling benefits include increased accessibility to several opportunities (Faghih Imani et al., 2019; Kent and Karner, 2019), health gains (Babagoli et al., 2019; Standen et al., 2021), bicycle-sharing service level (Duran-Rodas et al., 2020; Hamidi et al., 2019; Teixeira and Cunha, 2022), access to infrastructure (Tiznado-Aitken et al., 2022; Tucker and Manaugh, 2018) and CO2 emissions mitigation (Goodman et al., 2019). In contrast, the costs refer to bike injuries and accidents (Davison et al., 2013; Vandenbulcke et al., 2009), as well as exposure to atmospheric and noise pollution (Gelb and Apparicio, 2021). In short, these studies suggest that advantaged groups of society are more likely to benefit from bicycle-related investments than disadvantaged segments (Cunha and Silva, 2022).

Nonetheless, this body of literature is to some extent limited regarding the development of equity-oriented PSS tools to support the development of cycling plans, despite the increasing intersection of equity theories and changes in transportation systems (Doran et al., 2021; Karner and Levine, 2021; Lee et al., 2017).To the best of our knowledge, no study tried to bridge this debate by focusing on bicycle infrastructure provision and the geo-visualisation of the distributive effects of accessibility levels on advantaged and disadvantaged socioeconomic groups. Instead, most studies explore such binary perspectives focused on private vehicles and public transport (Behbahani et al., 2019; Ben-Elia and Benenson, 2019; Bocarejo and Oviedo, 2012).

In response, this research addresses this gap by introducing a novel PSS Tool to assess the relative equity impact of bicycle planning (TIRE). TIRE provides a micro-scale spatial assessment of the effects of cycling infrastructure provision on the accessibility levels of distinct socioeconomic groups, allowing a vertical equity assessment with high spatial detail. Specifically, the tool assesses the extent to which the cycling network allocation is equitable, measuring the proportion and location of distinct social groups and their accessibility gains.

The application of the tool to a real-case scenario encompasses a threefold-step quantitative approach. Firstly, based on the cycling network and land-use characteristics, the tool measures the levels of bicycle accessibility towards seven key geolocated activities. Subsequently, it assesses the relative distribution of advantaged and disadvantaged socioeconomic groups over the territory. Finally, the tool combines elements of both perspectives in a bivariate analysis, identifying four main clusters with distinct bicycle accessibility levels and socioeconomic groups.

This assessment method delivers crucial implications for research and planning practice since, up to date, there is a general lack of clear and suitable indicators to measure equity progress in bicycle planning. In response, TIRE identifies the equity effects of the distribution of cycling infrastructure, benchmarking socioeconomic characteristics and distinct bicycle accessibility levels. Hence, the accessibility levels and the socioeconomic groups are clustered based on the municipal average, allowing comparative assessment between and within groups of concern.

3.3. Research Approach, materials, and methods

3.3.1. TIRE operationalisation

To apply TIRE to the selected case study, we collected shapefile data on the cycling infrastructure network, land use, population count, and socioeconomic characteristics in open-source databases provided by the municipality, OpenStreetMap, and the latest available census data.

Onwards, we conducted a dasymetric interpolation of the collected data using hexagonal boundaries (Pereira et al., 2021), considering aerial intersection and variations in population sizes. Thenceforth, this study redistributed the population information across the study area from the smallest census tract level to a finer hexagonal grid that coincides with the global H3 index at resolution 10, with a short diagonal measuring 115,46 m and an area of 0.0115km².

3.3.1.1. Bicycle Accessibility

To measure bicycle accessibility, we developed a composite indicator using GIS. Hence, datasets on cycling network infrastructure, topography, and the location of points of interest (POIs) were processed within the municipality perimeter. Accordingly, based on the accuracy of the POIs available in the OpenStreetMap database, TIRE incorporates the following opportunities and activities into the accessibility model:

- Education (i.e., primary, secondary, and tertiary institutions);
- Health (i.e., health centres, public and private hospitals);
- Social services (i.e., job centres and social assistance buildings);
- Supermarkets;
- Public transport (i.e., metro and train stations);
- Culture (i.e., museums, theatres, cinemas and cultural centres);
- Green areas (i.e., parks and playgrounds).

This approach acknowledges that having access to education, health, nourishment sources, recreation, transport, and public services is fundamental to ensuring the well-being, social inclusion, and civic participation of individuals in society (Kent and Karner, 2019; Qian and Niemeier, 2019; Wahlgren and Schantz, 2014). However, this study did not measure access to employment since this information was not available within the open-source database provided by the municipality.

The 15-minute city vision (Moreno et al., 2021) guided the threshold calibration of the Bicycle Accessibility indicator (BA). Such a framework expects the development of more liveable, human-scale cities, emphasising equal access to opportunities to the most underserved city zones and disadvantaged groups, ensuring that people with distinct needs and abilities can meet their daily needs locally in a short 15-minute bike ride from home.

Therefore, TIRE incorporates an activity-based contour measure[7] of accessibility, which sums the number of reachable opportunities through the network within a fixed travel time threshold of 5 and 15 minutes. Previous research identified the proposed timeframes as common and feasible for bike users in European cities (Puello and Geurs, 2015). Hence, this model limits access to education, health, social services, and cultural activities to 15 minutes. In contrast, since supermarkets, public transport, and green areas are widely spread over the territory, we defined a threshold of 5 minutes to avoid overrepresenting these activities in the final aggregate indicator.

The proposed indicator does not consider the size of the facilities nor the attractiveness and impedance of reaching the opportunities. Conversely, to foster simplicity, communicative value and transparency of the tool (te Brömmelstroet, 2012), BA represents the sum of activities with no associated weight. This approach intends to avoid a multitude of bottlenecks within planning and decision-making processes (e.g., lack of experience with PSS tools, operational limitations), which can lead to an implementation gap of planning support tools in practice (Geertman, 2017; Vonk et al., 2005).

[7] Also defined as a cumulative opportunity or isochronic measure.

In ESRI ArcMap version 10.3, we measured accessibility contour areas for each hexagonal origin using Network Analyst with the service area function. In this study, we overlayed the topographic elevation with the cycling network, calibrating it according to the network segment length and average slope. Following the calculation functions detailed elsewhere (Silva et al., 2018), the calibration of the cycling network considered an average speed of 16km/h for a gradient slope below 3%, previously identified as an average cycling speed for non-commuting trips (Broach et al., 2012). Accessibility was calculated for each hexagonal cell, using the centroid of the hexagon as the origin and the measured travel time on the network.

The composite Bicycle Accessibility indicator (BA) results from the arithmetic sum of the individual accessibility levels to each destination type, calculated for each hexagonal cell and standardised into z-scores, with the value of 0 for cells representing mean accessibility levels and 1 for cells with accessibility levels equal to 1 standard deviation of the sample of BA. The z-scores offered aggregate accessibility levels above or below the municipal average.

Unlike the most common approach that measures bicycle accessibility to the infrastructure (Parra et al., 2018; Teunissen et al., 2015), the proposed indicator counts the number of accessible opportunities by bike throughout the cycling network. Therefore, TIRE illustrates the bicycle accessibility conditions, assessing the percentage of the population and municipal area covered with distinct levels of BA. Results for this indicator are grouped into four categories, ranging from the lowest to the highest-level using quartiles (Table 3).

3.3.1.2. Socioeconomic Index

Scholars acknowledge a whole range of deprivations relevant to a socioeconomic differentiation analysis (Krishnan, 2010; Xiao et al., 2018). For instance, structural unemployment, transport poverty, insufficient educational level and poor housing conditions potentially jeopardise the access of disadvantaged representatives to crucial activities and opportunities in cities (Cass et al., 2005; Lucas, 2017, 2012; Lucas et al., 2001). In addition, low educational attainment decreases labour market participation and limits the quality of life since employment is considered a significant source of income for an outstanding share of the population (Israel and Beaulieu, 2004; Müller, 2005).

Likewise, owning a house implies security of tenure, while renting is likely to represent a significant household income expenditure, especially critical for socioeconomically disadvantaged segments (Gunn et al., 2022; Hulse and Reynolds, 2018; Thurber et al., 2018). Moreover, housing disadvantages and low-quality dwellings negatively impact individual health and social participation (Singh et al., 2019). Among the often examined resource parameters, previous studies have highlighted the dimension of the living space (Drever and Clark, 2002; Xie et al., 2021), the number of rooms, and the presence of appliances and amenities (Meyer and Sullivan, 2012).

Regarding individual mobility and capabilities (Beyazit, 2011), immobile people have considerable difficulty in carrying out essential daily activities, while transportation services have restricted capacity to meet the travel needs of disadvantaged representatives who cannot afford transportation costs (Sanchez, 2008). The automobile plays a dual role in this debate. For instance, some studies regard car-dependent households as socially disadvantaged in peripheries and rural areas (Carroll et al., 2021; Farrington and Farrington, 2005; van Dülmen et al., 2022).

Contrastingly, car drivers are less exposed to transportation negative externalities compared to public transport users, cyclists, and pedestrians (Iglesias et al., 2019). Additionally, car ownership

communicates individual wealth since a car represents both a material resource and a transportation mode that enables longer distances (Gössling, 2016). For instance, in the USA, the car ownership rate in the lowest income quintile is significantly low compared to the national average (Lucas, 2012). In Portugal, lower income classes have substantially lower car ownership rates than higher income classes, with the percentage of car ownership in the lowest income quintile standing at 52%, well below the national average of 76% and the highest income class of 91% (INE, 2017).

In line with such a multidimensional rationale, this study sought to understand the interaction between interrelated variables encompassing employment, education, housing, and mobility dimensions, which earlier research demonstrated to play an essential role within the transport-related social exclusion debate (Lucas, 2012; Lucas et al., 2016a; Stanley et al., 2011). To create a socioeconomic index (SE) and distinguish socioeconomic groups of concern, we conducted the Principal Component Analysis (PCA) in SPSS statistics to measure the phenomenon of socioeconomic advantage and disadvantage.

Scholars recognise that PCA-based composite indexing is a valuable technique for quantitatively identifying social vulnerability (Krishnan, 2010; Vyas and Kumaranayake, 2006). Such a statistical approach processes several correlated variables into a set of new uncorrelated components accompanied by an eigenvalue representing the amount of variance in the original data explained by the component. In addition, each variable correlates with a component through a loading, which helps to interpret which aspects of advantage and disadvantage a component may represent (Field, 2013).

All chosen variables were represented as proportions and standardised using z-scores to prevent confounding effects from using variables with different magnitudes in the analysis. Hence, we conducted a Pearson's correlation analysis with the initial set of variables to obtain the loading for each variable in the principal component analysis.

Subsequently, based on mathematical procedures proposed in previous research (Pink, 2013), this study divided each loading component value by the square root of the eigenvalue to generate the raw scores of the SE index. As a result, indicators related to socioeconomic advantage received positive weights and loadings, while indicators related to disadvantage were attributed negative weights and loadings. Therefore, each hexagonal origin received a SE score by taking the product of each standardised variable with its respective weight and then taking the sum across all variables (Pink, 2013).

Table 3 – Description of the indicators used in the TIRE tool (BA indicator and SE index)

BA	Category	SE	Category
1st quartile	Very Low accessibility	1st quartile	Very High incidence of disadvantage
2ndquartile	Low accessibility	2ndquartile	High incidence of disadvantage
3rd quartile	High accessibility	3rd quartile	High incidence of advantage
4th quartile	Very High accessibility	4th quartile	Very High incidence of advantage

Finally, as was done for the BA, the SE index was grouped into four categories using quartiles, as presented in Table 3, ranging from the most disadvantaged to the most advantaged group. Therefore, an area with high SE has a relatively high incidence of advantage and a relatively low incidence of disadvantage. Areas without population did not receive an index score.

3.4. EQUITY ANALYSIS

TIRE spatially intersects both the BA indicator and SE Index to explore the equity impacts of cycling infrastructure allocation, providing a descriptive analysis of the areas and population groups affected by the local cycling strategy. Through a bivariate choropleth mapping procedure with a tritanopia scale colour, TIRE reveals the distribution of socioeconomic characteristics vis-à-vis bicycle accessibility levels, geolocating four main clusters (Fig. 17).

The proposed dashboard (Fig. 17) reveals the number of standard deviations from the mean for the accessibility indicator and socioeconomic index, with the central axes representing the municipal average for each indicator. While the vertical axis depicts the SE index, the horizontal one distributes the distinct levels of cycling accessibility (BA).

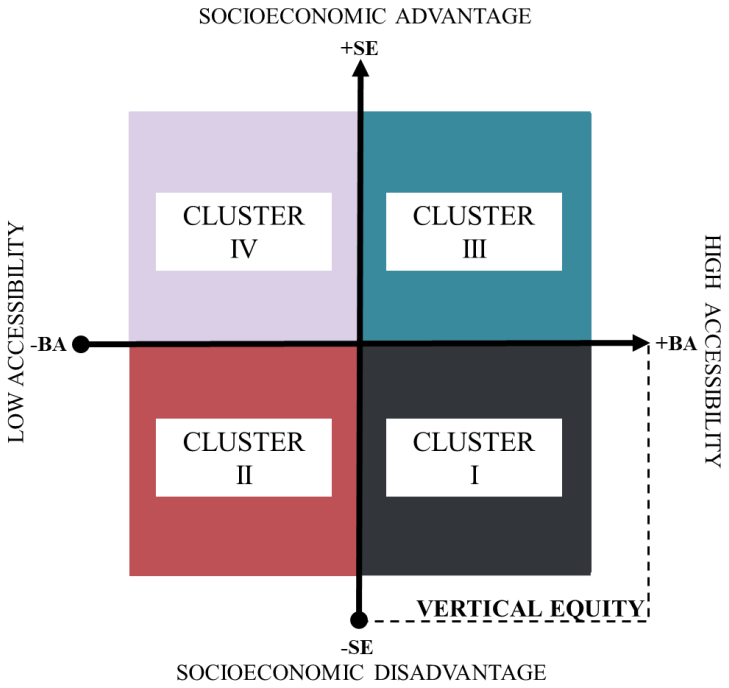


Fig. 17 – TIRE dashboard for equity analysis

By incorporating a vertical equity perspective, TIRE indicates an equitable distribution of increased BA as one that favours socioeconomically disadvantaged groups. In other words, the equitable cluster (I) reveals areas with prominent levels of bicycle accessibility to opportunities and a higher concentration of disadvantaged representatives.

Whereas cluster I depicts an equitable allocation of the cycling network, cluster II highlights zones which could be prioritised in future equity-oriented interventions since it concentrates disadvantaged representatives with lower levels of accessibility. Cluster III highlights territorial areas where socioeconomic-advantaged profiles have levels of accessibility above the municipality average. Finally, cluster IV reveals socioeconomically advantaged shares with lower bicycle accessibility conditions.

Overall, TIRE indicates where inequalities are occurring in terms of cycling infrastructure provision and accessibility improvements, considering the concentration of socioeconomic disadvantaged and advantaged population groups. The main outputs of the tool are 2-D maps with a gradual colour scale, including the descriptive analysis of accessibility disparities between and within each cluster.

3.4.1. TESTBED SELECTION

The selected case study in this research is the municipality of Lisbon, the capital of Portugal. Lisbon, located in the western part of the country, has experienced significant changes in land use and transportation systems during the last twenty years (Arbaci and Malheiros, 2010; Félix et al., 2019; Pritchard et al., 2014). The municipality, illustrated in Fig. 18, occupies an area of approximately 89 km^2, with a population of 552,700 inhabitants, according to the last available Census data (INE, 2011).

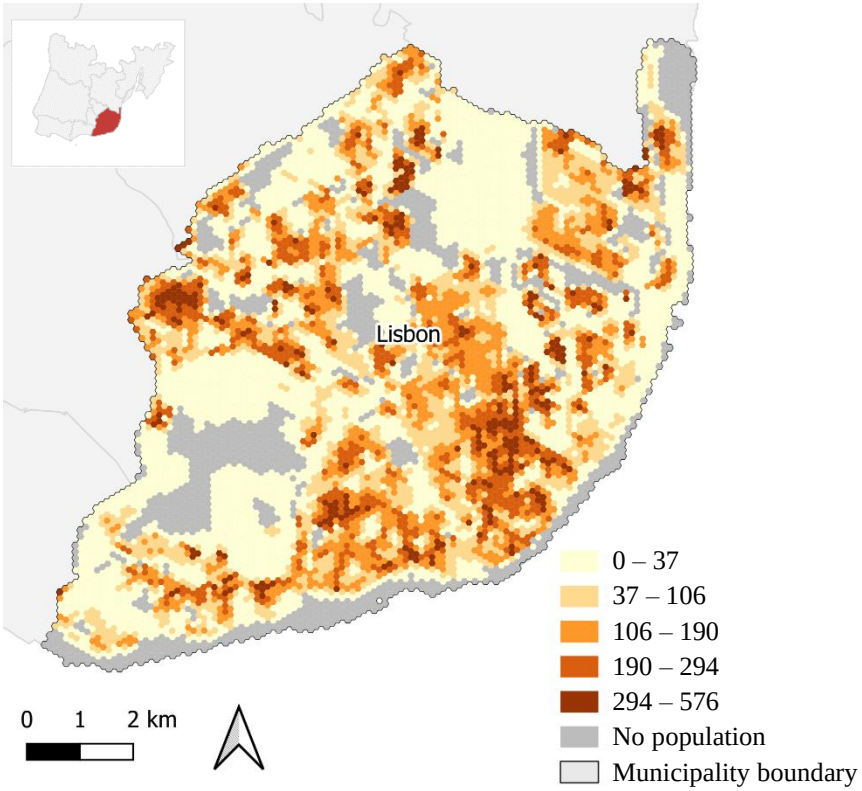


Fig. 18 – Lisbon's population (n)

Considered a starter cycling city (Félix et al., 2019; Lopes et al., 2021; Urbanczyk, 2010b), Lisbon presents a general overreliance on motorised modes of transport and, consequently, a low rate of bicycle usage. According to the last national mobility survey (INE, 2018), the private automobile is the primary mode of transport in the metropolitan area, accounting for 58.9% of all trips in a general week.

The municipality of Lisbon developed a strategic mobility vision to overcome such a scenario and create an accessible, functional, reliable, safe, and sustainable mobility ecosystem (Lisbon, 2020). One of the strategic pillars encompasses the implementation of a cycling infrastructure network (Fig. 19) to enable daily commuting and leisure trips by bicycle. The future cycling network comprises distinct cycle path topologies, such as contra-flow cycle lanes with road marking separating cyclists from other road traffic, unidirectional and bidirectional cycle tracks exclusively for cyclists and shared or coexistence zones with a speed limit of 30km/h.

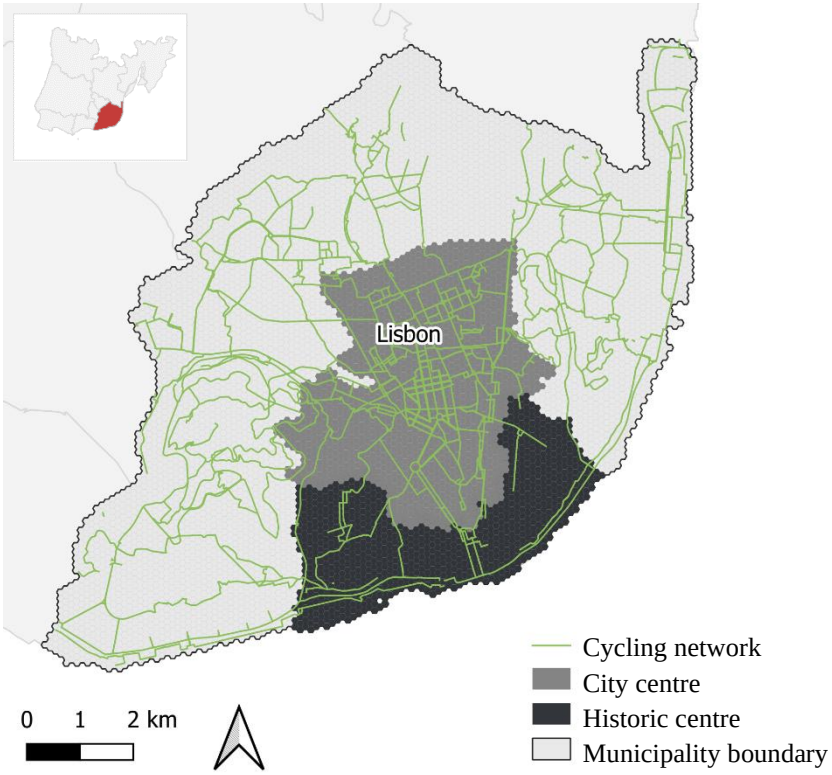


Fig. 19 – Cycling network allocation in Lisbon, with highlighted historic and city centres

Such a plan aims to encourage a robust shift towards the bicycle during the next decade, increasing the current bicycle modal share, below 1%, to get closer to the European average, around 7% (Lisbon, 2019). Nevertheless, a recent study has shown that the planned cycling network and the local bicycle-sharing systems in Lisbon do not benefit the most deprived areas, with significant disparities in coverage, distance and connectivity (Padeiro, 2022).

Thus, there is a compelling need to assess and communicate to what extent the allocation of cycling infrastructure promotes accessibility to essential activities and how these gains are distributed across different social strata to support planning practitioners towards more equitable bicycle planning directions. Indeed, since Lisbon has been transforming the urban landscape with increasing spatial fragmentation and sprawl of residential and production sites (Malheiros and Vala, 2004), this municipality emerges as a suitable testbed for the proposed equity-based assessment framework.

3.4.2. TIRE WORKSHOP WORKFLOW

This study developed an experiential workshop involving local bicycle planning practitioners to explore the potential applicability of TIRE to a real planning scenario and examine to what extent the tool is user-friendly and useful for planning practice. The workshop was organised in three sessions, with a total duration of approximately ninety minutes, allowing the participants to comprehend the concept of relative bicycle equity and experiment with the tool. Furthermore, based on the experiential rationale discussed in previous research (Straatemeier et al., 2010), the proposed workshop sought to encourage joint reflections on how to prioritise equity in planning and decision-making processes, leading to an adaptation of existing practices.

Thus, a first meeting was organised with the mobility department director of the municipality of Lisbon to explain the research scope and objectives encompassing the experiential workshop. Once the cooperation agreement was established, professionals involved in the local cycling mobility plan were invited to attend the workshop. The municipality conducted an internal selection of participants, respecting employees' availability.

The workshop involved eight planning practitioners from the Mobility Department of Lisbon city council, including the head of the department and experienced technicians directly involved in the local cycling strategy. More than half of the participants were women (i.e., five participants), and the majority were experienced professionals aged between 45 and 59 years old (i.e., seven participants). All participants signed a confidentiality agreement before the start of the research activity. The workshop took place in June 2022 through an online meeting platform, supported by two workshop facilitators; researchers specialised in spatial planning, architecture, and civil engineering.

Thus, the workshop started with a presentation of the tool, including the conceptual framework, required database, indicators, and operationalisation of tire. then, the workshop facilitator detailed the main outputs generated, focusing on the maps for each indicator (Fig. 22) and the bivariate analysis (Fig. 23), picturing the different distributive clusters. afterwards, participants had the chance to ask questions and debate the main outputs generated by the tool.

Once familiar with the method, the involved participants were split into two groups to develop new strategic interventions to increase cycling conditions in disadvantaged areas with low levels of accessibility (cluster II). in other words, planning practitioners explored the outputs generated by the tool to define an equity-oriented action plan, fostering a shared understanding of how to approach equity issues during the decision-making process.

Since previous research suggested that the effectiveness of decision workshops decreases as the size of the group and the number of participants increase (Papamichail et al., 2007), we decided to limit the size of the groups to up to four participants. Indeed, the main goal of allocating participants into working groups was to foster a greater exchange of ideas and better involve all in the decision-making process. Therefore, the breakdown of the participants into groups took place randomly.

In the last part of the workshop, each group had the opportunity to share their strategies to tackle the equity gap encountered within the current cycling planning framework. finally, the workshop ended with a survey assessing tire’s perceived user-friendliness and usefulness for planning practice. according to the established literature on PSS instruments (te Brömmelstroet, 2017), user-friendliness refers to the ease of use for planning practitioners (e.g., transparency, communicative value, focus, credibility, and level of detail), and the perceived usefulness relates to the PSS added value to the planning tasks and strategic planning process (e.g., individual reaction, insight, development of shared language, consensus, cohesion, and efficiency).

3.5. THE EQUITY IMPACTS OF BICYCLE PLANNING REVEALED

3.5.1. ASSESSMENT OF ACCESSIBILITY CONDITIONS

Through mapping the bicycle accessibility conditions (Fig. 20) and delineating comparisons between quartiles, the spatial assessment revealed that the fourth quartile, representing zones with very high levels of accessibility, has nearly 24 times more accessible opportunities by bicycle than the outskirts,

represented by the first quartile, which stands for 3% of the population within a surface area of approximately 7km^2 (Table 4).

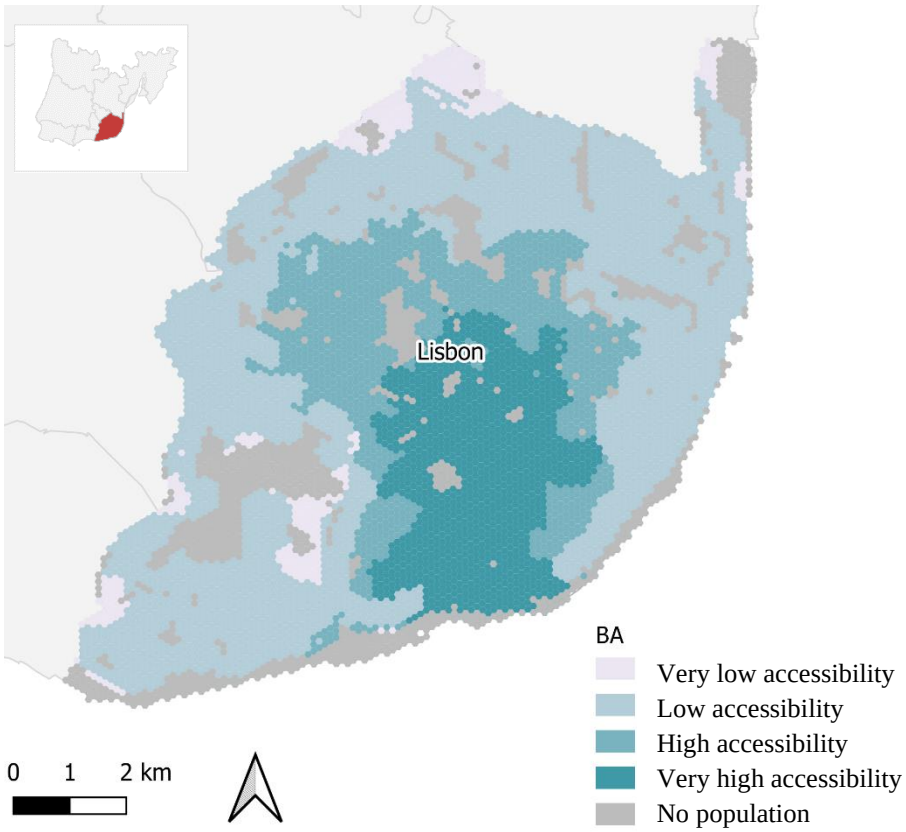


Fig. 20 – Bicycle accessibility conditions in Lisbon

Table 4 – Bicycle Accessibility levels, opportunities accessible by bicycle, share of population and area

BA	Category	Opportunities (n)	Population (%)	Area (%)
1st quartile	Very Low accessibility	8	3	8
2nd quartile	Low accessibility	39	47	56
3rd quartile	High accessibility	100	24	19
4th quartile	Very High accessibility	192	26	17

The zones with a lower level of bicycle accessibility encompass the northern periphery of Lisbon, characterised by the presence of decaying residential neighbourhoods, large clusters of social housing, small industries, warehouses, and pockets of formerly rural areas segregated from the main commercial and service centres. These territories are often stigmatised and socially excluded, inhabited by low-socioeconomic, unemployed representatives and poor immigrants (Fonseca et al., 2008).

The inner city and the edges of the historic centre of Lisbon present higher levels of bicycle accessibility. However, previous studies revealed that these zones experienced intense processes of urbanisation, revitalisation, and gentrification (Daly et al., 2021). These spatial phenomena, reinforced by the expansion of the tertiary economic sector in central areas and the exponential increase in land prices, pushed youth and low-income people to the peripherical regions of the municipality (Fonseca et al., 2008).

3.5.2. INDEXING SOCIO-ECONOMIC ADVANTAGE-DISADVANTAGE

This study collected the most recent and publicly available socioeconomic data from the Portuguese Census Bureau (INE, 2011) using the smallest geographic area (i.e., census tract) to identify the phenomena of socioeconomic disadvantage and advantage.

An initial list of 19 variables was transformed into proportions and standardised using the z-score statistic to serve as an input matrix for PCA analysis. Then, by applying the exclusion rules proposed by previous research (Pink, 2013), the final matrix input was reduced to a list of 14 variables (Table 5). The PCA analysis returned two principal components with eigenvalues greater than 1. The first explained almost 34% of the total variance, grouping advantage-related variables. The second component grouped disadvantaged variables, representing 25% of the total variance.

Table 5 – Input variables for PCA analysis

Dimensions	Socioeconomic advantage and disadvantaged variables	First component*[a]	Second component*[o]	Derived Weights
Employment	No_Job: % People searching for a job		0,765	-0,407
	F_1PNoJob: % Family with one person searching for a job		0,758	-0,404
	FY_Job: % Family with employed people	0,809		0,373
Education	Student: % People attending primary, secondary, or tertiary education	0,713		0,328
	No_edu: % People who have no education attainment		0,560	-0,298
	Bas_edu: % People whose highest level of education attainment is primary		0,662	-0,353
	Sec_edu: % People whose highest level of education attainment is the secondary	0,668		0,307
	Ter_edu: % People whose highest level of education is a	0,800		0,368

	higher degree qualification			
Housing	H_rent: % House under rent tenure		0,787	-0,419
	H_own: % House occupied by the owner	0,838		0,385
	H_50m 2: %Housing measuring up to 50m 2		0,759	-0,404
	H_100m 2-200m 2: %Housing measuring between 100m 2 and 200m 2	0,791		0,364
Mobility	Y_car: % People who commute by car (as driver or passenger)	0,811		0,373
	Immobile: %People who do not make utilitarian trips	-0,598		-0,275
Excluded Variables	P_Y_Job: % People with a job			
	P_S_1Job: % People searching for a first job			
	F_2PNoJob: % Family with two people searching for a job			
	H_50m 2-100m 2: %Housing measuring between 50m 2 and 100m 2			
	No_car: % People who do not commute by car (as driver or passenger)			

* Rotation method: Varimax with Kaiser normalisation.

Kaiser-meyer-olkin adequacy measure: 0,820

Bartlett's sphericity test: 0,000

ª λ 4,718 (33,699% of total variance)

º λ 3,525 (25,182% of total variance)

The SE index disclosed a balanced distribution of both disadvantaged and advantaged shares over the territory. The former accounts for 47% of the population sample, encompassing an area of 57 km^2, representing about 64% of the study area (Table 6).

The distribution of the most disadvantaged cluster (first quartile) occurs in specific areas in the traditional city centre and within the west, east, and extreme north zones of the municipality (Fig. 21). Previous research suggested that the historic centre had undergone an accentuated population decline in the last years (Maria et al., 2017). Hence these zones present a predominance of the elderly and immigrant population living in rented housing and poor-quality buildings (Malheiros and Vala, 2004).

Likewise, a significant share of disadvantaged segments inhabits peripheral neighbourhoods. Such a phenomenon is explained and reinforced by centrifugal forces imposed by the market, which push households with fewer resources to more peripheral and devalued areas with lower rents. Therefore,

larger low-income young families settle in social dwellings in the extreme north and west zones of the city (Maria et al., 2017).

The advantaged quartiles comprise around 53% of the population, concentrated in the inner city and certain pocket areas encompassing the northwest, northeast, and southwest zones, occupying 36% of the study area. The most advantaged zones include residential areas, characterised as gated communities with good living conditions (Raposo, 2006). These neighbourhoods are inhabited by well-qualified upper and middle-class residents that occupy majority positions in the tertiary sector (Fonseca et al., 2008). Scholars consider the current housing and urban policies ineffective in addressing inequalities in residential patterns (Pato and Pereira, 2016).

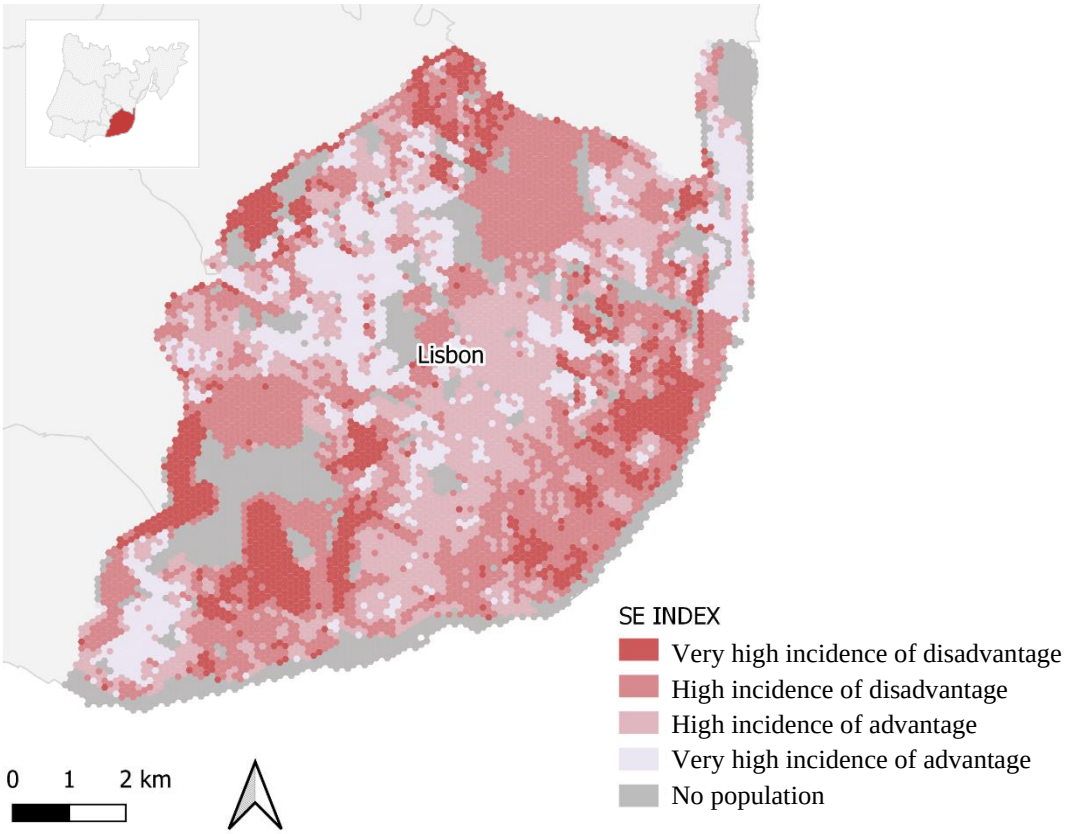


Fig. 21 – SE index distribution of socioeconomic conditions

Table 6 – SE index distribution by population and area

SE index	Category	Population (%)	Area (%)
1st quartile	Very high incidence of disadvantage	14	7.8
2nd quartile	High incidence of disadvantage	33	56.2
3rd quartile	High incidence of advantage	35	19
4th quartile	Very high incidence of advantage	18	17

3.5.3. EQUITY IMPACT OF CYCLING INFRASTRUCTURE ALLOCATION

TIRE inputs a simplified representation of the BA indicator and the SE index into a bivariate analysis. Whilst the former illustrates where accessibility levels are high or below the municipality average, the latter geolocates the phenomenon of socioeconomic disadvantage and advantage (Fig. 22).

Following the intersection of BA and SE, TIRE geolocates four main clusters (Fig. 23). TIRE application to the case of Lisbon revealed that disadvantaged zones with high accessibility, which meets the vertical equity perspective, encompass 14.42% of the study area and 20.17% of the total population. This cluster covers the central and historic neighbourhoods of the municipality. Although these areas present greater accessibility to opportunities and activities, they are often inhabited by elderly representatives with low levels of education and training and high percentages of economically active in low-skilled professions. Moreover, according to a previous study, the housing conditions in these areas are inadequate for the needs of an ageing population or those with reduced mobility (Fonseca et al., 2008).

A sizeable portion of disadvantaged segments has levels of bicycle accessibility below the municipality average. The cluster comprising disadvantaged zones with low accessibility, which encompasses 38.09% of the study area and 26.59% of the total population, is dispersed over the territory, especially within the peripherical neighbourhoods in the north, east and southwest zones. Previous studies revealed that low-income families are more likely to reside in these zones, especially in social resettlements (Maria et al., 2017). Accordingly, the SE index showed a concentration of unemployed and immobile population segments with lower education attainment.

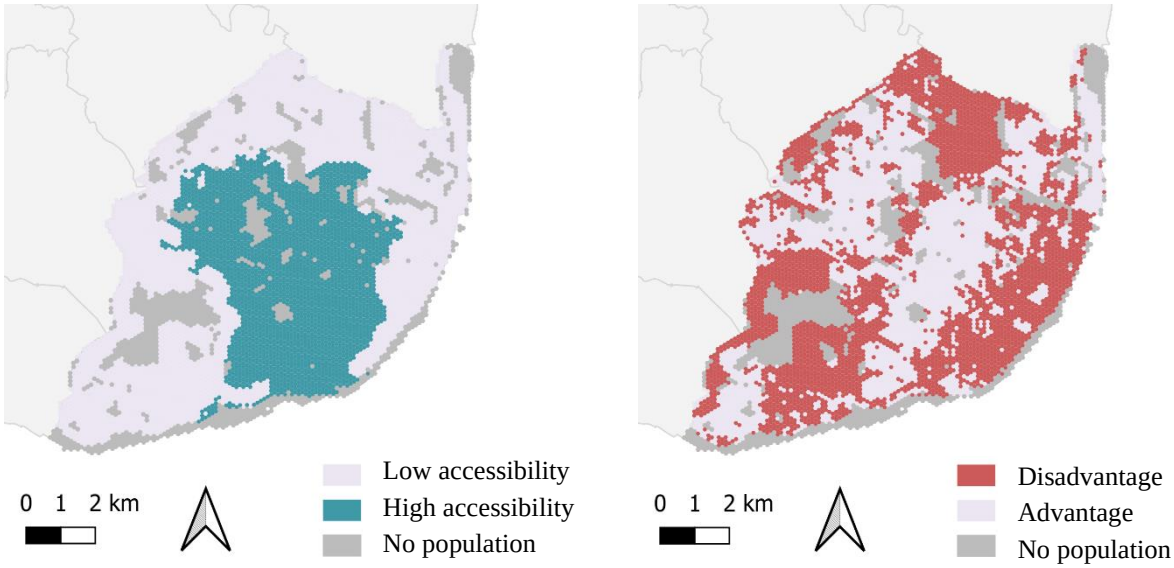


Fig. 22 – Representation of BA and SE within the bivariate analysis

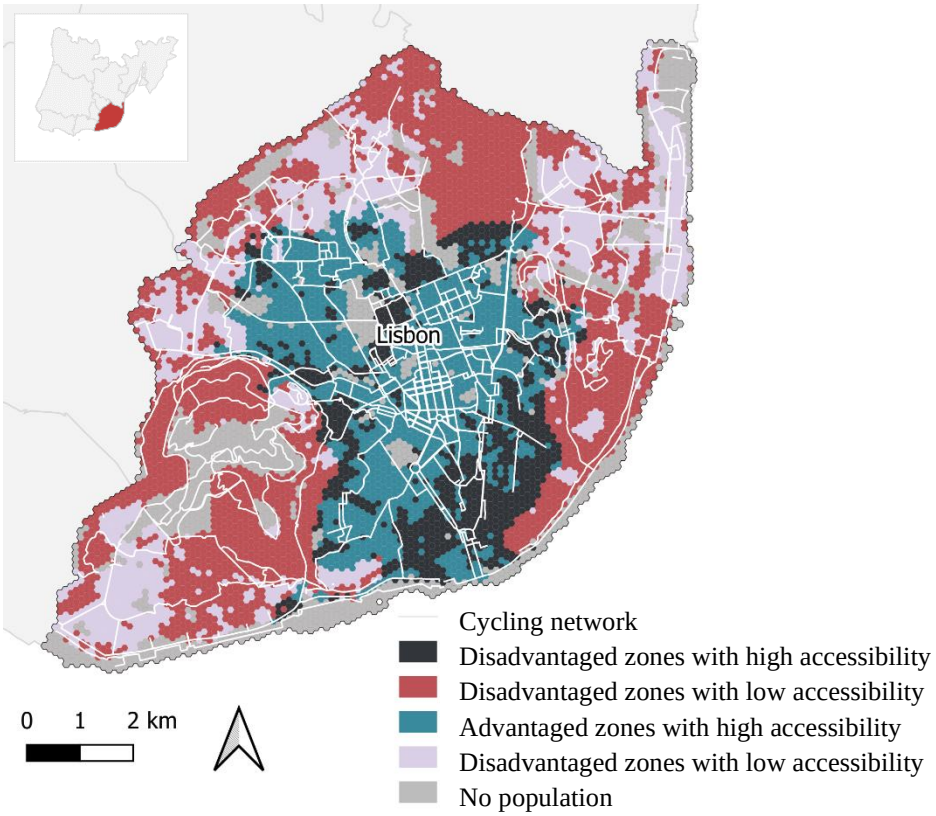


Fig. 23 – TIRE application to the case of Lisbon

TIRE disclosed an elevated concentration of advantaged segments with increased access to opportunities by bicycle in the territory under analysis. This cluster comprises 24.6% of the study area and 30.7% of the population, distributed within the city centre, northeast and southwest zones of the municipality. Unlike the historic centre, these areas have a higher proportion of private vehicle owners residing in new buildings or private condominiums. Likewise, the residents are remarkably young, with better academic qualifications and greater access to jobs in the tertiary sector (Gaspar, 2004).

Finally, the fourth cluster includes advantaged socioeconomic segments with low levels of bicycle accessibility, representing 22.89% of the study area and 22.54% of the population. There are qualified population segments throughout the northwest, northeast, and southeast parts of the city with greater economic and purchasing power (Gaspar, 2004).

When evaluating the proportions of each cluster individually (Fig. 24), TIRE revealed that disadvantaged zones with accessibility conditions below the municipality average are predominant in terms of area, comprising 40% of the territory. Likewise, the tool identified a considerable proportion of socioeconomically advantaged representatives with accessibility conditions above the municipality average. Furthermore, a meaningful difference was observed when comparing the average number of accessible activities between these two groups (Fig. 25). Finally, when evaluating inequalities in accessibility levels across the clusters, the analysis revealed that advantaged groups have systematically better access to opportunities, as indicated in Table 7.

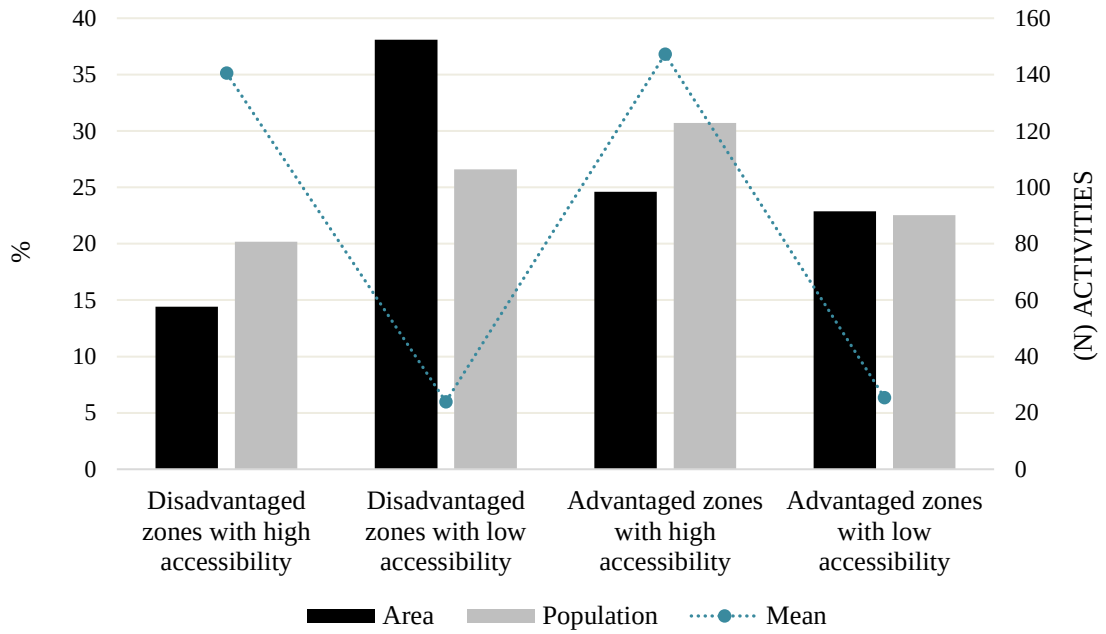


Fig. 24 – Cluster size by area (%), population (%) and average (n) of accessible activities by bicycle

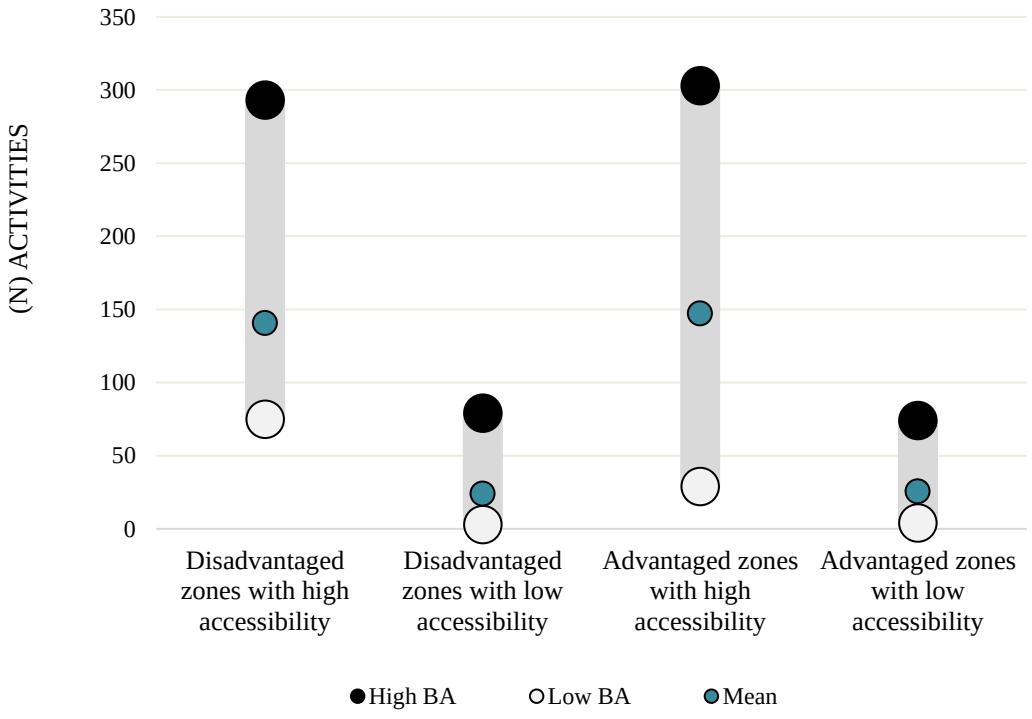


Fig. 25 – Average accessibility (number of activities) by cluster

The municipality of Lisbon presents striking inequalities in access to opportunities among people of different socioeconomic characteristics and even within a specific group. For instance, Fig. 25 compares the distribution of accessible activities by cluster, highlighting significant accessibility disparities, especially for the disadvantaged group with low accessibility and the advantaged one with high accessibility.

Table 7 – Cluster characterisation (average accessible activities, population, and area sizes)

Cluster	Accessible activities (mean)	Population (%)	Area (%)
Disadvantaged zones with high accessibility	140	20.17	14.42
Disadvantaged zones with low accessibility	24	26.59	38.09
Advantaged zones with high accessibility	147	30.70	24.60
Advantaged zones with low accessibility	25	22.54	22.89

Overall, TIRE revealed discrepancies in the distribution of bicycle accessibility over the municipality. For instance, the tool communicated higher levels of bicycle accessibility in areas with a higher concentration of advantaged socioeconomic representatives. Conversely, socioeconomically disadvantaged representatives are likely to have levels of accessibility below the municipality average. Finally, disadvantaged zones with high accessibility levels represented a smaller share of the expected equitable distribution of bicycle accessibility.

3.6. IMPLICATIONS FOR PLANNING AND PRACTICE

The experiential workshop provided a dynamic discussion environment, fostering a shared commitment towards developing an equity-oriented action plan. A workshop facilitator initiated the activities by presenting the TIRE tool and how to operationalise the indicators. Following this introduction, participants had the opportunity to clarify a few queries encompassing the proposed equity analysis. For example, the facilitator further explained the rationale encompassing the socioeconomic index due to the lack of open-source variables related to household income at the census tract level.

During the second part of the workshop, the participants examined the outcomes generated by the tool to propose new strategies and define an equity-oriented action plan. Thenceforth, planning practitioners identified the main challenges that have constrained the development of equitable and inclusive bicycle planning. Among the discussed issues, the participants highlighted the following key points:

- Lack of infrastructure and accessibility in the outskirts of the city;
- Limited road space in some disadvantaged neighbourhoods;
- Barriers faced by vulnerable and disadvantaged groups.

In response to the first identified challenging point, planners defined as a primary strategic measure the densification of the cycling network connected with essential destinations and trip-generating facilities in deprived areas. Nevertheless, one of the planners argued: "*Although the first step is to densify the cycling network in these territories, ensuring safe circulation conditions [...] our biggest challenge has to do with the limited space available*." Participant #1 (free translation from Portuguese).

This argument steered the debate towards the second challenging point, encompassing the reallocation of road space in favour of active modes of transport. To illustrate, one participant stated: "*Since our goal is also to reduce car use, we could reduce parking lots or motorways, replacing them with cycle lanes[...]"* Participant #2 (free translation from Portuguese). In addition, planners suggested parallel measures to foster micro-mobility and micro-logistics in disadvantaged communities.

Furthermore, the participants centred the discussion on tackling the constraints experienced by disadvantaged groups and those at risk of social exclusion. One planner claimed: "*These ideas are all interesting, but they are generic for the whole city [...] perhaps we should think about complementary measures."* Participant #3 (free translation from Portuguese). Accordingly, planners agreed that integrating cycling and public transport and expanding the cycling network with the local bicycle-sharing system could increase accessibility conditions for disadvantaged socioeconomic groups. Finally, participants proposed education programs and awareness campaigns to promote safe bicycle use for all citizens.

Afterwards, participants had the opportunity to present their perceptions on the applicability of the TIRE tool in planning practice. For instance, one participant stated: "*[...] we are grateful for the opportunity to share our doubts and foster knowledge about this topic [...] it is always constructive to learn new works that have been developed."* Participant #4 (free translation from Portuguese). Subsequently, participants agreed that the proposed tool supported the development of equity-oriented complementary strategies. For example, a participant reported that: *"TIRE can be helpful because it reveals the location of disadvantaged areas and where accessibility could be improved [...]"* Participant #5 (free translation from Portuguese). Likewise, Participant #6 claimed: *"[...]this tool gives us important inputs for adjusting the current planning priorities to include equity issues."* (free translation from Portuguese).

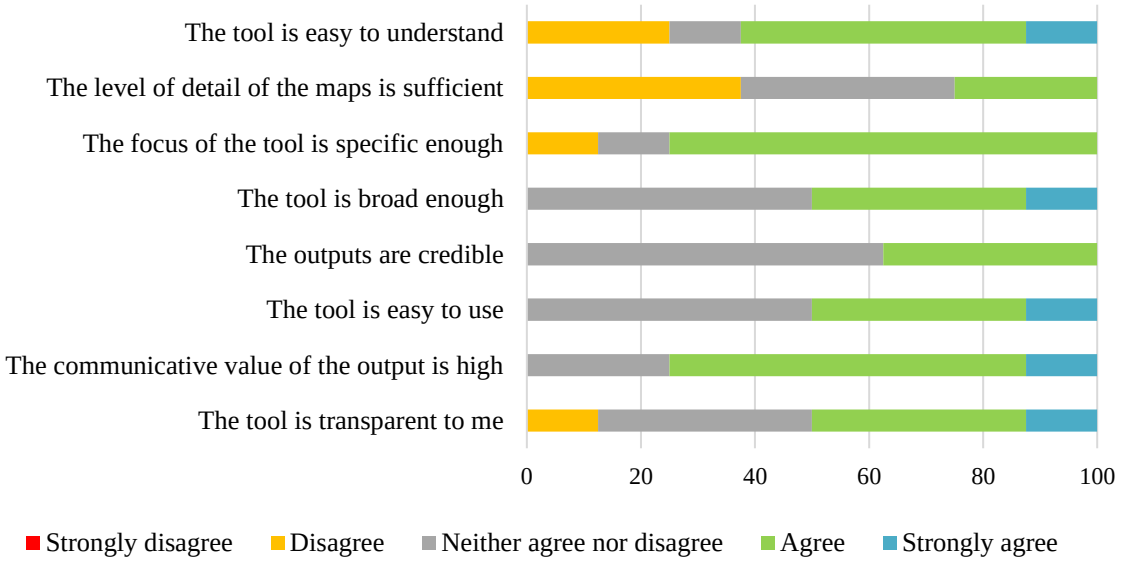


Fig. 26 – Perceived user-friendliness of the tool

At the end of the workshop, a facilitator applied a survey to assess to what extent the proposed equity-oriented tool can support planning and decision-making processes. The survey results indicate that planning practitioners positively perceived the TIRE tool, considering the dimensions of user-

friendliness and usefulness. For example, more than half of the participants agreed that the tool is easy to understand, with a perceived high focus and communicative value. Likewise, participants considered the tool broad, transparent, and easy to use (Fig. 26). However, more than half of the participants remained neutral regarding the credibility of the generated outputs. During the session, one of the discussed limitations of the tool was the list of variables used as input for generating the SE index since an up-to-date socioeconomic dataset was not freely available in the local census database.

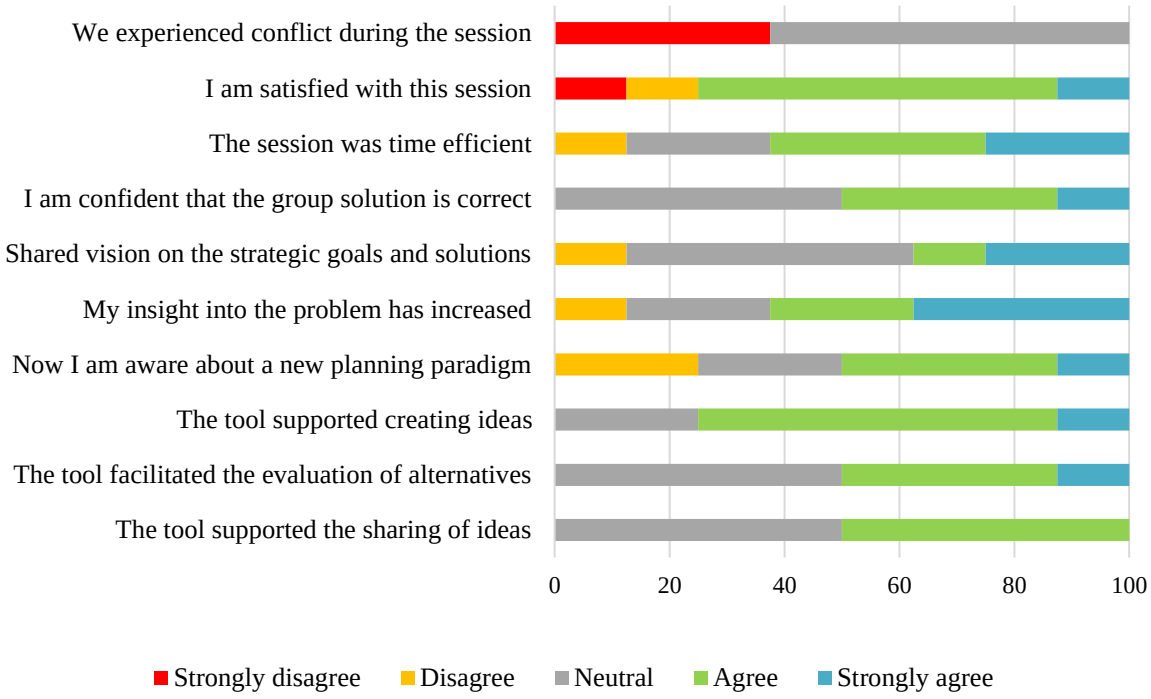


Fig. 27 – Perceives usefulness of the tool

Regarding the added value of the tool to planning and decision-making processes (Fig. 27), most of the planning practitioners (75%) were satisfied with the workshop, agreeing that the TIRE tool supported the creation of ideas (75%), fostering insights into equity issues in planning practice (62,5%). In addition, half of the respondents agreed that the tool facilitated the evaluation of planning alternatives and the definition of shared ideas and solutions, increasing awareness about an equity-oriented planning paradigm. No participants reported conflict during the session.

3.7. Discussion and conclusions

The present research introduced a planning support tool to assess the vertical equity impact of cycling infrastructure allocation. The novel TIRE tool examined the distribution of bicycle accessibility levels across distinct socioeconomic groups, revealing to what extent the distribution of the cycling network impacts advantaged and disadvantaged socioeconomic groups of society.

The testbed application of the TIRE tool to the case of Lisbon generated an evidence base to guide planning practitioners towards new strategies, fostering awareness of the equity impacts of bicycle planning in the earlier stages of planning and decision-making processes. Therefore, by visualising distributive imbalances, planners could identify hotspots in the city to prioritise strategies, fostering cycling conditions and social inclusion in disadvantaged areas.

The TIRE tool disclosed significant social-spatial asymmetries and fragmented hotspots across the territory. However, the distributional analysis exposed that the allocation of the cycling network in Lisbon is equitable over 14,4% of the municipal area, encompassing 20,17% of the total population. Accordingly, it revealed higher accessibility levels in the inner city and historic centre, benefiting mostly socioeconomically advantaged areas and a residual proportion of disadvantaged segments. Hence, to improve accessibility levels for deprived representatives, there is a need to implement new axes of cycling infrastructure and promote greater land-use diversity in socioeconomically disadvantaged zones.

Based on the perceived user-friendliness and usefulness of the tool, this study demonstrated that the TIRE tool has potential applicability in planning practice. A significant share of planning practitioners considered the communicative value of the output and its focus specific enough. Likewise, most participants understood how to operationalise the tool, considering it user-friendly. Moreover, the tool supported the creation and sharing of ideas, fostering insight into a planning problem, and creating awareness about the equity implications of cycling infrastructure allocation. With the tool, the participants defined a set of strategies to improve cycling accessibility conditions in disadvantaged areas. For example, planning practitioners highlighted as crucial measures the expansion of the cycling network, the reallocation of road space, education programmes and awareness campaigns.

Nevertheless, applying the TIRE tool in practice has drawbacks related to the subjectivity of the method and the chosen variables. For instance, the proposed contour measure of accessibility sums up the opportunities available without weighting or distinguishing the attractiveness of each activity. On the one hand, scholars argue that such a measure of accessibility is easier to understand and interpret by planners, practitioners, and stakeholders (El-Geneidy and Levinson, 2006; Geurs and van Wee, 2004). However, on the other hand, this metric implies that even if the cycling network covers the entire municipality, the accessibility levels will be limited to the number of accessible opportunities, regardless of land use diversity.

Accordingly, the tool did not include adjustments for delays at traffic signals as well as the effect of the level of traffic stress on bicycle accessibility levels (Faghih Imani et al., 2019; Kent and Karner, 2019). To address these limitations, a forthcoming research pathway refers to upgrading the tool to include more specific parameters on road safety and the built environment tailored to the constraints faced by vulnerable representatives. Indeed, such attributes affect cycling perceptions and attitudes across distinct demographic groups (Gatersleben and Appleton, 2007; Prati et al., 2019). Nonetheless, complex, rigid and non-transparent mathematic and visualisation operations (te Brömmelstroet, 2012; Vonk et al., 2005) might jeopardise the usefulness of the tool, considering the dynamic nature of planning and strategy-making processes.

Although some jurisdictions have already published spatial indexes of socioeconomic advantage and disadvantage (ABS, 2016), the development of the proposed SE index is limited to the availability of socioeconomic data and technical personnel with statistical knowledge and skills to conduct and interpret PCA. Furthermore, since this analysis relies on a census database, the transferability of the tool to a different context is limited to the availability and compatibility of high-resolution data. Nevertheless, scholars defend the PCA-based composite indicator as a potential approach for examining transportation poverty. Such a technique can effectively keep the essential information and reduce the redundancy of the original data set, especially when exploring an extensive list of socioeconomic and demographic variables (Xiao et al., 2018).

Even though the TIRE tool depends on a certain degree of GIS and statistical knowledge, the baseline of the tool is flexible and adaptable. For instance, planners could replace the accessibility indicator

with one that considers the diversity of land use rather than the number of accessible activities. Additionally, the composite SE index can be replaced by single indicators to measure accessibility levels among different socioeconomic groups (i.e., unemployed and employed, illiterate and highly educated individuals) and minority or vulnerable representatives (i.e., elderly, children, immigrants).

Likewise, the tool could be operationalised for both ex-ante and ex-post analysis. On the one hand, the TIRE tool can assess the equity effect of a fully implemented cycling network, highlighting hotspots in the city for future equity-oriented interventions identified in cluster III. On the other hand, planners could use the tool to assess different planning scenarios, including the proposed cycling network and recalculating the indicators. In this process, planners could compare de size and location of the different clusters and define new strategies to reduce inequalities in the distribution of the future cycling network (i.e., increasing cluster I and reducing cluster III).

A future research pathway refers to expanding the application of the instrument to a regional scale, examining the integration of bicycles and public transport as a strategy to reduce access inequalities in areas with lower population densities. Likewise, future research could evaluate the distributional effect of cycling infrastructure provision throughout the distinct stages of implementation. Finally, the TIRE tool could be applied in other geographical and cultural contexts to assess the extent to which cities with distinct policies and social attitudes towards cycling incorporate equity issues during planning and decision-making processes.

Above all, this research represents a step toward establishing a method for assessing the equity effects of bicycle planning and cycling infrastructure allocation, creating an evidence base to promote a shift towards equitable planning practices. The proposed equity-oriented approach aims to reinforce the general principles of equity and social inclusion to reduce inequalities in the distribution of cycling infrastructure and increase awareness of the social benefits of bicycle-related investments in the earlier stages of the planning and decision-making processes.

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4

Pursuing cycling equity? A mixed-methods analysis of cycling plans in European cities

This chapter presents an integral reproduction of: "Cunha, I., Silva, C., Büttner, B., and Toivonen, T. (n.d.) 'Pursuing cycling equity? A mixed-methods analysis of cycling plans in European cities', Transport Policy (Under review)."

ABSTRACT

Although equity issues are emphasised in sustainable mobility policy worldwide, there is evidence that cycling planning often prioritises advantaged areas and central zones of cities. To overcome such an inequitable scenario, scholars have called for greater attention towards disadvantaged representatives within the planning and decision-making processes.

This study contributes to this debate by exploring the equity impacts of cycling infrastructure allocation in three European cities. Through GIS and statistical analysis, we quantitively assessed the equity gap of each plan, measuring the distribution of cycling infrastructure and accessibility gains across socio-economic advantaged and disadvantaged groups. In addition, this study performed a content analysis of each plan to investigate to what extent equity issues are prioritised.

The main results suggest the most equitable scenario in a city with a long tradition of cycling planning, which has been providing denser cycling infrastructure to connect important activities and neighbourhoods within central zones and outskirts. Conversely, the implementation of the cycling plan in central areas is likely to overlook socio-economic disadvantaged zones. Despite increasing attention towards accessibility, social inclusion and safety issues within the planning guidelines, the evaluated plans did not prioritise or appraise equity in cycling planning practice.

KEYWORDS: Equity, Cycling infrastructure, Transport Plans, Accessibility, GIS, Content analysis.

4.1. INTRODUCTION

Promoting cycling has been highlighted as a crucial strategy to foster the transition toward low-carbon, resilient and inclusive transport systems (Banister, 2008; Kennedy et al., 2005), directly contributing to the 2030 Agenda for Sustainable Development (Johnston, 2016). Accordingly, bicycle

planning offers guidance and a blueprint for planning, design, development, and programming related to cycling (Welleman, 1999; Welleman et al., 2004). Among several measures, providing a cycling network infrastructure is highlighted as a paramount strategy to encourage bicycle use as a daily means of transport (Aldred et al., 2016; Oosterhuis, 2016; Pucher and Buehler, 2007).

However, despite the planning and political efforts to democratise bicycle use in cities, previous research revealed that the benefits of cycling (i.e., accessibility, health gains, commuting and recreational trips, infrastructure provision) are systematically unevenly distributed in cities around the globe (Cunha and Silva, 2022; Lee et al., 2017). In other words, bicycle-related projects and investments are likely to target central and wealthy areas of cities, overlooking peripherical neighbourhoods and zones with a higher concentration of disadvantaged and vulnerable segments of society. Such empirical evidence suggests that transport planners may neglect equity issues within the planning process and project appraisal against different planning priorities.

In this field of research, a distributive perspective is often employed to explore the equity impacts of transport systems (Cook and Hegtvedt, 1983; Pereira et al., 2017), which examines how different transport-related benefits and costs impact specific areas of cities and social groups. Among the various methods employed, quantitative assessments encompassing spatial and network analysis and the adaptation of the Gini index with the Lorenz curve are commonly applied in transport equity research (Carleton and Porter, 2018).

Although previous studies suggested that bicycle planning and decision-making processes overlook issues of equity in several cities across the global north and south (Cunha and Silva, 2022; Doran et al., 2021; Lee et al., 2017), few studies assessed the effects of cycling network allocation and accessibility distribution in European starter and climber cycling cities. The former typology refers to a city with low levels of bicycle use (i.e., bicycle modal share below 10%), residual cycling infrastructure, and higher political and social resistance (Bicalho et al., 2019; Silva et al., 2019). The latter encompasses cities with growing levels of cyclists (i.e., bicycle modal share above 10% and below 20%), with increasing political commitment and positive social attitudes toward cycling as a transport mode (Urbanczyk, 2010b).

Indeed, recognising the bicycle as a viable transport mode alters across disparate cultures. For instance, considering national aggregate data, residents in countries with a relatively robust bicycle culture (i.e., Netherlands, Denmark and Germany) are likely to have a positive perception and attitude toward cycling (Pucher and Buehler, 2008). Nevertheless, in communities with higher dependence on private vehicles, as well as low levels of bicycle use and residual cycling infrastructure, the use of the bicycle is frequently associated with negative perceptions (i.e., old-fashioned, uncomfortable, dangerous, unsuitable for utilitarian trips) and prejudices (i.e., a symbol of poverty) (Urbanczyk, 2010b).

In response, cities have undertaken planning strategies in recent decades to promote cycling as a feasible and safe transport mode. For instance, in the nineties, the Netherlands implemented its first bicycle master plan[8] (BMP), regarded as a pioneering action in the European context. On this occasion, the Dutch Cyclists' Union and urban consultants conceived a plan to improve alternatives to the car by stimulating cycling. The proposed plan focused on enhancing the image of the bicycle, theft prevention, improving cycling infrastructure, increasing cyclists' safety, and fostering the overall transport system's resilience (Welleman, 1999).

[8] Also called bicycle action plan and bicycle traffic plan.

Following this vision, numerous European bicycle-related strategies have gained momentum over the last years. From a national-level perspective, a joint effort of member states, NGOs, and international organisations resulted in the adoption of the first Pan-European Master Plan for Cycling Promotion in 2021, which aims to support the development of national master plans and investments in cycling infrastructure by integrating the promotion of cycling policies as an equal factor of an integrated transport and mobility policy (Kuester, 2018; WHO, 2021).

Nevertheless, despite the outstanding joint effort to improve cycling conditions in European cities, it remains uncertain whether BMPs under development at the local level address equity issues when providing and allocating cycling infrastructure. Likewise, to the best of our knowledge, there is a lack of comparative studies examining the equity impacts of cycling strategies across different geographical contexts and bicycle cultures.

Hence, to fully capture the potential of the bicycle in reducing social inequalities in cities and increasing accessibility to opportunities to populations in situations of socio-economic disadvantage and risk of social exclusion, this paper quantitatively assesses the equity impacts of bicycle planning and cycling network allocation, highlighting the strengths and limitations of transferring such framework of analysis across different geographic contexts. In this paper, we applied a planning support tool for assessing the equity impacts of bicycle planning, the so-called TIRE, (Cunha and Silva, 2023) to explore the BMP developed and implemented in both starter and climber cycling contexts.

Therefore, the objective of this research is twofold. Firstly, it assesses the extent to which BMP developed in European cities addresses a vertical equity approach within the allocation of cycling networks and accessibility improvements across specific groups of concern. Secondly, it examines the extent to which the local planning guidelines address and target equity issues amid other priorities. The comparison of different social-spatial contexts is supported by the confrontation of the quantitative results with the interpretation of each BMP document.

All in all, this research aims to answer the following research questions:

1) To what extent is the allocation of the cycling infrastructure network equitable, considering the distribution of accessibility levels of socioeconomically disadvantaged and advantaged areas in European cities?
2) To what extent is equity prioritised in European cycling planning guidelines?

The remainder of this manuscript is structured as follows. After this introduction, we present an overview of the relevant literature encompassing the challenges in assessing cycling equity. The third section presents the mixed-method approach applied in this research. Then, the next section uncovers the main results, focusing on the equity gap found in each case study, highlighting the planning priorities in each context. The last two sections discuss the main findings, limitations, and conclusions of this research.

4.2. Challenges in measuring Cycling Equity

Despite the endorsed individual and societal benefits of cycling, empirical evidence suggests that such benefits are not always evenly distributed across groups of concern in cities worldwide (Cunha and Silva, 2022). Bearing in mind the distributive justice perspective, scholars claim that in planning practice, the equity impacts of BMP and its benefits are not thoroughly assessed due to the shortage of

adequate indicators or tools for measuring equity progress in transport (Doran et al., 2021; Geurs et al., 2009; Lee et al., 2017).

Essentially, most of the equity-oriented transport literature is concerned with situations where there is inequity experienced by disadvantaged individuals, vulnerable and minority groups. Accordingly, to fully explore this phenomenon, a cohort of researchers has been developing concise and responsive quantitative equity measures to enable a straightforward analysis of the mobility needs of the aggregate disadvantaged population to the transport service supplied (Carleton and Porter, 2018).

When approaching vertical equity, researchers often choose a set of factors to define potentially disadvantaged groups. For example, in cycling, the highlighted groups of concern are women (Carroll et al., 2020; Grudgings et al., 2018; Lovelace et al., 2020), children and adolescents (Houde et al., 2018; Russell et al., 2021), unemployed and low-income populations (Chandra et al., 2017; Conrow et al., 2018; Day, 2006), ethnic groups, people of colour and immigrants (Barajas, 2021; Lugo, 2013; Reid-Musson, 2018).

Regarding the cycling benefits, previous studies assessed the distributive impacts of infrastructure coverage (Flanagan et al., 2016; Tiznado-Aitken et al., 2022; Zhao et al., 2018b), access to bike lanes (Chandra et al., 2017; Tucker and Manaugh, 2018), access to opportunities by bike (Faghih Imani et al., 2019; Nielsen and Skov-Petersen, 2018; Saghapour et al., 2017), bike sharing service level (Maas et al., 2020; Qian and Jaller, 2020; Saud and Thomopoulos, 2021; Teixeira and Cunha, 2022), health gains (Babagoli et al., 2019; Qian and Wu, 2019), among others (Cunha and Silva, 2022).

Based on the established literature, there is significant variability in the definitions and methods for some key metrics to measure cycling equity. As a result, some authors have resorted to spatial analysis, which includes accessibility, connectivity, and network coverage measures (Bhuyan et al., 2019; Conrow et al., 2018; Winters et al., 2013). For example, based on the accessibility planning theory, a previous study introduced a GIS-based tool to assess the equity impacts of more than 750 projects within the BMP under development in Washington, DC, USA. The proposed tool prioritised bicycle investments, producing priority rankings based on the project's ability to improve connectivity and accessibility to essential destinations (Lowry et al., 2016).

Although connectivity and accessibility are often intertwined, they are conceptually distinct (Tal and Handy, 2012). Whereas accessibility was earliest defined as the potential of opportunities for interaction (Hansen, 1959), and thus, commonly measured with regard to the cost of reaching activities or potential destinations spatially distributed (Handy, 2005), connectivity refers to the quantity and quality of the connections in the network, which directly influences accessibility levels (Gehrke et al., 2020; Lowry and Loh, 2017).

Another common approach to quantify cycling equity is to perform statistical analysis and the adaptation of distributional indices found in economics, such as the Gini index with the Lorenz curve (Chen et al., 2019; Wang and Lindsey, 2017) and Theil index (Hamidi et al., 2019). Such an approach measures the deviation from complete equality (i.e., horizontal equity) in the cumulative distribution of service or accessibility improvements to the population. In addition, such assessments mapped geographic differences with disaggregated data to reveal discrepancies among distinct sociodemographic groups.

Nevertheless, scholars acknowledged several drawbacks and pitfalls when measuring cycling equity. Among other barriers, the availability of the necessary data at the desired scale of analysis, the transferability of such an approach across different social contexts and the incorporation of the proposed metrics in planning practice are critical issues to be addressed in future research (Carleton

and Porter, 2018; Karner and Niemeier, 2013). In response, to address these research gaps, this study examines the equity implications of bicycle planning in three different European cities since little attention has been taken to such geographical zone when compared to both north and south Americas (Barajas, 2017; Doran et al., 2021; Lee et al., 2017; Mora et al., 2021; Torres et al., 2013).

4.3. METHODOLOGY AND ANALYTICAL FRAMEWORK

To measure the equity impacts of bicycle planning in both starter and climbing cycling settings, this article focused on cycling-related transport plans implemented or under development in European cities with a bicycle modal share below 10% and between 10% and 25%. The cities of Lisbon, the capital of Portugal, Helsinki, the capital of Finland, and Munich, the capital of the State of Bavaria in Germany, were chosen as case studies based on the availability of the required database to conduct the proposed assessment. In addition, Helsinki and Munich are cities of similar area sizes whose cycling strategies have already been compared in a former study (City of Helsinki, 2020).

Data on the cycling network and bicycle planning documentation were provided by the local municipality or collected through open-source databases. In addition, socio-economic data and population count were collected via census and local mobility surveys. Finally, information encompassing geographic boundaries, points of interest (POIs), as well as the road network was collected via Open Street Maps (OSM).

Despite the similarity in terms of area and population density, as described in Table 8, the selected cities have distinct mobility patterns and cycling policies. For instance, as a starter cycling city, Lisbon presents a residual share of less than 1% of bicycle users since the residents often rely on motorised vehicles and public transport in their daily activities. Regarding the selected climber cycling cities, on the one hand, in the capital of Finland, more than half of the residents walk for daily journeys, while around 11% of residents use the bicycle as a mode of transport. In Helsinki, a share of 20% of the population relies on private motorised vehicles and 17% on public transport. On the other hand, in Munich, a more significant share of the residents uses the car as a transport mode, while public transport and walking counts each for 24% of the modal split. Moreover, cycling in Munich is more established, representing a share of 18% of all trips made.

Considering the geographical conditions, the cities of Munich and Helsinki are generally flat, whilst, in Lisbon, around 73% of the streets are flat or present an inclination below 5%; therefore, it is accessible to most road users (Lisbon, 2020). Concerning the effect of seasonal variation in active transport, cycling levels decrease drastically during the winter season in Helsinki (Kajosaari et al., 2022), and in this case, the maintenance of the cycling infrastructure is considered a critical issue.

Table 8 – Description of the case studies

	Helsinki	Lisbon	Munich
Population[a]	658,457	545,923	1,566,000
Area (km^2)	214.2	100	310.7
Population density	3,074.2	5,459.2	4,540.5
BMP (Year)	2020-2025	2020-2030	2009-2014

Cycling Infrastructure (km)	130	200	>1200
Cycling Status	Climber	Starter	Climber
Modal Split[b] (%)			
Car	20	43.8	34
Public Transport	17	29.8	24
Walking	52	15.6	24
Cycling	11	1.7	18
Others	-	9.1	-

a Helsinki: resident population in 2021, data source: Statistics Finland, https://statfin.stat.fi/. Lisbon: resident population in 2021, data source: https://www.ine.pt/. München: resident population in 2021, data source: Statistisches Amt München.

b Modal split for all journeys. Helsinki: Transport behaviour of Helsinki's residents in 2020. Data source:(City of Helsinki, 2020). Lisbon: Mobility Survey 2020-2021 (Lisbon, 2021). Munchen: data referring to the year 2017 (Germany, 2017).

To illustrate, Fig. 28, Fig. 29 and Fig. 30 identify the cycle network planned for each city, overlaying the population count for Helsinki, Lisbon and Munich, respectively.

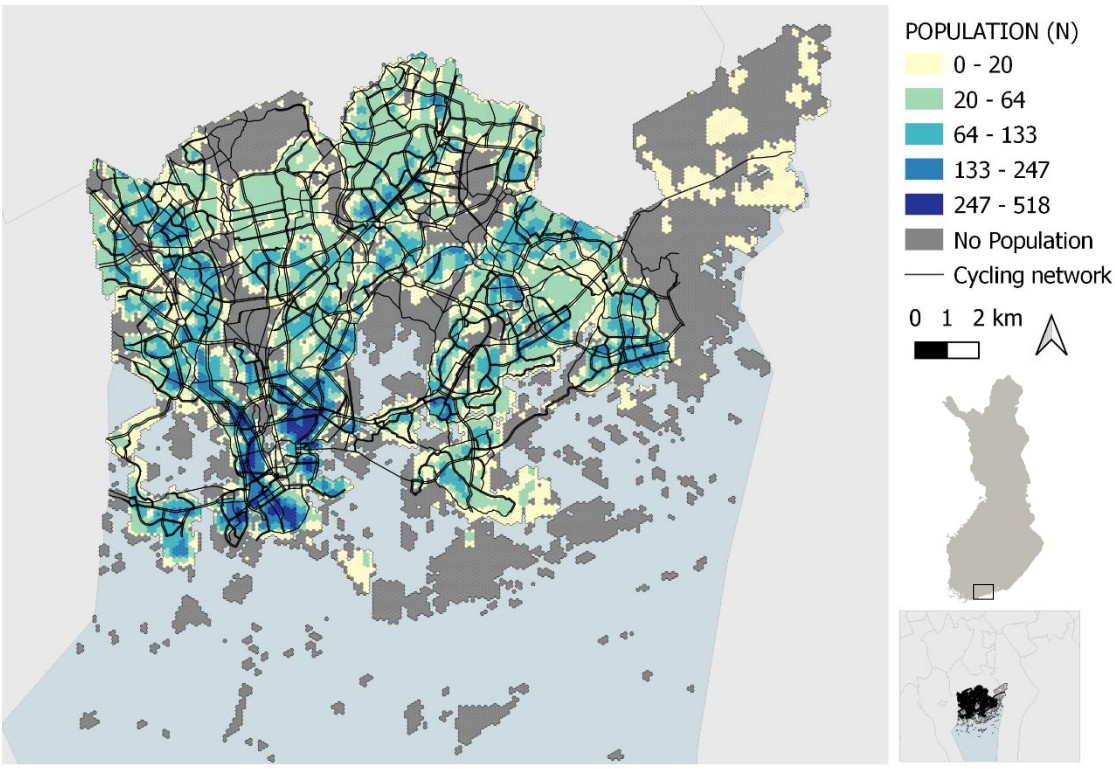


Fig. 28 – Population(n) and cycling infrastructure in Helsinki, Finland

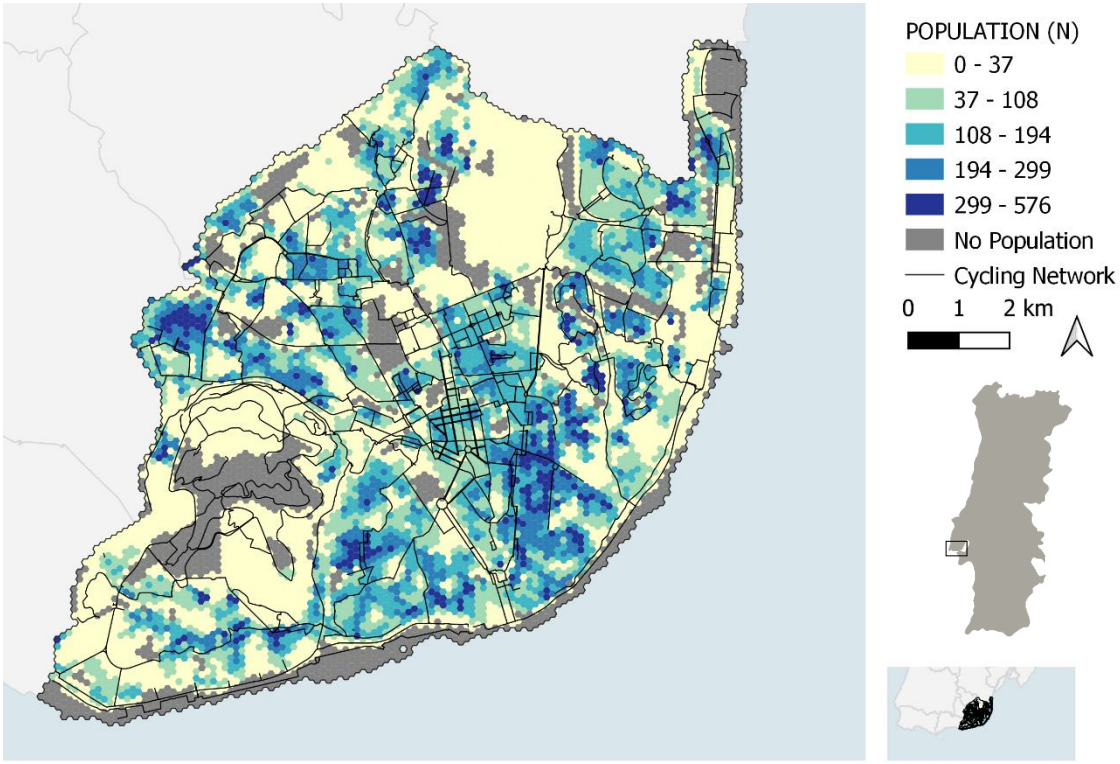


Fig. 29 – Population (n) and cycling infrastructure in Lisbon, Portugal

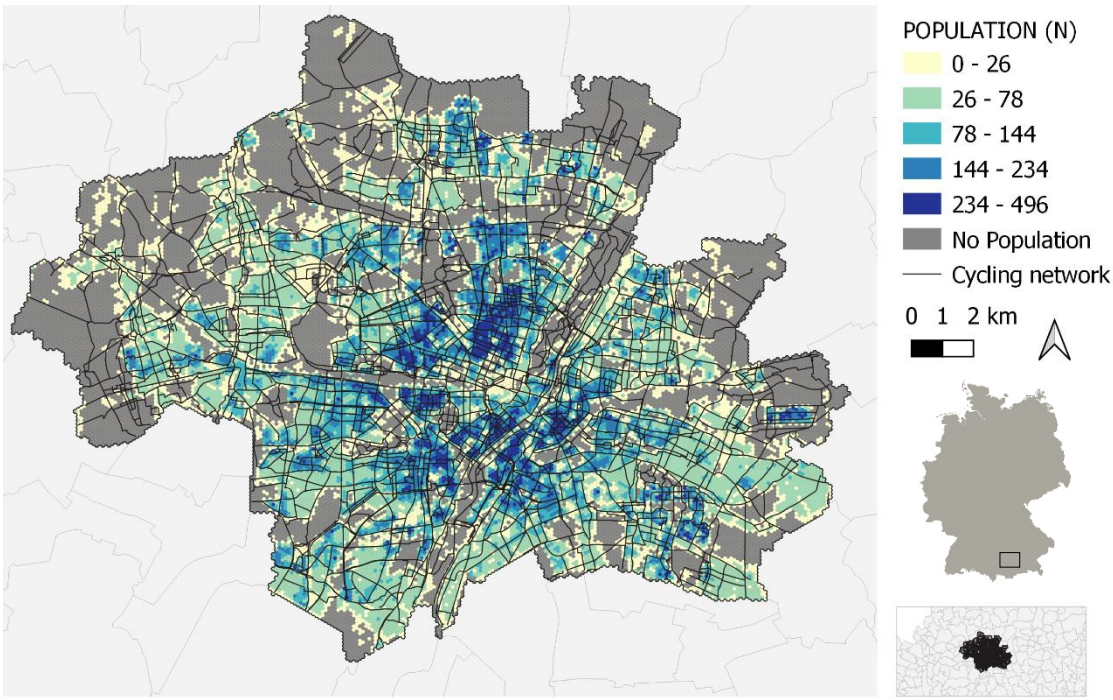


Fig. 30 – Population(n) and cycling infrastructure in Munich, Germany

Promoting the bicycle as a transport mode has been endorsed in Helsinki since 1995, and the political strategies have grown and become more systematic around 2010. The city of Helsinki communicates the bicycle as a safe, comfortable, feasible and environmentally friendly mode of transport. Accordingly, the city deployed a new BMP (Bicycle Action Plan 2020-2025) to increase bicycle traffic in the city and foster the decarbonisation of the transport systems (City of Helsinki, 2020). Based on Helsinki's cycling barometer for 2020, the residents perceive the bicycle as a viable transport mode for commuting, recreational and multi-modal trips. In addition, they acknowledge the positive impact of cycling on individual well-being, health and fitness (Helsinki's Urban Environment Division, 2019).

In Lisbon, this scenario is significantly different. This city has a residual bicycle modal share, accounting for less than 1% of all trips made. Due to the current overreliance on motorised modes of transport and general sceptical social and political attitudes towards cycling (Lopes et al., 2021), the challenge of promoting the bicycle as a viable urban transport mode is more demanding (Bicalho et al., 2019). Therefore, the municipality launched a plan to increase bicycle uptake by improving and expanding the cycling network, ultimately promoting cycling for commuting and recreation trips for people of all ages (Lisbon, 2020).

Over the past years, bicycle traffic in Munich has been increasing considerably. Since the early nineties, when a private planning office conceived a comprehensive network of cycle paths for Munich, the municipality has consistently promoted cycling (Lanzendorf and Busch-Geertsema, 2014). Nowadays, the cycling network has more than 1200 km extension, and according to a local survey (München, 2010), almost equal numbers of men and women use the bicycle for commuting, shopping, and other private activities. Accordingly, approximately 80% of Munich's residents own a bicycle, and almost half of all residents use it at least once a week. Considering issues of gender, this survey indicates that men and boys ride their bicycles more often to reach educational institutions and for leisure, whereas women cycle more frequently for shopping.

All in all, the selected BMPs aim to broadly cover the whole municipal unity, with a relatively denser cycling network in the city centres. In these cities, the cycling network comprises distinct cycle path topologies, including contra-flow cycle lanes, unidirectional and bidirectional cycle tracks exclusively for cyclists and coexistence zones with a speed limit of 30km/h. Additionally, to serve the most peripheral areas, the municipalities o Munich and Helsinki have also proposed bike highways segregated from traffic to increase the accessibility conditions in these zones (City of Helsinki, 2020; Oldenziel, 2020).

4.3.1. QUANTITATIVE APPROACH: SOCIO-SPATIAL ANALYSIS

This research applied a planning support tool for assessing the relative equity impact of bicycle planning – TIRE, to measure the equity gap within distinct European bicycle master plans. This tool measures the equity implications encompassing the cycling network provision and the distribution of bicycle accessibility levels across both advantaged and disadvantaged socio-economic groups (Cunha and Silva, 2023).

The application of TIRE to the selected case studies relies on the bivariate analysis of two indicators. Whereas the first indicator measures the level of bicycle accessibility (BA) to a set of opportunities in the city, the socio-economic index (SE) measures the concentration of the phenomenon of socio-economic advantage and disadvantage.

To measure the equity impact of cycling infrastructure allocation, we assessed the distribution of bicycle accessibility levels considering both implemented and planned cycling networks. Following a previous research (Cunha and Silva, 2023), we aggregated the number of activities accessible by bicycle in a given travel time threshold.

This study conducted a Principal Component Analysis (PCA) in SPSS statistics to measure the phenomenon of socio-economic advantage and disadvantage, creating a socio-economic index (SE), as described in Table 9.

Table 9 – Socioeconomic Index

City, Country	Socio-economic variables (%)	Weights*
Helsinki, FI	Employed people	+0,21
	Unemployed people	-0,36
	People whose highest level of educational attainment is primary	-0,43
	People whose highest level of educational is a higher degree	+0,43
	Students	-0,76
	Households with low economic conditions;	-0,29
	Households with medium economic conditions;	+0,42
	Households with high economic conditions;	+0,49
* Rotation method: Varimax with Kaiser normalisation. Kaiser-meyer-olkin adequacy measure: 0,765. Bartlett's sphericity test: 0,000. 1st λ 3,788 (47,3% of total variance), 2ndλ 1,451 (18,1% of total variance).		
Lisbon, PT	People searching for a job	-0,41
	Family with one person searching for a job	-0,40
	Family with at least one employed person	0,37
	Students	0,33
	People who have no educational attainment	-0,30
	People whose highest level of educational attainment is primary	-0,35
	People whose highest level of educational attainment is secondary	0,31
	People whose highest level of educational is a higher degree	0,37
	Housing under rent tenure	-0,42

	Housing occupied by the owner	0,39
	Housing measuring up to 50m^2	-0,40
	Housing measuring between 100 and 200m^2	0,36
	People who commute by car	0,37
	People who do not make utilitarian trips	-0,28
* Rotation method: Varimax with Kaiser normalisation. Kaiser-meyer-olkin adequacy measure: 0,820. Bartlett's sphericity test: 0,000. 1st λ 4,718 (33,699% of total variance), 2ndλ 3,525 (25,182% of total variance).		
Munich, DE	Employed people	+0,55
	Retired or pensioner people	-0,60
	People whose highest level of educational attainment is primary	-0,82
	People whose highest level of educational is a higher degree	+0,73
	Households with low economic conditions	-0,86
	Households with high economic conditions	+0,72
* Rotation method: Varimax with Kaiser normalisation. Kaiser-meyer-olkin adequacy measure: 0,576. Bartlett's sphericity test: <0,001. 1st λ 2,486 (41,5% of total variance), 2ndλ 1,226 (20,4% of total variance), 3rd λ 1,068 (17,8% of total variance)		

To operationalise the bivariate assessment, the tool TIRE resorts to Geographic Information Systems (GIS), revealing four distributive clusters:

- Cluster I: zones with an equitable allocation of cycling infrastructure. The distribution of increased accessibility levels favours disadvantaged segments.
- Cluster II: zones to be prioritised in future equity-oriented interventions. This cluster aggregates disadvantaged representatives with low levels of bicycle accessibility.
- Cluster III: zones with a higher concentration of advantaged representatives with higher levels of accessibility.
- Cluster IV: zones with a higher concentration of advantaged representatives with lower levels of accessibility.

4.3.2. QUALITATIVE APPROACH: REVIEW OF OFFICIAL DOCUMENTS

To answer the second research question, the selected bicycle master plans were subject to a more in-depth evaluation to understand if and how equity issues are addressed in the planning guidelines. First, based on previous research (Doran et al., 2021), we examined the BMP overarching goals and objectives, the measured impacts and the monitoring techniques applied to assess the impacts of the plan. Then, we examined the extent to which the selected BMP incorporated equity in the project guidelines by examining planning priorities, defined strategies, and expected outcomes.

4.4. BICYCLE MASTER PLANS FROM AN EQUITY PERSPECTIVE

4.4.1. TIRE ASSESSMENT: CASE STUDY TESTBED

The application of the tool TIRE to the selected cases revealed the equity gap of each BMP under analysis, measuring to what extent the plan approaches a vertical equity distribution of cycling network across socio-economic advantaged and disadvantaged groups, highlighting areas for future equity-oriented prioritisation (Table 10).

Table 10 – Assessment of the equity impact of the selected Bicycle Master Plans

	Helsinki	Lisbon	Munich
Cluster[a] I (Equitable distribution)	13.4	20.2	24.2
Cluster II (Inequitable distribution)	25	26.6	23.6
Cluster III	37.5	30.7	36.3
Cluster IV	24.1	22.5	15.9
Vertical Equity			
Population (n)	84,933	113,452	283,386
Area (km^2)	13,8	10,81	36,14
Equity-oriented prioritisation			
Population (n)	158,751	149,516	276,273
Area (km^2)	36.3	28.6	69.9

[a] Population (%) located in each cluster.

The assessment of the main outputs generated by TIRE (see Fig. 32,Fig. 33 and Fig. 34) indicates better bicycle accessibility conditions in the central zones of all cities when compared to the outskirts. In all cases (Fig. 31), *Cluster III* is proportionately higher than the others, meaning that in these cities, the biggest share of advantaged representatives has bicycle accessibility conditions above the municipality average. For instance, this phenomenon represents almost half of the distributive pattern in Munich and Helsinki. Regarding socioeconomically advantaged representatives with low levels of bicycle accessibility (*Cluster IV*), Helsinki and Lisbon depict a similar distributive pattern, ranging between 22% and 25% of residents. In Munich, this number is slightly smaller.

Cluster II illustrates priority areas for future equity-oriented interventions since it includes disadvantaged residents with low bicycle accessibility conditions. By comparing the different cities, Lisbon presents a higher proportion of the population in a disadvantaged situation, followed by Helsinki and Munich. Interestingly, this cluster commonly emerges in each municipality's outskirts or peripheral zones, commonly inhabited by a more significant share of disadvantaged representatives. Likewise, these areas have less land-use diversity and fewer accessible activities by bicycle compared to the city core.

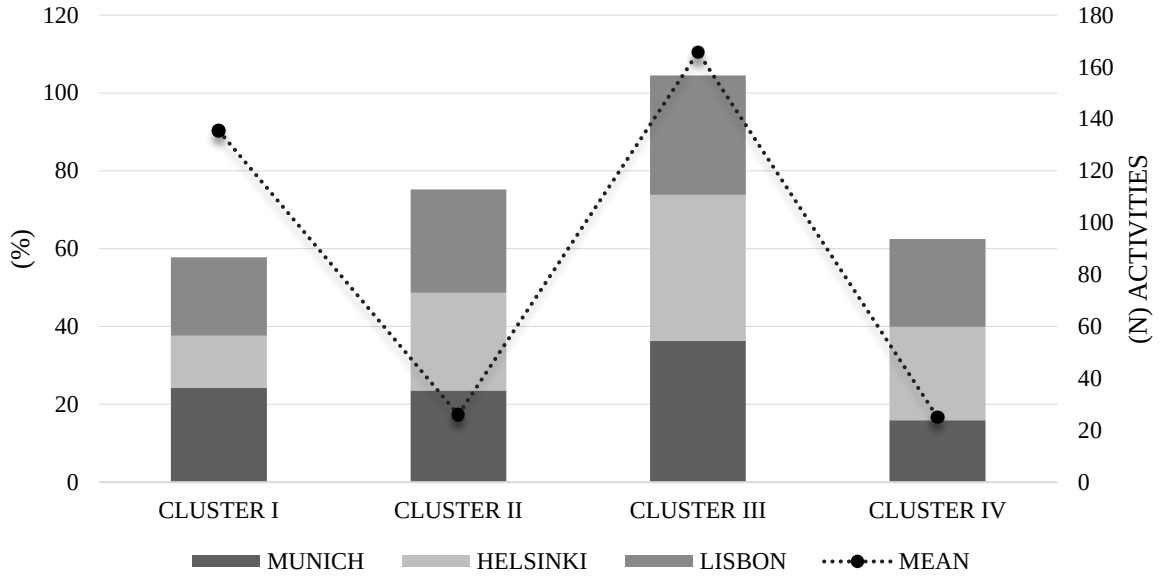


Fig. 31 – Clusters sizes in each city, by area (%), population (%), and average (n) accessible activities

TIRE identified a significant discrepancy in cycling accessibility conditions within each distributive cluster (Fig. 31). For example, across the three assessed European cities, advantaged representatives located in Cluster III, have disproportionately more accessible activities by bicycle than disadvantaged people located in both Clusters I and II.

Regarding the equity impact of each BMP, this study suggests that Munich presents a more equitable scenario, with the largest Cluster I, which indicates that disadvantaged representatives have levels of bicycle accessibility above the municipality average. Likewise, in Munich, Cluster II, encompassing disadvantaged people with low accessibility levels, is minor in population terms. Nevertheless, this cluster is quite scattered in the territory, within a greater territorial extension, in the eastern and western zones (Fig. 34).

Helsinki, regarded as the capital of one of the most egalitarian countries (Vaattovaara and Kortteinen, 2003), presents a smaller share of disadvantaged population compared to the other case studies. Although the city has practised mixed housing policy for decades (Skifter Andersen et al., 2016) intending to reduce segregation, this study indicates a share of 25% of the total population, socio-economic disadvantaged representatives, with bicycle accessibility levels below the municipality average. This evidence is in agreement with earlier research indicating that the impact of the local bicycle-sharing system in terms of social inclusion is still limited (Willberg et al., 2021). Thus, to improve the cycling conditions for disadvantaged representatives, this analysis suggests an area of 36km², primarily located in the northern part of the city (Fig. 32), to be prioritised in future equity-oriented cycling strategies.

Finally, results indicate a wider equity gap within Lisbon's BMP, which aligns with previous research findings (Cunha and Silva, 2023; Padeiro, 2022; Teixeira and Cunha, 2022). Therefore, to reduce the equity gap in this city, the tool highlights the northern, eastern, and western zones of the city (Fig. 33) as potential priority areas for onward equity-oriented interventions.

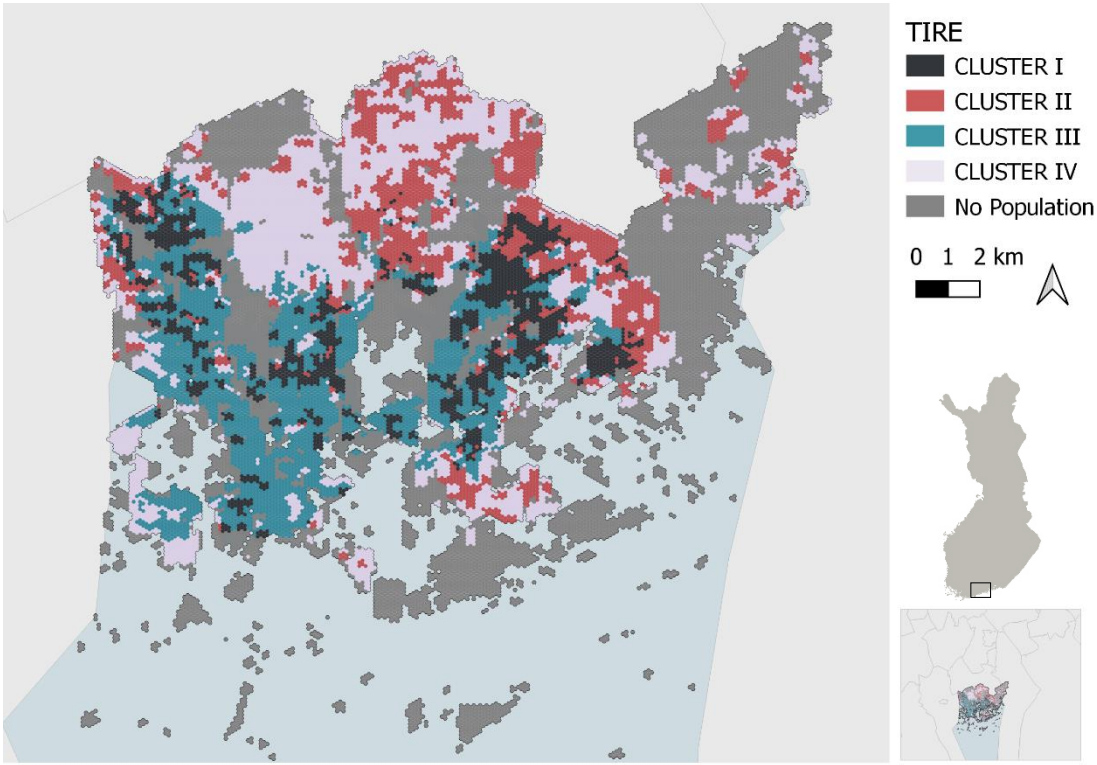


Fig. 32 – TIRE applied to the case of Helsinki, Finland

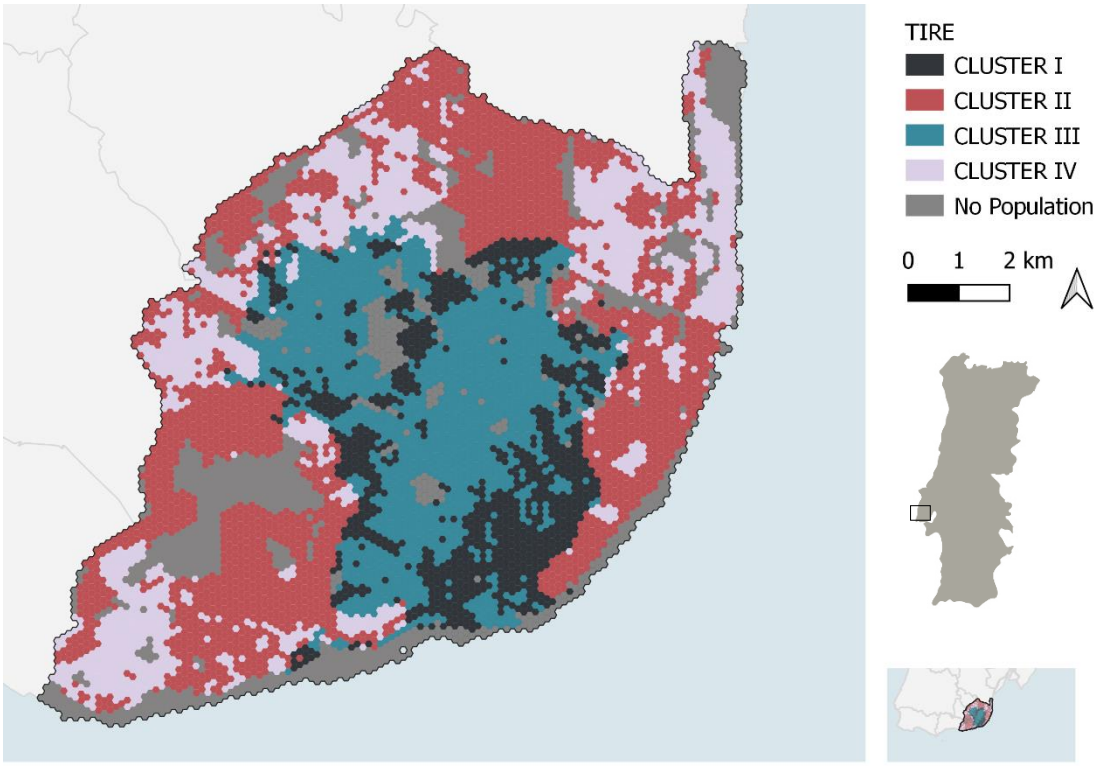


Fig. 33 – TIRE applied to the case of Lisbon, Portugal

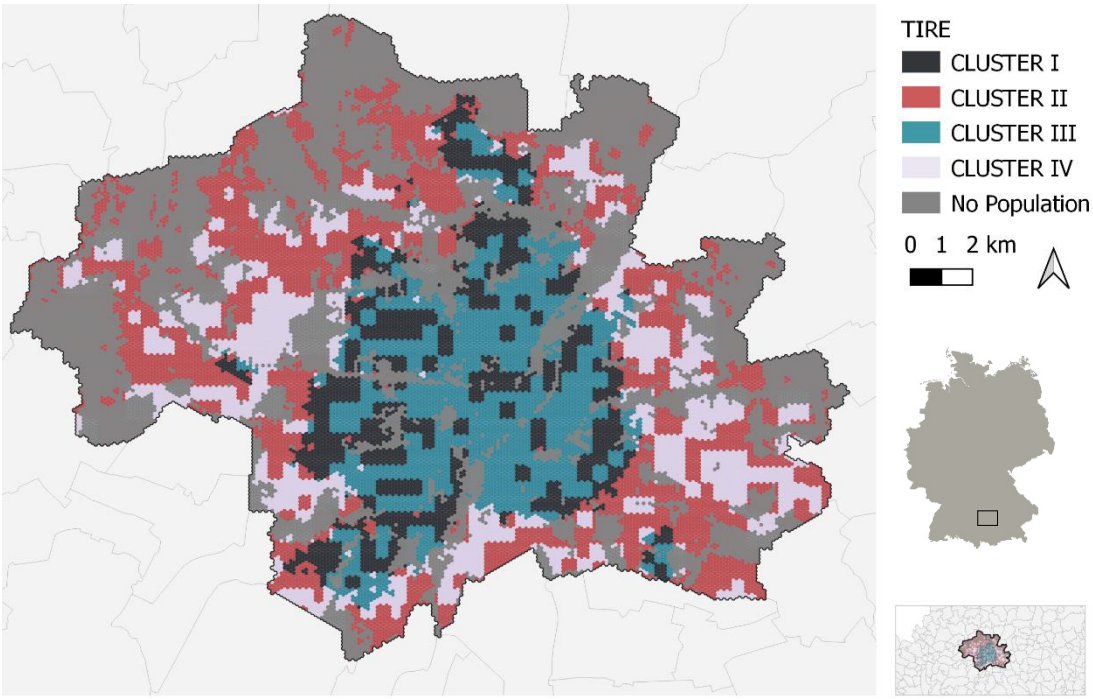


Fig. 34 – TIRE applied to the case of Munich, Germany

4.4.2. Review of BMP Guidelines

To better comprehend to what extent the local planning guidelines approach equity issues, this study thoroughly examined each plan document, identifying the overarching goals, the measured impacts, and the employed monitoring techniques. Overall, these cities generally rely on bicycle counts, interviews, and mobility surveys to appraise the success of the local BMP.

The City of Helsinki implemented its first BMP in 2014, aiming to increase bicycle traffic's modal share to 15% by 2020. However, despite the rise of bicycle traffic during this period, the modal share has not increased enough to meet the overarching targeted goal. In response, the new plan called Bicycle Action 2020-2025 encompasses thirty-four measures, organised into five sub-goals encompassing cycling infrastructure provision, safety measures, parking, maintenance, marketing, and communication strategies.

The plan guidelines recognise the following benefits of cycling: time savings, efficient use of public space, health benefits, environmental benefits, financial benefits, and improved traffic safety (City of Helsinki, 2020). This mobility plan is part of the municipality's strategy to become carbon-neutral by 2035. Thus, it aims to increase cycling levels for people of all ages, with an expected modal share of cycling around 20% by 2035. The guiding principle of this plan is that all destinations should be safely and efficiently accessible by bicycle via the most direct route possible. To accomplish such a goal, the city has designed a cycling network of 132 kilometres, 35 of which are in the inner city and 97 km in suburban areas.

From a participatory perspective, the city has involved the residents in a series of events, encouraging sharing of ideas and wishes and presenting updated information about the current state of BMP

implementation and bicycle traffic. All in all, to measure the BMP impacts, the city of Helsinki relies on the following quantitative performance indicators: bicycle counts, the extension of built kilometres of the network, the number of built parking spots for park-and-ride services, the number of routes in maintenance, the number of observed shortcomings at worksites and compiling and implementation of the bicycle traffic communication plan (City of Helsinki, 2020).

In Munich, Germany, the political scenario encompassing bicycle planning is slightly distinct. Since the eighties, the city has been supporting the use of bicycles through its own "Transport Development Plans – Bicycle Traffic". However, the initial approach focused on allocating dedicated cycling lanes along the main roads, which proved insufficient to increase the bicycle modal share. Thus, in 2002, the plan was updated to provide integrated transport systems, considering the needs of daily and leisure cyclists from door-to-door destinations (Oldenziel, 2020).

In 2009 the Munich city council passed the resolution "Bicycle Traffic in Munich" to promote a substantial mobility shift from motorised options to more environmentally sustainable modes of transport, especially cycling and walking, ultimately achieving the targets for air quality, climate and noise control. Recently, a public referendum took place to improve the city's cycling conditions, ultimately creating the basis for establishing a dedicated budget for cycling. Afterwards, the city has been promoting campaigns (e.g., marketing, cycling lessons and bike repair events) to increase the cycling share (Radentscheid, 2019). In Munich, distances suitable for bicycle traffic are acknowledged as up to five kilometres, representing more than 60% of the distances travelled in the city. The bicycle is therefore considered a competitive mode of transport compared to the car (München, 2010).

The primary overarching strategy in Munich encompasses expanding the cycling network and bicycle parking spots. Hence, the improvement of cycling intersections aimed at providing quick, safe, and convenient access to different destinations within the city and outskirts. Nowadays, the network covers 1,200 kilometres, increasing bicycle attractiveness among users of different ages and backgrounds. Furthermore, through the BMP implementation, the city has expected to safely increase bicycle traffic, reduce the number of killed and seriously injured cyclists, promote bike-and-ride trips, and improve accessibility to different opportunities, including shops, workplaces, education buildings, and cultural and leisure facilities. Regarding marketing and communication, the city aims to strengthen the bicycle image, raise awareness of its benefits, and arouse the interest of the citizens who are not yet convinced about cycling in everyday life (München, 2010).

Lisbon implemented its BMP to increase the bicycle modal share to reach the European average of 7% (Lisbon, 2019). This plan integrates the municipal mobility plan, which focuses on motorised vehicles, public transport, and active modes. Its strategic pillars include promoting mobility solutions integrated at the metropolitan scale, fostering the reliability and safety of public transport, providing intermodal transport systems, fostering accessibility, inclusion, convenience and proximity, stimulating innovation, and increasing awareness and trust among citizens. In addition, the city recognises that the bicycle is competitive compared to other modes of transport, especially for travel distances up to 5km.

Therefore, Lisbon's BMP aims to provide a continuous, safe and efficient cycling network to improve the general conditions for cycling for both commuting and recreational activities for people of all ages. Accordingly, the city targets the provision of safe bike parking and expanding the local bicycle-sharing systems to make cycling attractive (Lisbon, 2020). Furthermore, this plan aims to promote inclusive accessibility, reduce carbon emissions, and traffic congestion, and increase energy efficiency and road safety.

This research disclosed that all plans target people of all ages without socio-economic or demographic determinants. Nevertheless, equity is not directly mentioned or assessed throughout the planning guidelines. Moreover, even though the plans highlight issues of accessibility, social inclusion, and safety within the main goals, they do not directly indicate if these concepts or impacts are assessed within the monitoring process. Overall, Table 11 summarises the main priorities, strategies, and expected outcomes.

Table 11 – BMPs planning priorities, strategies and expected outcomes

		Helsinki	Lisbon	Munich
Planning priorities	Accessibility	✓	✓	✓
	Connectivity	✓	✓	✓
	Directness	✓	-	-
	Efficiency	✓	✓	✓
	Information	-	✓	✓
	Maintenance	✓	-	✓
	Marketing	✓	-	✓
	Reliability	-	✓	✓
	Safety	-	✓	✓
	Equity	-	-	-
Strategies	Awareness campaigns	✓	-	✓
	Bike lanes	✓	✓	✓
	Bike parking	✓	✓	✓
	Bike sharing systems	-	✓	-
	Bike and ride facilities	-	✓	✓
	Cycling routes app	-	✓	✓
	Public participation	✓	-	✓
	Traffic calming	-	✓	-
	Subsidy to bicycle purchase	-	✓	-
	Signalling	-	-	✓
	30 km zones	-	✓	✓
Expected outcomes	Energy efficiency	-	✓	-
	Increasing bicycle traffic	✓	✓	✓
	Increasing road safety	-	✓	✓

Noise control	-	-	✓
Reducing CO2	✓	✓	✓
Reducing Congestion	-	✓	-
Reducing bike injuries	-	-	✓

4.5. DISCUSSION

In order to measure the equity impacts of bicycle master plans developed in Europe and understand if equity is regarded as a planning priority, this paper examined three specific cases considering both quantitative and qualitative perspectives.

The quantitative assessment sought to elucidate the first research question, uncovering that in all assessed cities, socioeconomically advantaged zones are likely to have levels of accessibility above the municipality average. Based on TIRE's outputs, the climber cycling cities, Munich and Helsinki, have the most equitable scenario. Both cities have a denser cycling network connecting crucial activities over the city centre and the outskirts, presenting minor spatial-socioeconomic discrepancies. Conversely, in Lisbon, a greater share of disadvantaged segments has lower bicycle accessibility conditions. This outcome might be explained by the greater concentration of cycling network and land-use diversity in the central zone of the city compared to the outskirts.

The documentation analysis shed light on the second research question, revealing that equity issues are not directly assessed or measured in the local planning guidelines of the assessed case studies, despite the general attention given to accessibility, connectivity, efficiency and road safety issues. Whereas, in the climber cycling cities, the chosen analytical metrics include cyclist counts and surveys to measure cyclists' perceptions and travel behaviour, the starter cycling city under analysis did not mention which analysis tools and impacts were applied to measure the BMP progress. This result is not surprising, given the general focus on infrastructure provision as a strategy to increase ridership levels in these cities. In other words, the chosen evaluation metrics are those more widely used and consolidated within the cycling planning practice (Griffin and Jiao, 2019; Nelson et al., 2021). However, it may also indicate a lack of more innovative methods and perspectives to measure the cycling plan's impacts.

This study contributes to the equity debate in active transport research and planning practice in several ways. First, the operationalisation of TIRE across three different geographical contexts revealed crucial insights into how European cities are addressing and prioritising equity in cycling plans. Second, this study suggests that equity issues are not fully integrated into the BMP documents due to the general application of traditional appraisal methods focused on attending mobility demand. Notwithstanding, there is an outstanding potential for a planning paradigm change towards an equitable approach in cycling planning since the assessed guidelines consider accessibility, safety, and inclusion issues as critical factors to improve cycling conditions in cities.

Albeit this research is one of the first papers assessing the equity impact of European bicycle master plans from both quantitative and qualitative perspectives, this study has certain caveats to be addressed in future research. For example, transferring the method TIRE across different geographical contexts was challenging, due to the absence of a standardised socio-economic database at the European level, on a more specific unit of analysis, such as the census tract level. Hence, the main limitation refers to the quality of the socio-economic database and the aggregating processing, which compromised some

of the original characteristics of the data. Therefore, future research could refine and benchmark the selected socio-economic factors to tackle the data accuracy pitfall, offering a robust basis for comparative analysis.

4.6. CONCLUSIONS

This article employs a mixed-method approach to assess aims the equity implications of cycling plans under development and implementation in distinct European cities, since such a comparative study is absent in the current literature.

Drawing on the quantitative analysis, the GIS-based tool TIRE unveiled significant social-spatial asymmetries and fragmented hotspots across the case studies, measuring the magnitude of the equity gap within cycling planning. This study suggests that over these cities, socioeconomically advantaged zones are likely to be better provisioned, presenting levels of bicycle accessibility above the municipality average. Accordingly, the documentation analysis of each BMP demonstrates that equity issues are not directly measured through all planning guidelines, regardless of the remarks about accessibility, connectivity, efficiency, and road safety concerns. Finally, this thesis provides both quantitative and qualitative empirical evidence on how equity is addressed and prioritised in the European context. Above all, this article represents a step toward creating an evidence base to encourage a shift towards equitable planning practices in cycling planning.

4.7. REFERENCES

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5

Planners' perspectives on cycling equity: bridging the gap between planning priorities

This chapter presents an integral reproduction of: "Cunha, I., Silva, C., and Büttner, B., 'Planners' perspectives on cycling equity: bridging the gap between planning priorities', Transportation Research Part D: Transport and Environment (Under review)."

ABSTRACT

This study examines the extent to which practitioners in three European cities address and prioritise equity in cycling planning practice and if this criterion is considered compared to competing planning priorities. Through focus groups, interviews, and surveys, participants leveraged debate on crucial issues encompassing overarching planning goals, strategic roadmaps, decision-making process, and the pathways towards an equity-oriented agenda for cycling planning.

This research revealed that equity is not directly addressed or prioritised in cycling planning practice. On the contrary, there is a tendency towards the horizontal perspective, which expects an equal distribution of investments, resources, and service levels among all social groups, regardless of individual needs and constraints. Moreover, participants claimed that the lack of social acceptance and political commitment as well as the dominant car-oriented mindset negatively impact such a planning paradigm change in favour of active modes of transport, jeopardising the normalisation of cycling in cities.

KEYWORDS: Cycling planning, Equity, Interview, Focus group, Decision-making.

5.1. INTRODUCTION

Active modes of transport, notably cycling, have played a crucial role in mitigating the negative burdens created by transport systems (Bagloee et al., 2016; Nielsen et al., 2013; Pucher and Buehler, 2008). Accordingly, the bicycle is regarded as a low-carbon, efficient, flexible and affordable mobility option for utilitarian (Rérat, 2018), recreational (Goodman and Aldred, 2018) and logistic trips (Melo and Baptista, 2017). In addition, to overcome long distances, empirical evidence has shown that combining the bicycle with public transport and implementing bike-sharing systems stations close to public transport interfaces can potentially solve the last-mile issue, encouraging bicycle uptake (Chen et al., 2020; Li and Joh, 2017; Teixeira et al., 2021).

Respectively, cities around the world have committed efforts to provide and improve cycling infrastructure, including bicycle-oriented measures in transport plans (Larsen, 2017; Zhao et al., 2018a) and developing local and national bicycle master plans (Doran et al., 2021; Welleman, 1999; Welleman et al., 2004). However, despite increasing planning and political endeavours to democratise the use of the bicycle as a reliable mode of transport, stigmatised views towards cycling remain major hurdles to overcome (Gatersleben and Appleton, 2007; Nasrin and Bunker, 2021; Prati, 2018). Accordingly, previous studies examined the extent to which cycling development projects intertwine with gentrification processes, as well as gender and racial discrimination experiences (Lubitow et al., 2019; Lubitow and Miller, 2013).

For instance, in cities with low bicycle usage and residual cycling infrastructure, the so-called starter cycling cities (Urbanczyk, 2010a, 2010b), empirical evidence disclosed significant political and social scepticism towards the potential of the bicycle as a daily transport mode (Bicalho et al., 2019). In these settings, the bicycle is still prejudiced and perceived as an option aimed at men, young and sportive segments of society (Aldred et al., 2016; Félix et al., 2017; Mogaji and Uzondu, 2022). Correspondingly, previous studies suggest that the gender gap in cycling is influenced by the built environment characteristics (Goodman and Aldred, 2018; Wang and Akar, 2019), social or cultural norms (Abasahl et al., 2018; Prati, 2018), safety concerns and trip purposes (i.e., carrying children or grocery) (Ravensbergen et al., 2019, 2020b; Teixeira and Cunha, 2022). Such empirical evidence implies the need for a more holistic approach within the cycling planning process to foster diversity in cycling use, tackle the barriers and needs experienced by distinct social groups and create awareness about the benefits of such a mode of transport.

Considering the planning and decision-making processes, this research asserts the importance of discussing cycling planning through the social equity perspective, focusing on the practitioners directly involved in cycling plan development and investment allocation. Furthermore, a proper consideration of equity in planning practice is needed since empirical evidence suggested a shortcoming of equity-oriented practices in cycling planning and decision-making processes (Cunha and Silva, 2022) which may perpetuate distributional inequalities in cities. Accordingly, socioeconomic advantaged and privileged representatives of society are more likely to benefit from cycling-related investments than disadvantaged and minority groups.

This phenomenon might be directly related to the absence of equity-oriented metrics for project appraisal in the earlier stages of planning and decision-making processes. Likewise, since equity is barely the main focus of transport project assessments (Nahmias-Biran et al., 2017; Thomopoulos et al., 2009; Thomopoulos and Grant-Muller, 2013), it remains unclear whether planning practitioners address and prioritise equity issues in the development and implementation of cycling plans.

Hence, this research aims to provide compelling evidence to bridge this knowledge and empirical gap and contribute to the active transport literature, examining cycling plans and policies under development and implementation in the European context. Therefore, this research aims to elucidate the following research questions:

1) To what extent do planners address and prioritise equity-oriented strategies within European cycling plans?
2) To what extent are equity issues considered compared to competing planning priorities?

The remainder of this manuscript is organised as follows. After this introduction, the second section reviews the theoretical background of equity in transport and examines how equity is currently measured and prioritised in planning practice, with particular attention to cycling planning. Then the

third section describes the methodology applied in this research and the sample used to address the abovementioned questions. The fourth section describes the main findings organised into themes. The fifth critically discusses the main results, the theoretical contributions, and the implications for planning practice. Finally, the last section of this manuscript summarises the main conclusions, research limitations and the potential future research pathways.

5.2. Transport Equity in Theory and Practice

5.2.1. The Equity Impact of Transport Investments

According to the literature, assessing the equity impact of transport investments implies inherent justice principles to support the distributive approach underlying the planning and decision-making processes (Golub and Martens, 2014; Martens, 2006; Pereira et al., 2017). Correspondingly, tackling social justice encompasses distinct dimensions of concern, such as fairness within the decision-making process (i.e., procedural justice) (Bullard, 2005), the role of civic participation (i.e., participatory justice) (Sagaris et al., 2020), and the distributive impacts of transport benefits and costs over segments of society (i.e., distributive justice) (Nahmias-Biran et al., 2017; Pereira, 2018).

More often, researchers dig deeper into the multifaceted distributive dimension of justice since transport systems systematically distribute benefits (i.e., infrastructure coverage, accessibility, levels of service) and costs (i.e., congestion, pollution, casualties) in societies. Accordingly, distinct values or rules (i.e., equality, equity, utility) (Cook and Hegtvedt, 1983) can offer the basis for assessing the distribution of transport-related investments, projects and funding (Krapp et al., 2021).

Amidst the available frameworks circumscribing the distributive justice approach, transport literature undeniably operates a more in-depth analysis of the equity principle (Caggiani et al., 2017; Hernandez, 2018; Martens, 2020). Essential to this notion is the normative condition in which people in a disadvantaged condition should be better provisioned in order to improve their access to opportunities, ensuring social inclusion and participation in society (Karner et al., 2020; Litman, 2005). In other words, addressing equity in transport involves addressing the needs and constraints experienced by disadvantaged representatives or the so-called groups of concern (Martens, 2011).

5.2.2. Prioritising Strategies in Transport Plans

Transport planning agencies across distinct jurisdictions levels (i.e., national, regional and municipal) pursue multiple goals simultaneously to achieve consensus on crucial contemporary challenges (Manaugh et al., 2015). However, most of these goals are predominantly mobility-oriented, with justice and social equity issues receiving comparatively less attention in transport appraisal (Karner, 2016). However, although these concepts are not considered the most urgent criteria, they have gained increasing relevance at the national level over the last decades (Trinder et al., 1991).

Commonly, transport planning goals encompass tangible and measurable outcomes affecting the local environment (i.e., reduced congestion and pollutant emissions, air and noise quality, and road safety). Nonetheless, compared to these approaches, the equity impact of transport plans remains abstract and often neglected in the decision-making process. Previous studies evidenced that policymakers and planning practitioners struggle to define, conceptualise and measure equity, whereas it represents a less tangible outcome (Doran et al., 2021; Manaugh et al., 2015). Consequently, since distinct policy goals generate conflicts and trade-offs to a certain extent (Litman, 2005), scholars argue that more

easily quantified goals are likely to be prioritised during the planning and decision-making process at the expense of intangible or elusive objectives (Manaugh et al., 2015).

Therefore, incorporating the equity dimension in transport plans appraisal in a synergetic manner, and translating this impact into clearly specified objectives, represents a daunting task for planners and policymakers. Furthermore, scholars argued that prioritising planning goals is remarkably and inherently political since planning practitioners and elected officials set the distribution of transport-related costs and benefits, ultimately framing the importance of fairness and social equity in planning practice (Linovski et al., 2022, 2018).

To illustrate, previous research examined forty urbanised areas in the United States (US) to explore if transport agencies and organisations include equity-related criteria in project prioritisation. Accordingly, the findings suggest that the incorporation of equity into performance analysis is generally inconsistent or absent. In other words, equity is not fully operationalised and is prioritised lower than other planning goals. However, such a study unveiled that half of the plans directed some funds based on the spatial-equity criterion, allocating investments in communities of concern or zones with higher volumes of marginalised residents (Krapp et al., 2021).

Similarly, another study interviewed several transit administrators in the US to verify if the political realm influences the implementation and maintenance of the social equity agenda (Wellman, 2016). Such analysis revealed that the pursuit of equity in transport is frequently humbled by policymakers who fail to support the agenda, encountering challenges of funding mechanisms and budget limitations. As already examined elsewhere, transport equity presumes a rational and political approach encompassing the decision to allocate sources and investments (Martens, 2011).

In Canada, empirical analysis in metropolitan areas indicated that planning practitioners and policymakers misinterpret the equity concept and related goals. The research disclosed that equity is defined and measured horizontally rather than vertically in planning guidelines and legislative contexts. The former approach is guided by the egalitarian principle, expecting an equal distribution of resources for all groups, disregarding the limitations of disadvantaged representatives (Linovski et al., 2018). Such an equality-oriented approach was also recognised in an earlier study conducted in the United Kingdom with local planners and politicians (Trinder et al., 1991).

Scholars acknowledge that transport planning is strongly affected and dependent on the political dimension of decision-making (Vigar, 2017). Thus, leveraging debate around such a conceptual framework is paramount to integrate equity issues in planning practice better. Moreover, dialoguing with planning practitioners, policymakers, and stakeholders might raise awareness about the equity impacts of transport plans and investment allocation.

5.2.3. Equity measures in Planning Practice

Despite the increasing dissemination of evaluation methods and metrics in transport for different planning purposes, it remains a challenge to measure the equity impact of transport interventions (Martens et al., 2022; Oswald Beiler and Mohammed, 2016; Wellman, 2015). Moreover, scholars argue that the most widely applied method, the cost-benefit analysis (CBA), has limited engagement with theories of justice, especially the equity principle (Nazari Adli et al., 2019).

Traditionally, transport planners rely on CBA as an evaluation tool framed by a utilitarian perspective (Thomopoulos and Grant-Muller, 2013). Nonetheless, CBA is limited in addressing intangible impacts, such as equity issues, since it compels a monetisation of such an impact. Consequently, a

growing scholarship criticises this dominant method, seeking to define suitable frameworks to assess the equity impact of transport planning (Hananel and Berechman, 2016; Martens, 2011; Martens et al., 2014a; Thomopoulos and Grant-Muller, 2013).

As an alternative to CBA, researchers are discussing the use of Multicriteria analysis (MCA) due to its capability to include a range of distributional impacts, including equity issues. For example, in Europe, MCA was applied to measure the impacts of transport infrastructure investments over several equity criteria (Thomopoulos and Grant-Muller, 2013). Furthermore, unlike CBA, stakeholders can directly judge the contribution of each performance criterion with MCA. Thus, this approach has been suitable for addressing multiple conflicting planning goals, enabling trade-offs to address different perspectives and affected groups (Manaugh et al., 2015), and finding synergies in the outcome (Bulckaen et al., 2016).

Over the last decade, the accessibility planning theory has provided solid grounds to assess the equity impacts of transport projects and investments (Kent and Karner, 2019; Papa et al., 2016; Venter et al., 2018). Conceptually, accessibility measures the ease of access to a desired set of opportunities (Hansen, 1959). When adapted to an equity-oriented framework, accessibility metrics can be employed with regard to specific segments of society, such as disadvantaged and vulnerable groups (Boisjoly and El-Geneidy, 2017; Manaugh et al., 2017), also considering issues of social health, safety, and level of traffic stress (Antonson and Levin, 2020; Doran et al., 2021). Nevertheless, the complete application of accessibility assessments by planning practitioners remains limited due to technical limitations (Boisjoly and El-Geneidy, 2017).

According to the literature, planning efforts to address equity concerns have been even more narrow regarding active transport, such as the bicycle. For example, in the US, there is a significant discrepancy in the extent to which equity is prioritised in cycling plans, with some cities acknowledging the importance of such impact and others, deliberately or not, overlooking them. Such a study revealed the commitment level towards equity issues through the content analysis of several official documents, concluding that most implemented plans lack equity considerations (Lee et al., 2017).

Considering the European context, there is little evidence of how planning practitioners tackle equity concerns in planning practice. Likewise, it is unclear to what extent planning practitioners perceive equity as a priority or if they address and appraise this criterion during planning and decision-making. Conversely, previous research indicates that cycling plans often rely on bicycle volume counts as a performance metric. However, such an assessment approach is questionable since it overlooks bicycle users circulating over unmonitored tracks (Kent and Karner, 2019).

Previous research proposed new methodological tools to measure the equity implications of cycling planning to address this knowledge gap. For example, a study proposed an optimisation framework to plan and design an equitable network of bike lanes in an urban context considering the available budget, able to increase accessibility to specific population groups (Caggiani et al., 2019).

Recently, a study developed a planning support system (PSS) tool, the so-called TIRE, to measure the equity impacts of cycling infrastructure allocation, considering accessibility and socioeconomic metrics (Cunha and Silva, 2023). The study mapped the equity implications of a cycling plan under implementation in a given territory, revealing that more than half of the distribution of bicycle accessibility conditions primarily benefits socioeconomically advantaged zones. Furthermore, most disadvantaged representatives inhabit the outskirts and neighbourhoods, which have levels of accessibility below the municipality average. Confronted by these results, the local planning

practitioners evaluated the usefulness and user-friendliness of this PSS tool for planning practice (Cunha and Silva, 2023).

In short, although recent studies have employed assessment frameworks to discuss equity in active transport, no study sought to examine to what extent equity is addressed and prioritised in cycling planning practice considering distinct social and urban contexts from a qualitative perspective.

5.3. METHODOLOGY

5.3.1. CASE STUDY

This study is contextualised in three European cities aiming to explore to what extent planning practitioners address or prioritise equity issues in cycling planning and if such an approach conflicts with other planning priorities. Hence, this research focuses on cities with different cycling statuses, subject to the maturity of the cycling network and bicycle modal split.

Therefore, this research focuses on three cities in Portugal, Germany, and Finland to examine how distinct social and urban contexts influence the cycling planning process. The cities were selected based on prior academic and professional networks and research agreements.

The Portuguese city presents a bicycle modal share below 10%, a car-oriented built environment and residual cycling infrastructure. The Finish and German cities depict a bicycle modal share between 10% and 30% and have increasing planning efforts to improve network cohesion, quality and road safety (Dufour, 2010). This research opted against naming the cities under study to ensure the anonymity of the participants.

Hence, this research employed a framework epistemologically oriented to interpretivism and an inductive approach based on qualitative methods – focus groups, semi-structured interviews, and surveys – to explore and understand how equity is addressed or prioritised in cycling planning in the selected European cities. Qualitative research often gathers multiple forms of data to develop a holistic perspective of the problem or issue under study (Bryman, 2012; Creswell, 2014).

In order to identify potential participants to contribute to this research, formal emails were sent to the heads of mobility departments of the respective cities to introduce the research scope and goals. In addition, the breakdown of the envisaged research activities targeting practitioners involved in cycling planning was discussed. Afterwards, all the contacted heads expressed their willingness to participate by extending invitations to the concerned professionals. Subsequently, the heads of departments suggested optimal dates and timeframes for the research activities and a list of potential participants (n= 30 in total). Based on the preliminary lists, a second round of emails was sent to the concerned professionals, with the presentation of the research topic and the proposed research activities. Among the professionals contacted, 21 replied positively, expressing interest in contributing to this research, as shown in Table 12.

Thus, this study scrutinises a sample of 21 planning practitioners directly involved in cycling planning through focus groups, interviews, and surveys. Previous studies considered this number appropriate to reach qualitative data saturation in a homogenous sample formed by participants with specialised knowledge (Krueger, 1994; Morgan, 2012). According to previous research, a focus group commonly involves six to eleven participants (Brotherson, 1994; Powell and Single, 1996). Nevertheless, when the focus group involves participants with specialised knowledge, scholars have endorsed using the so-called min focus groups, including three (Morgan, 2012) or four participants (Krueger, 1994).

However, as described in Table 12, in one of the three cities, the focus group was replaced by interviews as the invited participants had tight, busy schedules, hampering the definition of a suitable date and time slot. Hence, two focus groups (with eight and three participants) and ten interviews were conducted based on the established contacts.

Table 12 – Sample description

	Invites sent	Final Sample	Focus Group*	Expert Interviews
Germany	9	6	3	3
Finland	9	4	-	4
Portugal	12	11	8	3
Gender ratio (women/men)	11/30	9/21	5/11	4/10

* Number of participants

The data collection was conducted online between June 2022 and March 2023

Concerning the sociodemographic characteristics of the involved planning practitioners (Table 13), more than half of the sample were male, aged 30 to 59 years old. The professional positions of the sample include architects, urban planners, civil and transport engineers, geographers and mobility project managers.

Table 13 – Profile of the focus group participants and interviewees

Sample Codes	Professional role	Age	Gender	Country
Focus Group				
Participant #1	Civil engineer, technician	45-49	Female	Portugal
Participant #2	Project manager, team leader	50-54	Female	Portugal
Participant #3	Geographer, technician	30-34	Male	Portugal
Participant #4	Architect, technician	50-54	Female	Portugal
Participant #5	Architect, technician	50-54	Female	Portugal
Participant #6	Architect, technician	55-59	Female	Portugal
Participant #7	Architect, technician	55-59	Male	Portugal
Participant #8	Civil engineer, technician	45-49	Male	Portugal
Participant #9	Project manager, team leader	55-59	Male	Germany
Participant #10	Transport planner, technician	35-39	Male	Germany
Participant #11	Transport engineer, technician	30-34	Male	Germany
Interviewee				
Interviewee #1	Architect, technician	55-59	Female	Portugal

Interviewee #2	Civil engineer, technician	50-54	Female	Portugal
Interviewee #3	Landscape architect, technician	50-54	Female	Portugal
Interviewee #4	Geographer, team leader	35-39	Male	Germany
Interviewee #5	Geographer, data analyst	45-49	Male	Germany
Interviewee #6	Urban planner, technician	40-44	Male	Germany
Interviewee #7	Transport planner, technician	40-44	Male	Finland
Interviewee #8	Project manager, team leader	30-34	Male	Finland
Interviewee #9	Transport engineer, technician	35-39	Male	Finland
Interviewee #10	Mobility management, team leader	50-54	Female	Finland

5.3.2. FOCUS GROUP: WORKSHOP INTERVIEWING

The Focus group was organised in a format of workshop interviewing, encompassing three sections defined as a 3Is framework (i.e., Introduction, Interaction and Interview), illustrated in Fig. 35. This structure was designed to be fairly light in terms of facilitation, placing participants as active players in the discussion. Therefore, the focus group lasted 1.5 hours to capture the uniqueness of each case study based on the synergy of the group interaction and the narratives generated by professionals working in cycling in distinct social and geographical contexts (Table 14).

The first part of the workshop (Introduction) was dedicated to the application of a survey (*Annex A1*: *Pre-workshop Survey*) and the presentation of the conceptual framework and outputs generated by the planning support tool TIRE for the respective city under study. This tool maps the equity implications of cycling plans based on a detailed spatial analysis of the distribution of cycling infrastructure and accessibility levels across distinct socioeconomic groups (Cunha and Silva, 2023). Next, the workshop facilitator explained how to operationalise the tool and interpret the generated results. Afterwards, the participants had the opportunity to ask in-depth questions about the tool's results, calibration, and operationalisation.

In the second session (Interaction), the involved planning practitioners had the opportunity to discuss strategies to foster the equity impact of their local cycling plan. Then, to address this objective, the participants defined a list of measures and reflected on possible implementation barriers. Finally, to better convey the participants' perspectives on the equity impact of the proposed measures, the discussion revolved around prioritising the more urgent measures and the potential challenges encompassing their concrete implementation. Moreover, since the participants did not use the tool in their professional practice, this approach enables the discussion of the potential of the TIRE tool in supporting the definition of equitable strategies.

Finally, in the third section (Interview), the groups had the opportunity to discuss the defined intervention plan through the semi-structured group interview (*Annex B1: Semi-structured interview*) enquired by the workshop moderator. At this moment, the participants could reflect on the prioritisation of strategies, identifying key learning points towards defining an equity-oriented intervention plan.

Table 14 – Focus group – 3Is Workshop Framework

Step 1: Introduction	Step 2: Interaction*	Step 3: Interview
Opening[a]	Prioritisation exercise[o]	Interview
Survey (5min)	List of measures (15min)	Semi-structured questions (30min)
TIRE presentation[a] (20 min)	Intervention plan (15 min)	Feedback[o]
Q&A[a] (5 min)		Closing words[a]

* Activity performed only in the focus group

[a] Facilitator tasks

[o] Participants' tasks

5.3.3. INTERVIEWS WITH PLANNING PRACTITIONERS

In order to gain a depth understanding of the research questions and increase the qualitative sample, this study conducted semi-structured interviews with the available planning practitioners who could not attend the workshop on the scheduled day. Hence, semi-structured interviews were conducted following the same interview protocol defined for the focus group (*Annex B1: Semi-structured interview*).

Scholars consider this data collection procedure versatile and flexible enough to combine with individual and group interview methods (Rabiee, 2004). Thus, the interview guide comprises four sections to explore questions related to the overarching planning priorities, network design, and how planning practitioners seize the equity concept in decision-making and planning processes. The total number of participants was based on data saturation, meaning that the tenth interview identified no further insights. The interviews last around 40 minutes on average.

5.3.4. SURVEY

This research surveyed the focus group participants to explore and collect genuine visions of the cycling planning priorities in each city before discussing the cycling equity concept and conducting the interactive exercise. This survey has a three-fold structure (*Annex A1: Pre-workshop Survey*). The first section of the survey questioned how participants considered the importance given to a range of 22 planning priorities. The second section examined how local planning practitioners prioritise nine distinct population groups, including minorities, vulnerable and socioeconomic disadvantaged representatives, and six target areas, encompassing the inner city, periphery, and rural zones. Both sections used a 5-point Likert scale (1- “Not at all important”, 2- “Low importance”, 3- “Neutral”, 4- “Important”, 5- “Very important”). This section ended with an open question, asking which analysis tools are commonly applied to assess the performance or impact of the cycling network implemented or under implementation. Finally, the third and last section of the survey collected sociodemographic information about the participants, including their years of working experience and professional roles. The survey results facilitated the triangulation of the collected data in the qualitative approach and the subsequent identification of themes for further analysis.

5.3.5. DATA ANALYSIS

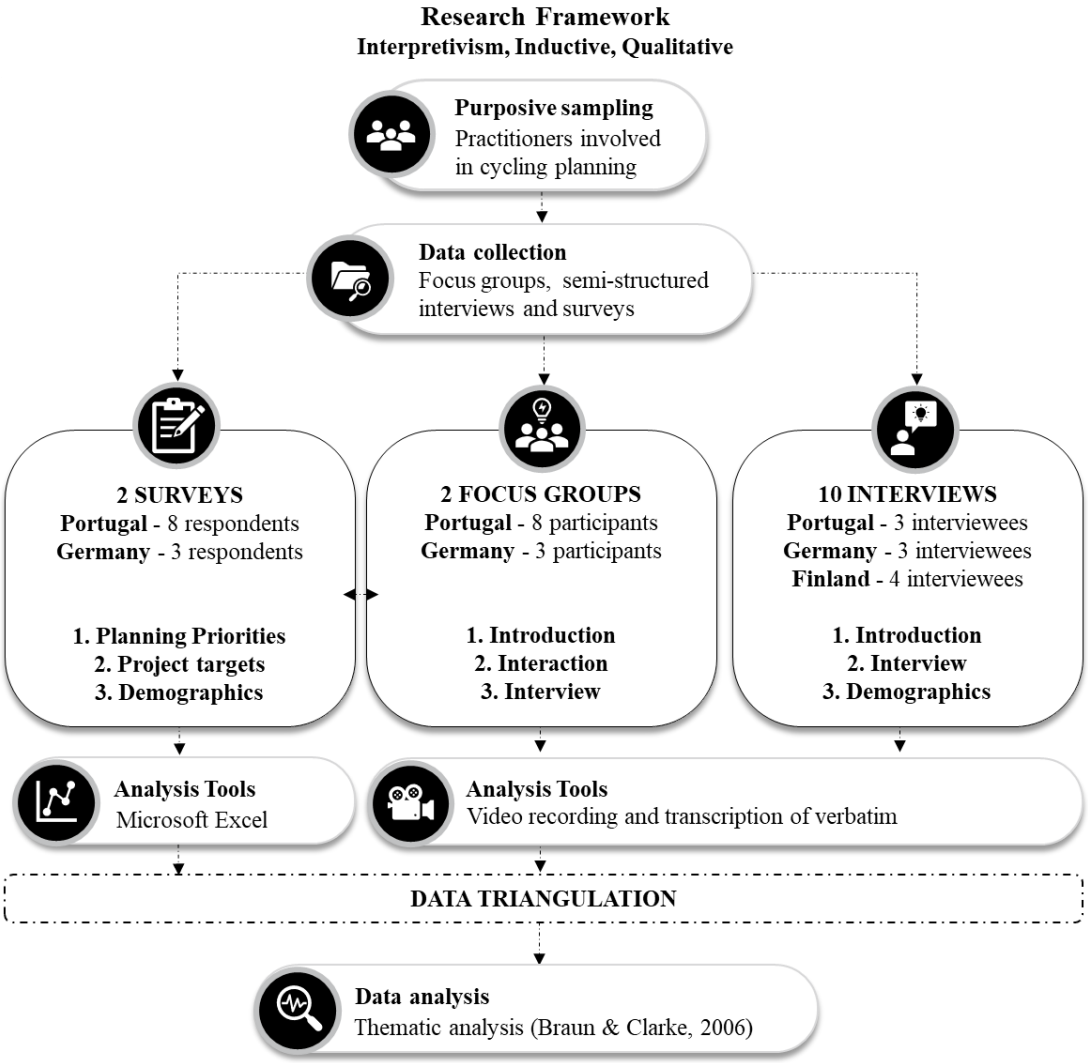


Fig. 35 – Research workflow

The focus group and interviews were conducted in English and Portuguese, according to the case study under analysis, and recorded in video and audio format. The verbatim dialogues and responses were transcribed following a commonly applied and standardised transcription protocol (McLellan et al., 2003). In addition, the collected data were manually transcribed to avoid recurrent grammatical and cohesions errors from automated transcription tools.

Afterwards, this study applied the thematic analysis and the 6-step approach to arrange and interpret the data obtained from the focus groups and the individual interviews. Thematic analysis is one of the most commonly applied qualitative methods to trace patterns in the collected data, the so-called themes (Braun et al., 2017; Braun and Clarke, 2012, 2006).

Firstly, to proceed with the analysis, a process of familiarisation and immersion with the data collected (i.e., transcripts, work notes and videos) was conducted. Secondly, this research systematically analysed the whole dataset, grouping the data's recurring characteristics into codes. In this process, 55 codes were identified. Subsequently, the generated codes were grouped into potential themes. After,

the initial themes were discussed and reviewed according to their consistency, representativeness, and relevance to the research objective and questions. In the last step, the final themes were organised into four main themes and ten sub-themes as described in Table 15 and further discussed following the focus group and interview excerpts for each theme.

5.3.6. DATA CREDIBILITY

In qualitative research, credibility concerns truth value and internal validity (Korstjens and Moser, 2018). Among the potential strategies to ensure credibility, this study relied on triangulation, prolonged engagement, and member checks.

The triangulation relied on different data sources, investigators, and data collection methods. Hence, to ensure data triangulation, this research examined multiple data sources in space by focusing on three cities with unique social and geographic backgrounds. Moreover, the investigator triangulation encompassed the involvement of two researchers in the process of coding, analysis, and interpretation decisions. Finally, the method triangulation encompassed the use of multiple data collection methods.

This research required a prolonged engagement with the participants of the focus groups and interviews, allowing compliance with the research setting and context. Moreover, this credibility strategy enabled solving doubts or misinformation, building trust and getting familiar with the data collected. Finally, the interviews and focus group transcript were sent to the interested parties for member check.

5.4. THEMATIC ANALYSIS

This research identified four major themes, as indicated in Table 15. Accordingly, the first theme uncovers the overarching planning goals encompassing the cycling plans in each city under analysis. The second one discusses the strategic roadmap based on the measures commonly prioritised in planning practice. The third theme delves into the decision-making process, examining the often-applied criteria prioritisation and the consequent implementation barriers. Afterwards, the fourth theme examines potential pathways towards an equity-oriented agenda for cycling planning, considering how planning practitioners grasp the equity concept in practice, the potential investment targets, the possible trade-off effects and the potential applicability of an equity-oriented tool in planning practice.

Table 15 – Codes, Subthemes and Themes resulting from the thematic analysis

Thematic analysis		
Codes	Subthemes	Main themes
Cycling integration Improve infrastructure Increase bicycle modal share Meet the EU strategic goals	-	1st theme Planning overarching goals

Increase cycling network	Infrastructure	2nd theme Strategic roadmap
Provide cycling highways		
Solve missing links		
Improve connectivity		
Safe intersections		
Expand Bike sharing systems (BSS)		
Road space redistribution		
30 km zones and shared streets		
Good quality bicycle parking		
Bicycle traffic signs		
Implement traffic calming measures		
Winter maintenance		
Rehabilitation of infrastructure		
Temporary streets closures	Management and services	
Mobility management measures		
Improve access to BSS		
Bike repair provided by the municipality		
Educational programmes	Attitudes and Behaviour	
Awareness campaigns		
Information and communication		
Tax incentives	Finance	
Aid for bicycle purchase		
Reducing costs of electric bikes		
Political will	Barriers and challenges	3rd theme Decision-making process
Car-dependence		
Social acceptance		
Lack of indicators		
Road space distribution		
Budget restriction		
Improve road safety	Criteria	
Ensure security		
Increase accessibility		

Improve directness		
Ensure safety Equal access Universal access Social participation Address individual barriers	Defining Equity	
Women Elderly Children Students Immigrants Low incomers Outskirts	Investment targets	4th theme Building an equity-oriented agenda
Equity is overlooked Equity vs Equality Equity vs Plan Priorities	Trade-off effect	
Prioritisation guidance Support decision-making process Awareness creation	Planning support tool	

5.4.1. OVERARCHING PLANNING GOALS

The survey results (Fig. 36) revealed the planners' consideration towards several planning goals. Among the assessed measures, more than half of the respondents (n=10) considered ensuring road safety a crucial goal underlying their local cycling strategy, followed by environmental-related measures, such as mitigating climate change and reducing CO2 emissions, recommended by 10 and 8 planning practitioners respectively.

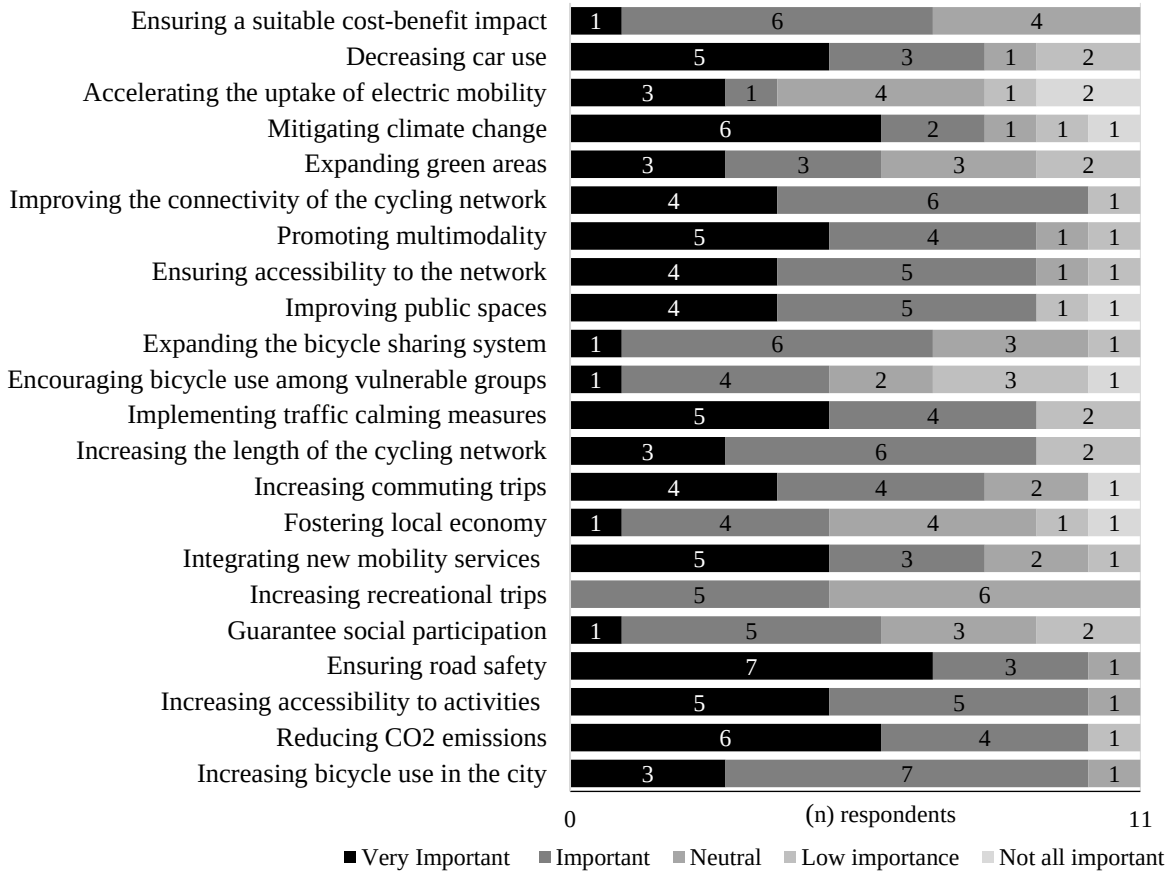


Fig. 36 – Respondents' consideration of different planning goals

Around half of the respondents recommend implementing traffic-calming measures and multimodality strategies to decrease car use, foster cycling network connectivity, and increase accessibility to activities, ultimately fostering the positive impact of the bicycle plan under development or implementation.

The survey results highlight a planning focus on strategies to encourage commuting trips rather than recreational, which suggests efforts towards a more robust approach to normalising cycling in the cities.

Regarding the priority target populations, more than half of the respondents considered fundamental the definition of strategies focused on the youth community (n=11), children (n=8) and student population (n=9). However, as illustrated in Fig. 37, little attention is paid to immigrants, disabled and low-income people. Concerning target areas, nine respondents acknowledged that their strategic plans tend to prioritise high-density zones, whilst six respondents highlighted the importance of defining strategies targeting the city's outskirts.

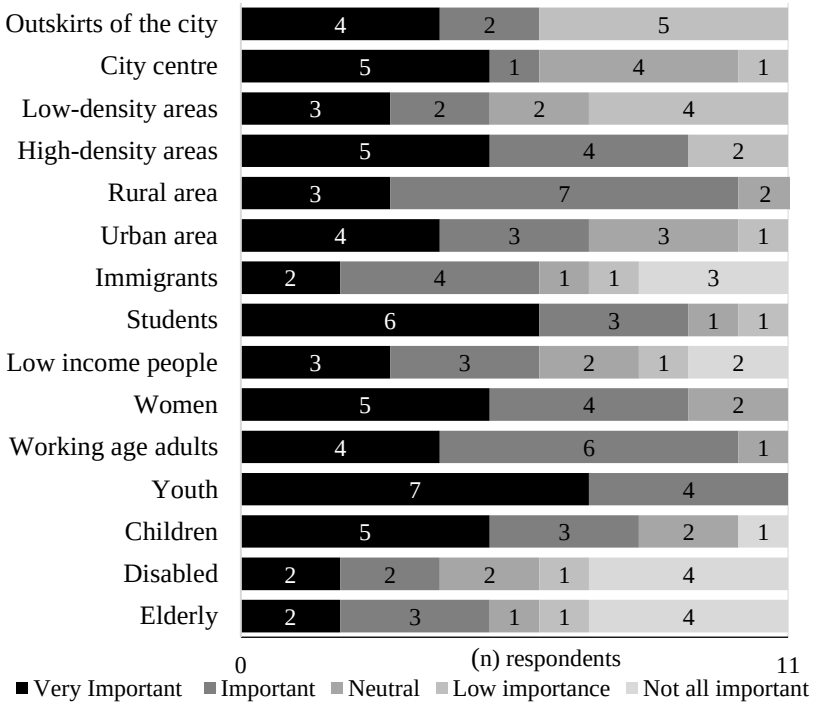


Fig. 37 – Respondents' consideration of different populations groups and areas

These findings align with the results derived from the thematic analysis, which revealed that the assessed cities aim to integrate cycling into transport systems and normalise bicycle use by improving the infrastructure and adopting the strategic guidelines developed at the European level (Table 16).

Table 16 – Overview of the overarching planning goals

1st theme: Planning Overarching Goals	
Codes	Sample
Cycling integration	Participants #2 #3 #7 #9 Interviewees #2 #3 #4 #5 #6 #7 #8 #9 #10
Improve infrastructure	Participants #1 #2 #3 #4 #5 #6 #7 #8 #9 #10 #11 Interviewees #1 #2 #3 #4 #5 #6 #7 #8 #9 #10
Increase bicycle modal share	Participants #1 #2 #3 #6 #9 Interviewees #1 #2 #4 #5 #8 #9
Meet the EU strategic goals	Participants #2 #3 #5 Interviewees #2 #4 #6 #7 #8 #9

Thus, these cities have targeted the improvement and expansion of the network, enhancing accessibility conditions for utilitarian trips, as evidenced in the following excerpts:

> *"[…] our previous cycling network was essentially recreational. At a certain point, this planning approach changed, and we started to rethink the network for utilitarian trips […] there has been much progress in terms of solution and design; therefore, we should solve those links considered inadequate and unsafe."* (Interviewee #2)

> *" I believe that road safety is a crucial factor to be considered in cycling promotion […] if the network is unsafe, children, elderly and women will not uptake the bicycle as a mode of transport."* (Interviewee #10)

In order to normalise cycling in European cities, these plans are seeking to integrate cycling into the transportation system in a holistic way through intramodality strategies to address the last-mile issue:

> *"The main goal is to normalise and integrate cycling into the urban fabric and transport systems because the bicycle remains a little bit segregated or marginalised in many European cities due to the car revolution in the 60s and 70s."* (Interviewee #8)

> *"[…] if we create the links between cycling and public transport, we are offering people the opportunity to have a car-free life."* (Participant #2)

This theme also revealed that the examined cycling plans are highly goal-related with the EU climate action, which proposes an ambitious plan to cut greenhouse gas emissions by 2030 to achieve climate neutrality in the following decades (Parliament, 2020):

> *"Once we have our planned infrastructure in place, we still have to keep promoting cycling […] not only we want to be carbon neutral by 2030, but also carbon zero by 2040".* (Interviewee #7)

5.4.2. STRATEGIC ROADMAP: MEASURES SELECTION

This research identified that the assessed cities pursue a strategic roadmap encompassing four main approaches, as indicated in Table 17. Throughout the focus group, interviews, and survey results, great emphasis was given to infrastructure provision, followed by measures related to management and services. Conversely, little attention was given to measures encompassing attitude, behaviour change, and financial support.

Table 17 – Recommended measures within the assessed strategic roadmaps

2nd theme: Strategic roadmap	
Subtheme	Sample codes
Infrastructure	
Increase cycling network	Participants #1 #2 #4 #5 #9, Interviewees #1 #2 #4 #5 #6 #8 #9 #10
Provide bicycle superhighways	Participants #9 #10, Interviewees #5 #7 #8 #9
Solve missing links	Participants #2 #4 #8, Interviewees #1 #2 #8 #9
Improve connectivity	Participants #2 #5 #10, Interviewees #1 #2 #4 #5 #7 #8
Safe intersections	Participants #2 #7, Interviewees #2 #5 #4 #7 #8

Expand Bike sharing systems (BSS)	Participants #1 #4 #10, Interviewees #1 #2 #3
Road space redistribution	Participants #1 #2 #8 #10, Interviewees #3 #8
30 km zones and shared streets	Interviewees #3 #8
Good quality bicycle parking	Participants #2 #6 #11, Interviewees #4 #5 #7 #9 #9 #10
Bicycle traffic signs	Participant #7, Interviewee #5 #9
Implement traffic calming measures	Interviewee #3 #8
Winter maintenance	Interviewee #5 #8
Rehabilitation of infrastructure	Interviewee #5 #8
Management and Services	
Temporary streets closures	Participants #10 #11
Mobility management measures	Participants #2 #3 #5 #9 #10 #11, Interviewees #2 #3 #8 #9 #10
Improve access to BSS	Participants #2 #4 Interviewees #1 #3
Bike repair provided by the municipality	Interviewees #1 #3
Attitudes and Behaviour	
Educational programmes	Participants #1 #2 #3 #5 #10 #11, Interviewees #1 #2 #3 # 8#10
Awareness campaigns	Participants #1 #3 #5 #6 #9 #10, Interviewees #1 #3 #4 #8 #10
Information and communication	Participant #5, Interviewees #3 #4
Finance	
Tax incentives	Participant #2 #3 #5, Interviewee #3
Aid for bicycle purchase	Participant #5, Interviewee #3
Reducing costs of electric bikes	Interviewee #3

Considering the starter cycling city context, the roadmap is strongly oriented towards implementing a cohesive cycling network integrated with bicycle sharing systems (BSS) in high-density urban areas with higher mobility demand and, therefore, more likely to attract new bicycle users. Furthermore, in order to address the residual and fragmented infrastructure as well as the limited road space and budget, planners prioritise the implementation of traffic-calming measures in residential zonas and 30km zones in city centres and commercial zones:

> *"Our general goal was to create and expand the network, and then solve the missing links, and provide safer intersections [...]it is also important to expand the local BBS over the whole territory."* (Interviewee #1)

> *"[…] initially, the cycling network would be essentially segregated, but we verified that this would be an extremely ambitious goal. Therefore, we are implementing different typologies, including 30km zones and shared streets."* (Interviewee #3)

Considering the climber cycling city context, planners are likely to focus on the improvement and maintenance of the network and the implementation of bicycle superhighways connecting different zones of the city to increase the accessibility conditions for utilitarian trips for those living at longer distances:

> *"The target network is the measure we are emphasising right now […] we need to guarantee the maintenance of the direct and efficient routes, making sure they are safe, with good quality bicycle parking, enough width, and bicycle traffic signs, like the other transport modes."* (Interviewee #5)

> *" I guess that infrastructure provision in the city centre linked with the bicycle superhighway plan can definitely connect different zones of the city and increase bicycle trips."* (Participant #9)

The thematic analysis disclosed that these cities are also seeking to adopt strategies and measures successfully experienced by the so-called champion cycling cities (Urbanczyk, 2010a), which have an established bicycle culture and policies, with a cycling modal share above 30%:

> *"[…] back to '70s, the design principles were quite different. Now we have new planners with fresh ideas and knowledge […] that is why the Netherlands and Denmark are still heavily investing millions of euros in cycling infrastructure. In my opinion, this is something that we could start to consider, working more in the fundamental principles."* (Interviewee #8)

Concerning management and services, planners from both starter and climber cycling city contexts advocate greater integration of cycling into public transport (PT). The provision of BSS at PT interfaces and the possibility of carrying bicycles inside the carriages emerged as crucial measures:

> *"[…] it is fundamental to expand the BSS through the entire city, also covering the peripheric zones […] fostering the integration with public transport could be a good alternative, where it is not possible to densify or provide the cycling network".* (Participant #4)

With regards to measures intended to change attitudes and behaviour, the participants highlighted educational programmes, awareness campaigns and mobility management measures, especially in the educational sector:

> *"[…] education is essential to promote the safe use of bicycle […] at primary schools our kids have a curriculum module dedicated to cycling, with specialised staff to teach them how to ride a bike."* (Interviewee #3)

> *"We promote bicycle culture in schools and kindergartens because it is imperative to create this culture since the very beginning [...] children are everywhere if we teach them these principles, it will be easier to change the whole community."* (Interviewee #1)

Finance-related measures were mainly related to strategies aimed at facilitating access to the bicycle itself, including support for bicycle purchase (i.e., conventional, second-hand, cargo-bike, electric) and accessible maintenance services:

"We have had thousands of sign-ups to our bike purchase programme […] those who could not afford a bicycle could have access to a second-hand or donated bicycle." (Interviewee #3)

5.4.3. DECISION-MAKING PROCESS: PRIORITISATION CRITERIA AND IMPLEMENTATION BARRIERS

Throughout the focus group and interviews, planning practitioners reflected on the main prioritisation criteria and implementation barriers encompassing their local cycling strategy (Table 18). The thematic analysis revealed that ensuring road safety is considered the highest criteria underlying the prioritisation and allocation of investments and cycling infrastructure, followed by improving accessibility and network connectivity:

"The prioritisation of the bicycle network means improving cycling safety at the intersections, providing more bicycle parking facilities, ensuring the comfort and connectivity of the existing and new bicycle infrastructure." (Interviewee #4)

"The reason for implementing this plan is ensuring cycling safety, of course, and also to improve accessibility and easiness of riding." (Interviewee #7)

Nevertheless, prioritising such criteria within BMP raises several political and social barriers. This research undercovers that political will is decisive in defining and allocating cycling-related investments. In order to have a cohesive approach, planners assert a more holistic planning and policy approach:

"[…] neighbourhoods with committed politicians usually have more bicycle infrastructure than others. But it should be the aim for the whole city." (Interviewee #5)

"We need to identify the politicians who are on board that have the same mindset, […], but we also want to make the opposition understand that this makes sense." (Interviewee #8)

Accordingly, budget restrictions emerged as an obstacle hindering the full implementation a cycling strategy, with planners claiming that providing a safe and extensive network covering the whole city, as well as the main origins and destinations, can be "*very expensive*":

"[…] we are looking where to allocate the network based on a certain budget per year. To do so, we have to look at the numbers [...] we simulate the impact of the km-built network on cycling trips." (Interviewee #9)

"It costs money; we cannot just paint lanes, there is a need to create dedicated infrastructure, which will cost some millions, but if we invest these millions properly, we will have a return." (Interviewee #7)

Following this discussion, participants also argued that the lack of social acceptance and the dominant car-oriented mindset, also mentioned as "*the ultimate faith in automobiles*", negatively impact such "*planning paradigm change*", which involves the "*redistribution of urban space*" and the road space allocation in favour of active modes of transport:

"I dare to say the automobile lobby is a big barrier, which affects the road space distribution and the social acceptance of alternative modes of transport." (Interviewee #3)

"[…] to create more human-friendly cities, we have to redistribute the space, which is currently occupied by cars […] we have between 70% to 80% of the public space for private cars." (Participant #4)

Concerning the challenges encompassing the planning practices, the practitioners highlighted a general lack of robust methods and indicators to support the development and assessment of bicycle plans:

> *"I think we do not need to get rid of cost-benefit analysis, but we have to improve it, including more criteria. "* (Participant #9)

> *" […] planning for cycling is not so restricted to the cost-benefit ratio […], but we are still lacking data for cycling. So, we need to create the data to support planning."* (Interviewee #7)

Table 18 – Overview of the planning criteria, barriers and challenges

3rd theme: Decision-making process	
Subthemes	Sample
Planning criteria	
Improve road safety	Participants #1 #2 #5, Interviewees #1 #4 #5 #6 #7 #8 #10
Ensure security	Participants #1 #2 #3, Interviewees #1 #2 #10
Increase accessibility	Participants #2 #9 #10, Interviewees #2 #3 #4 #7 #8 #10
Improve directness	Participants #2 #9 #10, Interviewees #2 #3 #4 #5 #6 #7 #8
Barriers and challenges	
Political will	Participants #1 #2 #3 #6 #10 #11, Interviewees #1 #2 #3 #4 #5 #6 #7 #8
Car-dependence	Participants #2 #3 #9, Interviewees #2 #3 #4 #8 #9 #10
Social acceptance	Participants #2 #3 #6 #9, Interviewees #2 #3 #4 #8 #9 #10
Lack of indicators	Participants #2 #5 #7 #8 #9 #10, Interviewees #4 #5 #6 #7 #8 #9
Road space distribution	Participants #2 #3 #6 , Interviewees #1 #2 #3 #4 #10
Budget restriction	Participants #2 #3 #6 #9 #10, Interviewees #1 #7 #8 #9

5.4.4. Building an equity-oriented Agenda for Cycling Planning

This research disclosed that the equity concept is hardly a planning goal in the assessed cycling plans (Table 19). Occasionally, planners used the equity and equality concepts interchangeably or questioned the difference between both. Such a conceptual misunderstanding has already been identified in previous studies (Trinder et al., 1991). Through the qualitative analysis, this research discloses a general tendency towards an egalitarian approach in cycling planning, as these cities have been aiming at providing cycling network throughout the whole territory in order to normalise cycling and "encourage people from all ages and abilities to cycle more often":

> *"Equity is not necessarily addressed directly. I think equity is more like an outcome because we are providing such an extensive bicycle network, where you can go from anywhere to everywhere."* (Interviewee #10)

> *"I do not believe equity has been considered planning goal […] we wanted to attend the majority of the population with a network that serves everyone. "* (Participant #2)

> *"I guess our approach is more focused on equality […] We are trying to make choices and strategies that should work for all people."* (Interviewee #9)

Nevertheless, cycling planning planners acknowledge the importance of "*understanding the needs of specific groups*" in order to develop a "*holistic cycling strategy*":

> *"Our plan should be able to accommodate people with different needs, speeds, and bikes, such as e-bikes, cargo bikes, scooters [...]"* (Participant #5)

> *"[…] we should have a holistic approach […], if we build a network, but people do not have access to bikes or do not know how to ride a bike, then the network worths noting, we need to assist them."* (Interviewee #10)

When discussing an equity-oriented framework for cycling planning, planners reflected on a potential market segmentation based on demographic and socioeconomic factors. Accordingly, the participants highlighted special attention towards the needs, abilities and obstacles experienced by women, children, elderly people, immigrants, and low-income segments:

> *"We have noticed that the bicycle can foster social inclusion, creating business and job opportunities. In that sense, our financial aid for bicycle acquisition has received many applications from immigrants who use the bicycle as a mode of work to increase their earnings."* (Interviewee #3)

> *"Now we are aiming to encourage women to uptake cycling and ride more often because their participation is still residual compared to men."* (Participant #2)

> *"We should start planning for the ones that need safety and security the most, meaning children, elderly and women."* (Interviewee #10)

Whereas little attention has been paid to the distributive equity dimension in planning practice, this study identified participatory equity practices. The assessed cities have been promoting petitions and referendums involving politicians and citizens, as well as meetings and consultation with activist groups, NGOs and neighbourhoods or district representatives, in order to foster social participation in the planning and decision-making process:

> *"In our plan, we are aiming to include the citizens in the decision-making […] we had a referendum with thousands of people, which supported many decisions and the creation of our new bicycle plan."* (Participant #11)

> *"At this point, we approach all available partners, ranging from associations, activists, borough councils, that often endorse the implementation of pilot projects […]"* (Interviewee #3)

However, this research found potential trade-off issues encompassing the development of an equity-oriented agenda. As discussed earlier, addressing equity in planning and decision-making processes implies trade-offs with other transport planning objectives (Litman, 2005). During the interviews and focus group, the participants argued that equity issues are not fully considered or adopted in planning practice because equity is not perceived as a primary objective. Consequently, planning practitioners are likely to overlook equity-related measures compared to other planning priorities:

> *"[…] at the first stage of planning, we can do without equity analysis because there are well-established principles that work elsewhere."* (Interviewee #8)

> *"[…] we have different criteria such as road safety, environmental protection, economic progress and equity is just another criterion. In the end, planners and politicians must balance*

> *everything […] I assume that sometimes, fairness is not the number one priority."* (Participant #10)

> *" We are focusing on providing and expanding the cycling network, without complying with the equity criterion […] Perhaps this concern will come up now."* (Interviewee #2)

From the open question in the survey, planning practitioners indicated that the performance assessment of bicycle plans often relies on mobility surveys, cycling flow data, bicycle counts, modal shift analysis, accident statistics and mobility behaviour studies. Hence, this research disclosed a general lack of analysis methods to evaluate the equity impact of the cycling infrastructure allocation. Likewise, earlier research evidenced a general shortage of indicators and methods to assess the equity impact of transport planning (Nahmias-Biran et al., 2017; Thomopoulos et al., 2009; Thomopoulos and Grant-Muller, 2013). In order to bridge this technical gap, the present study demonstrates that planners require technical support to develop performance indicators tailored to equity issues:

> *"[…] to put equity into agenda, we really need have specialised professionals working in the background to support planners and decision-makers."* (Interviewee #8)

> *"We have not developed good indicators to measure equity yet […] we do not know the impact of our investments across different population groups, or socioeconomic groups."* (Participant #5)

Whereas this study brings evidence that planning practitioners do not address and prioritise equity issues in the assessed cities, the presentation of the TIRE tool and the discussion of its applicability in planning practice helped to create awareness about the equity implications of cycling infrastructure provision, as already discussed in previous research (Cunha and Silva, 2023):

> *"This tool TIRE is fascinating […] it definitely helped me think about these problems and think outside the box [...] this is something we should start to take into consideration."* (Interviewee #8)

> *"Right now, we have already set our cycling plan, but maybe in the future, we can renew it and then, supported by this tool, we could see the planned network with new eyes."* (Interviewee #9)

Accordingly, the involved planners suggest that TIRE could be used as a "*prioritisation tool*" in planning practice. Among other suggestions, planners reflected on giving a "*relative value to the TIRE results*" and then including such output in a multicriteria analysis:

> *"TIRE could be a decision-making tool for prioritisation […] you know cities usually have a certain amount of money to spend, and planners could use the tool to check areas that need this investment the most."* (Interviewee #10)

> *"We could use this outcome and the maps produced by TIRE to fix the gaps and prioritise the network and future investments in disadvantaged zones."* (Interviewee #4)

Likewise, planners believe that tool could also be useful to bridge the knowledge and technical gap encompassing equity analysis of transport investments:

> *"I think planning practitioners and professionals are unfamiliar with this topic. We could learn more with researchers, universities, and schools to apply this concept in practice."* (Participant #9)

Finally, planners argue that data-driven decision-making could be beneficial for planners, politicians, and citizens in discussing the issues of redistribution of space in favour of active modes:

"These maps produced by TIRE are a fantastic way to illustrate such a problem […] a picture worth more than thousands of words […] data is important, especially when translated into insights or knowledge. This tool could be handy for planners, politicians and citizens." (Interviewee #10)

Table 19 – Building an equity-oriented agenda for cycling

4th theme: Building an equity-oriented agenda	
Subthemes	Sample
Defining equity	
Ensure safety	Participants #1 #2 #3 #5 #7, Interviewees #1 #4 #5 #6 #7 #8 #10
Equal access	Participants #2 #3, Interviewees #2 #3 #8 #7 #9 #10
Universal access	Participants #1 #2 #3 #10, Interviewees #1 #3 #7 #8 #9 #10
Social participation	Participants #9 #10 #11, Interviewees #3 #4 #5 #6 #8 #10
Address individual barriers	Participants #2 #9, Interviewees #8 #9 #10
Investment targets	
Women	Participants #1 #2 #3, Interviewees #2 #10
Elderly	Participants #2 #3, Interviewees #7 #8 #10
Children	Participants #1 #2 #3 #5 #7 #9 #11, Interviewees #1 #2 #3 #4 #7 #10
Students	Participants #1 #3, Interviewees #1 #2
Immigrants	Interviewee #3
Low incomers	Participants #2 #5 #8 #9, Interviewees #2 #3
Outskirts	Participants #1 #2 #5 #9 #10, Interviewees #2 #4 #8
Trade-off effect	
Equity is overlooked	Participants #1 #2 #4 #7 #9 #10, Interviewees #2 #5 #6 #7 #8 #10
Equity vs Equality	Participants #1 #3 #5 #10, Interviewees #1 #3 #5 #7 #9 #10
Equity vs Plan priorities	Participants #3 #4 #5 #8 #9 #10, Interviewees #1 #2 #3 #5 #7 #8
Planning support tool	
Prioritisation guidance	Participants #2 #3 #7 #9 #10 #11, Interviewees #2 #4 #5 #6 #7 #8 #9 #10
Support the decision-making	Participants #2 #3 #5 #6 #9 #10, Interviewees #2 #3 #4 #5 #8 #9 #10
Awareness creation	Participants #2 #5 #6 #9 #10 #11, Interviewees #2 #4 #6 #7 #8 #9

5.5. DISCUSSION

Through a qualitative approach, this study sought to explore to what extent planning practitioners based in the EU address and prioritise equity in cycling plans and if equity issues are considered compared to competing planning priorities. Firstly, the focus group participants and interviewees had the opportunity to experience the tool TIRE (Cunha and Silva, 2023) and discuss its potential applicability in practice. Afterwards, participants leveraged debate on crucial issues encompassing equity in cycling plans in European starter and climber cycling cities. As a result, the thematic analysis brought insights into the overarching goals encompassing cycling plans, the often-applied measures and prioritisation criteria, as well as the subsequent barriers to implementation. Moreover, this study elucidated potential trade-off issues between an equity-oriented agenda and other planning priorities.

This study disclosed that the assessed cycling plans often target the whole territory and citizens, providing cycling infrastructure, management and services, and measures intended to change attitudes and mobility behaviour towards cycling. However, certain commonalities and divergences emerged across the case studies. For instance, the starter cycling city has a strategic plan primarily focused on central areas, with high demand for investment and a likelihood of social and political acceptance. In this case, much of the investment seeks to provide a cohesive and safe cycling network, solving the missing links and dangerous intersections. Nevertheless, the budget restrictions hinder the plan implementation. In contrast, the studied climber cycling cities have a more established infrastructure and higher bicycle use. Therefore, these cities focus on expanding and maintaining the network by implementing bicycle superhighways to improve speed and accessibility conditions throughout the territory.

The similarities between the studied cases encompass the overarching planning goals, the barriers and how practitioners perceive equity issues in planning practice. First, this study identified that these cities aim to foster sustainable urban development by integrating cycling into transport systems. As a result, these plans expect a significant modal shift to cycling to reduce the overreliance on motorised modes and address the environmental-related goals.

Nevertheless, the participants argued that the lack of political will and social acceptance negatively impact such a planning paradigm change and the redistribution of urban and road space in favour of active modes of transport. To illustrate, participants claim that the car-oriented mindset keeps dominating the decision-making process, consequently undermining the allocation of cycling plans.

Regarding the first research question, this research reveals that issues of equity are not directly addressed and prioritised in cycling planning practice, and consequently, equity is not at the top of cycling planning priorities in the EU context. Instead, the equity concept was so-often mentioned as a consequent by-product or an intangible outcome of a strategic roadmap focused on increasing cycling rates, ensuring road safety and environmental protection. Moreover, this study evidenced a planning tendency towards an egalitarian approach. In other words, both starter and climber cycling cities aim to increase the bicycle modal share throughout the whole territory, and therefore, the allocation of investment occurs without socioeconomic differentiation. Finally, this study suggests that high-density and central zones are favoured over low-density and peripherical zones in such a distributive process.

Concerning the second research question, this study discloses that equity is likely to be overlooked or disregarded vis-á-vis other planning priorities. Nevertheless, such a phenomenon is not deliberate. On the contrary, planning practitioners acknowledge the importance of developing a holistic planning strategy to address the needs and barriers of distinct social groups, including children, the elderly, the disabled, low-income people, immigrants, and women. Even so, equity is currently absent in

investment appraisal due to the general shortage of indicators to measure the equity impact of cycling investments, jeopardising the complete application of an equity-oriented framework in planning practice. These findings align with previous empirical evidence (Nahmias-Biran et al., 2017; Thomopoulos et al., 2009; Thomopoulos and Grant-Muller, 2013).

In order to bridge this knowledge and technical gap, this study explored the potential applicability of the TIRE tool (Cunha and Silva, 2023) in planning practice. Accordingly, cycling planning practitioners suggested that the PSS tool TIRE could work as a data-driven prioritisation tool in future endeavours, guiding planners, politicians, and other stakeholders to spatially identify disadvantaged areas in the territory to receive future bicycle-related investments.

5.5.1 Theoretical contribution

This study contributes to equitable active transport research and policy in several ways. Firstly, it provides an in-depth understanding of how equity is approached in cycling planning practice, considering the strategic roadmap and obstacles experienced in different European cities, which is currently lacking in the literature (Cunha and Silva, 2022). Another critical contribution is the methodological approach encompassing the triangulation of different data sources, investigators, and data collection methods, ensuring the credibility of the qualitative findings. Furthermore, this research approach enabled testing the accuracy and calibration of the TIRE tool for the three different geographic contexts.

The applied qualitative approach revealed that although practitioners are conscious of the social benefits of cycling, equity is not a broadly acknowledged concept. Moreover, this criterion is not perceived as a planning priority and therefore is not assessed or addressed in planning practice. As discussed in previous research, equity is often perceived as an intangible outcome, and therefore measuring this impact in practice is not straightforward (Linovski et al., 2018).

Thus, the discussion of the planning support tool TIRE with practitioners sought to bridge this gap by providing means to measure and interpret the equitable effects of the distribution of a cycling plan (Cunha and Silva, 2023). As a result, participants reasoned that this research helped create awareness about the social benefits of cycling and the equity implications of planning and decision-making processes. Furthermore, given the general shortage of indicators to measure equity in active transport, the participants argued that TIRE could support future equity-oriented interventions as a data-driven prioritisation tool.

5.5.2 Research Implications

This research brings important implications for planning practitioners, policymakers and stakeholders engaged in cycling planning.

According to the participants of this qualitative research, the equity assessment of their local cycling plans and the discussion of more equitable and inclusive planning initiatives have helped to create awareness about a new planning paradigm, enlightening new perspectives to consider in forthcoming projects. Nevertheless, this research calls for greater collaboration between research centres, local authorities, bicycle advocacy groups and the local community to leverage debate and foster such theoretical and technical exchanges.

Furthermore, this research argues that ensuring social participation in planning and decision-making is crucial to develop holistic cycling plans. In this regard, the municipalities could conduct workshops, surveys and referendums involving the citizens to fully grasp and address the needs and limitations experienced by distinct groups of society, especially those in a situation of social exclusion and vulnerability. Scholars argue that participatory action has the potential to transform social structures and policy agendas robustly (Karner et al., 2020; Sagaris et al., 2020).

Practitioners involved in designing and implementing cycling strategies may benefit from this study by acknowledging the often-applied measures in the European context and the ongoing challenges and potential barriers experienced by cities with different levels of cycling participation. As found in previous research (Dias et al., 2021; Pucher et al., 2010; Pucher and Buehler, 2008), whereas cycling planning encompasses a range of infrastructure and management measures to influence travel attitudes and behaviours, the coordination and transferability of such measures cannot be generalised and should be reasoned from an in-depth understanding of the concerned social and spatial structures.

In line with previous studies (Barajas, 2019; Caggiani et al., 2019; Clark et al., 2019; Mora et al., 2021), this research study emphasises the importance of defining and implementing strategies to improve the accessibility and safety conditions for cycling, through the provision a cohesive network that comprehensively connects different origins and destinations in the city. Furthermore, the provided network should be safe and comfortable enough to accommodate different types of bicycles and speeds and users with distinct needs and abilities.

Cities could implement mobility management measures and adequate bicycle facilities in commercial hubs, schools and universities, companies, and public institutions to encourage a robust model shift from motorised modes of transport and normalise bicycle use. In addition, pilot projects could facilitate access to the bicycle itself through incentives and educational programmes in socioeconomically disadvantaged neighbourhoods and peripheric zones.

Regarding BSS services, operators should ensure that local BSS covers the city comprehensively, considering the major trip generators and the latent demand in underserved communities. Furthermore, according to previous research, providing shared electric bicycles could address individual barriers and increase cycling attractiveness (Teixeira et al., 2022). However, the fee scheme should be affordable to address the limitations of those facing poverty and at risk of social exclusion.

5.6. CONCLUSIONS

Cities worldwide are under tremendous pressure to cope with sustainable development goals and climate action to mitigate the negative burdens created by transport systems, advancing more inclusive and liveable urban spaces. In response, cities are developing and implementing bicycle plans essentially outlined on infrastructure provision, management and services, and strategies aimed at changing attitudes and travel behaviour to increase bicycle uptake in cities. In this study, we examined to what extent cycling planners address and prioritise equity-oriented strategies in planning practice and if such a perspective is considered in contrast to competing project priorities.

This research suggests that equity is not directly addressed and prioritised in cycling planning practice. The involved EU planning practitioners alleged that this concept is not fully apprehended and assessed due to the paucity of frameworks and indicators to measure equity progress in transport planning. Consequently, planning practitioners have frequently perceived the equity and egalitarian approaches as interchangeable. However, an egalitarian distributive framework seeks to provide the same level of

service and accessibility to all travellers (Lee et al., 2017; Litman, 2005), regardless of individual needs, abilities and limitations. Nevertheless, this study provides clues that planning practitioners do not ignore the importance of equity, with an increasing interest in fostering social participation in the decision-making process to develop a more holistic cycling strategy.

Although this study brings new insights into how EU planning practitioners located in distinct socioeconomic and geographic contexts address equity in cycling plans, it is essential to reiterate that the results of this study cannot be generalised. Bridging the gap between research and professional practice depends on robust networking and communicative skills to build trust and translate theoretical knowledge into practical information to support planning practitioners. Furthermore, finding suitable timeframes for focus groups and interviews can be challenging since practitioners are often overloaded with tasks and deadlines, presenting insufficient free time to participate in exploratory research activities.

In order to further explore the equity implications of cycling planning, future research could comparatively examine cities with an established bicycle culture and residual social disparities and cities facing severe problems of urban sprawl, increasing motorisation and socioeconomic segregation. Likewise, forthcoming studies can improve and expand the survey applied during the focus groups to a wider scale encompassing a variety of countries and geographic regions. Such an analysis may provide new evidence of how planning practitioners prioritise distinct measures and how equity prioritisation is affected by other planning criteria.

Another potential research pathway refers to expanding this research framework, including the perspective of policymakers and the directly impacted citizens. Fundamentally, to foster debate and raise awareness about the equity impact of active transport planning, it is paramount better understand the priorities, barriers, and values of those directly involved in planning and political decision-making processes.

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6
Conclusion

This doctoral thesis was motivated by a personal concern about the growing urban degradation and social inequalities associated with increasing motorisation levels in urban settings in both the global north and south. In order to reduce the negative impacts of transport systems, it is grounded on the assumption that fostering policies to promote active modes of transport such as cycling has the potential to address the multifaceted sustainable development approach. Nevertheless, among several priorities (i.e., economic development, environmental preservation and social equity) (Lucas et al., 2013; Manaugh et al., 2015), there is evidence that the equity dimension has been far less addressed in transport planning practice.

This research had three main objectives. Firstly, by building on the literature produced in the last decade, this research developed the PSS tool, TIRE, to quantitatively measure the equity impact of cycling plans. Then, this tool was tested in three European cities, focusing on how the increased cycling accessibility levels benefit different socioeconomic groups. Thirdly, from a qualitative perspective, this research examined to what extent equity issues are addressed and prioritised in cycling planning and decision-making processes in the European context. Hence, this thesis sought to provide compelling evidence through a mixed-methods approach and contribute to the active transport literature. Based on the three aforementioned objectives, this thesis sought to elucidate three main research questions and derived sub-questions.

Concerning the first research question, findings suggest that the PSS tool TIRE, developed and tested within the scope of this thesis, could be useful for assessing the equity impacts of cycling plans and encouraging the development of equity-oriented strategies. Throughout the focus groups, the planning practitioners positively perceived the PSS tool TIRE considering its user-friendliness and usefulness for planning practice.

To answer the second research question, the tool TIRE was calibrated for three different European cities to assess the equity impact of cycling infrastructure allocation and the distribution of accessibility levels across socioeconomic groups. The tool disclosed social-spatial asymmetries and fragmented hotspots across the assessed cities, suggesting that socioeconomically advantaged zones are likely to be better provisioned, with levels of bicycle accessibility above the municipality average. Comparatively, Munich and Helsinki (i.e., climber cycling cities) have the most equitable scenarios. On the one hand, Munich has a denser network covering the primary origin and destination points. On

the other hand, Helsinki has lower socioeconomic discrepancies. Finally, the starter cycling city Lisbon has a greater share of disadvantaged groups with lower bicycle accessibility conditions, with more concentration of cycling network and activities in the central zones compared to the outskirts.

This thesis employed a framework epistemologically oriented to the interpretivism and an inductive approach based on qualitative methods to explore if planners address and prioritise equity in planning practice and elucidate the third research question. The results suggest that the equity dimension is often overlooked in cycling planning, given that the equity concept is acknowledged as an intangible outcome and rarely discussed or perceived as a planning objective. Therefore, this concept is hardly measured and monitored in planning practice. Additionally, the content analysis of each BMP document suggests that equity issues are not directly measured through all planning guidelines, regardless of the remarks about accessibility, connectivity, and road safety concerns.

Throughout the qualitative analysis, this research suggests that equity is not directly prioritised or addressed over the selected case studies. Conversely, the results indicate a planning tendency towards an egalitarian approach as the assessed cities aim to provide bicycle infrastructure, management measures and services throughout the territory to normalise cycling without socioeconomic and demographic differentiation. Finally, this thesis brings evidence that planning practitioners do not ignore the importance of equity in planning and decision-making processes, with participants expressing growing interest in involving the local population and different stakeholders in the decision-making process to develop a more holistic cycling plan and overcome the dominant car-oriented mindset, social resistance and the lack of political commitment towards active modes of transport.

In sum, the main conclusions to be drawn from this thesis are:

- During the focus group at the starter cycling city, planning practitioners positively perceived the TIRE tool in all user-friendliness and usefulness dimensions, acknowledging potential applicability in planning practice;
- The results generated by the TIRE tool suggested that socioeconomically advantaged zones are likely to be better provisioned in the assessed case studies;
- The examined cycling plans indirectly address equity, often associated with road safety, public health, and environmental related-measures;
- The findings of the case studies suggest that equity is not at the top of priorities in cycling planning. Due to a general lack of indicators and theoretical-technical knowledge, equity is not prioritised, assessed, or monitored throughout the plan's implementation. Nevertheless, planning practitioners do not ignore the relevance of equity in planning practice.

6.1. RESEARCH CONTRIBUTIONS

Over the last decade, scholars have developed methods for examining the distribution of bicycle-related benefits in cities worldwide and the consequential social and spatial impacts. However, despite increasing research interest towards the ex-post impacts of cycling investments allocation, through the adaptation of economic measures (i.e., Gini coefficient, Lorenz Curve, Theil Index and Palma ratio), it remains unclear whether such indicators could encourage the development of holistic BMP and more equity-oriented strategies in planning practice. Moreover, due to the general shortfall of clear and suitable indicators for measuring equity progress in transport, cycling equity remains under debate with no concrete theoretical formulation.

In this sense, this thesis brings crucial contributions to the active transport literature in several ways. Firstly, cycling equity is conceptualised with regard to planning practice. The equity analysis of cycling plans and infrastructure allocation considers the average impact captured at the municipal level. This approach allows the comparative analysis of different municipality units, revealing deprived hotspots to be prioritised in future equity-oriented interventions.

Secondly, based on the cycling equity concept, this thesis introduces a novel PSS tool to measure the equity impact of cycling infrastructure allocation, which addresses ex-ante and ex-post perspectives. Based on the literature review (*Chapter 2*), no study has tried to bridge both perspectives in cycling planning based on the geo-visualisation of cycling infrastructure provision and the distributive effects of accessibility levels on advantaged and disadvantaged socioeconomic groups. Accordingly, through GIS, statistical analysis, and a bivariate choropleth mapping procedure, TIRE identifies and benchmarks four main distributive clusters with distinct bicycle accessibility levels and socioeconomic groups (*Chapter 3*).

Thirdly, this thesis discusses the potential transferability of the tool to different scenarios (*Chapter 4*). Testing TIRE in three different cities allowed the calibration of the tool and the identification of the primary implementation barriers concerning the input data. The method's strength lies in using an open database to collect data encompassing transport and land-use components to measure bicycle accessibility levels. Moreover, due to the absence of standardised socioeconomic data at the census tract level in Europe, this thesis produces a PCA-based index to examine the magnitude of socioeconomic disparities, operating common or similar variables collected over different cities, using mobility surveys or census data. Finally, this tool sought to fill the current gap in the literature, looking beyond adapted indicators from economics, with the geo-visualisation of the results into 2D maps with a gradual colour scale.

This thesis bridges the gap between research and planning practitioners, fostering debate on critical issues encompassing equity in cycling plans in European starter and climber cycling cities (*Chapter 5*). The practical experience with the tool TIRE has fostered awareness about the equity implications of cycling infrastructure allocation among the planning practitioners directly involved in the assessed BMP. The participants of the focus groups positively perceived the tool in its user-friendliness and usefulness dimensions, arguing that TIRE has a potential application in planning practice as a data-driven prioritisation tool. Moreover, the participants believe the tool TIRE could foster the involvement of citizens, policymakers, and other stakeholders in the decision-making process, contributing to the participatory dimension of equity. Given the general shortage of indicators to measure equity in active transport, planners believe the tool TIRE can support future equity-oriented interventions.

Finally, this thesis provides both quantitative and qualitative empirical evidence on how equity is addressed and prioritised in the European context. Above all, this thesis represents a step toward establishing a method for assessing the equity implications of cycling planning and infrastructure provision, creating an evidence base to encourage a shift towards equitable planning practices. All in all, such an equity-oriented framework aims to reinforce and elucidate the general principles of equity in planning practice to reduce inequalities in the distribution of cycling-related investments, ultimately increasing awareness about the equity impact of cycling infrastructure allocation.

6.2. RESEARCH LIMITATIONS

Albeit this thesis presents a novel research framework to assess the equity impact of BMP from both quantitative and qualitative perspectives, undercovering substantial empirical evidence from the European context, this research has certain caveats to be addressed in future research.

The tool TIRE has drawbacks related to the subjectivity of the method and the chosen variables. For instance, with regard to the accessibility metric (BA), the tool did not include adjustments for delays at traffic signals as the effect of the level of traffic stress on bicycle accessibility levels (Faghih Imani et al., 2019; Kent and Karner, 2019). Instead, the proposed contour measure sums up the activities available without weighting or distinguishing the attractiveness of each activity. On the one hand, scholars consider this measure easier to understand and interpret, with the highest potential to be apprehended by planners, practitioners, and stakeholders (El-Geneidy and Levinson, 2006; Geurs and van Wee, 2004). Nevertheless, on the other hand, this metric implies that even if the cycling network covers the entire municipality, the accessibility levels will be limited to the number of accessible opportunities, regardless of land use diversity.

Concerning the quantitative assessment, transferring the tool TIRE across distinct contexts is challenging and limited to the availability and compatibility of high-resolution data. Consequently, the chosen variables for the socioeconomic index (SE) varied according to the case study. For instance, whilst in Munich and Helsinki, the SE comprises employment, educational and income disparities, in Lisbon, the SE includes housing characteristics (i.e., dimensions, ownership) and mobility indicators (i.e., immobile people and automobile commuters), as income data is not freely available in local census database, at the desirable unit scale.

Furthermore, the qualitative analysis indicates that applying the TIRE in planning practice is not straightforward because its operationalisation requires specific knowledge of GIS and statistical tools and a deep understanding of the cycling equity concept. Therefore, building dialogue and capacity at the local level is paramount to addressing this limitation and bridging the gap between researchers, planning practitioners and other stakeholders. Finally, although this thesis brings new insights about the equity implications of BMP developed in starter and climber cycling cities, indicating to what extent planning practitioners based in Europe address equity in the planning and decision-making processes, it is essential to reiterate that the results of this thesis cannot be generalised.

6.3. FUTURE RESEARCH

The thesis limitations uncover several new research branches to be addressed in the future. Firstly, seeing that the analytical framework of the PSS tool TIRE is flexible, future studies can input different indicators to measure bicycle accessibility and the socioeconomic differentiation phenomenon, provided that the bivariate analysis and normalisation of indicators into clusters are maintained. For instance, one could measure bicycle accessibility by considering different travel-time thresholds, calibration and network characteristics, such as the gravity measure, which considers the activities' attractiveness (Vale et al., 2016). In addition, instead of using an aggregate index of interrelated variables, such as the proposed composite SE index, researchers and planners can input a single socioeconomic or demographic variable to assess the distribution of accessibility levels across specific disadvantaged socioeconomic groups (i.e., unemployed, illiterate, low-incomers), and minority and vulnerable representatives (i.e., elderly, children).

This thesis reveals that the tool TIRE has a potential application as a data-driven PSS tool. Nevertheless, to foster its implementation in planning practice, future research could convert the results generated by the tool into weights to be considered for a multi-criteria analysis. Scholars acknowledge that in planning practice, professionals usually rely on multi-criteria analysis to cope with several goals and priorities (Bulckaen et al., 2016; Manaugh et al., 2015). In that sense, TIRE results could offer the theoretical and practical grounds for including an equity-oriented slot in this prioritisation process to foster more equitable cycling planning practices.

Since the tool TIRE can be operated in both ex-ante and ex-post analysis, future research could assess the equity impact of BMP implementation over time in a longitudinal analysis. Accordingly, future research could automate the operationalisation of the tool TIRE, using programming tools. Accordingly, researchers and planners could verify the equity implications of several strategic measures throughout distinct stages of cycling network allocation, engaging in an in-depth discussion to minimise the equity gaps. These discussions should cover infrastructure-based measures, mobility management strategies, educational campaigns and programmes, and financial support to increase bicycle attractiveness among groups of concern.

Another future research pathway concerns rescaling the tool for the regional and national levels, examining to what extent the allowance of the bicycle into public transportation and bicycle-sharing systems at metro, bus and train stations can reduce access inequalities in cities. Such analysis could highlight crucial empirical evidence to support policymaking at the European level. Concerning other geographical and cultural contexts, the application of the tool TIRE to several case studies can bring greater diversity and solid empirical evidence to this debate. To that end, future research could assess cities facing severe urban sprawl problems, increasing motorisation, and deeper socioeconomic and spatial segregation.

Finally, another potential research pathway refers to expanding the target group of the qualitative analysis to include the perspective of policymakers, decision-makers, politicians, and the impacted citizens. This approach would require a more sophisticated framework to explore to what extent policymakers and politicians perceive the equity concept and how prioritising equity could affect the decision-making process. Likewise, the participation of citizens and NGO groups could bring new insights into the debate that has been limited mainly to professionals and researchers.

In a nutshell, the main future research pathways drawn from this thesis are:

- Developing and testing new indicators to measure bicycle accessibility and socioeconomic differentiation using TIRE analytical framework;
- Converting TIRE outputs into weights to be considered in a multi-criteria analysis, testing the usefulness of this approach with planning practitioners;
- Operating TIRE in both ex-ante and ex-post analysis to assess the equity impact of BMP implementation within a longitudinal analysis;
- Rescaling the tool for the regional and national levels;
- Applying TIRE to several case studies to foster greater diversity and solid empirical evidence to support planners and decision-makers;
- Expanding the target group of the qualitative analysis, including the perspectives of policymakers, decision-makers, politicians, and the impacted citizens, to foster the development of holistic and equitable BMP.

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ANNEX A1: PRE-WORKSHOP SURVEY

A1. Survey

This survey aims to identify the strategies and priorities adjacent to cycling planning in European cities. The collaboration in the research is anonymous and voluntary.

01. In planning and decision-making processes, how do you rate the importance given to the following priorities (1- Not at all important, 2- Low importance, 3- Neutral, 4-Important, 5- Very important)?

	1	2	3	4	5
Increasing bicycle use in the city	□	□	□	□	□
Reducing CO2 emissions	□	□	□	□	□
Increasing accessibility to activities (e.g., education, jobs)	□	□	□	□	□
Ensuring road safety	□	□	□	□	□
Social participation in planning and decision-making	□	□	□	□	□
Increasing recreational bike trips	□	□	□	□	□
Integrating new mobility services	□	□	□	□	□
Fostering local economy	□	□	□	□	□
Increasing commuting bike trips	□	□	□	□	□
Increasing the length (km) of the cycling network	□	□	□	□	□
Implementing traffic-calming measures	□	□	□	□	□
Encouraging bicycle use among vulnerable social groups	□	□	□	□	□
Expanding the bicycle-sharing system	□	□	□	□	□
Improving public space	□	□	□	□	□
Ensuring access to the cycling network	□	□	□	□	□
Promoting multimodality	□	□	□	□	□
Improving the connectivity of the cycling network	□	□	□	□	□
Expanding green areas	□	□	□	□	□
Mitigating the harmful effects of climate change	□	□	□	□	□
Accelerating the uptake of electric mobility	□	□	□	□	□
Decreasing private car use	□	□	□	□	□
Ensuring a suitable cost-benefit impact	□	□	□	□	□

02. In planning and decision-making processes, how do you rate the importance given to the following target groups and areas (1- Not at all important, 2- Low importance, 3- Neutral, 4-Important, 5- Very important)?

	1	2	3	4	5
Elderly	□	□	□	□	□

Disabled (Physically and cognitively)	□	□	□	□	□
Children	□	□	□	□	□
Youth	□	□	□	□	□
Working age Adults	□	□	□	□	□
Women	□	□	□	□	□
Economically disadvantaged groups	□	□	□	□	□
Students	□	□	□	□	□
Immigrants	□	□	□	□	□
Urban area	□	□	□	□	□
Rural area	□	□	□	□	□
High-density areas	□	□	□	□	□
Low-density areas	□	□	□	□	□
City centre	□	□	□	□	□
Outskirts of the city	□	□	□	□	□

03. Which analysis tools are commonly used in practice to measure the performance or impact of the planned cycling network?

05. Sociodemographic details:

Please indicate your age:

Identify your gender:

Please indicate which department you work in:

Please indicate your professional position and years of experience:

ANNEX A2: POST-WORKSHOP SURVEY

A2. Survey

This survey aims to evaluate the planning support tool TIRE presented during the workshop held with planning practitioners from the city councils. The collaboration in the research is anonymous and voluntary.

01. To what extent do you agree with the following statements (1- I totally disagree, 2- Disagree, 3- I neither agree nor disagree, 4- Agree, 5- I totally agree)?

	1	2	3	4	5
The TIRE tool is transparent to me	□	□	□	□	□
The communicative value of the TIRE tool is high	□	□	□	□	□
The TIRE tool is easy to use	□	□	□	□	□
The generated results are credible	□	□	□	□	□
The tool is comprehensive enough	□	□	□	□	□
The focus of the tool is specific enough	□	□	□	□	□
The level of detail of the maps is sufficient	□	□	□	□	□
The tool is easy to understand	□	□	□	□	□
The tool supports the exchange of ideas	□	□	□	□	□
The tool facilitates the evaluation of alternatives	□	□	□	□	□
The tool supports the creation of ideas	□	□	□	□	□
The tool has created awareness about a new paradigm	□	□	□	□	□
My perception of equity has improved	□	□	□	□	□
We had a shared vision of the strategies and solutions	□	□	□	□	□
Ensuring access to the cycling network	□	□	□	□	□
I am confident that the group's solution is adequate	□	□	□	□	□
The session was time-efficient	□	□	□	□	□
I am satisfied with the session	□	□	□	□	□
We had conflicts during the session	□	□	□	□	□

02. Do you have any other observations to make about the TIRE tool? (e.g., strengths and limitations)

ANNEX B1: SEMI-STRUCTURED INTERVIEW

Focus Group and Individual interviews – Questions guide

1) Currently, what are the ultimate BMP goals/priorities? Could you describe them?
2) Which of the BMP priorities would you consider more important or urgent?
3) How have equity-related strategies been considered as part of the development of the BMP?
4) Do you believe conflicts exist between equity-related planning strategies and other planning priorities?
5) What are the main barriers faced while prioritising equity-related strategies?
6) Based on your professional background and knowledge, how could planners put the equity agenda into the scale of planning priorities?
7) Do you believe the tool TIRE has helped you to create awareness about the equity impacts of cycling infrastructure allocation?
8) In your opinion, to what extent TIRE can contribute in the future to the development of equity-oriented strategies?

ANNEX C1: INFORMED CONSENT – INTERVIEW

PhD Thesis Title: Bicycle Accessibility Planning towards an Equitable Approach

PhD researcher: Isabel Bezerra da Cunha

Supervisor: Cecília Silva

Doctoral Program: Spatial Planning

We kindly request your collaboration in the PhD thesis entitled "Bicycle Accessibility Planning towards an Equitable Approach", which aims to identify the strategies and priorities adjacent to the development of the municipal cycling mobility plan.

This research encompasses one online interview, which will be held remotely on the ZOOM platform. During the interview, the moderator will present a tool to support cycling planning - TIRE. This activity is organised interactively, and participants can ask questions and discuss the results presented by the tool. In addition, the session will be recorded (in audio format) for research purposes. Therefore, only the researcher and the supervisor will access the files.

The data will be stored in protected digital files during the qualitative analysis, which lasts about two months. After the end of the research, the data collected will be destroyed. To ensure anonymity, no publication from this research will reveal the participant's name. Any data that may identify the participant will be omitted in the dissemination of the research results. The results will be disseminated in scientific articles and in the PhD Thesis in Spatial Planning.

The collaboration in the research is voluntary, and the respondent will have the right not to participate or to withdraw at any time without any compromise in the collaboration provided. Specific questions about the processing of your data or the rights you can exercise as a data subject can also be addressed to the Data Protection Officer of the University of Porto at dpo@reit.up.pt.

The PhD candidate Isabel Bezerra da Cunha can be contacted at any time in case of questions or issues through the following e-mails isabelcunha.arqurb@gmail.com, up201607875@up.pt and mobile phone +351 939742891.

I, _____, declare that I was informed about the research objectives, and I deliberately agree to contribute to the research mentioned above.

_____, ____ of _____ of 2023.

The declarant,

_____

ANNEX C2: INFORMED CONSENT – FOCUS GROUP

PhD Thesis Title: Bicycle Accessibility Planning towards an Equitable Approach

PhD researcher: Isabel Bezerra da Cunha

Supervisor: Cecília Silva

Doctoral Program: Spatial Planning

We kindly request your collaboration in the PhD thesis entitled "Bicycle Accessibility Planning towards an Equitable Approach", which aims to identify the strategies and priorities adjacent to the development of the municipal cycling mobility plan.

This research encompasses one workshop and two surveys. The workshop will last 1h30 and will be held remotely on the ZOOM platform. During the workshop, the moderator will present a tool to support cycling planning. This activity is organised interactively, and participants can ask questions and discuss the results presented by the tool. In addition, the session will be recorded (in audio format) for research purposes. The surveys will remain confidential and completed on the Google Forms online platform to identify the strategies and priorities adjacent to the local cycling planning.

Therefore, only the researcher and the supervisor will access the files. The data will be stored in protected digital files during the qualitative analysis, which lasts about two months. After the end of the research, the data collected will be destroyed. To ensure anonymity, no publication from this research will reveal the participant's name. Any data that may identify the participant will be omitted in the dissemination of the research results. The results will be disseminated in scientific articles and in the PhD Thesis in Spatial Planning.

The collaboration in the research is voluntary, and the respondent will have the right not to participate or to withdraw at any time without any compromise in the collaboration provided. Specific questions about the processing of your data or the rights you can exercise as a data subject can also be addressed to the Data Protection Officer of the University of Porto at dpo@reit.up.pt.

The PhD candidate Isabel Bezerra da Cunha can be contacted at any time in case of questions or issues through the following e-mails isabelcunha.arqurb@gmail.com, up201607875@up.pt and mobile phone +351 939742891.

I, _____, declare that I was informed about the research objectives, and I deliberately agree to contribute to the research mentioned above.

_____, ____ of _____ of 2023.

The declarant,

_____

ANNEX D1: LITERATURE REVIEW TABLE

Table 20 – Overview of Bicycle Benefits and Distributive Frameworks

DISTRIBUTIVE FRAMEWORK					
Literature	**Country**	**Bicycle Benefits**	**Units of analysis**	**Population Segments**	**Methods**
(Barajas and Braun, 2021)	USA	Health	Bicycle users	Age, Education, Employment, Gender Income, Ethnicity, Race	Census, Survey, Regression model
(Braun, 2021)	USA	Trips	Cycling network	Education, Employment, Income, Ethnicity, Family composition, Housing tenure, Poverty and Race	Regression model
(Cusack, 2021)	USA	Trips	Bicycle users	Age, Gender, Education level, Employment, Ethnicity, Race, Occupation (Workers)	Survey, Statistical analysis, Regression model
(de Alba-Martínez et al., 2021)	Mexico	Accessibility	Cycling network	Students	GIS, Principal Component analysis, Cluster analysis
(Duran-Rodas et al., 2021)	Germany	Infrastructure Service Accessibility	Bicycle Sharing Grocery, Healthcare Public transport	Education, Immigrants, Income, Occupation	Accessibility measure Regression model
(Ferenchak and Marshall, 2021)	USA	Infrastructure coverage	Cycling network	Ethnicity, Income, Race	Census, Multi-level regression model
(Firth et al., 2021)	Canada	Infrastructure Trips	Cycling network	Age, Education, Ethnicity, Immigrants	Census, Statistical analysis
(Fischer and Winters, 2021)	Canada	Infrastructure Accessibility	Cycling network	Age, Ethnicity, Income, Race	Accessibility measure, Spatial analysis Descriptive statistics
(Mora et al.,	Chile	Accessibility	Cycling network	Cyclists, Education, Housing tenure,	Accessibility measure

2021)			Jobs	Income	
(Moran, 2021)	USA	Infrastructure coverage	Bicycle Sharing	Age, Education, Income, Housing tenure, Family, Physical disability	Census, Spatial analysis
(Russell et al., 2021)	New Zealand	Trips Safety	Bicycle users	Gender	Focus group
(Saud and Thomopoulos, 2021)	Chile	Infrastructure Accessibility	Bicycle Sharing	Cyclists, Income	Survey, Interviews, Observation studies
(Standen et al., 2021)	Australia	Accessibility Health	Cycling network	Age, Gender, Income	Accessibility measure, Survey
(Stehlin and Payne, 2021)	USA	Infrastructure	Bicycle Sharing	Ethnicity, Income	Survey, Spatial analysis, Interviews, Site observation studies
(Parker et al., 2021)	USA	Infrastructure	Cycling network	Gender, Education level, Employment, Income, Health deprivation Housing tenure, Occupation, Race	Census, Statistical analysis Spatial analysis
(Tortosa et al., 2021)	UK	Trips	Cycling network	Age, Education level, Ethnicity, Employment, Gender, Housing, Income,	Survey, Descriptive statistics, Multilevel regression models
(Caggiani et al., 2020)	-	Infrastructure Accessibility	Bicycle sharing	Income	Accessibility measure, Theil Index
(Sagaris et al., 2020)	Chile	Infrastructure Accessibility Inclusiveness	Cycling network	Age, Gender, Income, Ethnicity, Capabilities	Workshop
(Grimes and Smirnova, 2020)	USA	Trips Accessibility Health	Bicycle sharing	Homelessness men	In-depth, open-ended interviews
(Rosas-Satizábal et al., 2020)	Colombia	Accessibility	Jobs and Education	Cyclists	Accessibility measure, Cluster Analysis, Gini index, Lorenz Curve, Palma Ratio
(Duran-Rodas et	Germany	Infrastructure	Bicycle Sharing	Social status and values	Accessibility measure, Gini index,

al., 2020)					Service area analysis, Interviews
(Qian and Jaller, 2020)	USA	Trips	Bicycle Sharing	Car ownership, Employment status, Income	Statistical analysis
(Lovelace et al., 2020)	UK	Inclusiveness Trips	Bicycle Sharing	Cyclists	Statistical analysis
(Maas et al., 2020)	Spain	Trips	Bicycle Sharing	Cyclists	Survey and Statistical analysis
(Chen and Wang, 2020)	USA	Accessibility	Jobs, Education, Restaurant, Church, Library and Parks	Age, Car ownership, Education, Income, Poverty, Race	Accessibility measure, Network analysis
(Qian et al., 2020)	USA	Service	Bicycle Sharing	Age, Car ownership, Education, Income, Ethnicity, Family composition, Housing tenure Physical disability and Race	Service area analysis
(Zuo et al., 2020)	USA	Accessibility	Public transportation	Income, Race	Accessibility measure, Atkinson index. Theil index
(Reilly et al., 2020)	USA	Trips	Bicycle Sharing	Gender	Survey and Statistical analysis
(Böcker and Anderson, 2020)	Norway	Inclusiveness Trips	Bicycle Sharing	Cyclists	Statistical analysis
(Ravensbergen et al., 2020a)	Canada	Safety	Cycling network	Citizenship status	Semi-structured interviews
(Barajas, 2020)	USA	Trips	Cycling network	Citizenship status, Income	In-depth interviews
(Iglesias et al., 2019)	Chile	Trips	Cycling network, Jobs, Education	Cyclists, Income	OD Survey, Statistical analysis
(Hamidi et al., 2019)	Sweden	Infrastructure	Cycling network	Citizenship status	Accessibility measure, Theil index
(Bhuyan et al., 2019)	USA	Infrastructure	Bicycle Sharing	Age, Car ownership, Ethnicity, Income, Poverty, Race	Accessibility measure, Atkinson index and RMD, Theil index

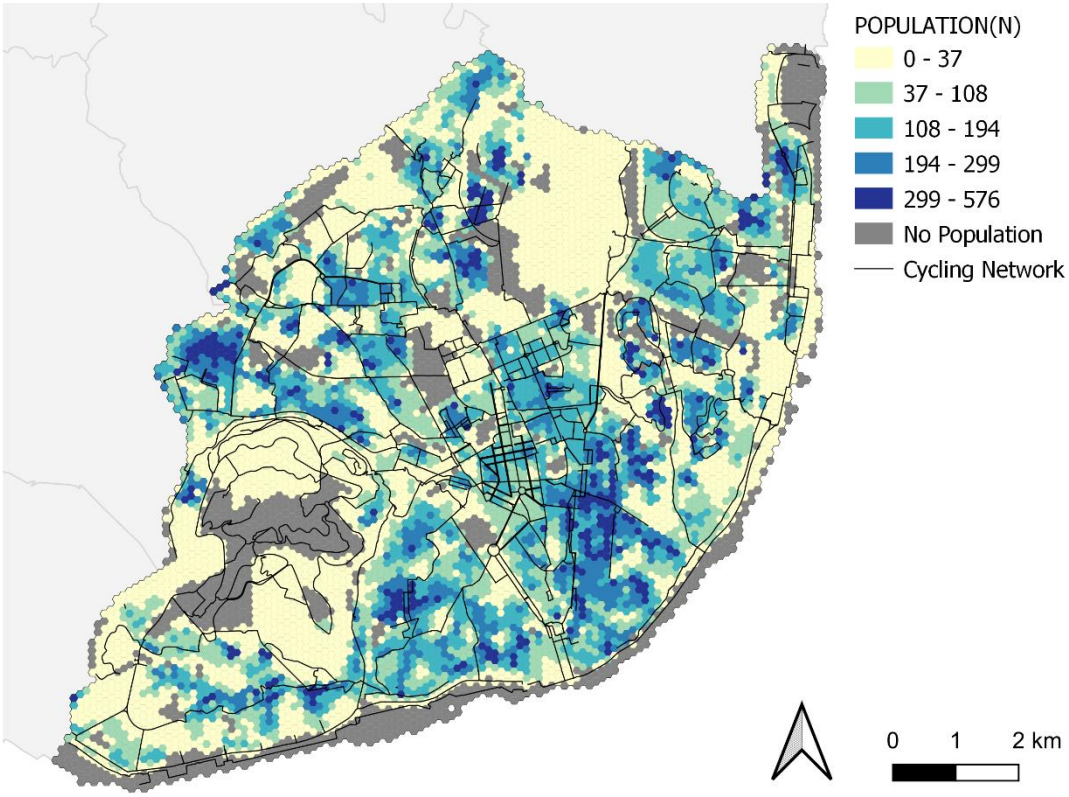
(Braun et al., 2019)	USA	Infrastructure	Cycling network	Education, Ethnicity, Income, Poverty, Race	Statistical analysis
(Qian and Wu, 2019)	USA	Health	Cycling network	Ethnicity, Income, Race	Spatial analysis, OD Matrix, Statistical analysis
(Barajas, 2019)	USA	Trips	Cycling network	Citizenship status	Survey and Statistical analysis
(Qian and Niemeier, 2019)	USA	Accessibility	Jobs and Essential Services	Ethnicity, Income, Race, Public Transport users	Accessibility measure, Network Analysis
(Wang and Lindsey, 2019)	USA	Trips	Bicycle Sharing	Car ownership, Education, Employment status, Ethnicity, Income, Poverty, Race	Statistical analysis
(Babagoli et al., 2019)	USA	Health	Bicycle Sharing	Poverty	Spatial analysis, HEAT, Statistical analysis
(Chen et al., 2019)	USA	Infrastructure Accessibility	Bicycle Sharing	Age, Ethnicity, Gender, Income, Race	Accessibility measure, Statistical analysis Gini Index and Lorenz curve
(Hirsch et al., 2019)	USA	Infrastructure Trips	Bicycle Sharing	Age, Gender, Housing tenure, Race	Survey and Statistical analysis
(Pritchard et al., 2019b)	Brazil	Accessibility Infrastructure	Jobs, Cycling Network	Employment status, Income,	Accessibility measure, Cluster analysis
(Kent and Karner, 2019)	USA	Accessibility	Supermarket, Pharmacy, Bank, Library	Car ownership, Ethnicity, Income, Poverty	Accessibility measure, Statistical analysis, Quintiles distribution
(Rebentisch et al., 2019)	USA	Safety	Cycling network	Income	Statistical analysis, Quintiles distribution
(Parker, 2019)	USA	Trips	Cycling network	Homeless	Ethnographic analysis
(Tan et al., 2019)	China	Trips	Cycling network	Education, Employment status, Income,	Statistical analysis
(Marshall and Ferenchak,	USA	Safety	Cycling network Bicycle users,	Age, Ethnicity, Income	Census, Survey, Statistical analysis, Regression model

2019)			Fatalities, Injuries		
(Mahmoudi et al., 2019)	USA	Trips	Cycling network	Income, Race	Spatial Analysis, Focus groups
(Mooney et al., 2019)	USA	Infrastructure Accessibility	Bicycle sharing	Age, Education, Income	Census, Survey, Accessibility measure, Spatial analysis
(Candipan, 2019)	USA	Trips	Cycling network	Gender, Ethnicity, Race	Observation studies
(Lubitow et al., 2019)	USA	Trips	Cycling network	Gender, Race	In-depth interviews
(Hosford and Winters, 2018)	Canada	Trips Health	Bicycle sharing	Age, Gender, Income	System data, Survey, Statistical analysis, Regression model
(Abasahl et al., 2018)	USA	Trips	Cycling network, Bicycle, Education	Age, Gender, Income, Occupation	Survey, Statistical analysis
(Winters et al., 2018)	Canada	Infrastructure	Cycling network	Income	Spatial analysis, Quintiles distribution, Statistical analysis
(Hosford and Winters, 2018)	Canada	Infrastructure	Bicycle Sharing	Age, Education, Employment status, Income,	Network analysis and Statistical analysis
(Frater and Kingham, 2018)	New Zealand	Health	Cycling network	Age, Gender	Survey and Focus groups
(Goodman and Aldred, 2018)	UK	Trips	Cycling network	Age, Car Ownership, Education, Gender, Physical disability	Survey analysis
(Houde et al., 2018)	Canada	Infrastructure	Cycling network	Age, Citizenship status, Income	Census data, Network analysis, Statistical analysis
(Grisé and El-Geneidy, 2018)	Canada	Trips	Bicycle facilities	Citizenship status, Employment status, Housing tenure, Income	Deciles distribution, Spatial analysis, Statistical analysis
(Tucker and Manaugh, 2018)	Brazil	Accessibility, Infrastructure	Commerce cycling network	Income	Accessibility measure, Spatial analysis, Statistical analysis, Quintiles distribution

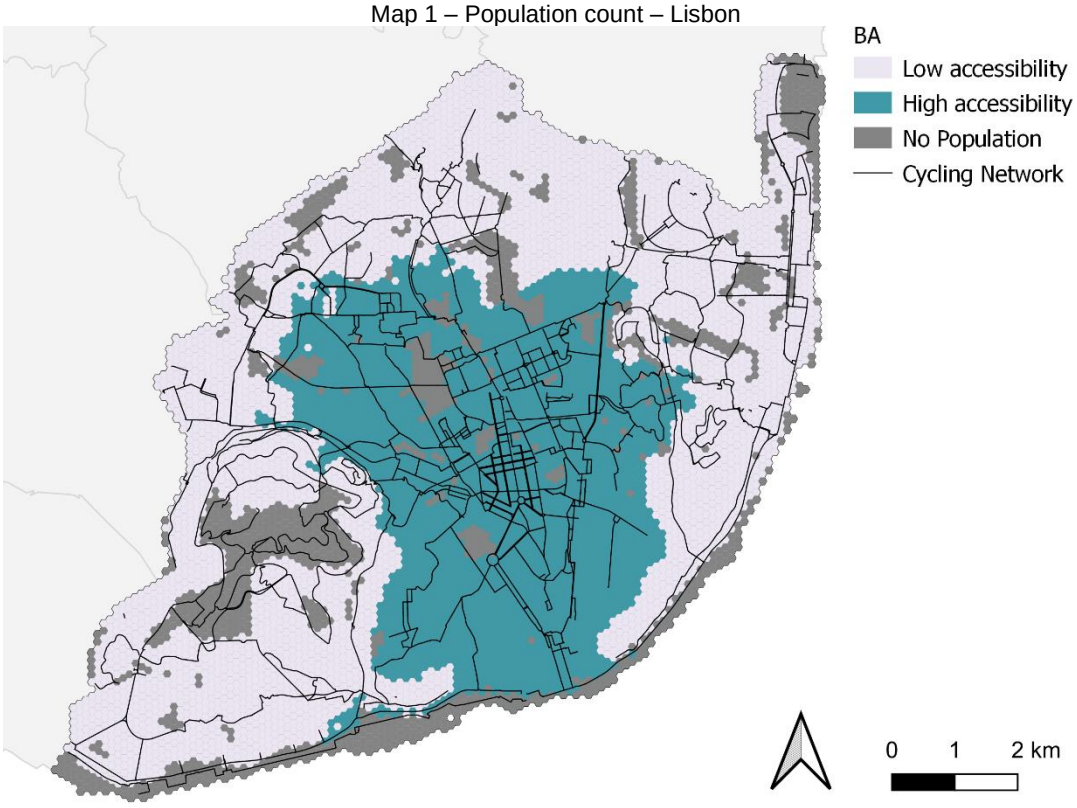
(Rahman et al., 2018)	USA	Health, Safety	Cycling network	Ethnicity, Income, Race	Survey and Spatial analysis
(Reid-Musson, 2018)	Canada	Trips	Cycling network	Citizenship status	Interviews and Qualitative analysis
(Parra et al., 2018)	Colombia	Accessibility Infrastructure	Cycling network	Age, Gender, Housing, Immigrants	Spatial analysis
(Cardona et al., 2017)	Colombia	Accessibility Infrastructure	Bike sharing	Income	Accessibility measure, Spatial analysis
(Lovelace et al., 2017)	UK	Trips	Cycling network	Gender	OD Survey
(Ji et al., 2017)	China	Accessibility, Infrastructure	Bike Sharing, Rail transit	Age, Employment Status, Gender, Income	Survey, Statistical analysis, Interviews
(Wang and Lindsey, 2017)	USA	Accessibility	Jobs	Age, Car ownership, Ethnicity, Poverty, Race,	Accessibility measure, Gini coefficient
(Chandra et al., 2017)	USA	Accessibility	Jobs	Income	Accessibility measure, Spatial analysis
(Lusk et al., 2017)	USA	Trips	Cycling network	Ethnicity, Income, Race	Observation analysis, Interviews
(Aldred et al., 2016)	UK	Trips	Cycling network	Age, Gender	Census and Statistical analysis
(Clark and Curl, 2016)	UK	Infrastructure	Bicycle Sharing	Age, Car ownership, Education, Employment status, Ethnicity, Gender, Housing tenure, Travel mode	Network analysis
(Gavin et al., 2016)	USA	Trips	Bicycle Sharing	Age, Education, Ethnicity, Gender, Income, Race	Statistical analysis
(Flanagan et al., 2016)	USA	Infrastructure	Cycling network	Education, Income, Age, Race, Ethnicity, Employment status, Housing tenure	Census and Statistical analysis
(Teunissen et	Colombia	Infrastructure	Cycling network	Income	Network analysis and Statistical

al., 2015)					analysis
(Sheller, 2015)	USA	Trips	Sustainable mobility network	Race	Qualitative analysis, Observation analysis
(Wahlgren and Schantz, 2014)	Sweden	Trips	Cycling network	Age, Education, Gender, Income	Spatial and Statistical analysis
(Harms et al., 2014)	Netherlands	Trips	Cycling network	Gender, age	Survey and Statistical analysis
(Macmillan et al., 2014)	New Zealand	Trips Health	Cycling network	Cyclists	System dynamics modeling
(Goodman et al., 2013)	UK	Trips	Cycling network	Education, Employment, Health deprivation, Housing tenure, Income, Physical disability	Census and Statistical analysis
(Davison et al., 2013)	Canada	Health	Cycling network	Age	Survey and Statistic Analysis
(Lugo, 2013)	USA	Trips	Cycling network	Cyclists	Ethnographic analysis
(Torres et al., 2013)	Colombia	Trips Health	Cycling network	Age, Car ownership Education, Gender, Income, Family. Occupation	Survey, Statistical analysis, Regression model

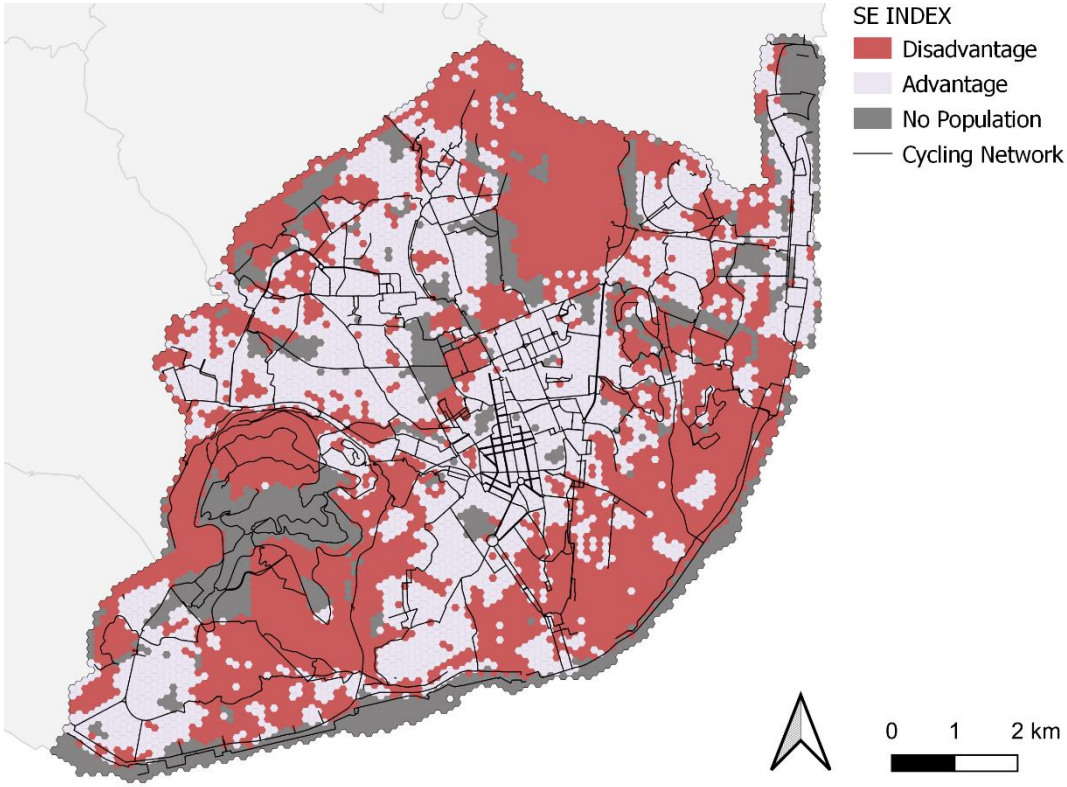
ANNEX E1: CASE STUDY (LISBON, PORTUGAL)



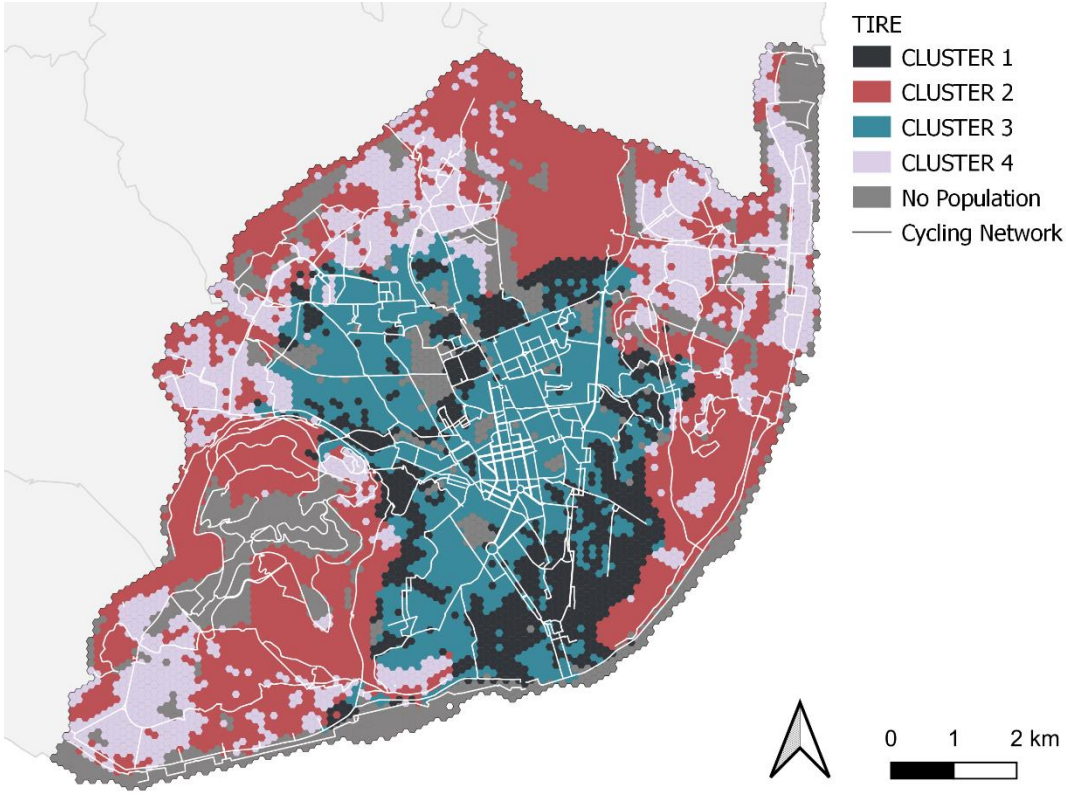
Map 1 – Population count – Lisbon



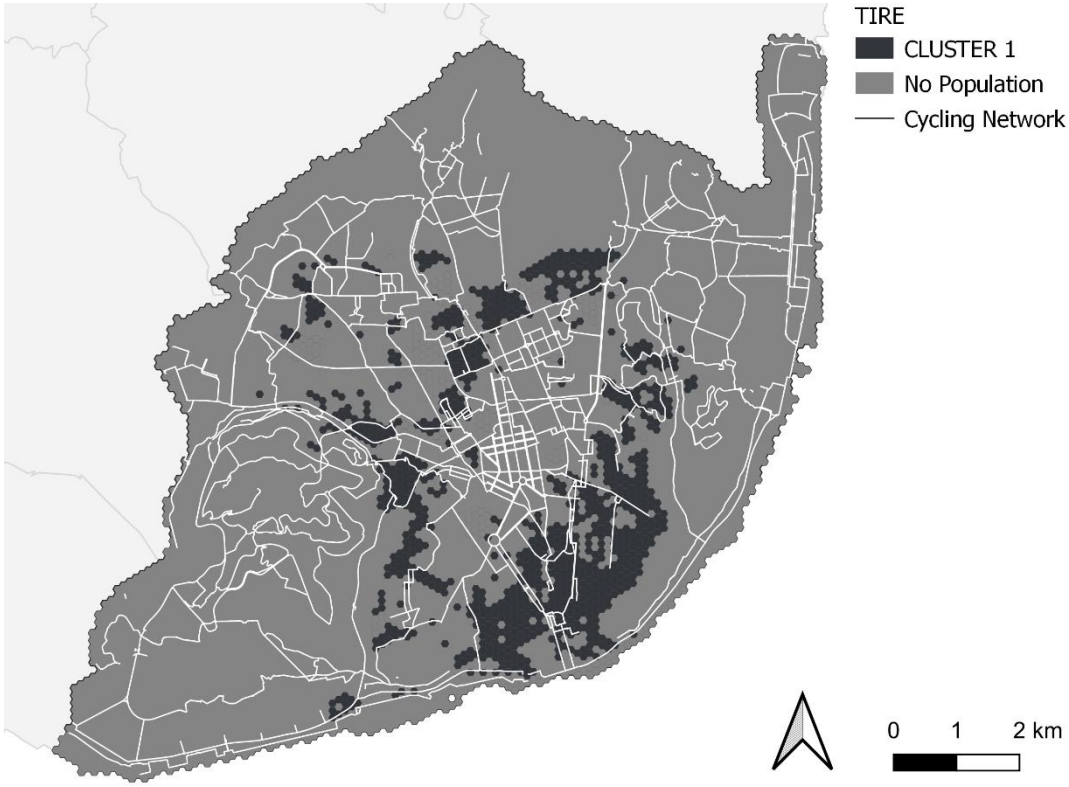
Map 2 – Bicycle Accessibility – Lisbon



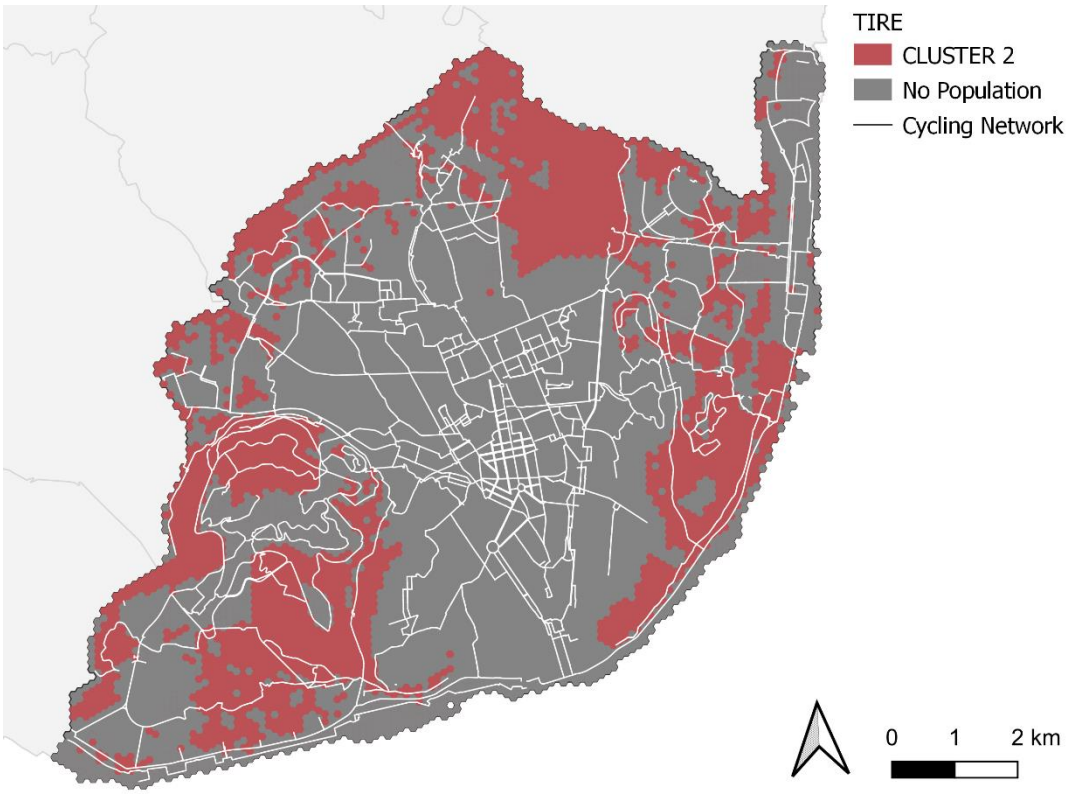
Map 3 – SE index – Lisbon



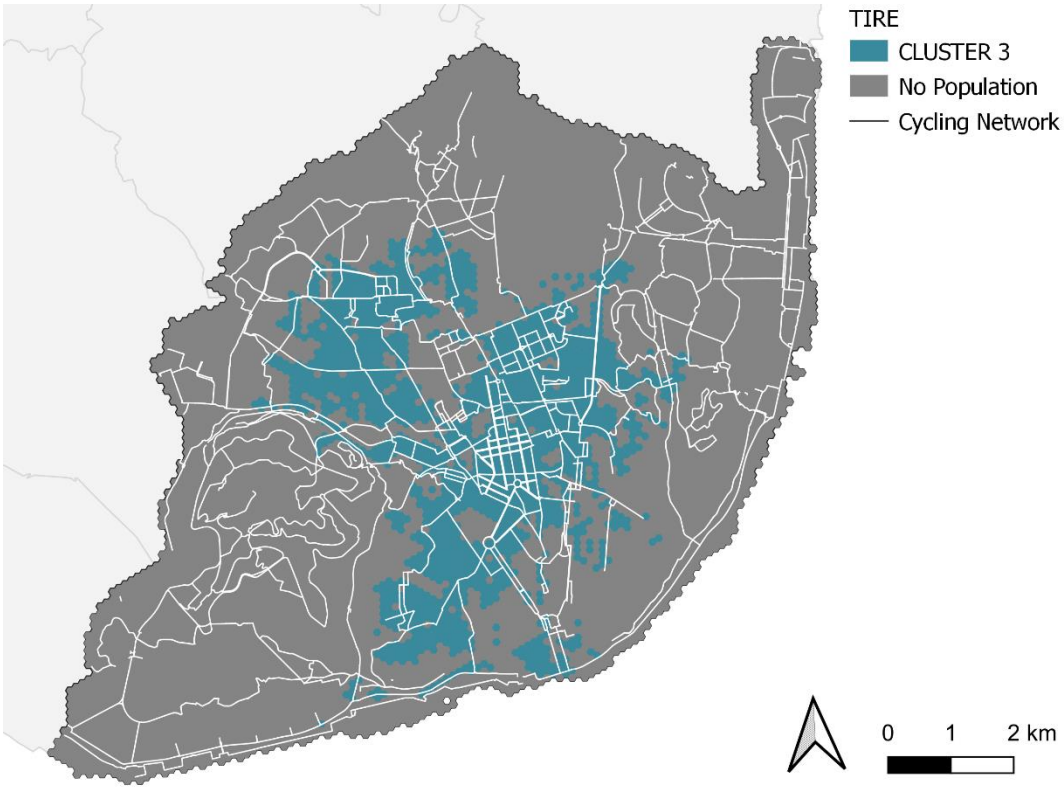
Map 4 – TIRE – Lisbon



Map 5 – Cluster I – Lisbon



Map 6 – Cluster II – Lisbon



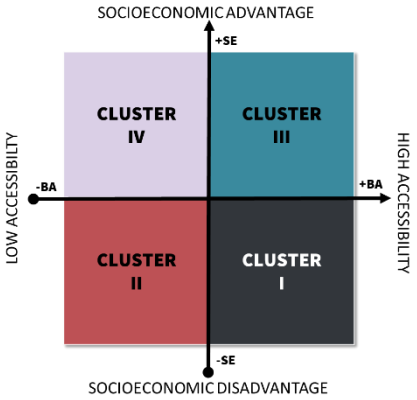
Map 7 – CLUSTER III – Lisbon



Map 8 – CLUSTER IV – Lisbon

Table 21 – TIRE results – Lisbon

Clusters	Population	Area	Activities
I	20.2 %	14.41%	140
II	26.8%	39.09%	24
III	30.7%	24.61%	148
IV	22.6%	21.09%	27



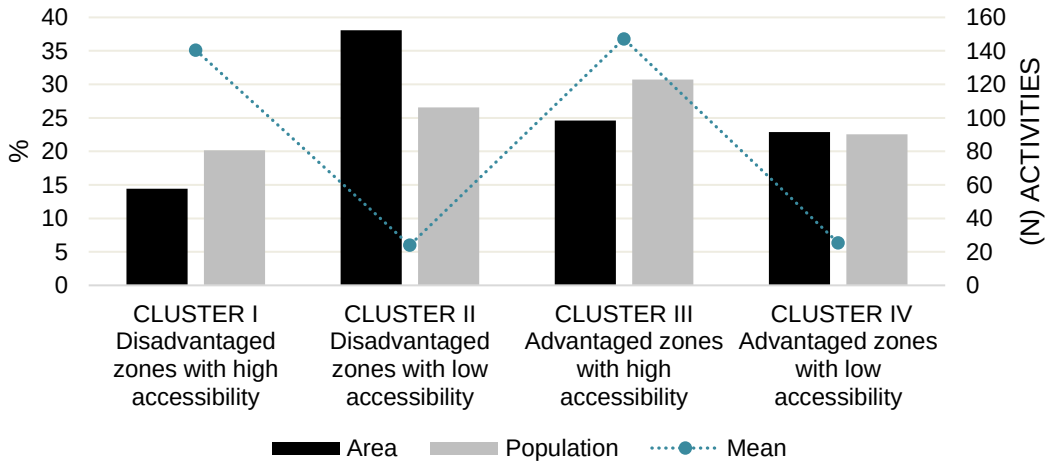


Fig. 38 – TIRE CLUSTERS – Lisbon

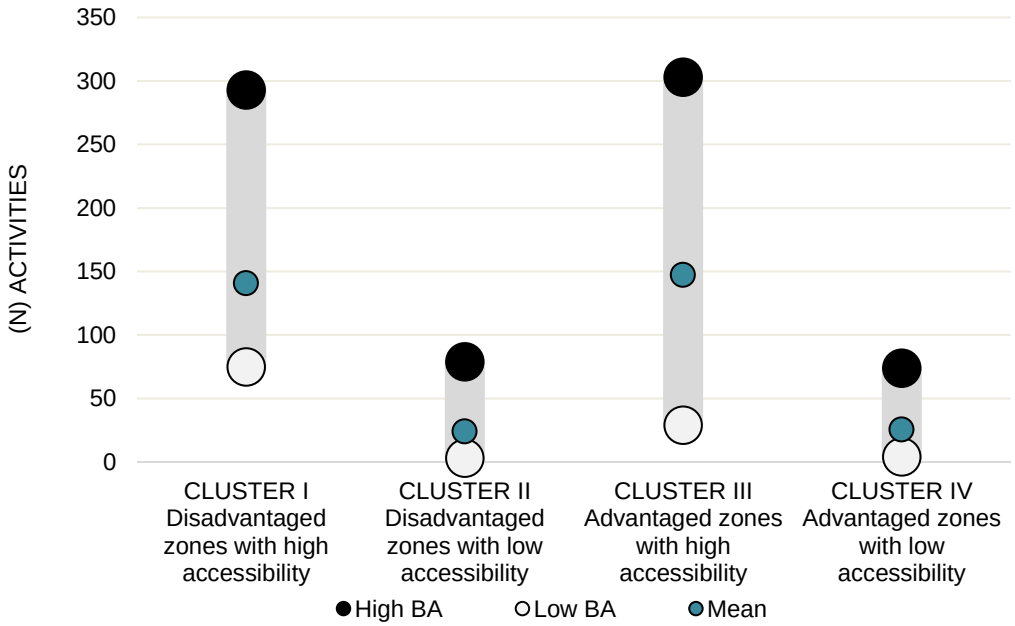
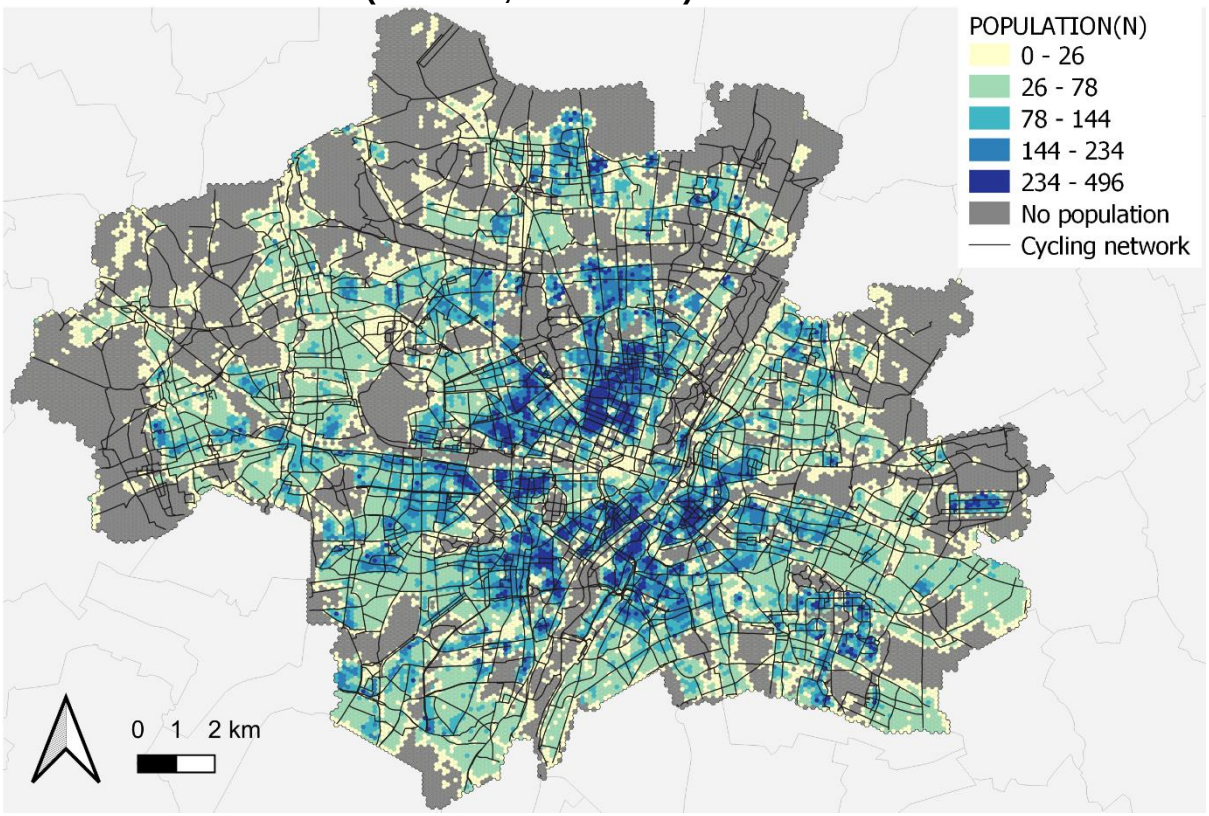
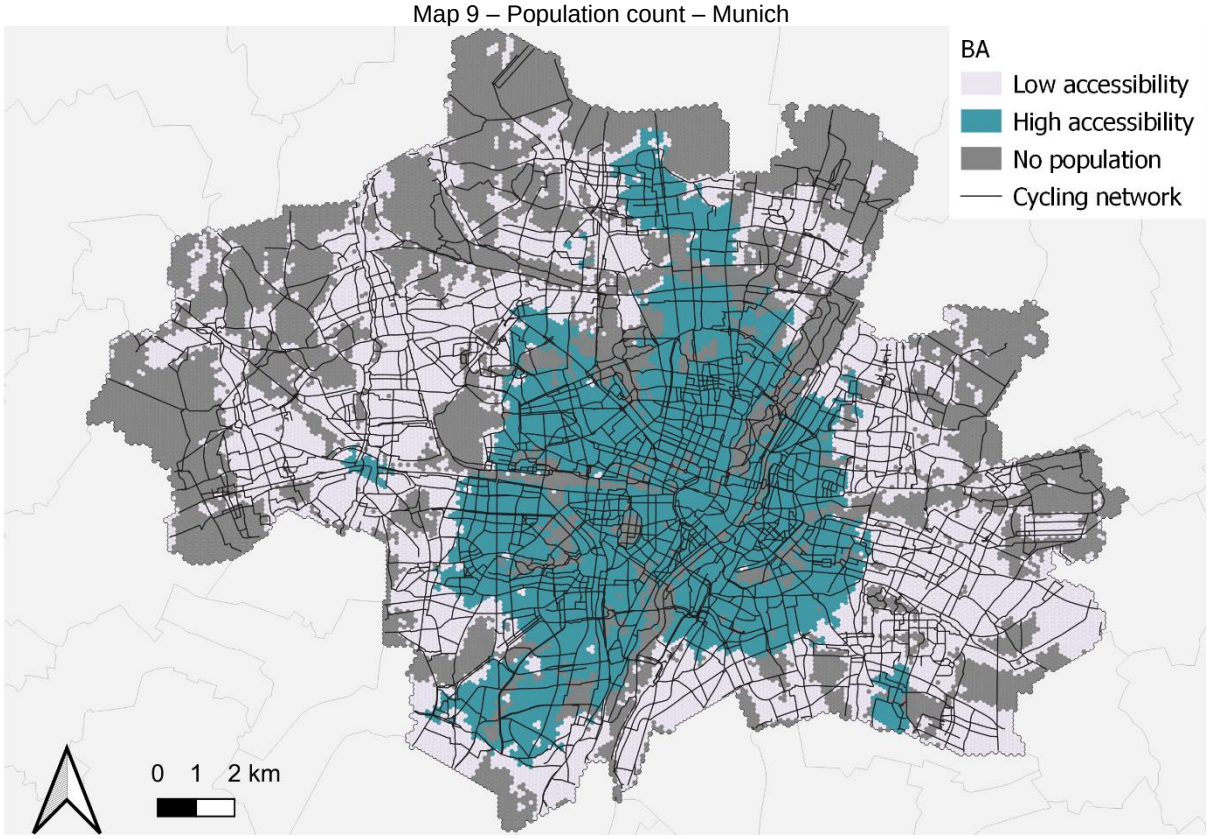


Fig. 39 – TIRE CLUSTERS SIZES – Lisbon

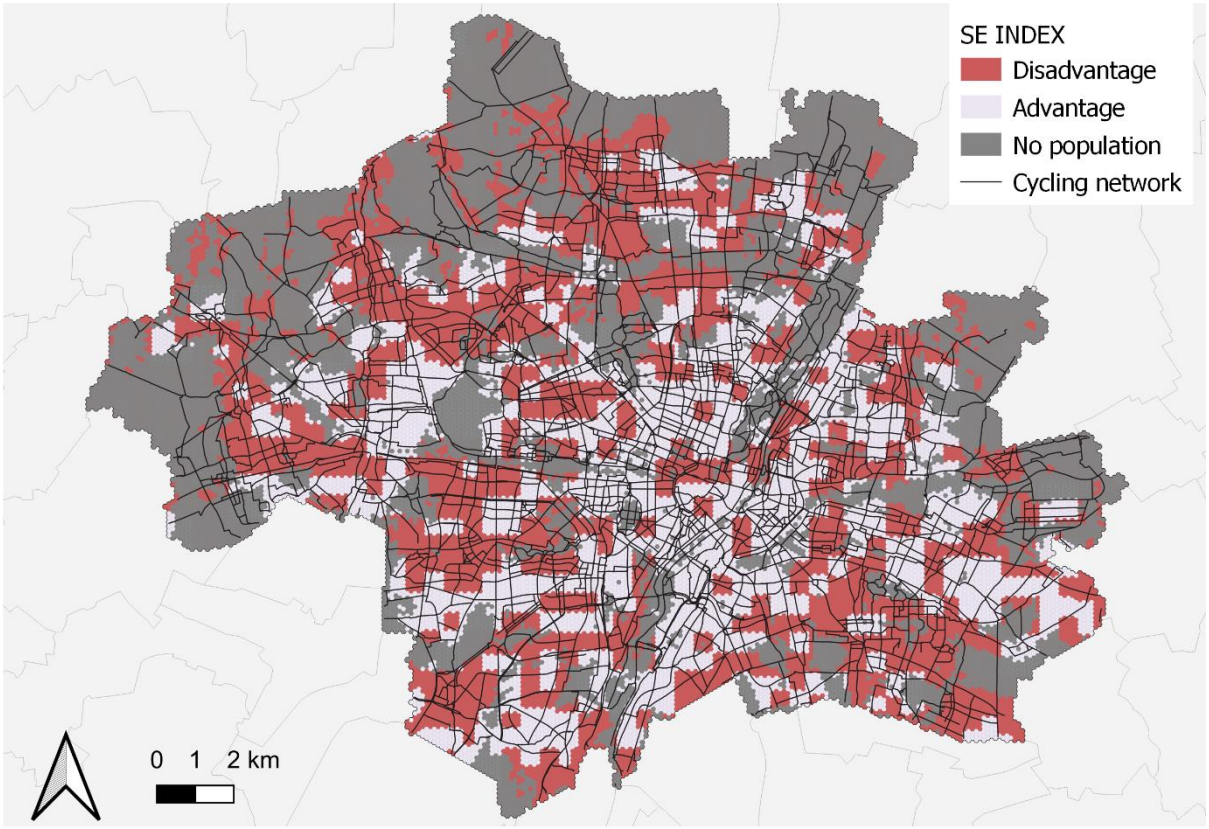
ANNEX E2: CASE STUDY (MUNICH, GERMANY)



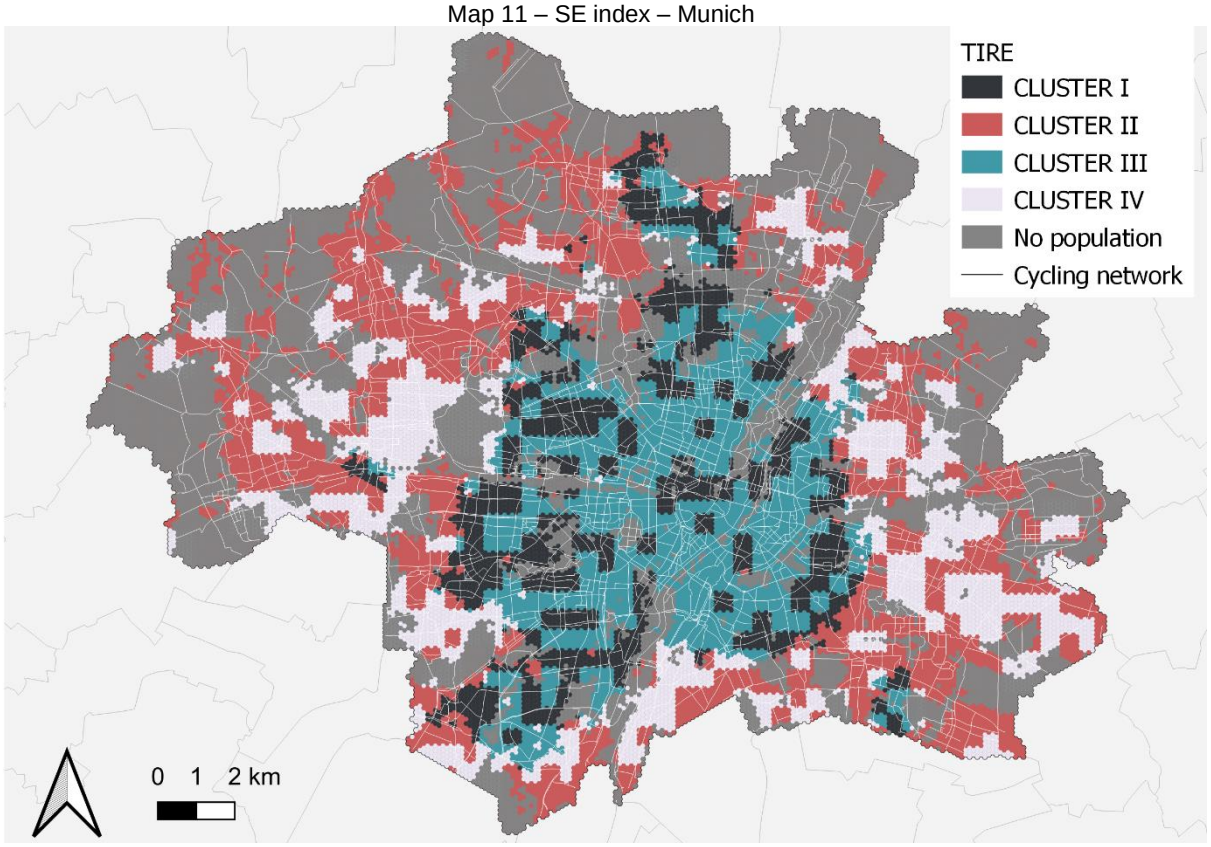
Map 9 – Population count – Munich



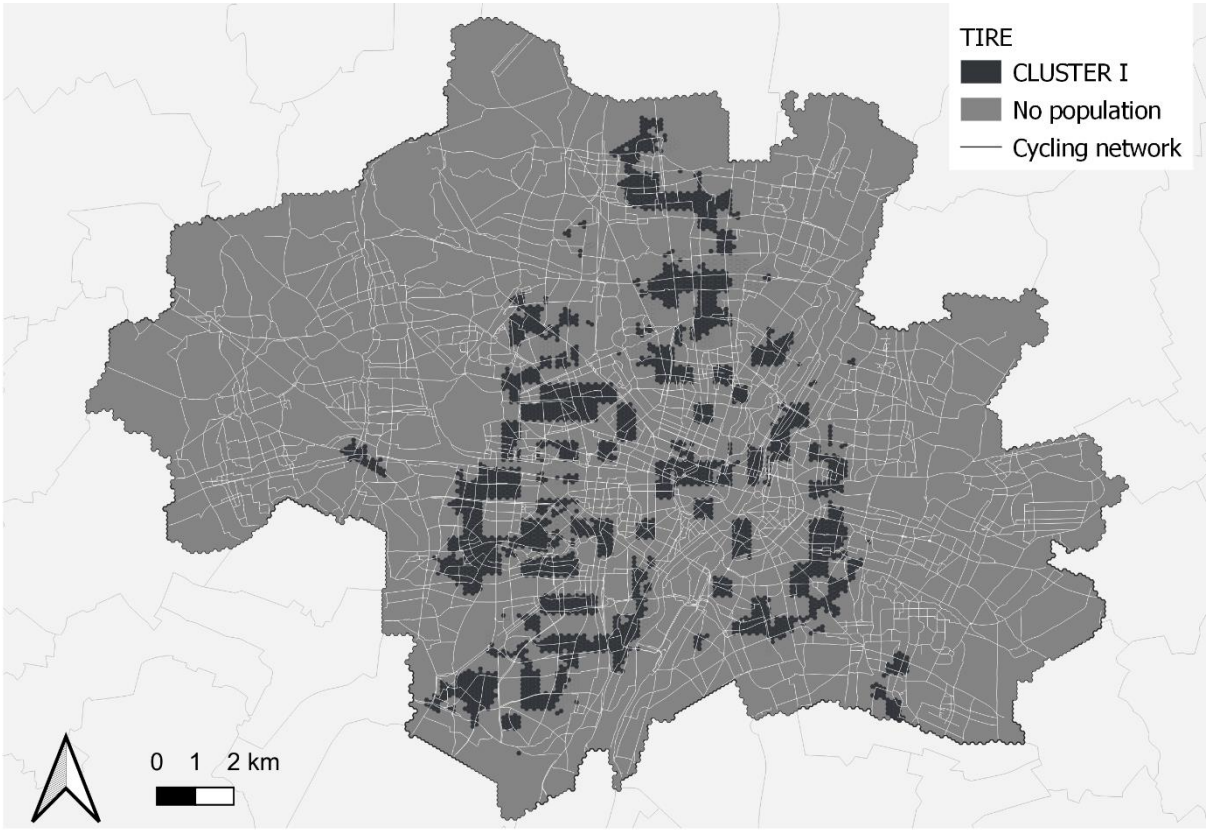
Map 10 – Bicycle Accessibility – Munich



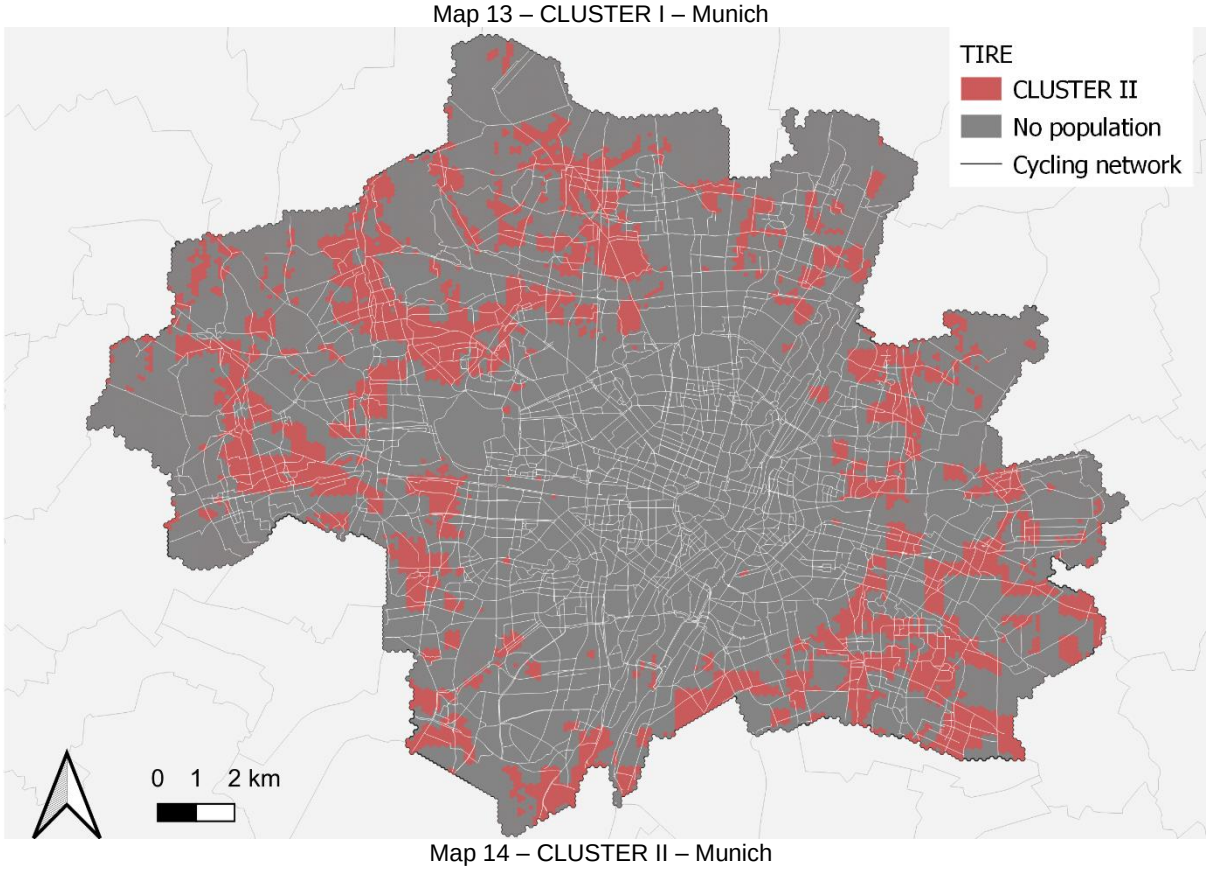
Map 11 – SE index – Munich



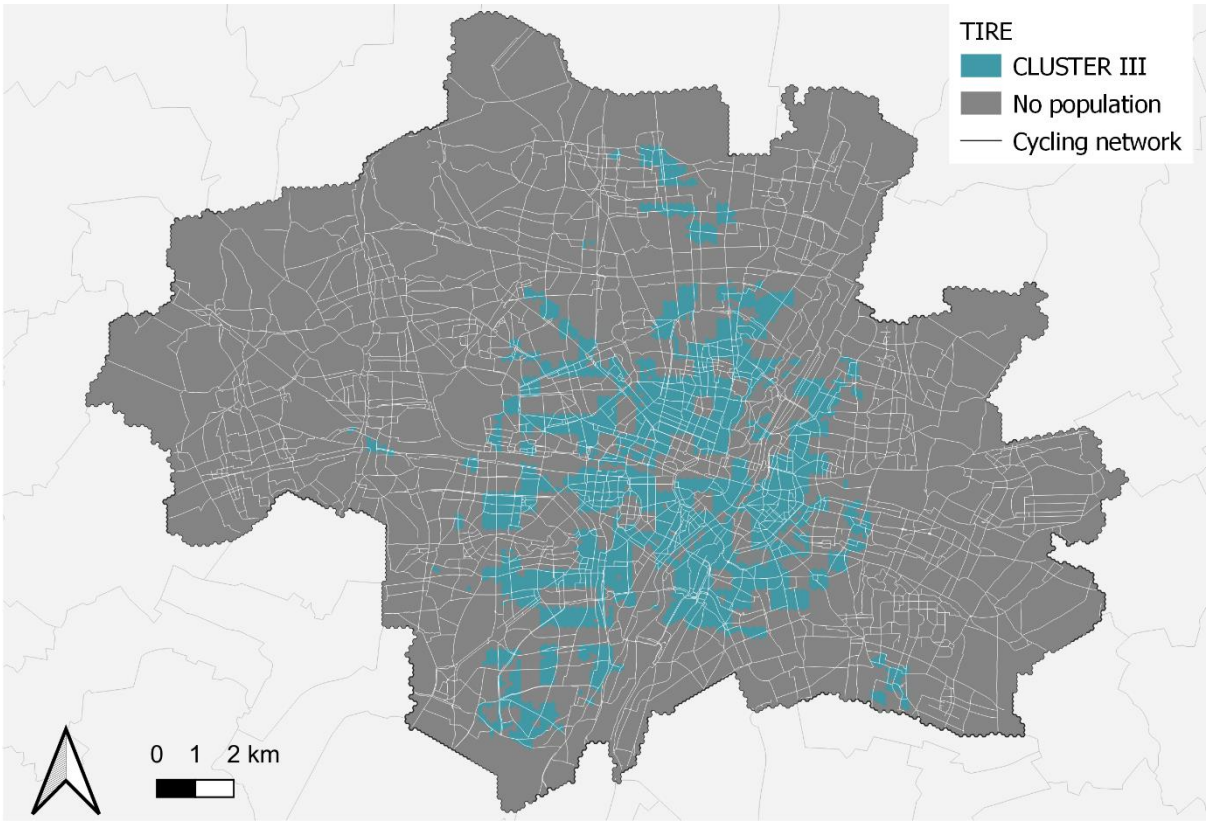
Map 12 – TIRE – Munich



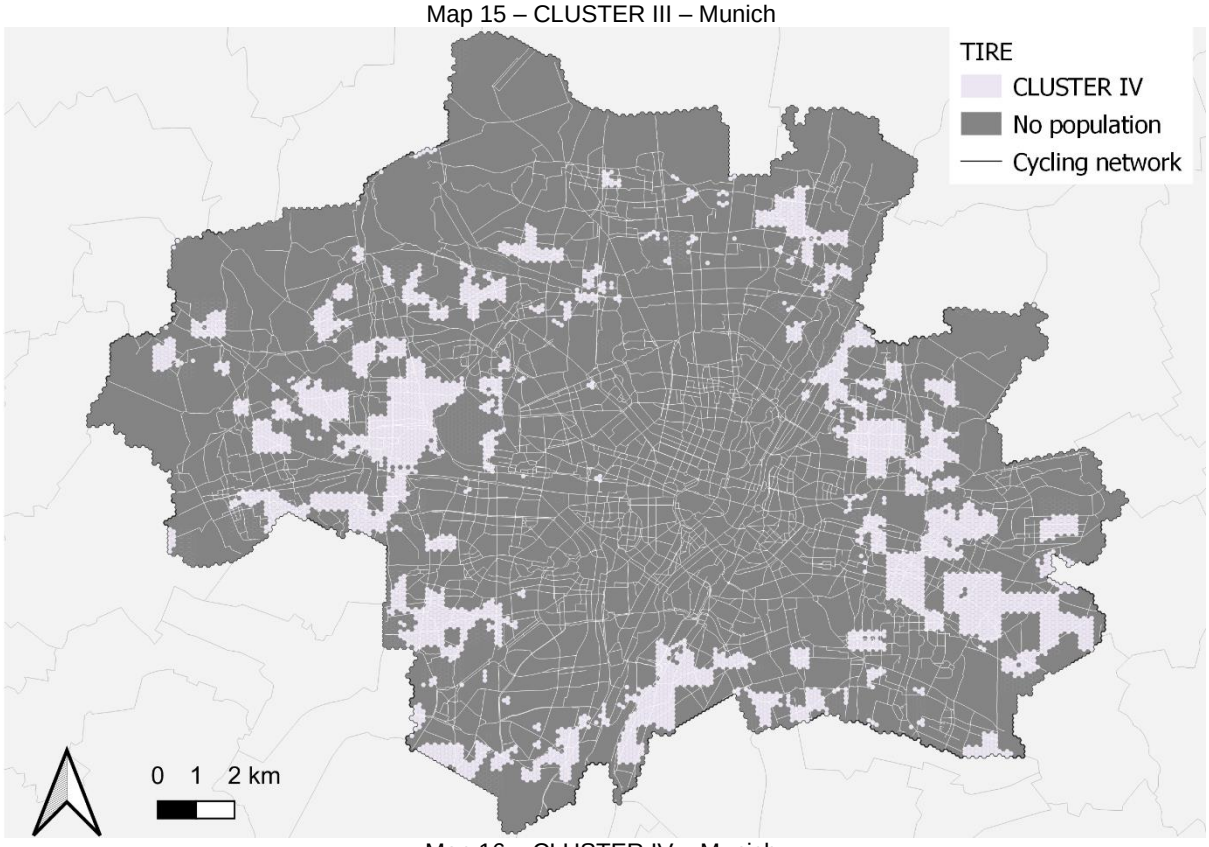
Map 13 – CLUSTER I – Munich



Map 14 – CLUSTER II – Munich



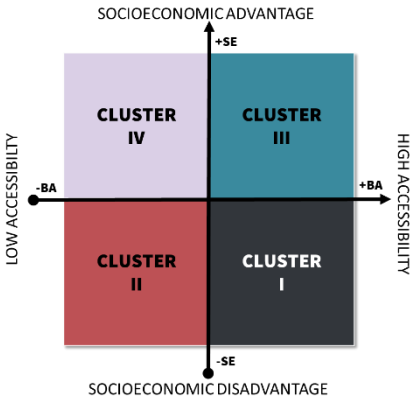
Map 15 – CLUSTER III – Munich



Map 16 – CLUSTER IV – Munich

Table 22 – TIRE results – Munich

Clusters	Population	Area	Activities
I	24.2 %	18.3%	79
II	23.6%	35.5%	16
III	36.3%	22.8%	109
IV	15.9%	23.4%	18



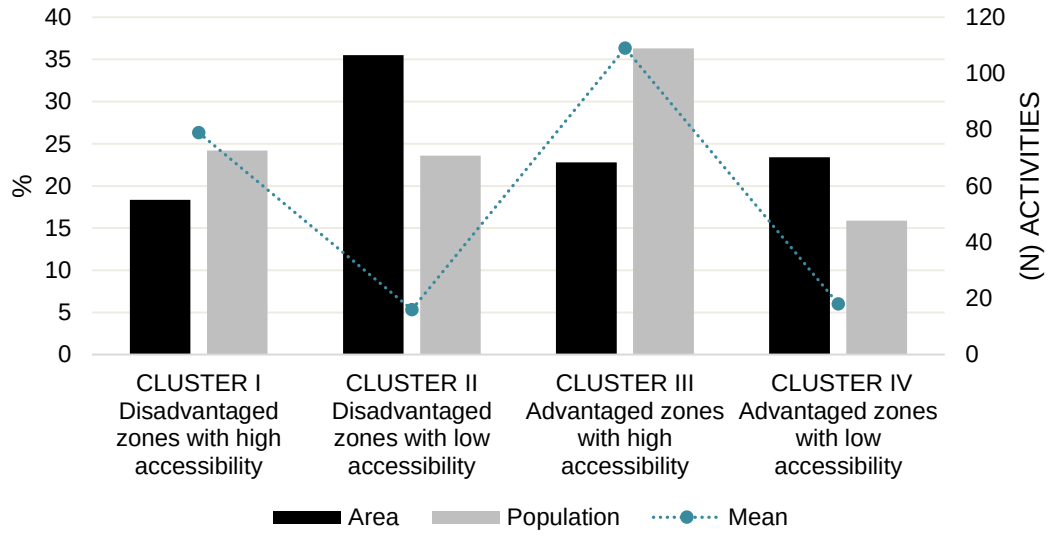


Fig. 40 – TIRE CLUSTERS – Munich

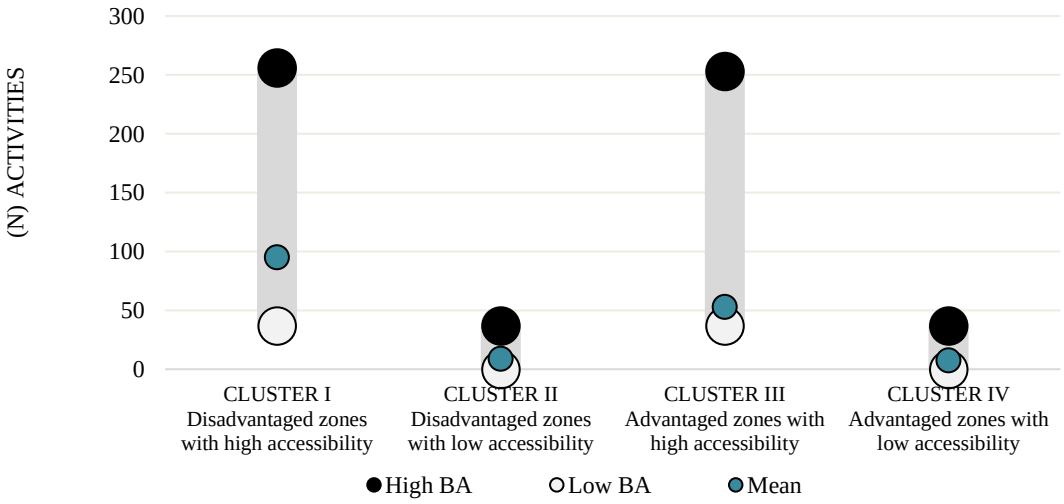
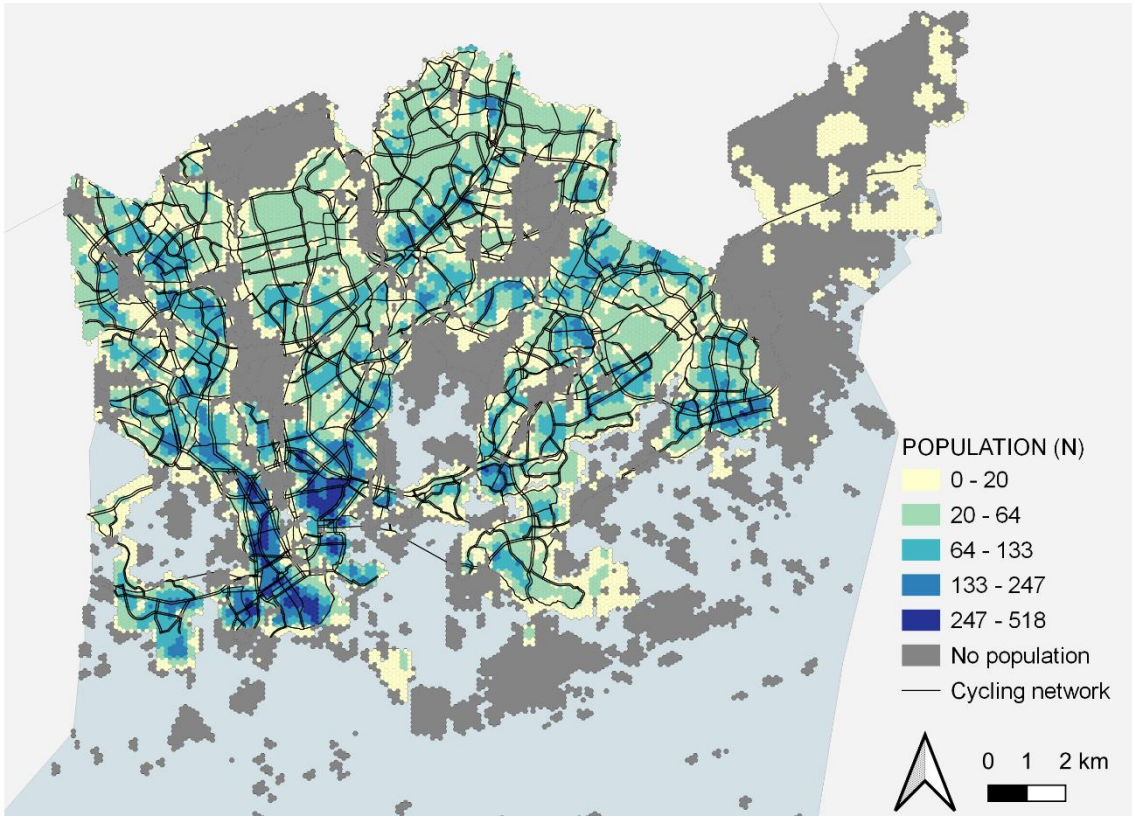
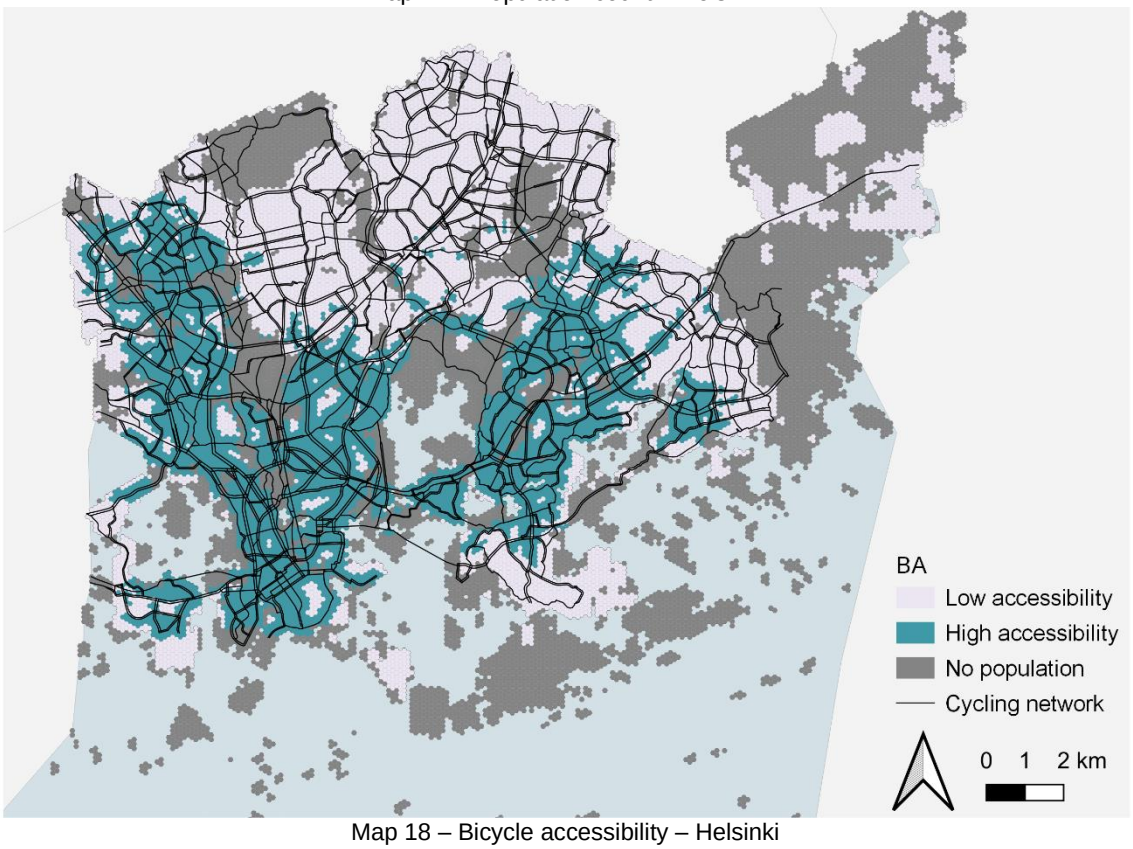


Fig. 41 – TIRE CLUSTERS SIZES – Munich

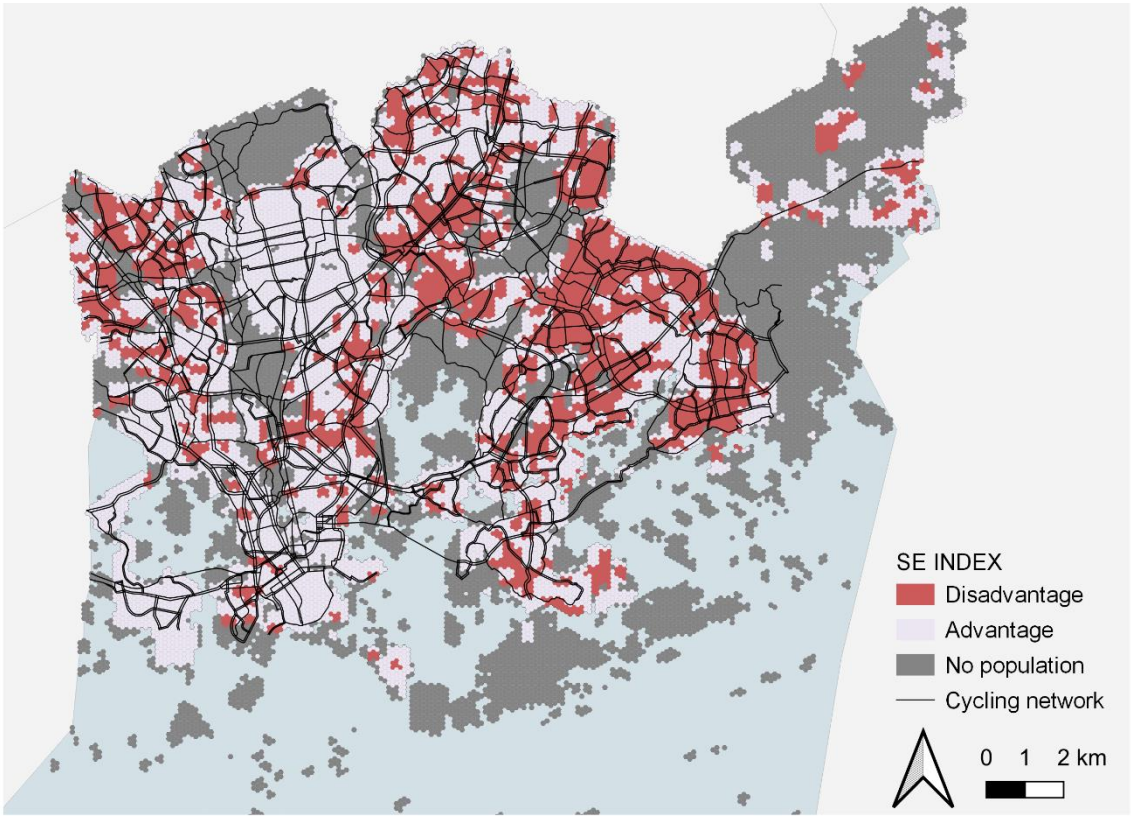
ANNEX E3: CASE STUDY (HELSINKI, FINLAND)



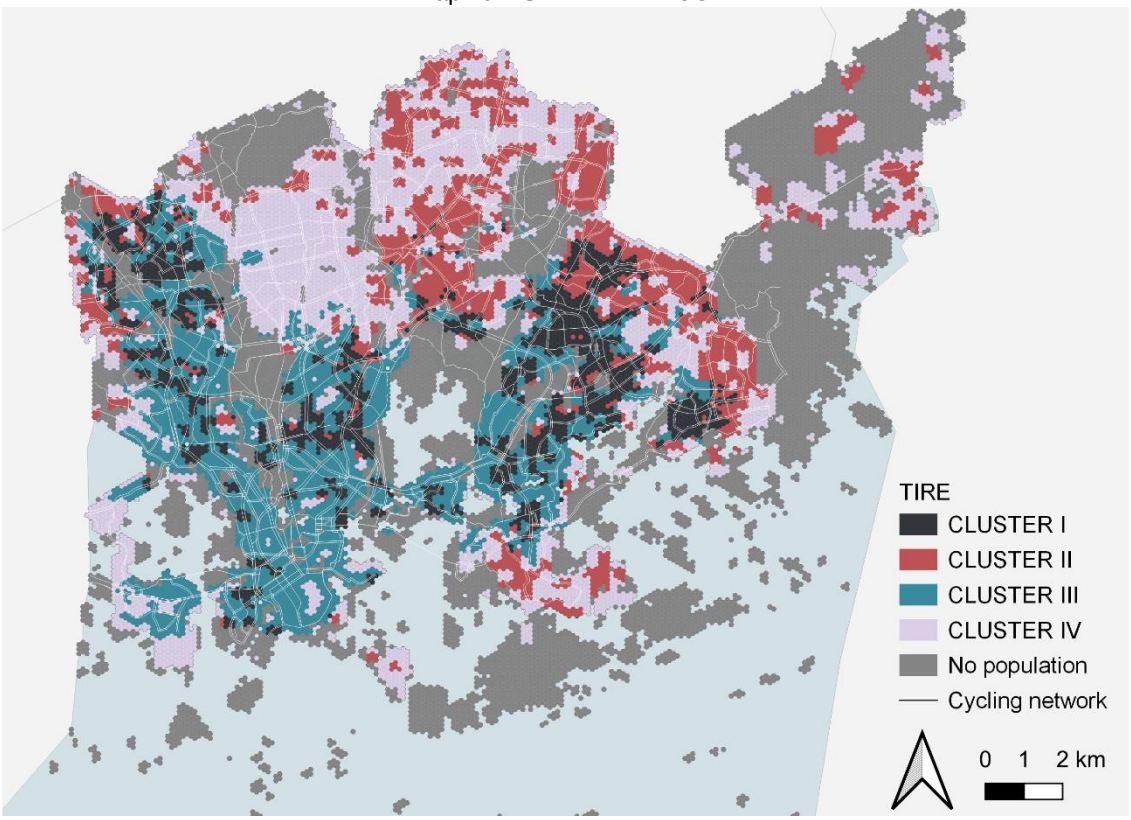
Map 17 – Population count – Helsinki



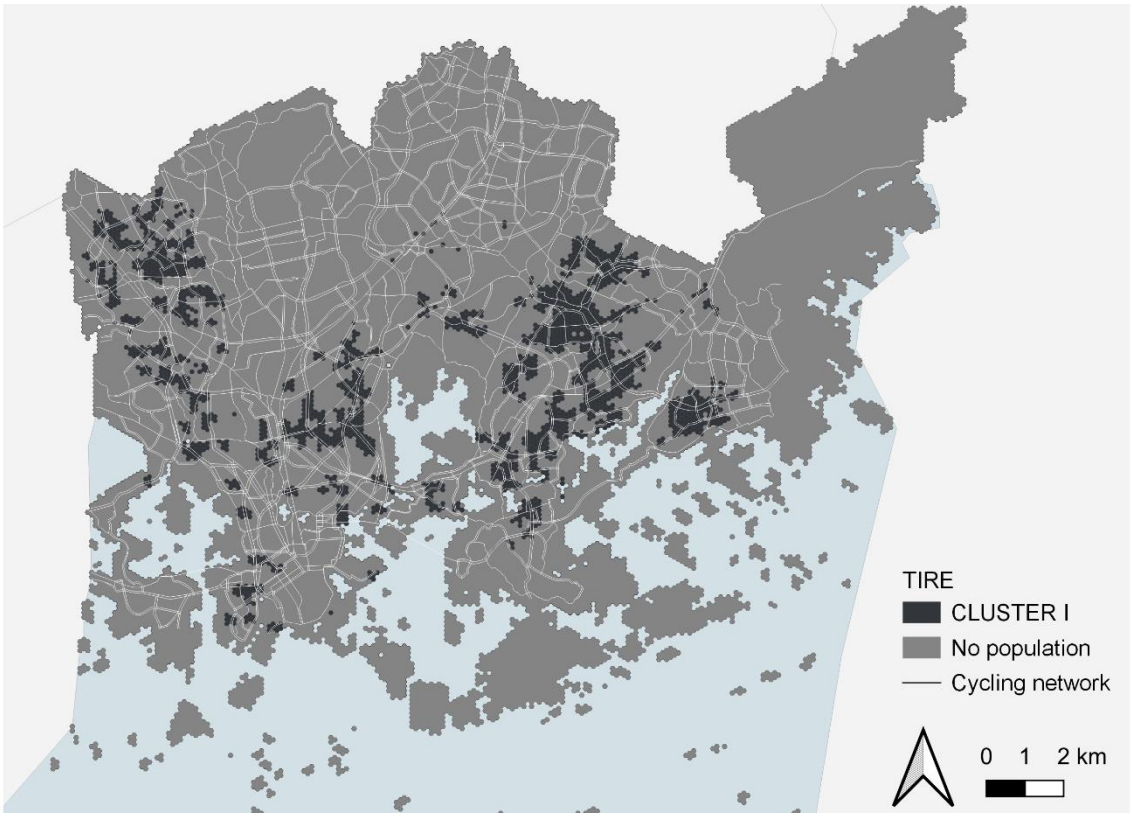
Map 18 – Bicycle accessibility – Helsinki



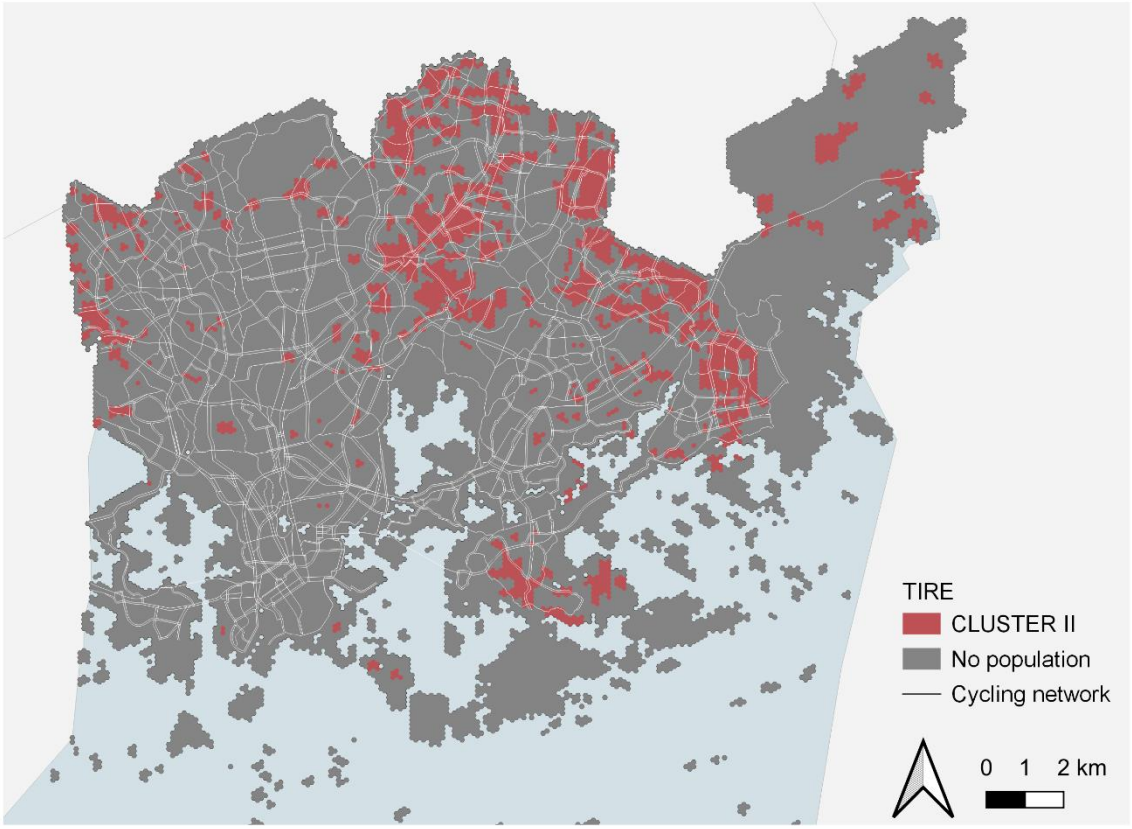
Map 19 – SE INDEX – Helsinki



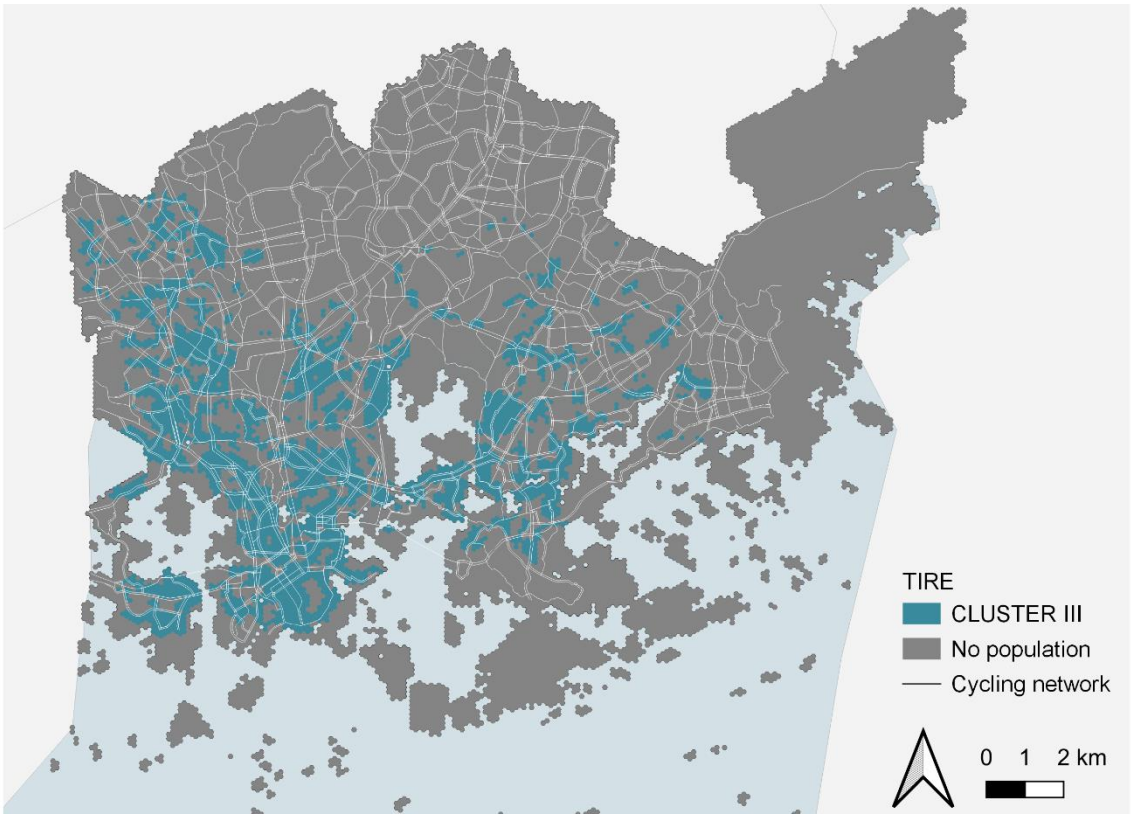
Map 20 – TIRE – Helsinki



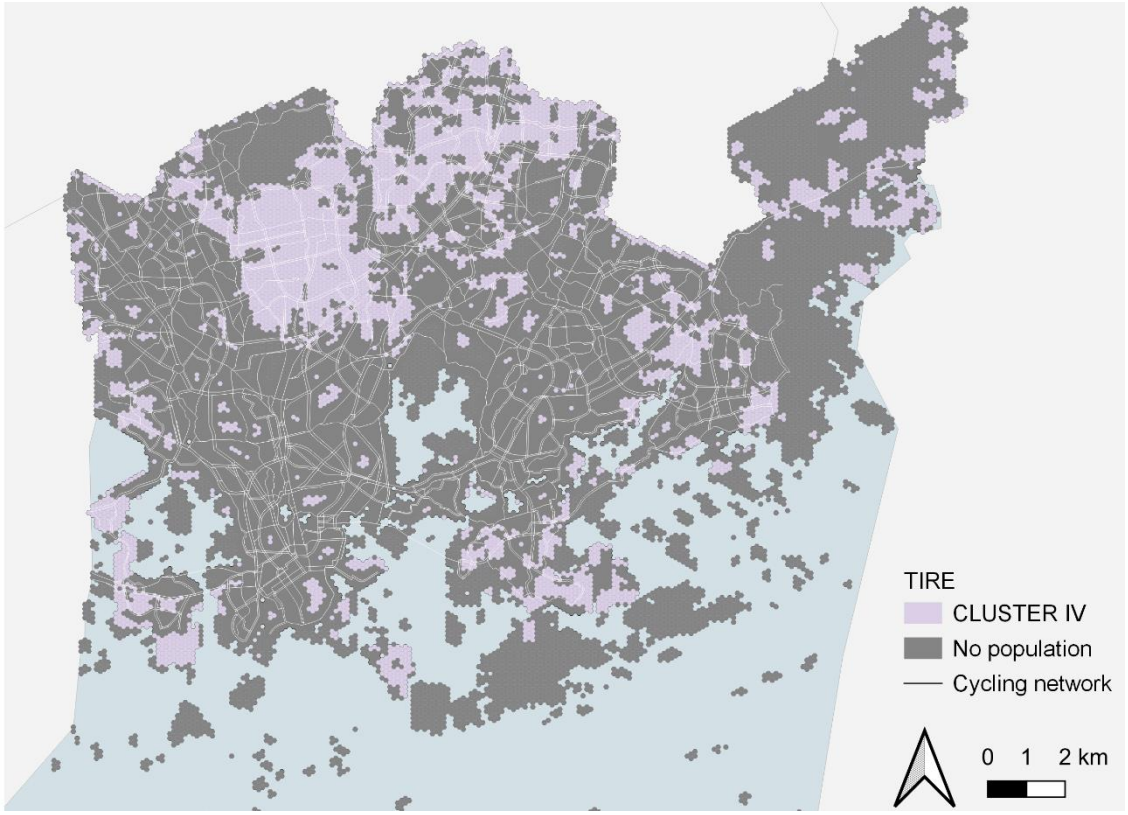
Map 21 – CLUSTER I – Helsinki



Map 22 – CLUSTER II – Helsinki



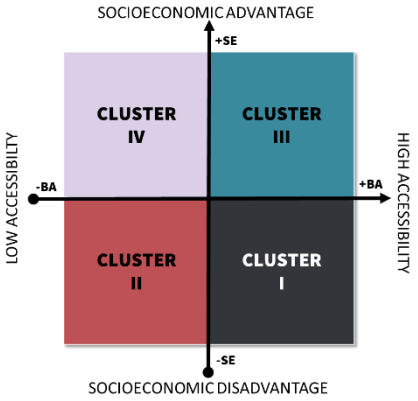
Map 23 – CLUSTER III – Helsinki



Map 24 – CLUSTER IV – Helsinki

Table 23 – TIRE results – Helsinki

Clusters	Population	Area	Activities
I	13.4 %	9.5%	186
II	25.0%	24.9%	38
III	37.5%	26.1%	241
IV	24.1%	39.5%	32



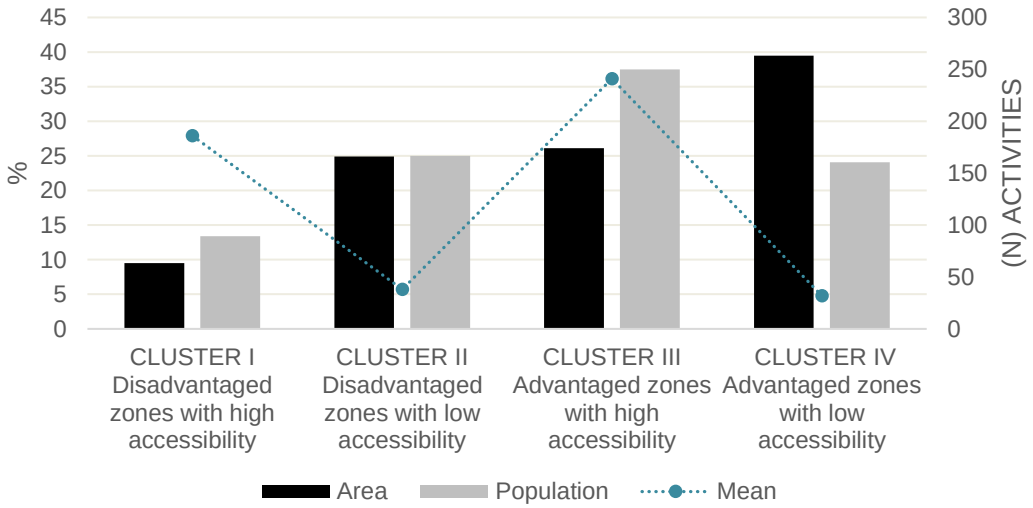


Fig. 42 – TIRE CLUSTERS – Helsinki

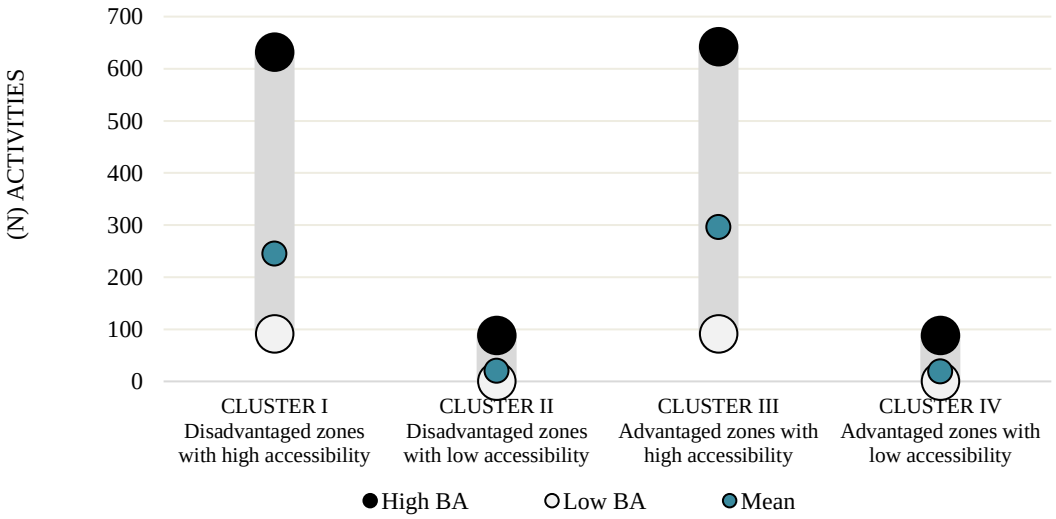


Fig. 43 – TIRE CLUSTERS SIZES – Helsinki