Towards a Fair Zero-Emission Zone

Exploring Equity and Accessibility in Amsterdam's Path to Emission-Free Mobility

MSc. Thesis Transport, Infrastructure & Logistics

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Towards a Fair Zero-Emission Zone

Exploring Equity and Accessibility in Amsterdam's Path to Emission-Free Mobility

by

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Preface

In front of you lies the thesis that marks the completion of my Master's programme in Transport Infrastructure & Logistics and, with it, the end of my time as a student at Delft University of Technology.

This thesis is the result of a long journey that began with searching for a suitable topic and a place to conduct my graduation research, followed by refining the research questions and ultimately carrying out and completing the study. It has been a challenging and demanding period, but also one that I look back on with pride.

This thesis would not have been possible without the support of several people, whom I would like to thank here.

First, I would like to thank Denise Hilster for several reasons. To begin with, I am grateful for the opportunity to work with you and, in particular, for giving me the chance to complete my graduation project at CE Delft. I also sincerely appreciate the time you made available whenever I felt stuck or uncertain about how to proceed with my thesis. During those moments, your valuable insights and critical feedback helped guide me in the right direction and played an important role in shaping this thesis. Furthermore, I would like to thank you for the freedom you gave me to explore this topic and for your support whenever it was needed.

Second, I would like to thank my TU Delft supervisors, Jan Anne Annema and Adam Pel, for their guidance throughout this research. I am grateful for the freedom they gave me to shape my thesis, as well as for their critical perspectives and constructive feedback, which greatly improved the quality of this work. Their enthusiasm for the topic was contagious and helped keep me motivated during the research process, especially during moments when I doubted my progress. I also greatly appreciated the openness with which they made time for discussions, whether during scheduled meetings or when I could simply walk in for advice. Those moments often provided the insights I needed to move forward again.

My gratitude also goes to CE Delft for providing me with the opportunity to conduct my graduation research there. I would also like to thank the colleagues I met during this period for their support and for creating a pleasant and motivating working environment.

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Summary

In some Dutch cities, zero-emission zones (ZEZs) are being considered as part of broader efforts to reduce greenhouse gas emissions and improve urban air quality. Although such measures can deliver important environmental benefits, they may also generate unintended social consequences. In particular, restricting access for fossil-fuel vehicles may create unequal accessibility impacts while the vehicle fleet remains only partially electrified. Experiences with low-emission zones (LEZs) and existing disparities in electric vehicle (EV) ownership suggest that the transition towards zero-emission mobility could disproportionately affect certain socio-economic groups. Despite these concerns, the equity implications of ZEZs for passenger cars remain relatively underexplored in the academic literature.

This issue must also be understood within the broader Dutch and European transition towards climate-neutral mobility. Current policy has largely relied on financial incentives, such as purchase subsidies and tax benefits, to stimulate EV adoption. However, these measures have been criticised for disproportionately benefiting higher-income households, as they are better able to afford new vehicles and take advantage of such incentives. At the same time, cities such as Amsterdam already have experience with emission regulation through LEZs and are moving towards zero-emission rules for logistics. These developments make it increasingly relevant to consider the potential social implications of extending such policies to passenger cars.

This research therefore examines the conditions under which ZEZs for passenger cars can be implemented in a socially equitable manner. Accessibility is used as the central benchmark for evaluating equity outcomes, focusing on whether residents are able to maintain access to essential destinations following the introduction of a ZEZ. By placing accessibility at the centre of the analysis, the study moves beyond conventional indicators such as vehicle ownership or emissions and instead evaluates how mobility policies affect participation in everyday activities.

This study develops a conceptual framework for assessing the equity implications of ZEZ policies, identifies which groups in Amsterdam may be most vulnerable to accessibility loss, and explores which policy conditions are necessary to support equitable implementation. Amsterdam is used as the primary case study, both because of its relevance for the potential introduction of passenger-car ZEZs and because insights from this context may provide useful lessons for other Dutch cities. The central research question guiding this study is therefore as follows: Under what conditions can zero-emission zones for passenger cars be implemented in a socially equitable manner in Amsterdam, and what lessons can be drawn for other Dutch cities?

The study adopts a mixed-methods approach combining theoretical and empirical analysis. First, a literature review was conducted to establish the normative framework of the study. Drawing on concepts such as sufficientarianism and egalitarianism, the review identifies key equity dimensions relevant to transport policy and forms the basis for evaluating the fairness of ZEZs. Building on these insights, a conceptual model was developed to structure the system surrounding a ZEZ. The model represents the causal mechanisms through which the introduction of a ZEZ may influence travel behaviour, accessibility and broader equity outcomes. It therefore serves as the analytical framework guiding the empirical analysis.

The empirical component of the research is primarily based on survey data collected in Amsterdam. The survey was used to assess levels of car dependence, perceptions of alternative transport options, perceived barriers to adaptation and the capacity of different groups to adjust to a ZEZ. The analysis combines descriptive statistics, comparisons between socio-demographic groups and qualitative coding of open-ended responses. Based on these results, an adaptation typology was developed to classify respondents according to their expected ability to adapt to the ZEZ. In addition, semi-structured interviews were conducted with experts and municipal policymakers. These interviews provided contextual insights into the practical conditions required for implementation and helped assess the extent to which findings from Amsterdam may be transferable to other Dutch cities.

The literature reviewed in this study suggests that equity in transport policy concerns the distribution of mobility-related benefits and burdens, particularly with regard to accessibility, exposure to environmental externalities, and the risk of social exclusion. Within this thesis, accessibility is treated as the central evaluative metric, as it determines whether individuals are able to reach essential destinations and participate in everyday activities. The analysis is guided primarily by sufficientarian and egalitarian perspectives. The sufficientarian approach focuses on ensuring that individuals maintain a minimum acceptable level of accessibility, which in this research is understood as the level of accessibility available before the implementation of the ZEZ. The egalitarian perspective emphasises the importance of preventing disproportionate burdens among disadvantaged groups. Together, these perspectives provide the normative framework used to assess the equity implications of ZEZs.

Building on the insights from the literature review, a conceptual model was developed to structure the relationships between the implementation of a ZEZ and its potential equity impacts. The model traces the causal pathways through which a ZEZ may influence travel behaviour, including shifts towards public transport (PT), active transport modes, shared mobility services or zero-emission vehicles (ZEVs). These behavioural changes subsequently affect system outcomes such as traffic levels, pollution and accessibility.

Through these mechanisms, the model highlights that the introduction of a ZEZ can produce both positive and negative outcomes. On the one hand, reductions in traffic and emissions can improve air quality, public health and road safety. On the other hand, access restrictions may lead to reduced accessibility for individuals who depend on private vehicles and lack viable alternatives, thereby increasing the risk of social exclusion. The model also indicates that traffic may be redistributed towards the boundaries of the zone, potentially increasing the importance of park-and-ride facilities and multimodal travel. Overall, the extent to which these outcomes emerge depends strongly on the availability and quality of alternative mobility options.

The results indicate that car dependence remains widespread among respondents. Approximately 88.6% reported that at least one activity cannot be undertaken without the use of a car. In most cases, car use is associated with occasional activities such as visiting family and friends, grocery shopping, care-related or medical trips, and transporting goods. By contrast, daily activities such as commuting were less frequently identified as requiring a car.

Although PT and e-bikes are widely perceived as suitable alternatives to private car use, respondents' willingness to adopt these options remains limited. This suggests that the presence of alternatives does not automatically lead to behavioural change.

The results also show that a substantial share of respondents face barriers to switching to EVs. Among drivers of internal combustion engine vehicles (ICEVs) or plug-in hybrid vehicles (PHEVs), 25.8% indicated that a transition to an EV would not be feasible for them. The most frequently cited barriers include financial costs, practical and technical constraints such as charging infrastructure and driving range, and age-related considerations.

To assess adaptation capacity more systematically, an adaptation typology was developed. The analysis shows that 74.5% of car-owning respondents can be considered potentially adaptable, meaning that they are either willing to switch to an EV or open to alternative forms of mobility. A further 11.0% are classified as policy-dependent, indicating that adaptation may be possible if supportive measures are introduced, while 14.5% are classified as structurally insufficient and therefore face a substantial risk of accessibility loss under a ZEZ. When considering the full sample, approximately 13.9% of respondents fall into the categories that are at risk of accessibility loss. Although this represents a minority of the population, it remains highly relevant from an equity perspective, as these risks are concentrated among specific socio-demographic groups. In particular, older residents, lower-educated individuals, and residents living further from the city centre appear more likely to experience difficulties adapting to the transition towards zero-emission mobility. Findings from the additional analysis on lower-income respondents reinforce this pattern, showing that lower-income residents who own a car are often strongly dependent on it and frequently perceive a switch to electric driving as infeasible, mainly for financial reasons. These findings suggest that access-restrictive policies such as a ZEZ could widen existing accessibility inequalities if implemented without accompanying measures, highlighting the importance of targeted policy support for vulnerable groups.

The findings also highlight a broader policy tension inherent to ZEZ implementation: the trade-off between environmental benefits and accessibility risks. While the policy aims to reduce emissions and improve urban air quality, it may simultaneously impose disproportionate accessibility burdens on certain residents. As a result, the legitimacy of a ZEZ depends on whether the resulting accessibility impacts remain within acceptable limits.

Even in Amsterdam, a city with relatively low car ownership and a strong presence of alternative transport modes, accessibility challenges still emerge for a portion of the population. This suggests that similar policies may generate even greater challenges in more car-dependent cities. Consequently, the transferability of these findings depends strongly on local mobility conditions and socio-spatial characteristics.

From a policy perspective, the findings suggest that a ZEZ can only be considered socially equitable under specific conditions. Equity should therefore be treated as a central design principle rather than as a secondary consideration. A socially equitable ZEZ requires five key conditions: gradual and transparent implementation, a limited initial spatial scope, targeted support measures for vulnerable groups, the prior availability of viable alternatives to private car use, and continuous monitoring of distributional impacts.

First, phased implementation and clear timelines are essential to allow households sufficient time to adapt and to reduce the risk of sudden accessibility loss. A gradual introduction makes it possible to first exclude the oldest and most polluting vehicles, while allowing lower-emission vehicles to continue entering the zone for longer before they too are phased out. It also gives residents the opportunity to anticipate when their vehicle will no longer comply, adjust their travel behaviour, replace vehicles where necessary, or explore alternative mobility options before restrictions take full effect.

Second, implementation could begin with a smaller zone, preferably in central areas where alternative transport options are already relatively strong, to further limit immediate impacts. Such areas generally offer better access to PT, cycling infrastructure and shared mobility services, which increases the feasibility of adaptation. At the same time, a smaller zone may involve trade-offs in terms of environmental effectiveness and may generate spillover effects if traffic is displaced towards surrounding areas.

Third, targeted support measures are also necessary for groups with lower adaptive capacity, particularly those facing financial, practical or structural barriers to adapting to the transition towards zero-emission mobility. These measures may include financial support schemes, temporary exemptions or programmes that improve access to alternative mobility options. In addition, improving the availability and affordability of EVs in the second-hand market is particularly important, as many lower-income households rely on this segment when purchasing a vehicle.

Fourth, viable alternatives to private car use must be available before restrictions are introduced. Reliable PT, high-quality cycling infrastructure and accessible shared mobility services play a crucial role in enabling residents to maintain access to essential destinations.

Fifth, continuous monitoring of policy impacts is necessary throughout the implementation process. Monitoring should focus on identifying emerging accessibility inequalities across socio-demographic groups and spatial areas, allowing policymakers to adjust the policy where unintended negative effects become visible. Such adaptive policy design is essential to ensure that environmental objectives are achieved without creating disproportionate accessibility losses for vulnerable groups.

Overall, the findings suggest that while some lessons from Amsterdam are transferable, the equity challenges associated with ZEZ implementation are likely to be greater in cities with higher levels of car ownership and dependence. Although such policies may be workable for many residents, they are not automatically equitable. Their legitimacy depends on preserving a minimum acceptable level of accessibility and preventing the widening of accessibility gaps between socio-demographic groups. Given that disparities in EV adoption already exist, a ZEZ risks reinforcing these inequalities if implemented without adequate accompanying measures. The success and fairness of such policies therefore depend strongly on the presence of measures that safeguard accessibility for vulnerable groups.

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List of Abbreviations

Abbreviation	Definition
BC	Black Carbon
BEV	Battery Electric Vehicle
CBS	Centraal Bureau voor de Statistiek
CLD	Causal Loop Diagram
DAG	Directed Acyclic Graphs
EC	Elemental Carbon
EU	European Union
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IenW	Ministerie van Infrastructuur en Waterstaat
KiM	Kennisinstituut voor Mobiliteitsbeleid
LEZ	Low-Emission Zone
MaaS	Mobility as a Service
MIRT	Meerjarenprogramma Infrastructuur, Ruimte en Transport
O&S	Onderzoek & Statistiek
PBL	Planbureau voor de Leefomgeving
PHEV	Plug-in Hybrid Electric Vehicle
P&R	Park-and-Ride
PT	Public Transport
SBCA	Social Cost-Benefit Analysis
TRSE	Transport Related Social Exclusion
WOZ	Waardering Onroerende Zaken
ZEV	Zero-Emission Vehicle
ZEZ	Zero-Emission Zone

1 Introduction

1.1. Background & Research Context

In 2015, the Paris Climate Agreement established an international commitment to limit global warming by achieving net-zero greenhouse gas emissions by 2050. In line with this broader ambition, the Netherlands has committed itself to reducing greenhouse gas emissions by 55% by 2030 under the European Union's Fit for 55 package, and to achieving full climate neutrality by 2050 (Council of the European Union, 2025; Rijksoverheid, n.d.-a). As one of the major sources of emissions, the mobility sector will need to change substantially if these targets are to be met.

A key part of this transition is the shift to zero-emission vehicles (ZEVs), particularly electric vehicles (EVs). To support this transition, the Dutch government aims to permit the sale of only new ZEVs from 2030 onwards, while comparable rules are to be introduced across the European Union by 2035 (European Parliament, 2024; Rijksoverheid, n.d.-b). Even so, projections suggest that these measures alone will not be enough to deliver a fully emission-free vehicle fleet by 2050 (Smit et al., 2024).

To date, the Dutch government has relied heavily on financial incentives, such as subsidies for vehicle purchases and tax benefits, to accelerate EV uptake. While relatively straightforward to implement and monitor, these measures have been criticised for their distributive effects. Studies indicate that subsidies tend to benefit higher-income households disproportionately, thereby exacerbating inequalities in access to sustainable mobility (Caulfield et al., 2022). More broadly, the high cost of ZEVs risks placing a heavier burden on lower-income households, raising concerns about how inclusive the transition can be in practice (Bauer et al., 2021; Stefaniec et al., 2025).

These distributive effects are already visible in patterns of EV uptake. Policies that primarily stimulate EV adoption risk reinforcing existing inequalities, as higher-income households are better positioned both to benefit from subsidies and to absorb the high upfront costs of new vehicles. In this way, the shift towards electrification may deepen socio-economic divides rather than bridge them.

Recognising these limitations, policymakers are increasingly turning to non-monetary instruments. Among the most prominent are zero-emission zones (ZEZs), which are already being introduced for urban freight and logistics in Dutch cities. Over the coming years, city centres are expected to progressively restrict access for fossil-fuelled delivery vehicles, with fines imposed for non-compliance. In this respect, ZEZs for passenger cars should not be regarded as a radical departure from current practice, but rather as the next step in an ongoing trajectory of urban environmental regulation. Many Dutch cities already enforce low-emission zones (LEZs) for older vehicles, and zero-emission rules for freight transport are scheduled to take effect by 2030.

At present, however, no equivalent framework exists for passenger vehicles. Nevertheless, it is plausible that such restrictions will eventually be extended to private cars as well. Anticipating this shift raises fundamental questions of fairness. Who bears the costs when conventional vehicles are excluded from city centres? How do these measures affect mobility patterns across socio-economic groups? And under what conditions can the implementation of ZEZs be considered socially equitable?

These questions become particularly important for groups whose mobility options are already limited. For many households, private car ownership remains the only feasible means of accessing jobs, services, and social networks. Policies such as ZEZs, if implemented without complementary measures, could therefore impose disproportionate burdens on such groups, who may lack affordable alternatives.

While ZEZs may be presented as straightforward solutions to environmental challenges, their equity implications warrant closer scrutiny. The central question is not simply whether such zones improve air quality, but who bears the costs of compliance, who benefits from the improved urban environment, and how these trade-offs can be managed. By shifting the analytical focus from environmental effectiveness to distributive justice, this research highlights the urgent need to consider inclusivity in the design of ZEZ policies.

1.2. Research Gap

Much has been written about the environmental impacts of low- and zero-emission zones. Existing studies consistently highlight reductions in CO_2, particulate matter, and nitrogen emissions across a wide range of cities, such as Amsterdam, Munich, Madrid, and London (Broster & Terzano, 2025; Panteliadis et al., 2014; Qadir et al., 2013; Tarriño-Ortiz et al., 2022). These zones also tend to reduce car use, as restrictions prevent certain vehicles from entering urban areas. Evidence from Madrid, for example, shows that LEZs can significantly decrease private car trips while stimulating public transport (PT) ridership, cycling, and walking. In this sense, the primary objectives of such measures, namely reducing emissions and car traffic, are often achieved (Tarriño-Ortiz et al., 2022).

Yet, transport policy rarely ends with achieving its immediate goals. As van Wee (2018) argues, good transport policy should not only be effective and efficient, but also fair. While the effectiveness and efficiency of LEZs and ZEZs have been demonstrated, their fairness remains underexplored. Restrictive mobility policies inevitably produce side effects. It is naïve to assume that all individuals can seamlessly substitute one mode of transport for another, or that adaptation is effortless for every group.

This raises the question of inclusivity. On the one hand, ZEZs create city-wide benefits in terms of improved air quality and liveability. On the other hand, they may undermine equity if certain groups are excluded from mobility systems or disproportionately burdened. To address this tension, a more holistic, system-level perspective is required, one that not only accounts for aggregate environmental benefits but also considers distributive impacts on different socio-demographic groups.

Against this backdrop, the aim of this research is to explore the conditions under which ZEZs for passenger cars can be implemented equitably in cities in the Netherlands. Using Amsterdam as a case study, it examines how ambitions translate into local realities, what barriers and enabling conditions emerge across different social groups, and what policy measures can mitigate inequities. By combining literature insights, survey analysis, historical case evidence, and stakeholder perspectives, the study seeks to clarify the boundaries of fair implementation and assess the transferability of lessons from Amsterdam to other Dutch municipalities. In doing so, it contributes to both the academic debate on transport justice and the practical challenge of designing inclusive climate policy.

1.3. Research Objective & Questions

This research aims to determine the conditions under which ZEZs for passenger cars can be implemented in a socially equitable manner. The research question is therefore:

> Under what conditions can zero-emission zones for passenger cars be implemented in a socially equitable manner in Amsterdam, and what lessons can be drawn for other Dutch cities?

In order to address the main research question, a set of sub-questions has been formulated to structure the analysis and add nuance to the broader problem. Each sub-question contributes to building a comprehensive answer to the central question by examining specific aspects of the issue.

The first step is to develop a general understanding of how emission zones relate to frameworks of equity. This requires building a strong theoretical foundation through a review of the scientific literature on equity within transport policy more broadly. Such a review clarifies the principles on which policy is justified and identifies the key equity dimensions through which these frameworks influence outcomes.

The purpose here is not to trace the origins of transport policy itself, but to understand the normative reasoning that underpins it and the ways in which policy decisions distribute benefits and burdens across society.

Establishing this foundation involves examining how equity has been conceptualised in transport policy and how these ideas translate into practice. It also requires identifying the distributive impacts that transport interventions, including emission zones, have on different societal groups. A justification for the implementation of an emission zone must therefore begin with an understanding of what constitutes a justification in the first place and how basic equity frameworks guide such reasoning.

Amsterdam already has experience with an emission zone, which provides an opportunity to draw lessons from its implementation. However, Amsterdam is far from unique in this regard. Between 2019 and 2022, the number of active emission zones in Europe grew by 40%, from 228 to 320, and by 2025 more than 500 zones are expected to be in operation (Clean Cities Campaign and Transport & Environment, 2022). These zones differ considerably in their size, design, scope, and level of stringency, leading to varied social and distributive outcomes. Examining how these policies have performed in other cities therefore offers valuable comparative insights.

At the same time, the wider social effects of transport policy should not be overlooked. By analysing how equity-related impacts have manifested across different socio-demographic groups, both in response to emission zones and to transport policies more generally, it becomes possible to identify the kinds of social and regional inequalities that such measures may reinforce or alleviate. In doing so, this discussion lays the theoretical and scientific foundation for the analysis that follows, from which the first sub-question of the research emerges:

1. How has equity been characterised and addressed in transport policy, and what do existing studies reveal about the distributional effects of emission zones?

Having established the basis for understanding what equity in transport policy entails, it is now possible to link these principles to the case of emission zones. While this connection can be described verbally, representing it conceptually allows for a clearer and more systematic understanding of how the different elements interact. The question then becomes: what direct effects do emission zones have, how do these effects influence measurable variables, and in what ways do they shape broader equity dimensions?

By visualising these mechanisms conceptually, the relationships between the policy intervention and its social outcomes can be better understood. Starting from the implementation of a ZEZ and progressing through the intermediate variables, the model ultimately shows how these processes contribute to, or challenge the overall equitability of the system. To this end, a conceptual model will be developed to illustrate the causal relationships between the ZEZ and various equity-related factors.

The purpose of the model is not to quantify these relationships, but to provide a structured representation of how the different variables interact. In doing so, it helps to make the complexity of the system more transparent and comprehensible. By clarifying these connections, the model establishes a framework for assessing the potential impacts of a ZEZ on the equity dimensions discussed earlier and thereby provides the basis for addressing the second sub-question:

2. How can the key mechanisms and relationships that shape the equitability of zero-emission zones be systematically represented in a conceptual model?

Having clarified the systemic elements that influence equity in the context of emission zones, the next step is to examine how these dynamics are experienced by different groups of people at the local level. Equity is not only a matter of abstract principles or institutional arrangements, but also of how individuals and communities are able to navigate and adapt to policy changes in their everyday lives.

Socio-spatial patterns of residence and income play a crucial role in shaping these experiences. In Amsterdam, higher-income groups are generally concentrated in central neighbourhoods, while lower-income groups are more likely to live in the outer districts of the city, as shown in Table 1.1.

Table 1.1: Average household income and housing price (WOZ) in Amsterdam and its districts, retrieved from Gemeente Amsterdam (2023b).

Indicator	Year	Amsterdam	Centrum	West	Nieuw-West	Zuid	Oost	Noord	Weesp	Zuidoost
Average disposable household income	2023	55,311	64,393	51,909	47,493	69,946	56,552	48,433	62,476	41,339
Average housing price (WOZ)	2023	523,265	660,555	527,568	400,816	679,692	549,339	438,675	481,994	312,115

These groups do not experience the emission zone in the same way, nor do they have equal access to resources or viable alternatives once restrictions on internal combustion vehicles (ICEVs) are introduced. Understanding these differences requires exploring the options available to residents in terms of mobility choices, the socio-economic barriers that constrain them, and the extent to which policy instruments can help to mitigate these barriers. It is also important to consider how people perceive the policy itself, how they adapt to the changing situation, and whether they are willing or able to transition to EVs. Gaining public support is a critical factor in the success of restrictive environmental measures, as trust in local government strongly influences how people respond to and comply with such policies. This shift from a systemic to a lived perspective therefore forms the basis for the third sub-question:

3. In what ways do mobility alternatives, socio-economic barriers, and supportive policy measures influence how different socio-demographic groups in Amsterdam experience and adapt to the transition towards a zero-emission zone?

After identifying how different socio-demographic groups experience the transition towards a ZEZ, the next step is to determine how this information can be used to inform policy. The conceptual model provides a framework for understanding how equity effects arise within the system, but it also highlights that complementary policy measures may be necessary to achieve a more equitable outcome overall.

To move towards such a system, it is essential to interpret responses with care. Individuals often express preferences that reflect their own circumstances and interests, which may not always align with the broader goal of equitable policy. For example, some respondents with limited financial means may call for purchase subsidies that others might need more urgently, while others may oppose policies that, in practice, are designed to support the groups most affected.

Therefore, careful analysis is required to identify which concerns are most widely shared and to validate whether these reflect genuine structural inequalities rather than individual perceptions. This process also allows for feedback to the conceptual model, showing how specific policy interventions might strengthen or weaken the equitability of a ZEZ. Validation is crucial to ensure that proposals emerging from public opinion can be translated into effective and just top-down policy. Establishing such checks and balances helps distinguish between what people believe would help them and what actually contributes to a fairer policy framework.

Ultimately, the focus should be on identifying who faces the greatest difficulties in adapting to the transition and why. This includes considering the financial and material circumstances of residents, whether they already own compliant vehicles, whether they face barriers to adaptation, and what forms of support could assist them. Once it becomes clear that certain groups are unable to adapt on their own, the central question becomes how they can be supported and through which measures. This leads to the fourth sub-question:

4. What conditions are necessary to ensure that the implementation of zero-emission zones in Amsterdam does not disproportionately disadvantage specific groups?

Although Amsterdam can be regarded as a pioneer in the implementation of ZEZs, the lessons drawn from this case cannot be applied wholesale to other cities. Amsterdam possesses a distinctive urban form, socio-economic composition, governance capacity, and mobility system, each of which shapes both the opportunities and the challenges associated with achieving an equitable transition. It is therefore necessary to treat Amsterdam as a case in its own right, while also examining to what extent its experiences can inform policy development elsewhere.

As shown in Table A.1 and Table A.2, clear differences exist in the spatial distribution of disposable income and housing values across the major Dutch cities. In Amsterdam, higher household incomes and property prices are concentrated in the central and southern districts, with costs generally increasing the closer one moves towards the city centre. In contrast, the pattern in The Hague and Rotterdam is less centralised. While some neighbourhoods display higher average incomes and property values, these areas are not necessarily located in the city core. Such variations suggest that the socio-spatial impacts of a ZEZ are likely to differ between cities, as wealth and housing are distributed according to different spatial logics.

This observation points to a broader consideration: policies designed for Amsterdam's specific socio-demographic and spatial conditions may not be directly suitable for other urban contexts such as Rotterdam or The Hague. Differences in income distribution, housing markets, city layout, and transport dependence all require careful attention to ensure that equity effects are appropriately addressed. For this reason, it is important not only to compare the progress of ZEZ implementation across cities, but also to examine the alternative strategies that municipalities may already be employing to promote sustainable mobility and social inclusion.

By reflecting on Amsterdam's unique characteristics while situating these within the wider Dutch context, this research aims to distinguish between findings that are context-specific and those that can be generalised more broadly. In this way, Amsterdam does not stand as an isolated case but rather as a reference point from which other municipalities may draw inspiration in developing socially equitable ZEZ policies. This leads to the fifth and final sub-question:

5. To what extent can the insights from Amsterdam's case be transferred to other Dutch municipalities in designing socially equitable zero-emission zone policies?

1.4. Study Area Context

To scope this research, this section outlines the development and current status of emission zones in Amsterdam, as well as the municipality's ambitions for the future. The focus will be on passenger cars, given their relevance to equity and accessibility, but logistics traffic is also briefly discussed as it provides a stepping stone towards a broader zero-emission policy.

Amsterdam introduced its LEZ on 9 October 2008 (Milieuzones.nl, n.d.). This zone covers almost all land within the A10 ring road, as can be seen in Figure 1.1. Initially, restrictions targeted the most polluting vehicles based on the European emission standards. For example, passenger cars built before 1992 were excluded from entering the inner city. The system has since evolved in line with technological progress, as newer vehicles generally emit less. Currently, the LEZ restricts diesel passenger cars with emission classes 0 to 4; only Euro 5 and higher, generally registered after 1 September 2009, are allowed (Gemeente Amsterdam, n.d.-e). Petrol cars remain unrestricted. Plug-in hybrid electric vehicles (PHEVs) are assessed based on their fuel type rather than their electric capability (Gemeente Amsterdam, n.d.-e). Access control is enforced automatically through licence plate recognition. Cameras register each entering vehicle, check its emission class, and issue fines where necessary.

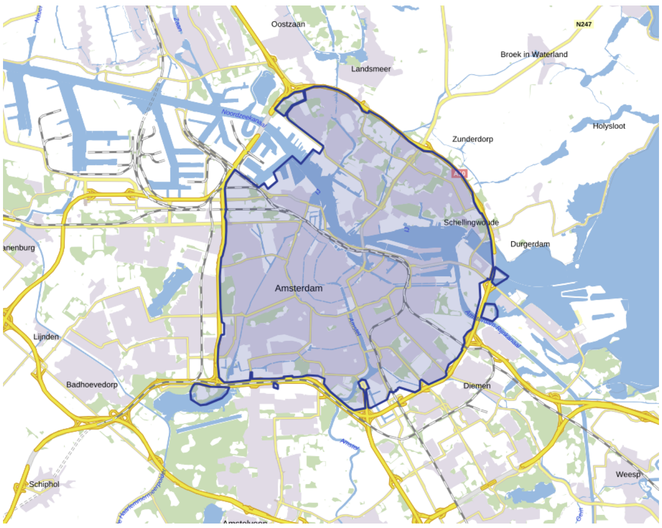

Figure 1.1: Geographical extent of the LEZ (blue area) in Amsterdam (Gemeente Amsterdam, n.d.-e).

The municipality has set out the ambition to expand the current system into a full ZEZ for all vehicles by 2030. This aligns with national climate policy, which stipulates that all newly produced passenger cars must be emission-free by that year (Gemeente Amsterdam, n.d.-e; van Zoelen, 2019). Such a transition would exclude all fossil-fuel-powered vehicles (diesel, petrol, hybrids, and other fossil fuels) from the city. However, legal implementation is currently restricted, as national guidelines for municipal passenger vehicle ZEZs are still under development (van Zoelen, 2019).

A first step has already been taken for logistics traffic. As of 1 January 2025, the existing LEZ has been converted into a ZEZ for delivery vans and lorries, with a phased-out trajectory for Euro 5 and Euro 6 vehicles (Ondernemersplein, n.d.). This regulation applies only to company-registered vans and/or trucks used for commercial purposes, meaning that private passenger cars are not yet affected at a personal level. The phased transition is defined as follows:

- Delivery vans Euro 5: permitted until 1 January 2027.
- Delivery vans Euro 6: permitted until 1 January 2028.
- Lorries (Euro 6, max. 8 years old in 2025): permitted until 1 January 2028.
- Lorries (Euro 6, max. 5 years old in 2025): permitted until 1 January 2030.
- Semi-trailer trucks (Euro 6, max. 8 years old in 2025): permitted until 1 January 2030.

From 1 July 2025, fines will be issued for non-compliant logistics vehicles. While this measure accelerates electrification in the sector, it has raised concerns among entrepreneurs about affordability and feasibility (Hielkema, 2024).

Vehicles allowed to access a ZEZ-F

Vehicle category		2025	2026	2027	2028	2029	2030
No transitional period							
New vehicles registered from January 1, 2025	N1 vans (≤ 3,5 tonnes) N2 trucks (3.5–12 tonnes) N3 trucks (> 12 tonnes)	Zero tailpipe emissions					
Transitional period							
Fleet vehicles registered before January 1, 2025	N1 vans (≤ 3,5 tonnes)	**Euro 5 vans**		Zero tailpipe emissions			
		Euro 6 vans				Zero tailpipe emissions	
	N2 trucks (3.5–12 tonnes) N3 trucks (> 12 tonnes)	**Euro VI box trucks** with a maximum age of 5 years on January 1, 2025					Zero tailpipe emissions
		Euro VI semi-trailer trucks with a maximum age of 8 years on January 1, 2025					
		Plug-in hybrid trucks provided they can drive emission-free					
Exemptions							
New and fleet vehicles	N1 vans (≤ 3,5 tonnes) N2 trucks (3.5-12 tonnes) N3 trucks (> 12 tonnes)	Exemptions for vans and trucks 40 years and older, wheelchair-accessible vans, and certain trucks (e.g., trucks for street cleaning, crane trucks, and fire trucks)					

Figure 1.2: Implementation schedule for the pathway towards zero-emission urban logistics, retrieved from Wappelhorst and Mulholland (2025).

A letter from the State Secretary for Infrastructure and Water Management (IenW) to the President of the House of Representatives sheds more light on this issue. The letter explains that, during the Spring Memorandum decision-making process on the climate package, the Cabinet decided not to include passenger cars in the ZEZ regime before 2030. The possibility of doing so from 2030 onwards would be left to the next government (Heijnen, 2023). This decision was taken under Cabinet Rutte IV. Since then, responsibility for any future extension has passed to Cabinet Schoof I, which has not provided a clear perspective. However, following the fall of this Cabinet, it is likely that the matter will be taken up only by the next administration.

At present, therefore, national policy enables municipalities to implement a ZEZ for logistics traffic, while also mandating that, from 2030, all newly registered passenger cars must be emission-free. Municipalities such as Amsterdam have already expressed their ambition to expand the ZEZ to include passenger vehicles. Yet the current legal framework prevents them from doing so, leaving a clear bottleneck at the national level.

Given these developments, it is reasonable to assume that once national policy permits it, Amsterdam will also extend the ZEZ to passenger cars. However, such a transition would affect a much larger group of residents, raising questions of feasibility and fairness. This thesis therefore examines the current options available to private individuals, such as switching to EVs or PT, and explores the equity implications of these policy changes.

1.5. Thesis Outline

This thesis follows a logical structure that reflects the progression of the research. Chapter 2 outlines the methodological approach, providing justification for the chosen methods and explaining how the data were collected and analysed. Chapter 3 forms the theoretical foundation of the study by addressing the first research question and reviewing the literature on equity in transport policy and the distributional effects of emission zones. Building on these insights, Chapter 4 presents the conceptual model developed in the research, explaining its structure, the relationships between its variables, and how it contributes to understanding the mechanisms that shape the equitability of an emission zone. Chapter 5 then presents the empirical findings, drawing on both survey results and expert consultations to answer the remaining sub-questions and to explore how different socio-demographic groups experience and adapt to the transition towards zero-emission mobility. The analysis is further deepened in Chapter 6, which interprets the results in relation to the theoretical framework, discusses their implications for policy, and reflects on the study's limitations and generalisability. Finally, Chapter 7 summarises the main findings, presents the overarching conclusions, and offers recommendations for future research and for ensuring the equitable implementation of ZEZs.

2 Methodology

This chapter outlines the methodological approach used to address the research questions of this thesis. The study adopts a mixed-methods design, combining conceptual, qualitative, and quantitative approaches in order to examine the equity implications of ZEZs. The conceptual model provides the analytical framework through which the system is understood, while survey data and expert interviews provide empirical and contextual insight into how these dynamics are experienced in practice.

The chapter proceeds as follows. Section 2.1 explains the overall research design and methodological logic. Section 2.2 describes the literature review and its role in shaping the theoretical foundation of the study. Section 2.3 outlines the development of the conceptual model. Section 2.4 presents the survey data, sampling, and analytical strategy. Section 2.5 describes the expert and stakeholder interviews and their analytical use. Finally, the integration of methods is discussed.

2.1. Research Design

This study adopts an exploratory mixed-methods approach that combines a literature review, the development of a conceptual model, quantitative and qualitative survey analysis, and expert and stakeholder interviews. The purpose of this design is to examine both the normative foundations of equity and the empirical distribution of impacts associated with the potential implementation of a ZEZ.

A mixed-methods approach is necessary because the research combines normative and empirical questions that cannot be addressed using a single method. The conceptual model requires a qualitative, system-oriented perspective to analyse complex relationships and equity mechanisms. The survey provides quantitative insight into how widespread certain effects are and which groups are most affected. Furthermore, equity is partly perceptual and subjective, which requires qualitative interpretation. The interviews provide contextual and policy-related insights that are not captured in the survey data and offer additional understanding of real-world developments.

The literature review addresses the first research question, namely how equity has been characterised and addressed in transport policy and what existing studies reveal about the distributional effects of emission zones. It does so by establishing the theoretical and normative foundation of the study, examining how equity is understood within transport policy, and identifying the principles through which distributive effects should be assessed.

The conceptual model relates to the second research question, which asks how the system surrounding a ZEZ can be conceptually visualised and what dynamics this reveals from an equity perspective. The model was developed iteratively based on insights from the literature and exploratory expert discussions. In this context, the expert interviews did not serve as direct empirical evidence, but instead provided contextual understanding that informed the theoretical and logical construction of the model. The conceptual model functions as the analytical framework of the study. It structures both the analysis and interpretation of the empirical findings and provides a basis for identifying policy pathways towards more equitable outcomes. Survey data were analysed using descriptive statistics, typology construction based on respondent answers, and group comparison across socio-demographic characteristics. The dataset is cross-sectional, meaning that it reflects expectations and perceptions at a single point in time and does not allow for causal inference.

Qualitative approaches were primarily used to explore the conceptual and normative dimensions of equity, drawing on academic and policy literature as well as insights from expert interviews. The quantitative analysis is based on survey data collected among residents of Amsterdam. Amsterdam was selected as the case study because of its policy relevance, the availability of detailed survey data, and its position as a representative urban context in which the introduction of a ZEZ is actively being considered. This makes it possible to assess how barriers, attitudes, and behavioural patterns are distributed across different population groups within a setting where these policy questions are especially salient. The survey also includes open-ended responses, which provide qualitative depth by capturing individual reasoning and lived experiences. Together, these approaches enable both an understanding of the structural dynamics of the system and an examination of how these dynamics are experienced across different groups.

The methods are linked to the research questions as follows. The literature review informs research questions 1 and 2. The survey analysis addresses research question 3. The interviews contribute to research question 5 and provide contextual background. Research question 4 represents a synthesis of earlier findings and therefore draws on all methods. The combination of methods enables triangulation, thereby strengthening the coherence and robustness of the analysis.

2.2. Literature Review

The literature review was undertaken to build a substantive foundation for research questions 1 and 2 and therefore to inform the development of the conceptual model. It served several purposes. First, it provided an overview of the current situation in Amsterdam regarding emission zones and the transition towards zero-emission mobility. This included examining the development of LEZs and the expected rollout of ZEZs, trends in EV uptake nationally and locally, and policy discussions at both municipal and national levels concerning feasibility and implementation timelines.

Second, the review focused on equity in transport systems. This was approached at two levels: the broad theoretical framing of equity in transport planning and the specific characteristics of equity debates within the Dutch context. From this, the equity dimensions most relevant to the evaluation of a ZEZ were identified and operationalised for use in later stages of the research.

Third, the review included an examination of international experiences with LEZs and related measures. Research on their impacts on air quality, mobility behaviour, and traffic volumes provided valuable reference points and offered insight into potential unintended consequences. Although empirical research on ZEZs is still relatively limited, studies on LEZs and system-level analysis contributed useful evidence that could be incorporated into the conceptual model to anticipate possible equity effects.

The literature search was carried out using Google Scholar, Scopus, and ScienceDirect. Search terms included: low-emission zones, zero-emission zones, EV adoption, transport equity, transport poverty, accessibility (inequality), inclusive transport policy, air pollution, health impacts, and systems modelling in transport. In addition to keyword searching, backward snowballing was used by reviewing reference lists of key studies to identify further relevant publications.

2.3. Conceptual Model

Early in the research process, it became clear that the transition from an LEZ to a ZEZ involves a complex and interconnected system. Various factors influence one another, including changes in vehicle fleets, shifts in travel behaviour, and the resulting equity dimensions. Because the system comprises both quantitative elements (such as numbers of ICEVs and ZEVs) and qualitative equity outcomes, a method was required that could represent these interactions in a structured and transparent way.

To do so, inspiration was drawn from systems-thinking approaches. In particular, the Causal Loop Diagram (CLD) was identified as a useful framework for illustrating relationships between variables. CLDs are traditionally used to analyse reinforcing and balancing feedback loops within dynamic systems. However, the purpose of this research was not to analyse feedback loops, but rather to map the directional and causal relationships underlying equity outcomes in the context of the ZEZ. Therefore, the visual language of the CLD was adopted (i.e. variables connected by causal arrows), while the focus on loop dynamics was intentionally set aside. This allowed the model to clearly illustrate how changes in one part of the system may influence conditions elsewhere, without requiring a full feedback analysis.

The development of the model was iterative. The initial structure and causal pathways were drafted based on logical reasoning about how the ZEZ would affect mobility choices and accessibility. These initial links were subsequently refined using scientific literature to ensure that each causal connection was theoretically supported. Where necessary, adjustments were made in discussion with supervisors to improve clarity, scope, and alignment with the research objectives. A full scientific justification of the causal relationships between variables is provided in Appendix A.3. The model serves as an analytical framework guiding the interpretation of empirical findings and identification of equity mechanisms.

2.4. Survey

The survey used in this research was originally distributed by the Municipality of Amsterdam. The municipality launched the survey as part of its preparations for the transition towards emission-free mobility, recognising that such a transition will affect all residents of the city. The aim of the survey was to understand how feasible and affordable zero-emission mobility is perceived to be, and to gather residents' concerns, expectations, and experiences regarding cleaner transport (Gemeente Amsterdam, n.d.-c). In this way, the municipality sought to assess where potential support or resistance exists in relation to introducing stricter emission regulations.

2.4.1. Data Sources and Data Collection

The dataset consists of responses collected through four distinct channels. First, the survey was administered through the O&S (Onderzoek & Statistiek) panel, a municipal panel designed to approximate the population of Amsterdam. Residents can voluntarily register for the panel, provided they are aged 16 or older and live in Amsterdam (Gemeente Amsterdam, n.d.-f). The survey was conducted in November 2024 (Gemeente Amsterdam, 2025c).

Second, the survey was distributed through the City Pass panel (Stadspaspanel). This panel consists of Amsterdam residents with lower incomes and is used by the municipality to ensure that groups who are often underrepresented in participation processes are more visible in municipal research. Previous research shows that residents in a more vulnerable socio-economic position tend to be less involved in political and policy-related participation trajectories, which can lead to their systematic underrepresentation in conventional survey instruments (ter Linden et al., 2024). The inclusion of the City Pass panel therefore serves to address this imbalance and to strengthen the equity perspective of the dataset. The City Pass panel fieldwork took place in May 2025 (Gemeente Amsterdam, 2025c). For both the O&S panel and the City Pass panel, participation was voluntary, and selected panel members were invited to complete the questionnaire.

Third, the survey was made publicly available via an open-link on the municipality's website during May, June, and July 2025 (Gemeente Amsterdam, n.d.-c). This channel enables broad participation, but it also introduces self-selection bias, meaning that individuals with stronger interests in the topic are more likely to participate (Elston, 2021). As a consequence, respondents may systematically differ from non-respondents in attitudes and perceptions, and some groups may be underrepresented (Stone et al., 2024). Although panel-based surveys are not entirely free from self-selection bias, this bias is more pronounced in open-link surveys, where participation is fully voluntary and unrestricted.

Finally, additional responses were collected through face-to-face fieldwork in June and July 2025 (Gemeente Amsterdam, 2025c). This approach was intended to reach residents who are less likely to participate through online surveys, thereby broadening the range of participants involved in the participation process. However, the researcher did not have access to detailed information regarding which individuals were approached during this fieldwork, the criteria used to select them, or how these responses were recorded and integrated into the broader dataset. As a result, these responses were not included in the analysis conducted in this research.

Access to the anonymised dataset was obtained in December 2025, enabling further analysis beyond the initial reporting. The complete list of survey questions is included in Appendix B. Table 2.1 provides an overview of the distribution of responses by data collection method.

Table 2.1: Distribution of respondents by data collection method

Method	Frequency	Percent	Included in analysis
O&S panel	1218	48.2	Yes (Section 5.1)
City Pass panel	140	5.5	Yes (Section 5.1.3)
Open-link	865	34.3	No
Face-to-face	302	12.0	No
Total	2525	100.0	

2.4.2. Survey Content and Structure

The questionnaire covers several themes relevant to this research. These include vehicle ownership, the frequency and purpose of car use, and which journeys cannot be substituted by other modes. Respondents were also asked about their experiences and views on EVs (e.g. charging in and outside Amsterdam, long-distance travel, commuting, maintenance, and cost). Several items assessed opinions on the potential implementation of a ZEZ and the extent to which this would personally affect respondents. Furthermore, the survey collected information on perceived barriers to reducing car use or transitioning to a ZEV, including financial, practical, and knowledge-related obstacles. Questions on shared mobility, PT use, and physical or functional limitations were also included. Finally, socio-demographic characteristics such as age, gender, education level, and residential district were recorded.

The survey consisted of multiple-choice and Likert-scale items, with additional open-ended responses triggered by specific answer choices. Because part of the questionnaire was open to voluntary public participation, this portion of the dataset is most suitable for exploratory and descriptive analysis rather than for drawing statistically representative conclusions. However, the responses collected through the municipality's representative city panel do reflect the population of Amsterdam more reliably, and can therefore be used to supplement the open responses with population-wide insight.

2.4.3. Sample Characteristics and Representativeness

To assess the extent to which the O&S panel approximates the population of Amsterdam, the distribution of key socio-demographic characteristics was compared with available population statistics. Tables 2.2, 2.3, 2.4, and 2.5 summarise the socio-demographic composition of the O&S panel sample and provide population reference values where available.

Table 2.2: Distribution of respondents by educational level

Educational level	Frequency	Percent	Population percent
Low	60	4.9	21.8
Medium	208	17.1	29.7
High	924	75.9	48.5
Other / unknown	26	2.1	0.0
Total	1218	100.0	100.0

Note. Population percentages are based on national statistics (CBS, 2023a).

Table 2.3: Distribution of respondents and population by city district

City district	Frequency	Percent	Population	Population percent
Centrum	174	14.3	91 014	9.7
West	179	14.7	149 607	16.0
Nieuw-West	175	14.4	166 462	17.8
Zuid	163	13.4	147 015	15.7
Oost	186	15.3	147 971	15.8
Noord	164	13.5	110 557	11.8
Weesp	51	4.2	26 725	2.9
Zuidoost	126	10.3	93 228	10.0
Westpoort	0	0.0	1795	0.2
Total	1218	100.0	934 374	100.0

Note. Population figures refer to the total registered population of Amsterdam in 2025 (Gemeente Amsterdam, 2025b).

Table 2.4: Distribution of respondents and population by age category

Age category	Frequency	Percent	Population	Population percent
16–29	0	0.0	220 239	23.6
30–39	37	3.0	179 231	19.2
40–49	120	9.9	115 924	12.4
50–59	269	22.1	108 946	11.7
60–69	384	31.5	93 474	10.0
70–79	357	29.3	60 059	6.4
80 or older	50	4.1	27 631	3.0
Unknown	1	0.1	0	0.0
Total	1218	100.0	934 526	77.3

Note. Population figures refer to the total registered population of Amsterdam in 2025 per age category (CBS, 2025a).

Table 2.5: Comparison of car ownership by drivetrain type between the survey sample and the Amsterdam vehicle fleet

Car type	Frequency	Percent	Fleet percent	Population	Population fleet share
ICEV	649	53.3	76.9	204 600	76.3
(P)HEV	112	9.2	13.3	19 885	7.4
BEV	83	6.8	9.8	43 755	16.3
Total cars	844		100.0	268 240	100.0

Note. Survey percentages refer to the full survey sample ($N = 1218$). Fleet percentages refer to the distribution of drivetrain types among car-owning respondents ($N = 844$). Population figures are from Rijksoverheid (2024); ICEVs are computed as total cars minus BEVs and PHEVs.

The comparison indicates several systematic deviations. Respondents with higher education are overrepresented, while those with low and medium education are underrepresented relative to population proportions (Table 2.2). By contrast, the distribution across city districts broadly aligns with population figures, with only modest differences across districts (Table 2.3). The age profile shows the strongest imbalance: younger residents are markedly underrepresented, while older age groups are overrepresented (Table 2.4).

Car ownership also appears higher among respondents than in Amsterdam's general population. While the average number of cars per household in Amsterdam is approximately 0.4 (Oomen & Heijnen, 2024), the survey does not directly measure cars per household because the relevant item records drivetrain type rather than the number of vehicles. Nevertheless, the proportion of respondents reporting car ownership implies an average of approximately 0.7 cars per household in the sample, indicating a higher prevalence of car ownership than in the city average. In addition, the drivetrain distribution among car owners differs from the population fleet, with BEVs underrepresented and (P)HEVs overrepresented relative to population figures, although the differences are not substantial (Table 2.5).

Taken together, the O&S panel remains suitable for analysing patterns and differences between socio-demographic groups within the sample, but the identified imbalances require caution when generalising descriptive percentages to Amsterdam's full population. For this reason, the analysis in this thesis focuses primarily on relationships and contrasts between groups, rather than on population-level prevalence. Because the dataset is not fully representative of the Amsterdam population, statistical generalisation should be interpreted with caution. The analysis is therefore mostly descriptive and comparative, focusing on patterns within the sample rather than population-level estimates. No weighting procedures were applied to adjust for sample imbalances, and the findings should be interpreted as indicative rather than statistically representative of the wider population.

2.4.4. City Pass panel and Other Channels

In addition to the O&S panel, the City Pass panel provides a targeted sample of Amsterdam residents with a lower socio-economic status. This dataset is analysed separately to support the equity perspective of the research rather than to represent the Amsterdam population as a whole. Representativeness for the full population cannot be assumed, and the dataset (N = 140) is therefore treated as a distinct group characterised by lower incomes. Due to the limited sample size, spatial and socio-demographic comparisons are not conducted, as subgroup sizes would be too small to produce meaningful or statistically robust comparisons. Instead, the analysis primarily relies on frequency tables, complemented by qualitative coding to capture open-ended responses in a structured manner.

Responses collected through the open-link and face-to-face channels are excluded from the analysis. The open-link allowed unrestricted participation, which introduces self-selection bias and may lead to systematically skewed responses (see Subsection 2.4.1). The face-to-face interviews were conducted by the Municipality of Amsterdam in selected locations and among specific individuals, but no information is available regarding how, on what basis, or from which population participants were selected. As a result, the sampling process cannot be assessed. Both channels therefore lack a clear and controlled sampling frame, which creates a risk of systematic bias and limits comparability with the panel data. For these reasons, the open-link and face-to-face datasets are not used in this study.

2.4.5. Survey Analysis

The survey analysis was conducted separately for the two panel-based datasets. The O&S panel formed the primary analytical basis of the study and was used to examine differences across socio-demographic and socio-economic groups. Descriptive cross-tabulations were employed to explore relationships between selected variables, and chi-square tests were applied to assess whether observed differences between groups were statistically significant. The chi-square test evaluates whether there is a statistically significant relationship between two categorical variables by comparing the observed distribution of responses with the distribution that would be expected if no relationship existed between them. In this study, a p-value below 0.05 was considered statistically significant, indicating that the observed differences between groups are unlikely to have occurred by chance.

Open-ended responses were analysed using qualitative coding. Individual responses were reviewed and grouped into thematic categories reflecting the main types of reasoning provided by respondents, such as financial constraints, age-related considerations, or practical limitations. This procedure enabled qualitative information to be incorporated into the analysis in a systematic and structured manner. In addition, a typology was constructed based on responses to selected survey items. This typology represents an empirically derived classification based on coded survey responses and was used to distinguish between different levels of adaptation capacity. The detailed operationalisation of this typology is presented in the Results chapter.

For the City Pass panel, the smaller sample size limited the scope for detailed subgroup analysis. As a result, certain socio-demographic comparisons were not conducted, and the analysis focused primarily on descriptive patterns within this group.

Finally, the dataset is cross-sectional and captures perceptions and expectations at a single point in time. Reported intentions and anticipated adaptation therefore do not necessarily correspond to realised behaviour, and the findings should be interpreted as reflecting expected rather than observed responses.

2.5. Stakeholder and Expert Interviews

In addition to the literature review and survey analysis, several interviews were conducted with experts and stakeholders. These interviews served two purposes. First, during the early stages of the research, exploratory conversations were held to help define the scope of the study, identify relevant themes, and refine the conceptual model. These discussions informed the research direction but did not constitute primary empirical evidence for the results and are therefore not cited in the results.

Second, a series of targeted expert interviews were conducted to gather substantive insights relevant to the research questions. These interviews focused on issues such as accessibility, the transition to zero-emission mobility, shared mobility, PT integration, and the implications of a ZEZ for different groups. Experts and stakeholders were purposively selected based on their institutional and professional involvement in mobility, accessibility, and transport policy. An overview of the interviewed experts and stakeholders is given in Table 2.6.

Table 2.6: Overview of experts and stakeholders interviewed and their relevance to the research

Expertise area	Institution	Primary focus of the interview
Shared mobility, car ownership and travel behaviour	KiM Netherlands Institute for Transport Policy Analysis	To gain background insights on mobility trends, car dependence and the role of park-and-ride facilities
Accessibility and mobility	PBL Netherlands Environmental Assessment Agency	To understand how accessibility is conceptualised and measured, and how a ZEZ may impact accessibility for different groups
Accessibility assessment in regional transport planning	Amsterdam Transport Region (Vervoerregio Amsterdam)	To understand how accessibility is assessed in regional transport planning and how a ZEZ may affect PT provision and areas with existing and future accessibility challenges
PT operations and accessibility	GVB Amsterdam	To understand how accessibility is managed within the organisation and how transport provision affects accessibility across areas
Freight transport and emission zone policy	CE Delft	To explore the implications of the freight ZEZ and what elements could be extrapolated to a ZEZ for passenger cars

A second set of interviews was conducted for the final research question, which examines how the findings of this study may extend to other Dutch municipalities. In this phase, the focus shifted from understanding the mechanics and equity dimensions of a ZEZ in Amsterdam to exploring how other cities are currently planning, implementing, or positioning themselves in relation to zero-emission mobility.

For this purpose, several large municipalities were selected: Rotterdam, The Hague, Utrecht, and Eindhoven. These cities were chosen because they are comparable to Amsterdam in scale, have significant transport challenges, and are each in different stages of sustainability policy development. The interviews aimed to understand whether and how these municipalities intend to introduce a ZEZ for passenger vehicles, what lessons they have drawn from the existing logistics ZEZ framework, and how they perceive the feasibility, timing, and equity dimensions of transitioning towards emission-free mobility. In addition, an interview was conducted with a principal transport planner from Oxford, where the first operational ZEZ has already been implemented. This provided additional insights into the planning process, practical challenges, and elements that have worked well in practice. An overview of these interviews with officials from various municipalities is presented in Table 2.7.

Table 2.7: Overview of interviews with municipal representatives regarding zero-emission mobility planning

Municipality	Role/department	Primary focus of the interview
Municipality of Rotterdam	Coordinator zero-emission passenger transport	Discussion of Rotterdam's position regarding a potential passenger-car ZEZ, including policy considerations and sustainability objectives
Municipality of The Hague	Policy Officer (Sustainable Mobility)	Current policy position regarding zero-emission mobility and constraints affecting the feasibility of a passenger-car ZEZ
Municipality of Eindhoven	Policy Advisor Sustainable Mobility	Long-term vision on emission-free mobility and the perceived feasibility of a ZEZ for passenger cars
Municipality of Utrecht	Policy Advisor / Project Manager Air and Noise	Long-term vision on emission-free mobility and the perceived feasibility of a ZEZ for passenger cars
Oxfordshire County Council	Principal Transport Planner	Experience with the Oxford ZEZ and its observed policy and implementation outcomes

All interviews were conducted using a semi-structured format. This approach ensured that key themes were consistently addressed across conversations while still allowing room for clarification, elaboration, and city-specific nuance. Interviews were held either online or in person and generally lasted between 30 and 50 minutes. Notes were taken during each session and, where consent was given, interviews were recorded to support accurate interpretation and reporting. All participants were informed about the purpose of the research and participated on a voluntary basis.

Across the discussions, attention was given to planning processes, implementation challenges, political and public acceptance, and the supporting measures required to enable a transition towards emission-free mobility. These included, for example, the provision of adequate charging infrastructure, improvements in PT services, and the integration of shared mobility options. The interview material was subsequently used to identify points of convergence and divergence between municipalities, as well as opportunities and barriers in moving towards a ZEZ framework. Analysis was conducted using thematic interpretation, focusing on recurring themes related to accessibility, implementation conditions, and equity considerations. The results of this analysis are presented in Section 5.3.

3

Literature Review

This chapter provides the foundation for understanding how equity considerations arise within transport policy, and how these relate to the introduction of emission zones. It informs the first sub-question, which examines how the effects of emission zones and transport policy more generally are distributed across different socio-demographic groups, and how these patterns compare with those anticipated in the conceptual model of ZEZs.

The literature review progresses in three parts. Section 3.1 discusses how questions of equity emerge in transport planning through the distribution of accessibility, mobility and exposure to externalities. Section 3.2 then outlines the different normative perspectives on fairness that underpin policy decisions and shape how (in)equality is assessed. Finally, Section 3.3 introduces the equity dimensions that are relevant for evaluating emission zones, which will later be operationalised in the conceptual model.

3.1. Equity in Transport Policy

Before discussing why equity is important in transport policy, it is essential to understand what the concept entails. Equity concerns the fair distribution of both the benefits and burdens of transport systems across different social groups (Z. Liu & Yu, 2025; Pereira & Karner, 2021). While transport policy often aims to serve the public interest as a whole, in practice not all individuals or communities benefit equally. Some groups may enjoy greater accessibility and mobility, while others face barriers or unintended disadvantages. Therefore, pursuing policies that explicitly consider equity helps to ensure that improvements in mobility do not come at the expense of fairness and inclusion.

Equity has been studied extensively across different disciplines and has taken on various interpretations. This diversity of perspectives has led to a situation in which there is no single, universally accepted definition of equity within transport planning. As a result, incorporating equity into the appraisal of transport projects remains a challenge. It is often difficult to formulate measurable equity goals, let alone to evaluate and enforce them effectively (Bruzzone et al., 2023). Consequently, considerations of equity are still limited in the planning and implementation of transport projects.

Transport policy traditionally seeks to improve the overall functioning of the transport system through measures such as infrastructure investment, pricing, land-use coordination, and PT enhancement (van Wee & Mouter, 2021). These policies are typically evaluated on the basis of efficiency and effectiveness, criteria that are relatively easy to measure through indicators such as travel time or accessibility levels. However, as Young and Tilley (2006) argue, good policy should also be just. Assessing whether a policy is just is far more complex, as perceptions of fairness vary across individuals and groups. Fairness often relates to the distribution of costs and benefits among different population groups or regions, and in transport policy these effects are rarely uniform (van Wee & Mouter, 2021). It is therefore increasingly important to address equity explicitly in the formulation and evaluation of mobility policies.

Policy interventions inevitably create both benefits and burdens. Over time, these can reinforce existing social disparities, which is why increasing attention has been paid to equity considerations in climate and transport policy. As highlighted by the EEA (2025), the impacts of climate change and related policies are not evenly distributed. Low-income households are more likely to live in poorly insulated housing, face higher energy costs, and have fewer resources to adapt. Similarly, ethnic minorities may experience barriers to participation in planning processes and to accessing transport. The EEA report Social fairness in preparing for climate change: how just resilience can benefit communities across Europe points out that many of these inequalities persist within current climate strategies (EEA, 2025).

This growing attention to equity is also reflected in broader policy commitments. The Netherlands has committed itself to international goals that emphasise social fairness (Ministry of Foreign Affairs, n.d.). The United Nations Sustainable Development Goals include Goal 10, which focuses on reducing inequality within countries (UN, 2025a), and Goal 11, which calls for the creation of inclusive, safe, resilient, and sustainable cities (UN, 2025b). These objectives provide a framework for national and local governments to ensure that sustainability policies also address fairness and accessibility.

These concerns are particularly relevant in the context of emission zones. The success of such policies depends on whether all groups in society are able to adapt. If certain groups, such as low-income households, are unable to comply, the effectiveness of the policy may be undermined. Promoting equity and inclusion is therefore not only a moral or legal responsibility, but also a practical requirement for achieving the intended environmental outcomes.

To address these challenges, it is necessary to develop new analytical and assessment methods that can better capture the equity implications of transport policies (Bruzzone et al., 2023). Accordingly, this section defines the key equity concepts and implications relevant to the implementation of ZEZs. It provides the foundation for assessing the fairness of such policies and forms the conceptual basis for the model presented in Chapter 4.

3.2. Equity Notions

This section explores the ethical and conceptual foundations that guide equitable decision-making in transport and mobility policy. It outlines how different philosophical perspectives can inform a fairer approach to transport planning and help policymakers make more ethically conscious decisions.

In Dutch mobility policy, questions of fairness are commonly examined through three ethical perspectives: utilitarianism, egalitarianism, and sufficientarianism. This classification is presented by the Knowledge Institute for Mobility Policy (KiM), an independent advisory body within the Ministry of Infrastructure and Water Management (IenW) (González et al., 2022). These three perspectives provide the foundation for evaluating how transport and accessibility policies affect society. Although all three perspectives are relevant, this thesis focuses primarily on egalitarian and sufficientarian approaches. These principles are more consistent with normative policy interventions such as ZEZs, whereas utilitarianism primarily concerns maximising overall welfare in monetary terms. Since financial efficiency is not the primary concern when discussing fairness in policies such as emission zones, the focus here remains on egalitarianism and sufficientarianism.

3.2.1. Utilitarianism

Utilitarianism is a common ethical framework in policy evaluation, largely because it allows decisions to be assessed through measurable outcomes, often expressed in monetary terms (Hausman et al., 2006). According to Kymlicka (2002), the approach rests on three central assumptions. First, human well-being, or utility, is considered the only intrinsic good and therefore the main concern of justice. Second, the principle of equal respect is interpreted as giving the welfare of every individual the same weight. Third, utilitarianism is inherently consequentialist: the moral value of an action or policy is judged solely by its outcomes, particularly the extent to which it increases overall welfare.

These assumptions underpin the rationale behind Social Cost–Benefit Analysis (SCBA), a tool widely used in Dutch transport planning, including for projects within the Meerjarenprogramma Infrastructuur, Ruimte en Transport (MIRT) programme (the multi-year framework for infrastructure, spatial planning and transport) (Rijkswaterstaat, n.d.-b). SCBA compares the total societal benefits of a measure with its total societal costs, and a policy is considered desirable when the aggregate benefits outweigh the aggregate burdens (González et al., 2022; Kymlicka, 2002). Within a utilitarian perspective, such a policy is viewed as equitable if it increases overall welfare, even when the gains and losses are distributed unevenly across different groups.

Although utilitarian reasoning plays an important role in Dutch mobility policy, it is not adopted in this research. Emission zones do not lend themselves well to assessment purely in monetary terms, and the focus of this thesis lies in questions of fairness rather than on maximising aggregate welfare. For completeness, utilitarianism is discussed here because it forms part of the broader ethical landscape within which Dutch transport policy operates. Beyond this section, however, it does not feature in the analysis, as the subsequent equity considerations align more closely with egalitarian and sufficientarian perspectives.

3.2.2. Egalitarianism

Egalitarianism is a branch of political philosophy that places equality at the centre of a just society (Bidadanure & Axelsen, 2025). Egalitarians are concerned with the relative distribution of benefits and burdens among members of society (Pereira & Karner, 2021). In the context of transport, this perspective asks why certain groups or neighbourhoods are disproportionately exposed to externalities such as pollution, or why others enjoy greater accessibility to PT and opportunities (Bullard & Johnson, 1997).

Rather than seeking to maximise total welfare, egalitarian reasoning emphasises the fair distribution of resources and opportunities across social groups (Rawls, 2017). John Rawls, for instance, argued that justice requires attention to what he called primary goods: resources and capabilities that every individual should possess in order to participate in society on fair terms. Later contributions have suggested that accessibility (the ability to reach essential destinations) should be recognised as one such primary good (van Wee & Geurs, 2011).

From this perspective, the fairness of a policy is assessed not only by its overall effects, but also by how it treats those who are least advantaged. In the context of emission zones, this distinction is particularly important. For people who already own an EV, the introduction of a ZEZ may have little effect on their mobility. In contrast, those who lack the financial means to purchase an EV risk losing access to essential destinations. Egalitarianism therefore calls for accompanying measures that prevent disadvantaged groups from being disproportionately affected. In this way, accessibility is safeguarded as a basic condition of justice, ensuring that the transition to cleaner mobility does not deepen existing inequalities.

3.2.3. Sufficientarianism

Sufficientarianism focuses on whether the distribution of benefits and burdens allows everyone to achieve a minimum acceptable standard of living (Pereira & Karner, 2021). According to Martens et al. (2012), adherents of this perspective are less concerned with differences across groups as long as all individuals remain above a certain threshold, for example, in terms of accessibility or environmental quality. In other words, what matters most is that everyone meets a sufficient standard, rather than that everyone is equal.

The principle of sufficiency holds that all individuals should have access to a basic standard of well-being. Applied to mobility, this implies that everyone should enjoy at least a baseline level of accessibility, even if perfect equality is unattainable (van Wee & Geurs, 2011). Unlike egalitarian approaches that seek to reduce disparities, sufficientarianism emphasises ensuring that no one falls below a level that prevents meaningful participation in society.

Defining such a threshold in transport policy is complex, as accessibility is shaped by spatial, social, and infrastructural contexts and is not inherently a quantitative concept. It cannot always be represented through a single numerical measure. Nevertheless, practical benchmarks have been proposed. One example is the 15-minute city concept, which suggests that essential services such as shops, schools, and healthcare should be reachable within a 15-minute walk or cycle (Moreno et al., 2021). Although conceptual, this example illustrates how sufficientarian principles can be operationalised in accessibility policy.

In practice, sufficientarianism complements egalitarianism. As van Wee and Geurs (2011) argues, particular attention should be paid to those with the lowest levels of accessibility, as they are most vulnerable to exclusion and least able to adapt to changing circumstances. Within ZEZs, residents with already high accessibility typically have alternative travel options, while those with fewer options risk being left behind.

As Pereira and Karner (2021) summarise:

> "A fair transport policy is guided by both sufficientarian and egalitarian concerns. It aims to improve overall levels of transport safety or accessibility and reduce transport externalities so that everyone is above acceptable thresholds, while at the same time prioritising improvements for disadvantaged groups and reducing inequalities."

In this research, sufficientarianism will be applied pragmatically. Instead of calculating detailed accessibility scores for each resident, the focus will be on whether individuals perceive their accessibility to worsen as a result of the ZEZ. The basic threshold is defined in relation to the situation before ZEZ implementation, meaning that the sufficientarian standard is the level of accessibility available prior to the introduction of the policy. Survey data from Amsterdam residents will be used to evaluate whether people are left without viable alternatives when conventional car use is restricted. A policy can therefore be considered sufficientarian if it maintains access to essential destinations and ensures that no group is pushed below this pre-existing basic threshold of mobility.

3.3. Equity Dimensions of the ZEZ

This section discusses the equity-related notions that are later represented in the conceptual model. Each of these factors influences the overall equitability of the ZEZ. The notions presented here are drawn from existing literature on transport equity and transport policy, with particular attention to studies examining the distributive impacts of emission zones.

Most of the research conducted on emission zones has focused on quantitative outcomes, such as the extent to which emissions have been reduced. While these studies are essential for evaluating environmental progress, they often overlook the equity dimension of such policies. Air quality improvements, for instance, are a fundamental benefit for urban residents and therefore remain an important component of this study. However, considerably less attention has been given to understanding how these zones affect accessibility or the distribution of benefits and burdens across social groups.

This section therefore draws on the limited but growing body of research that explores the social and distributional implications of emission zones and related transport and mobility policies. Each subsection examines one equity dimension in detail, outlining what the dimension entails, why it is important, how it relates to the implementation of a ZEZ, and in what way it contributes to or challenges the pursuit of an equitable ZEZ.

The equity themes addressed in this chapter include accessibility inequality and individual accessibility, air quality and health benefits, generational equity, road safety, social exclusion, and spatial equity. Together, these issues provide a foundation for understanding the broader social implications of the ZEZ. The visual representation of these relationships will be discussed in Chapter 4, particularly in Section 4.4.

Accessibility inequality and individual accessibility

Accessibility has long been recognised as a central concept in transport planning. Geurs and van Wee (2004) define it as "the extent to which land use and transport systems enable individuals or groups to reach activities or destinations by means of one or more modes of transport." From an equity perspective, accessibility is more than a measure of spatial connectivity: it determines who can meaningfully participate in various activities and who is left behind (van Wee & Geurs, 2011).

Research has shown that emission zones can have unequal effects on different social groups. Blandin et al. (2025), for instance, examined how LEZs affect vulnerable households and found that these groups tend to experience greater negative impacts than others. Many were left with no alternative but to purchase compliant vehicles, despite their limited financial means. The authors note that car dependence among vulnerable populations is particularly high, and when access restrictions are introduced, major accessibility challenges may emerge. However, they also highlight that encouraging a shift towards alternative modes of transport offers potential adaptation pathways for all households.

Lindsey et al. (2023) similarly observe that LEZs often have regressive effects because compliant vehicles are more expensive. This view is supported by Parkhurst (2016), who argues that lower-income households are more likely to own older vehicles that are subject to charges or bans, thereby bearing a disproportionate share of the policy's costs.

Overall, these findings suggest that the introduction of a ZEZ could create disparities in accessibility across different socio-demographic and economic groups. Some people may be able to adapt their travel behaviour, for example by switching to PT or by already owning an EV, while others may face greater challenges due to financial constraints or limited PT availability.

A detailed analysis by Liotta (2025) of eight French cities provides further insight into how such inequalities arise. Their research identified six key drivers explaining disparities in the effects of an LEZ on job accessibility, including car ownership, the location of residences and workplaces, and the accessibility of these areas by public or active transport. The study found that low-skilled workers faced the greatest losses, as they tended to live further from employment centres, owned a higher proportion of polluting vehicles, and had limited access to reliable PT. This resulted in marked inequalities in job accessibility between occupational groups.

Interestingly, the same study found that the impacts were smaller in Marseille and Reims. In Marseille, the limited size of the LEZ and the relatively strong PT provision for low-income residents mitigated accessibility losses. In Reims, few low-income households lived within the restricted area, and ownership of polluting vehicles was lower overall. These findings underline the importance of context: the spatial extent of the zone, PT quality, and car ownership patterns all shape the equity outcomes of such policies.

Although these results offer valuable lessons, direct comparison between France and the Netherlands should be made with caution. Differences in urban form, population density, and car dependence mean that the magnitude and nature of accessibility impacts are likely to vary.

When considering individual accessibility, it is important to recognise that disaggregated data on individual experiences do not always reflect the equity of the system as a whole. Nevertheless, individual accessibility contributes to broader accessibility inequality. If many individuals experience reduced access due to the implementation of a ZEZ, this leads to a systemic widening of accessibility gaps. Reduced individual accessibility can also contribute to social exclusion, as will be discussed later in this section.

In terms of justice, accessibility inequality directly challenges the equitability of a ZEZ. From an egalitarian perspective, policy should aim to reduce disparities in opportunities, as emphasised by González et al. (2022). At the same time, sufficientarian reasoning demands that everyone should maintain at least a minimum standard of accessibility, something that González et al. (2022) describe as "minimum standards for everyone." In this research, that minimum standard is interpreted as the level of accessibility currently experienced by residents, and a loss of accessibility would therefore indicate that sufficientarian principles are not being met.

Ensuring equitable outcomes will likely require complementary measures that mitigate accessibility losses for vulnerable groups. In this sense, accessibility inequality not only highlights a key challenge for the implementation of a ZEZ but also signals where corrective policy interventions are most needed to maintain fairness in urban mobility.

Air quality and health benefits

Air pollution is one of the most significant environmental health risks in urban areas, contributing to around seven million premature deaths globally each year (UN, 2023). To address this, local governments have implemented a range of policy instruments aimed at reducing pollutant concentrations and improving urban air quality. Among these, LEZs and ZEZs are the most widespread. Their primary purpose is not only to reduce the number of vehicles entering specific areas, but also to improve air quality and mitigate the adverse health effects associated with the high concentration of emissions produced by conventional vehicles (Sarmiento et al., 2023).

The literature on emission zones largely consists of empirical studies examining changes in air pollution before and after their implementation. These studies consistently report notable improvements in local air quality. For instance, Panteliadis et al. (2014) observed significant decreases in nitrogen dioxide, nitrogen oxides, particulate matter, and elemental carbon concentrations following the introduction of a LEZ in Amsterdam. Similarly, Qadir et al. (2013) reported lower concentrations of elemental carbon (EC) in Munich after its implementation. In Lisbon, the average annual concentrations of particulate matter and nitrogen dioxide declined by 23% and 11% respectively (Ferreira et al., 2015). In Malmö, the establishment of a LEZ led to a measurable decline in nitrogen dioxide emissions and was estimated to have prevented between 9 and 26 premature deaths (Flanagan et al., 2022). Comparable trends were observed in Antwerp and Brussels, where the introduction of LEZs led to a more rapid decline in concentrations of particulate matter, nitrogen dioxide, and black carbon (BC) compared to other Belgian cities without such measures (Bruyneel et al., 2025).

Beyond air quality improvements, several studies explore the broader health implications of such policies. Research has linked LEZs to reductions in cardiovascular and respiratory diseases, improved birth outcomes, lower incidences of dementia and lung cancer, and general declines in all-cause mortality (Broster & Terzano, 2025; Chamberlain et al., 2023; Sarmiento et al., 2023). These findings highlight that the benefits extend beyond cleaner air, contributing to wider public health gains and overall well-being.

However, while air quality and health are closely related, they should not be treated as identical concepts. Air quality concerns the concentration of pollutants in the environment, whereas health benefits encompass a broader set of physical and mental well-being outcomes. For instance, health improvements may also arise from behavioural shifts encouraged by cleaner mobility policies. Promoting active modes of transport, such as cycling, not only reduces emissions but also enhances population health through increased physical activity. As demonstrated by Oja et al. (2011), cycling is associated with improved fitness, lower rates of obesity, and reduced risks of chronic disease, making it an important co-benefit of sustainable transport policies.

The relevance of air quality to equity becomes evident when considering that the harms of pollution are not distributed evenly. Populations living in dense urban areas, often including low-income groups and ethnic minorities, are more exposed to traffic-related emissions (van den Brekel et al., 2024). By 2050, nearly 68% of the world's population will live in cities (UN, 2018), where exposure to poor air quality could lead to millions of premature deaths (Lelieveld et al., 2015). In the Netherlands, air pollution is estimated to contribute to approximately 12,000 premature deaths each year (Gezondheidsraad, 2018). At the local level, the health impacts are also substantial. In Amsterdam, around 18% of asthma cases among children are attributed to air pollution, while among residents aged 50 and older, approximately 12% of lung cancer cases are linked to long-term exposure to polluted air (Gemeente Amsterdam, 2026). As a consequence of these combined health effects, residents of Amsterdam live, on average, eleven months shorter lives (Gemeente Amsterdam, 2026). Ensuring that all citizens can breathe clean air is therefore not only an environmental priority but also an issue of social justice.

From an equity standpoint, the implementation of a ZEZ can thus be understood as a policy that safeguards a basic right: the right to a healthy and liveable urban environment. While a ZEZ alone cannot eliminate premature mortality caused by pollution, it represents one crucial element within a broader set of measures aimed at protecting public health. In this sense, improving air quality and ensuring equitable health outcomes are mutually reinforcing goals that underpin the pursuit of a fair and sustainable transition towards zero-emission mobility.

Generational equity

Generational equity concerns fairness across age groups and social categories within the present population. It is grounded in the idea that all members of society should have equal opportunities, resources, and access to essential services (Padilla, 2002). Intragenerational justice has been defined by Baumgärtner and Quaas (2010) as "justice between different humans of the same generation, in particular the present generation." In other words, intragenerational equity seeks to ensure fairness among people living today across different groups, regions, or social classes.

In the context of this research, attention is limited to intragenerational rather than intergenerational equity. While intergenerational equity addresses fairness between present and future generations, the focus here is on disparities experienced by groups living at the same time (Baumgärtner & Quaas, 2010). Within transport systems, this means recognising that different age groups may experience distinct barriers to mobility. Generally, younger and more mobile individuals are more adaptable to changes in transport policy, whereas elderly people often face greater challenges in adjusting their travel behaviour. Evidence from the Madrid Central LEZ supports this distinction: Tarriño-Ortiz et al. (2022) found that elderly residents were more reliant on private cars and less willing or able to alter their travel patterns than other groups.

Differences in transport accessibility between socio-demographic and socio-economic groups are also well documented. A study by Jorritsma et al. (2018) identifies several categories in the Netherlands that are more prone to transport poverty. These include low-income households, unemployed individuals, elderly people, those with a migration background, persons without a driving licence or access to a car, people with disabilities, and residents of rural areas. For urban areas such as Amsterdam, the study highlights particularly elevated risks among low-income groups, jobseekers, and residents with a migration background. These findings underline the relevance of considering generational and social differences when assessing the equitability of transport policies such as ZEZs.

In the Amsterdam context, the city's ageing population is steadily increasing, driven by rising life expectancy and the baby-boom generation reaching the age of 65 and above (Gemeente Amsterdam, 2024). This demographic shift makes older residents particularly relevant when assessing the effects of restrictive mobility policies such as the ZEZ. Evidence from the Madrid Central case study further supports this, showing that elderly residents are among those most affected by limitations on conventional car use (Tarriño-Ortiz et al., 2022).

Groups without access to a car or a driving licence are excluded from the analysis, since they already depend on alternative modes of transport and therefore do not experience additional losses in accessibility as a consequence of the policy. Similarly, rural populations are not considered, as this research focuses exclusively on an urban context.

In summary, (intra)generational equity contributes to the assessment of an equitable ZEZ by drawing attention to how different age and social groups are unequally positioned to adapt to restrictive mobility measures. Ensuring that elderly residents and other vulnerable populations retain sufficient access to essential destinations is therefore an important condition for achieving both the fairness and effectiveness of the policy.

Road safety

Road safety can also be regarded as an equity principle, as ensuring safer conditions for all road users contributes directly to the fairness and inclusiveness of transport systems. Measures that reduce accidents, injuries, and fatalities not only improve public health outcomes but also enhance societal well-being and economic productivity (Litman, 2022). From this perspective, making transport safer is not solely a technical or operational goal, but also a matter of social justice.

As noted by Pereira and Karner (2021), "A fair transport policy is guided by both sufficientarian and egalitarian concerns. It aims to improve, for example, overall levels of transport safety or accessibility and reduce transport externalities so that everyone is above acceptable thresholds, while at the same time prioritise improving the conditions of disadvantaged groups and reduce inequalities." This view explicitly links the pursuit of safety to equitable transport policy. A policy that reduces the risk of road casualties for all users, particularly those who are more vulnerable, such as pedestrians, cyclists, and older adults, aligns with both egalitarian and sufficientarian principles.

Within the context of ZEZs, road safety improvements can be considered an indirect but meaningful equity outcome. Reducing car traffic and promoting walking and cycling often lead to fewer traffic conflicts and lower accident severity, thereby contributing to safer and more liveable urban environments (Høye & Hesjevoll, 2020; Jacobsen, 2003). These effects, while not the primary motivation for implementing an emission zone, reinforce its broader societal benefits.

Although traditional cost–benefit analysis, grounded in utilitarian reasoning, often evaluates road safety improvements in monetary terms, this perspective overlooks crucial aspects of social justice. Equity-oriented approaches emphasise that safety should be regarded as a universal right rather than a calculable benefit. Everyone should be able to move safely, regardless of their background or means. However, disparities remain: individuals from lower socio-economic groups are disproportionately affected by traffic crashes and associated risks (Asadi et al., 2022). This highlights the need for road safety policies that explicitly address inequality and ensure that all members of society can benefit equally from safer transport environments.

Social exclusion

Levitas et al. (2007) defines social exclusion as “the lack or denial of resources, rights, goods and services, and the inability to participate in the normal relationships and activities available to the majority of people in a society, whether in economic, social, cultural or political arenas. It affects both the quality of life of individuals and the equity and cohesion of society as a whole.”

To place this concept within the scope of this research, it is necessary to relate social exclusion specifically to transport. As the notion encompasses a wide range of factors, narrowing its focus is essential. Bruno et al. (2024) describe Transport-Related Social Exclusion (TRSE) as “how people who are socially disadvantaged for reasons such as employment status, income, age, or ability, can face limitations in their ability to access transportation services.” Their work identifies ten forms of TRSE, based on a synthesis of earlier studies. For the purposes of this thesis, however, a simplified interpretation is adopted, following the general definition above.

Lucas (2012) developed a conceptual model to illustrate the relationships between transport disadvantage, social disadvantage, and social exclusion (see Figure 3.1). The model shows how these disadvantages interact to create transport poverty, which leads to inaccessibility to essential goods and services and exclusion from planning and decision-making processes. This process in turn reinforces wider social and transport inequalities.

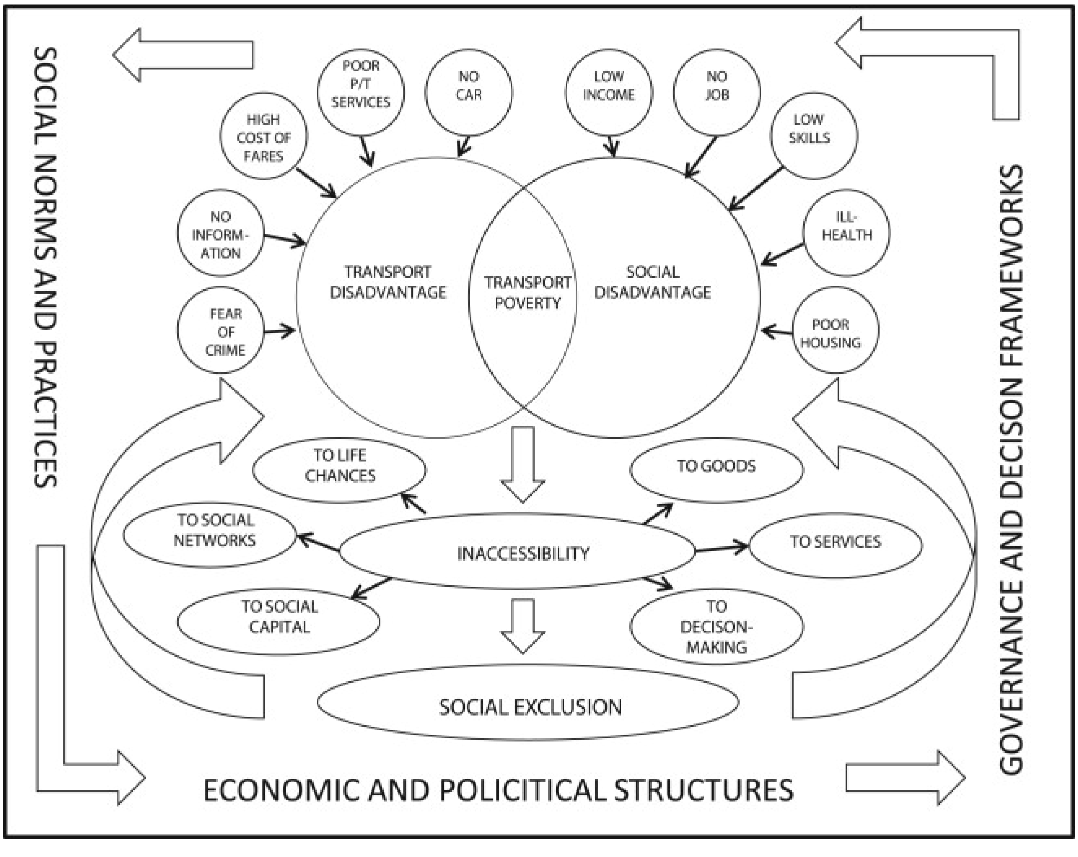

Figure 3.1: Relationship between transport disadvantage, social disadvantage and social exclusion, adapted from Lucas (2012).

The relevance of this issue becomes clear when considering the social impacts of emission zones. Mulder et al. (2024) estimate that between 113,000 and 270,000 households in the Netherlands have both a low income and high fuel expenses, with most living in medium-sized cities. These households are particularly vulnerable to fuel price fluctuations and face significant barriers to adopting more sustainable transport modes. As such, sustainable mobility policies, while environmentally beneficial, may place disproportionate burdens on these groups. Mulder et al. (2024) concludes that there exists a group of low-income car owners who risk being disproportionately affected by the transition to cleaner mobility. As a result, these households may face restricted access to employment, social networks, and essential services, which are key dimensions of social exclusion. As he notes, "these measures are intended to reduce emissions, but it is important to keep an eye on households that are unable to make the desired switch to sustainable transport on their own." Such households therefore require targeted support to ensure that they are not unfairly disadvantaged by the implementation of a ZEZ.

From an equity perspective, social exclusion highlights that uniform policy measures may lead to unequal outcomes. Without complementary support, groups that depend heavily on private vehicles risk being marginalised as access to urban areas becomes more restricted. Addressing this challenge is crucial to ensure that the transition to zero-emission mobility not only benefits the environment but also promotes social inclusion and equitable accessibility.

Spatial equity

Spatial equity concerns the fair distribution of opportunities, services, and benefits across different geographic areas. It focuses on how transport and land-use policies shape accessibility patterns within cities and regions. In essence, spatial equity examines whether people in different parts of a city have equal access to essential opportunities such as employment, education, healthcare, and social participation. Tsou et al. (2005) define spatial equity as the provision of benefits at a level that is consistent and fair throughout a geographical space.

Martens et al. (2012) argues that social equity in transport is often evaluated through the lens of accessibility, with observed gaps in accessibility helping to identify spatial, vertical, temporal, and intergenerational inequalities. Although the two concepts are closely related, this research distinguishes between them: accessibility refers to the ability of individuals to use the transport system, whereas spatial equity concerns how such opportunities are distributed geographically.

Spatial differences within urban areas often reflect existing socio-demographic and economic inequalities. For instance, neighbourhoods characterised by lower-income populations may rely more heavily on private vehicles and face limited access to PT (Leonardo et al., 2022; Mulder et al., 2024). Conversely, in Amsterdam, wealthier areas tend to benefit from better access to transit areas (Dixit et al., 2021). These structural imbalances reduce spatial equity, as residents in less connected areas experience lower accessibility and fewer mobility choices.

From the perspective of a ZEZ, spatial equity plays a crucial role. Implementing restrictive measures in certain areas without ensuring adequate transport alternatives can deepen existing inequalities. To maintain fairness, local governments should guarantee that every area within or surrounding the zone remains well connected through reliable and accessible transport services. A ZEZ can therefore only be considered equitable if it is accompanied by complementary investments in sustainable mobility, particularly in neighbourhoods that are currently underserved.

Ensuring spatial equity thus requires recognising the uneven geography of opportunity and addressing it through planning and policy. By providing comparable levels of accessibility across all parts of the city, municipalities can prevent new forms of exclusion and promote a fairer transition towards cleaner and more sustainable mobility systems.

3.4. Conclusion

To address the first research question 'How has equity been characterised and addressed in transport policy, and what do existing studies reveal about the distributional effects of emission zones?', the literature shows that equity in transport is understood as the fair distribution of mobility-related benefits and burdens, particularly in terms of accessibility, exposure to environmental risks, and wider social consequences. Different ethical approaches play a role in shaping this understanding. While utilitarian thinking remains influential in Dutch transport appraisal, especially through the use of SCBAs, the more normative concerns raised by egalitarianism and sufficientarianism have become increasingly prominent in discussions on fair mobility transitions. Together, these perspectives stress that transport policies should not only improve overall welfare, but also protect those who are least able to adapt and ensure that all individuals retain adequate access to essential destinations.

Studies of emission zones reveal a similar pattern, whereby these measures consistently generate improvements in air quality and public health, yet their social impacts tend to be uneven. Lower-income households, elderly residents, and those who rely heavily on older vehicles, which are more commonly owned by households with lower incomes, or who live in less well-connected neighbourhoods face greater challenges when restrictions are introduced. Research from various European cities highlights that these groups often experience declines in accessibility, higher adaptation costs, or increased risks of social exclusion, while households with more resources or better alternatives are less affected. The magnitude of these impacts also depends on local conditions such as the quality of PT, the size of the zone, and underlying spatial inequalities.

Taken together, the literature suggests that emission zones can deliver substantial environmental benefits, but they may also reinforce existing socio-economic, generational, and spatial disparities if equity is not explicitly addressed. Ensuring fairness therefore requires complementary measures, such as improving PT accessibility and other alternatives to private car use, providing targeted support for vulnerable households in the transition to cleaner mobility, and investing in sustainable transport options in underserved neighbourhoods, to maintain minimum levels of accessibility. Equity, in this sense, emerges not only as a moral consideration but also as a practical condition for achieving a socially just and effective transition to zero-emission mobility.

4

Conceptual Framework

A central component of this research is the development of a conceptual model. The purpose of the model is to explore how a ZEZ may generate equity impacts. While the existing literature often makes implicit or simplified assumptions about such effects, the model enables a step-by-step examination of the underlying system. In doing so, it provides a more nuanced understanding of how equity outcomes emerge and highlights the points at which interventions may be most effective. The model therefore serves both as an analytical framework and as a foundation for considering measures that could support a fairer and more inclusive implementation of the ZEZ.

This chapter also provides an answer to the second research question, which concerns how the entire system can be conceptually visualised and what dynamics it reveals from an equity perspective. In this sense, the conceptual model translates the theoretical insights from the literature into a structured representation of causal relationships, illustrating how different factors interact to shape the equitability of a ZEZ.

The chapter proceeds as follows. Section 4.1 discusses the theoretical underpinnings of the model, including its relationship to other forms of conceptual modelling. Section 4.2 explains the internal structure of the model and its interpretation. Finally, Section 4.3 outlines the causal relationships between the different variables represented within the model.

4.1. Nature of the Model

The model developed in this research draws inspiration from causal loop diagrams (CLDs), which typically illustrate systems through variables and the causal links between them. As noted by Barbrook-Johnson and Penn (2022), such variables can represent any element in the system, provided that it can meaningfully be conceived as increasing or decreasing in scale. In this sense, the present conceptual model shares with CLDs the use of variables and directional arrows to represent causal relationships.

There are, however, important differences. Traditional CLDs often emphasise reinforcing and balancing feedback loops that shape system dynamics over time. By contrast, the model presented here is not primarily concerned with uncovering feedback loops. Its focus lies instead on tracing the chronological pathway from the implementation of a ZEZ to its potential equity effects. A further distinction is the inclusion of explicitly normative elements, such as spatial or generational equity. These are not easily quantified but are nevertheless essential to evaluating the fairness of ZEZ implementation.

The model is also informed by the principles of directed acyclic graphs (DAGs). DAGs are constructed to represent prior knowledge about causal structures within a system and are widely used in addressing specific causal research questions. In particular, DAGs are valuable for identifying which variables, if controlled for during the design or analysis phase, are sufficient to eliminate confounding and certain forms of selection bias (Digitale et al., 2022). Two advantages highlighted by Digitale et al. (2022) are especially relevant here:

- Clear communication: By visually depicting causal assumptions, DAGs often convey relationships more effectively than narrative explanation. They are especially useful in distinguishing causation from prediction objectives.

- Guidance on confounding: DAGs assist researchers in recognising alternative sets of variables that may be sufficient to estimate causal effects. This helps in choosing appropriate control variables to block confounding paths, thereby reducing the risk of bias.

At the same time, DAGs also have limitations. As Digitale et al. (2022) notes, they do not capture the functional form of causal relationships, such as whether a relationship is positive or negative. The conceptual model developed here addresses this gap by explicitly indicating the direction of relationships. In doing so, it seeks to combine the strengths of both CLDs and DAGs while adapting their principles to the specific research focus on equity in ZEZ implementation.

It is worth noting that DAGs are widely applied in the clinical sciences, where they are particularly valued for their ability to account for confounding variables. For example, in medical studies, a patient's age may distort the observed relationship between a treatment and its outcome, and DAGs help to identify and correct for such influences. By contrast, the present research does not aim to correct for confounding in a strict statistical sense. Instead, it takes inspiration from the reasoning behind DAGs to structure the analysis in a more fine-grained way. Rather than focusing exclusively on identifying confounders, the model breaks down complex relationships into intermediate steps and highlights where complementary policy measures may intervene. In this sense, the model builds on the logic of DAGs but adapts it to the policy context, where explanatory nuance and attention to distributive implications are more important than statistical correction alone.

4.2. Structure of the Model

The model is structured in a chronological fashion. On the left-hand side, the ZEZ functions as the initiating variable. From this point, causal arrows extend towards intermediate variables such as the number of ICEVs and the uptake of ZEVs. These, in turn, influence broader social outcomes, including accessibility, dependence on private vehicles, and ultimately the equity dimensions of the ZEZ.

An illustrative example is shown in Figure 4.1, which depicts the direct relationship between the introduction of a ZEZ, the reduction in ICEVs, and the adoption of ZEVs. In this case, no additional scientific justification is required, since the causal logic is self-evident: restricting the use of ICEVs reduces their presence while incentivising a shift towards ZEVs.

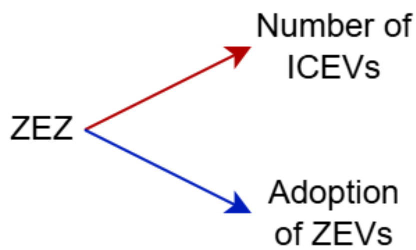

Figure 4.1: Example of a causal relationship between a ZEZ, ICEVs, and ZEV adoption.

4.3. Causal Relationships

The arrows in the model represent different types of causal relationships. In this context, a causal relationship implies that "A causes B, and in the absence of A, B would not have occurred" (Shrier & Platt, 2008). Variables in the model may be causally related if one directly influences the other, if they both arise from a common cause, or through a combination of these pathways (Hernán et al., 2002). Blue arrows are used to indicate positive relationships, where an increase in one variable leads to an increase in another (and conversely, a decrease leads to a decrease). Red arrows denote negative relationships, where an increase in one variable corresponds to a reduction in the other. Black arrows capture more qualitative links, which are not primarily numerical but remain important to represent, for instance, the relationship between socio-demographic characteristics and reliance on private vehicles. An overview of the relationships in the model can be seen in the table below.

Table 4.1: Overview of causal relationships and their symbols in the conceptual model

Type of relationship	Explanation	Symbol in conceptual model
Positive causal relationship	An increase in variable A leads to an increase in variable B	→
Negative causal relationship	An increase in A leads to a decrease in B	→
Qualitative relationship	A non-numerical but meaningful relationship	→

While many relationships can be derived from logical reasoning, others require empirical evidence to strengthen the model's integrity. For instance, the connection between ZEZ implementation and changes in the number of ICEVs or ZEVs requires little justification, as described above. By contrast, the link between active transport modes and broader health or environmental outcomes benefits from scientific substantiation.

Research by Rojas-Rueda et al. (2016) demonstrates that increased walking and cycling not only reduce particulate matter and CO_2 emissions, but also lower the number of traffic fatalities and improve public health through higher levels of physical activity. These findings justify the causal pathways illustrated in Figure 4.2.

The figure highlights three distinct mechanisms. First, active transportation modes (walking and cycling) directly generate health benefits, since physical activity is inherently beneficial for human health (Rojas-Rueda et al., 2016). This relationship is represented by a blue arrow, indicating that increased use of active modes leads to improved health outcomes.

Second, active transportation also influences the volume of motorised traffic in the context of the implementation of a ZEZ. As more people shift towards cycling or walking, car use declines, which is represented by a red arrow. A reduction in the amount of traffic produces two potential outcomes. On the one hand, fewer vehicles on the road improve road safety by lowering the likelihood of traffic accidents (Høye & Hesjevoll, 2020). On the other hand, the effect on pollution depends on the type of vehicles in use. If the remaining traffic largely consists of ICEVs, lower traffic volumes will reduce emissions. However, if most vehicles are already ZEVs, the link between traffic volume and pollution becomes weaker.

Third, even independent of changes in overall traffic volumes, substituting ICEV ownership with active modes inherently reduces emissions. Walking and cycling do not produce tailpipe emissions, meaning that each trip diverted from an ICEV to an active mode results in an immediate decrease in pollution. This mechanism reflects the intrinsic environmental advantage of active transportation and operates regardless of the composition or size of the remaining vehicle fleet.

In this way, the model adds an important layer of nuance to the findings of Rojas-Rueda et al. (2016). Rather than assuming that active transportation directly leads to improved road safety, it highlights the mediating role of traffic volumes and vehicle composition in shaping these outcomes. This aligns with one of the main objectives of causal analysis: to represent pathways with sufficient precision so that confounding variables are accounted for and biases are minimised (Shapiro & Msaouel, 2021).

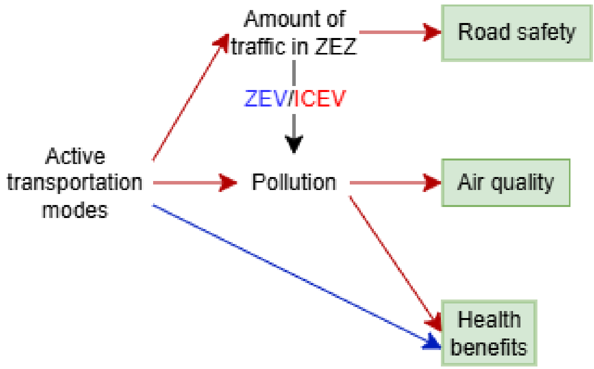

Figure 4.2: Relationship between active transport modes and their influence on pollution, road safety, and health benefits, based on Rojas-Rueda et al. (2016).

4.4. Variables

This section introduces the different types of variables included in the conceptual model. Each group of variables plays a distinct role in shaping how the system behaves and how equity outcomes emerge. The socio-demographic variables are discussed first in Subsection 4.4.1, followed by the behavioural variables in Subsection 4.4.2. The internal system variables are then outlined in Subsection 4.4.3, after which the equity-related variables are described in Subsection 4.4.4. Finally, the external variables, which influence the system from outside its boundaries, are presented in Subsection 4.4.5.

Table 4.2 at the end of this section summarises all variable categories, explains their roles, and shows how each type is visually represented in the conceptual model.

4.4.1. Socio-Demographic Variables

As this research focuses on equity, it is essential to distinguish between different groups within society. Following an egalitarian perspective, it is recognised that some groups are better positioned to adapt to policy changes, while others face greater challenges. In other words, the impacts of emission zones are unlikely to be distributed evenly across the population. Accounting for socio-demographic characteristics enables a more nuanced understanding of the system and allows the model to reflect these differences in distributional outcomes.

Socio-demographic variables, such as income, age, disability status, or household composition, influence the internal dynamics of the system. For instance, income levels affect the adoption of EVs, as studies by Tang and Sun (2019) and Salon et al. (2025) show a positive relationship between disposable income and the uptake of new energy vehicles. Importantly, these socio-demographic factors are not explained by the model itself; rather, they shape the behaviour of other variables within it. In modelling terms, such variables are considered exogenous, as they influence the endogenous variables but are not influenced by them. Recognising these as exogenous variables clarifies the model boundaries and highlights the contextual conditions under which equity effects emerge (Deistler & Scherrer, 2022).

4.4.2. Behavioural Variables

Behavioural variables capture changes in travel behaviour that result from the introduction of emission zones. One example is route choice: people may decide to avoid the zone altogether or find new ways to travel around it if entry is restricted. Another is vehicle dependence. Some groups, such as people with disabilities, rely more heavily on private vehicles. Evidence from the Madrid Central case shows that these groups have a stronger dependence on car use (Tarriño-Ortiz et al., 2022). Behavioural variables are shaped by socio-demographic characteristics but highlight how these differences are expressed in practice.

4.4.3. Internal Variables

Internal variables resemble those used in traditional CLDs. They have a numerical nature, meaning they can rise or fall within the model, adding dynamism and explanatory power. These variables can be adjusted to see how outcomes change, offering insight into how equitability might be influenced. As

Haraldsson (2004) puts it: “The variables reflect measurable quantities that can go up or down, rise or fall, grow. Units help us keep a focus on what story the diagram is telling.” Unlike the more qualitative variables, internal variables are quantifiable, which allows them to be represented simply as going “up” or “down”.

4.4.4. Equity Variables

Equity variables represent the outcomes of interest, located at the end of the model. The structure flows from left to right, with internal variables shaping the equity variables. While internal variables are primarily numerical, equity variables are more qualitative and require broader explanation. They include the equity dimensions explained in Section 3.3. With the exception of individual accessibility (which is more nuanced and does not always directly reflect overall equitability), these variables all contribute to the broader outcome of “equitability of a ZEZ”. As such, changes in the numerical values of internal variables can influence equity variables, thereby affecting the degree of justice achieved within the system.

4.4.5. External Variables

According to Haraldsson (2004) and Sterman (2000), external variables are components that lie outside the boundaries of the system but nonetheless exert influence upon it. They are not directly involved in the internal dynamics of the model and are unaffected by changes within it. Instead, these variables belong to their own independent systems, each shaped by distinct causal mechanisms. In principle, a separate model could be developed for any external variable to capture its specific processes and interdependencies. Similar to socio-demographic variables, external variables have no incoming causal links, meaning that nothing within the system influences them; they only act upon internal variables from the outside. Typical examples include energy prices or fuel costs, which are determined by broader market dynamics such as global supply and demand. While these external factors shape the conditions under which the system operates, their variation cannot be explained or controlled within the model itself.

Some of these external factors may, however, be influenced directly through governance or policy intervention. For example, local or national authorities may introduce subsidies, taxation schemes, or regulatory measures that alter the relative attractiveness of different modes of transport. The extent to which such steering is possible and how it may affect the system will be discussed further in Chapter 5. In the present chapter, external variables are only identified and acknowledged as contextual influences; their more detailed role and relevance are examined later when the results are interpreted.

Table 4.2: Overview of variable categories and their symbols in the conceptual model

Variable category	Explanation	Symbol in conceptual model
Socio-demographic variables	Group-level traits that determine unequal impacts	Socio-demographic variable
Behavioural variables	Changes in (travel) behaviour or vehicle use in response to the zone	Behavioural variable
Internal variables	Quantifiable system variables that can increase or decrease, giving the model its dynamics	Internal variable
Equity variables	Outcomes reflecting the fairness of the system, showing how impacts are distributed	Equity variable
External variables	External factors operating outside the system that influence its conditions, such as fuel or energy prices	External variable

4.4.6. Validation

The conceptual model has been validated in four complementary ways: through scientific evidence, logical reasoning, expert review, and survey data.

The first source of validation is scientific evidence. Several of the causal links in the model require empirical justification rather than relying solely on assumptions. As shown in Table A.3, many relationships between variables are supported by existing literature. While some links can be inferred intuitively, grounding them in published research strengthens the model and makes the justification more robust.

Secondly, as explained in Section 4.2, certain causal links are validated through logic. For instance, the relationship between the introduction of a ZEZ and the number of ICEVs is clearly negative: restrictions on ICEVs will logically reduce their use. In such straightforward cases, no additional scientific reference is required, as the causal direction is self-evident.

Nevertheless, not all links are as clear-cut. Some relationships based on logical reasoning were identified as debatable or open to interpretation. In these cases, expert feedback was sought from supervisors with experience in systems thinking. Their assessment guided whether a link could remain justified by logic alone or whether stronger scientific support was necessary. Where the latter was the case, additional literature was consulted to underpin the causal connection.

Finally, validation was also carried out through survey results, which will be discussed in more detail in the next chapter. This survey, conducted by the Municipality of Amsterdam, provides insights into how residents perceive and respond to the ZEZ. It highlights the barriers people face and the alternative choices they consider when certain options are no longer available. These findings act as a further test of the model's assumptions, particularly concerning equity-related outcomes, since they reflect the lived experiences of those directly affected.

4.5. Goal

The conceptual model aims to clarify how the dynamics within the system collectively shape the equitability of a ZEZ. Rather than providing a definitive answer to whether the system is entirely fair or unfair, the model allows for a structured exploration of the relationships and mechanisms that contribute to, or detract from, equitable outcomes. By tracing how changes in one part of the system influence others, it becomes possible to identify where interventions could strengthen fairness or mitigate unintended disadvantages.

Because the system consists of a wide range of interconnected elements, the first step is to present an aggregated version of the model. This simplified representation brings the core dynamics into view and clarifies how the model should be read. It highlights the main pathways through which the introduction of a ZEZ can affect travel behaviour, system conditions, and ultimately equity outcomes. The aggregated model thus provides an accessible entry point for understanding the flow of influences within the system and how broad equity mechanisms arise.

Building on this foundation, the full disaggregated model is then introduced. This more detailed representation captures the wide variety of socio-demographic, behavioural, internal, external, and equity variables that shape the functioning of the system. In contrast to the aggregated model, the disaggregated version provides a far more specific and granular view, showing how smaller, comparable groups of people, such as those sharing particular socio-economic characteristics or travel needs, may experience very different impacts. This degree of detail requires more careful analysis but is necessary for understanding the full range of mechanisms at play.

Taken together, the aggregated and disaggregated models serve as analytical tools that support system-based reasoning throughout the thesis. They offer a framework for visualising how different variables interact and where equity-related tensions may arise. The models also provide a reference point for interpreting empirical findings from the Amsterdam case study and the accompanying survey. These data help to reveal which groups are most affected by the transition towards a ZEZ and how their experiences align with the mechanisms represented in the model. By bringing these elements together, the conceptual model establishes a coherent foundation for examining equity effects and guiding the interpretation of results in later chapters.

4.6. Conceptual Model

This section introduces the conceptual model and explains how it can be used to trace the potential implications of an emission zone. An aggregated version of the model is shown in Figure 4.3, while the full conceptual model is presented in Figure 4.4. The aggregated model provides a simplified overview of how the system operates and how the main variable categories from Table 4.2 are connected. It also illustrates the basic causal structure of the model and how it should be read. The full model then expands this structure to show in more detail how the introduction of a ZEZ triggers a series of behavioural and systemic responses and how these responses interact with key equity dimensions.

In the subsections that follow, three particular pathways are examined in greater depth. First, the pathway reflecting the intended benefits of the ZEZ in terms of cleaner air and improved public health (Subsection 4.6.3). Second, the pathway relating to potential negative consequences for accessibility and transport-disadvantaged groups (Subsection 4.6.4). Third, the way in which the role of various P+Rs around the emission zone becomes more prominent (Subsection 4.6.5). After the explanation of these pathways, the variables influencing the various modalities will be explained in Subsection 4.6.6.

4.6.1. Aggregated Conceptual Model

Figure 4.3 presents the aggregated version of the conceptual model. The model is read from left to right and follows the direction of the arrows. It begins with the introduction of the ZEZ and sets two main processes in motion. The first concerns changes in trip patterns, as people may alter their destinations when they can no longer enter the zone with vehicles that do not meet the standards. The second concerns changes in the mode of transport, for example when individuals shift from a conventional vehicle to PT.

These changes in mode choice are shaped by a range of external factors. These include the costs associated with using different forms of transport, such as fares, fuel or electricity prices, and other operational expenses. Socio-demographic characteristics also play a role, as, for instance, income influences the extent to which people can afford certain modes of travel, which in turn affects their choices (Tang & Sun, 2019; Tarriño-Ortiz et al., 2022).

Both trip changes and mode changes feed into the internal dynamics of the model. This term refers to the underlying processes that respond to shifts in travel behaviour, such as variations in traffic levels within the zone or changes in pollution. These dynamics may increase or decrease depending on how people adapt to the ZEZ.

Finally, the internal dynamics influence several equity dimensions that determine how fair the ZEZ is in practice. These dimensions include air quality, road safety, and the risk of social exclusion. Together, they shape the overall assessment of the equitability of a ZEZ.

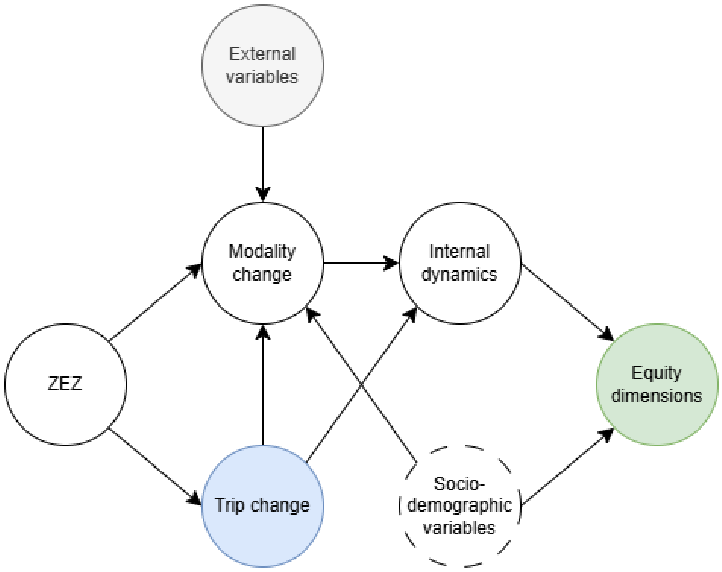

Figure 4.3: Aggregated conceptual model of the ZEZ system, highlighting the core processes linking the introduction of the zone to changes in mobility patterns and equity impacts.

4.6.2. Disaggregated Conceptual Model

Figure 4.4 presents the disaggregated version of the conceptual model. Whereas the aggregated model shows the main processes in simplified form, the disaggregated model provides more detail on how these processes interact. The implementation of a ZEZ sets several immediate changes in motion. Most directly, it reduces the use of ICEVs within the designated area. This decline may be accompanied by an increase in the adoption of ZEVs, shifts towards PT, greater uptake of shared mobility services, and increased use of active transportation modes such as walking and cycling. In some cases, the ZEZ may also lead to changes in travel destinations. For example, individuals without a compliant vehicle may reroute around the perimeter of the zone or avoid travelling there entirely, whereas those able to comply may continue accessing the zone as before.

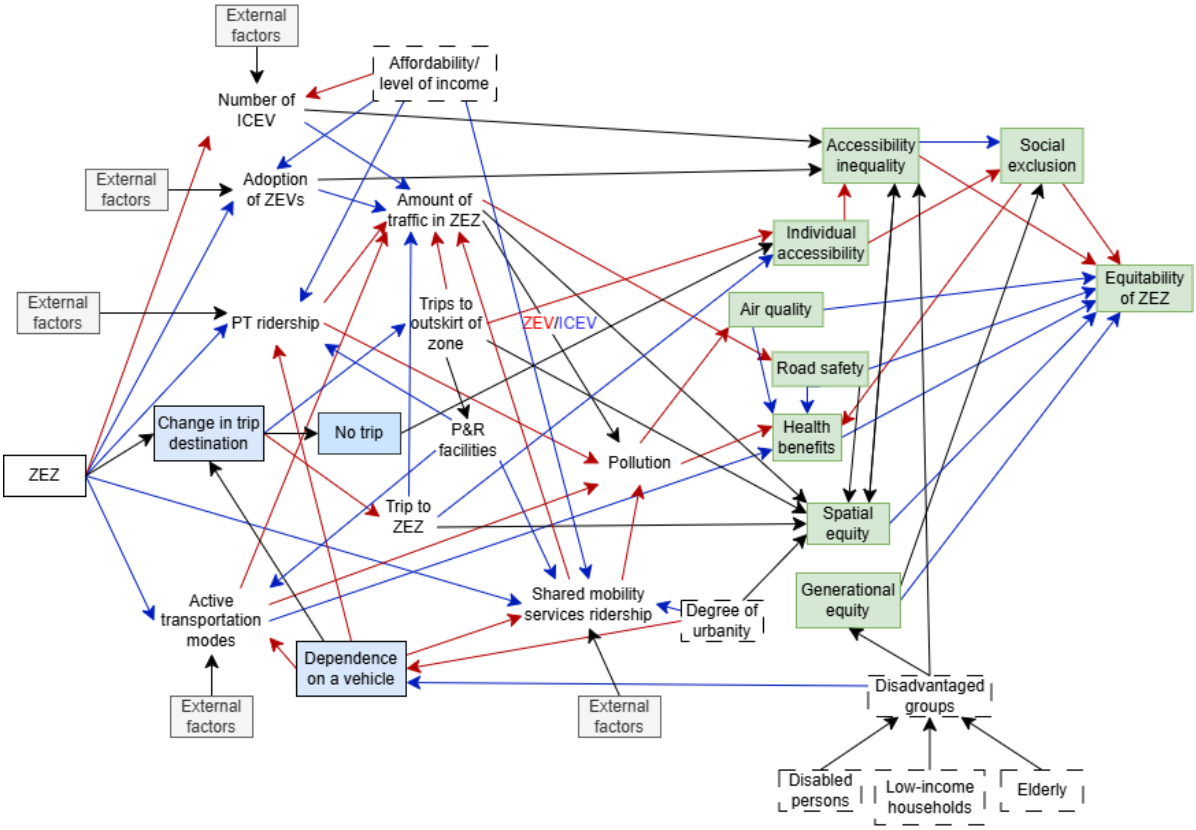

Figure 4.4: Disaggregated conceptual model of the ZEZ system, showing how changes in travel behaviour interact with accessibility and equity outcomes.

The disaggregated model provides a framework for understanding in more detail how the benefits and burdens of a ZEZ may be distributed across different groups and under which circumstances these distributions may lead to a more equitable outcome.

4.6.3. Goal of a ZEZ

A key motivation for introducing a ZEZ is the improvement of air quality in densely populated urban areas, alongside the intention to reduce the volume of motorised traffic entering certain parts of the city. Both of these objectives are represented within the conceptual model. The model is used to explore how different behavioural responses to the ZEZ may unfold and to assess how these responses connect to the equity dimensions that together determine the overall equitability of the ZEZ.

Figure 4.5 illustrates a potential pathway through the system. This example focuses on the shift towards ZEVs, PT, active modes and shared mobility services following the introduction of the ZEZ. The underlying assumption is that the restriction on ICEVs will encourage some people to adopt a ZEV, while others may switch to PT, shared mobility or active transportation. Increased use of PT, shared mobility and active modes removes some private cars from the road, thereby reducing traffic volumes and, in comparison with the baseline scenario dominated by ICEVs, decreasing pollution levels. In contrast, a rise in the number of ZEVs on the road may still contribute to traffic, though without the same emissions footprint.

Reduced traffic volumes are associated with improved road safety, as higher traffic density is positively related to the likelihood of collisions (Høye & Hesjevoll, 2020). Lower levels of pollution contribute to improved air quality (Malina & Scheffler, 2015; Pestel & Wozny, 2021), which in turn yields public health benefits, as demonstrated in wider environmental health research (Broster & Terzano, 2025). Taken together, these improvements correspond to positive outcomes for the equity dimensions of air quality, road safety and health benefits. In this particular pathway, therefore, the ZEZ supports a more equitable outcome, as the benefits of reduced pollution and safer streets are shared by all.

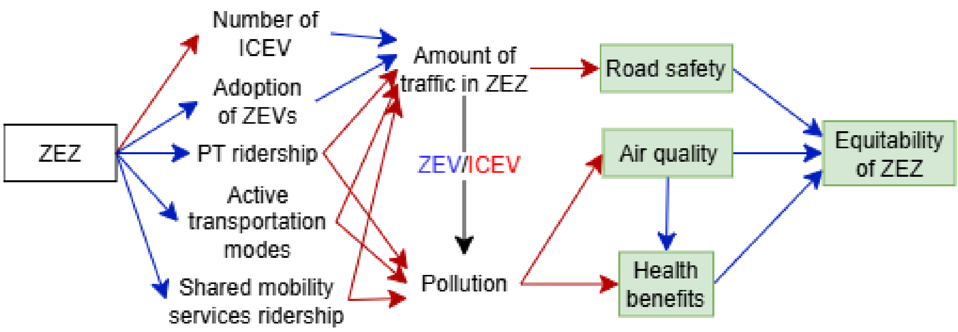

Figure 4.5: Pathway from the conceptual model highlighting the dynamics between the adoption of ZEVs, PT ridership, active transportation modes and shared mobility usage and their impacts on road safety, air quality and health benefits.

This example presents only one possible interpretation of the model. In reality, the dynamics are more complex, particularly with regard to the spatial distribution of traffic and the extent to which reduced car use reshapes urban mobility patterns. These aspects relate more directly to urban planning and policy design and are therefore not examined further here. Nonetheless, this pathway illustrates that if the overall number of cars decreases, rather than ICEVs being replaced one-to-one by ZEVs, a ZEZ may lead to a more equitable outcome through improvements in air quality, health, and road safety.

4.6.4. Transport Poverty

An important real-world concern, which the conceptual model makes explicit, is that for some individuals the car is not simply a preferred option but the only realistic way to maintain their accessibility. While the ZEZ creates a set of possible modal shifts towards ZEVs, PT, active modes, or shared mobility services, not everyone is equally able to make such a shift. For some low-income households, the private vehicle is essential for reaching employment, healthcare, education, or other daily activities, and the removal of an ICEV without a feasible alternative can therefore result in a substantial loss of accessibility (Mulder et al., 2024).

This issue connects directly to the sufficientarian interpretation of equity employed in this research. The sufficientarian view holds that individuals should have access to at least a minimum acceptable level of accessibility. In the context of the ZEZ, this means that if a person loses access to their ICEV, a functionally viable alternative should be available. If such an alternative does not exist due to distance, inadequate PT services, travel time constraints (such as lack of service at night) or the absence of feasible walking or cycling routes, then the individual experiences a decline in individual accessibility. A fall in accessibility contributes to increased social exclusion and consequently to a less equitable outcome of the ZEZ.

An important distinction should be made in how accessibility is understood and experienced. People differ not only in their actual ability to reach destinations, but also in how they perceive this ability. Whereas accessibility in a more conventional sense concerns the extent to which destinations can be reached within acceptable travel times, costs, and effort (Hamersma & Roeleveen, 2024), perceived accessibility refers to "how easy it is to live a satisfactory life using the transport system" (Lättman et al., 2016). Perceived accessibility therefore reflects whether individuals feel that the available travel alternatives are viable for their daily activities.

Within the context of the ZEZ, some individuals may perceive themselves to be highly dependent on their car, even where PT, cycling or shared mobility could reasonably meet their needs. Others genuinely face limited or unworkable alternatives due to the spatial location of workplaces, caregiving responsibilities or time-critical travel patterns (such as travelling to work at night). It is this gap between perceived accessibility and practically achievable accessibility that is particularly relevant for equity analysis. The survey analysis presented later in Section 5.1 will explore how these forms of perceived car dependence are expressed among residents in Amsterdam and which groups are at greater risk of experiencing a decline in accessibility as a result of the ZEZ.

Having outlined how accessibility may decline at the individual level, it is also necessary to consider which groups in the population are more likely to experience such impacts. This shifts the focus to the egalitarian dimension of the research, which concerns inequalities between social groups. Previous studies indicate that certain groups are more likely to experience transport-related accessibility constraints. For example, in Madrid Central, Tarriño-Ortiz et al. (2022) found that disabled persons and older adults showed higher levels of car dependence. While cultural and spatial differences mean these findings cannot be directly transferred to Amsterdam, they highlight which groups may be at increased risk of accessibility loss. In the Dutch context, research shows that levels of urbanisation play a significant role in shaping car dependence, with residents of less urbanised and suburban areas more likely to rely on the car (Witte et al., 2022).

Moreover, Mulder et al. (2024) argues that low-income households are particularly vulnerable to tax measures and policies that require an investment in sustainable vehicles like ZEVs. These ”at-risk households” may face both financial and accessibility disadvantages and are therefore more likely to be negatively affected by a ZEZ. Mulder et al. (2024) also highlights that promoting viable alternatives such as high-quality PT, shared mobility and (e-)bicycles appears promising, particularly because many at-risk households reside in urban areas where such modes could be effective, though further research is required to ensure practical feasibility.

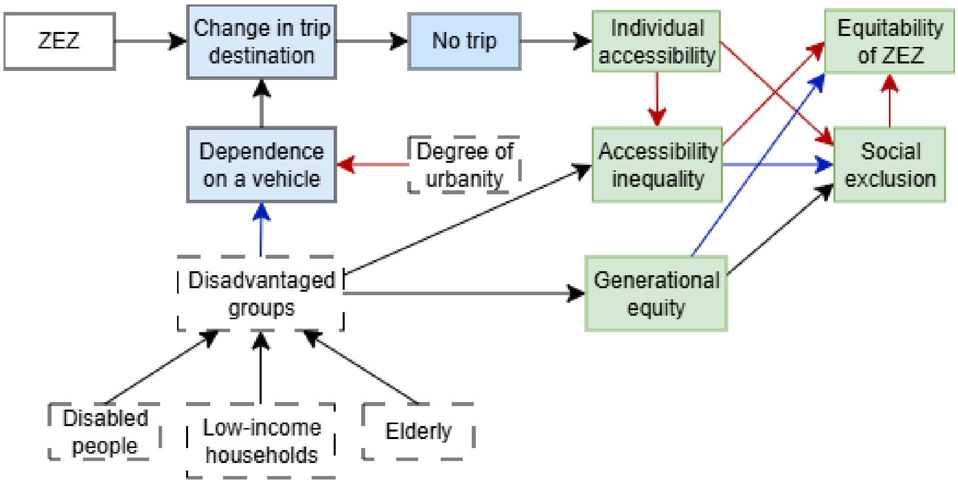

Figure 4.6: Pathway from the conceptual model illustrating how the absence of a viable alternative to the private vehicle can lead to a reduction in individual accessibility and increased risk of social exclusion.

4.6.5. Role of P+R

A further behavioural response that may arise alongside modal shifts or the decision not to undertake a trip at all is a change in trip destination. Travellers coming from outside the city may choose to re-route around the boundary of the zone, driving only as far as they are permitted with their ICEV and completing the remainder of their journey by PT, active modes, or shared mobility services. In this process, Park-and-Ride (P+R) facilities become a key component of the system.

P+Rs are parking areas located at or near transit nodes, enabling travellers to park their vehicle and transfer to a bus, tram, metro or train (Haque et al., 2021). Although traditionally used by commuters, they are also frequently used by people travelling for shopping or leisure purposes (Ortega et al., 2021). More recently, shared mobility services have become part of the first- and last-mile connections between P+Rs and final destinations, further expanding the range of feasible alternatives for completing the trip (Ma et al., 2022). By enabling a switch from the private car to less polluting modes, P+Rs can contribute to reductions in traffic volumes and emissions within the zone. Fewer cars entering the central area improve air quality, enhance public health and support safer street environments.

However, the increasing reliance on P+Rs also raises questions of spatial equity. Whereas in the baseline scenario vehicles would be distributed throughout the city in parking garages or on residential streets, the introduction of a ZEZ can shift parking pressure towards the boundary of the zone, as travellers drive up to the perimeter and park there before continuing their journey. At the same time, P+Rs located closer to the origin of the trip may also increase in importance. For example, a commuter living in a rural area may choose to drive only as far as a nearby P+R in or around the place of residence and then continue by PT or shared mobility to the final destination. In such cases, P+Rs function not only as gateways at the edge of the zone, but also as upstream hubs that structure the very first leg of the journey, provided that onward connections are frequent, reliable and well integrated.

A related concern is the spatial redistribution of traffic. Evidence from the Madrid LEZ shows that while traffic intensity declined within the restricted area, it increased along the boundaries, indicating the displacement of conventional vehicles to adjacent neighbourhoods (Moral-Carcedo, 2024; Tassinari, 2024). Such displacement may lead to localised increases in congestion and emissions outside the zone, potentially shifting environmental burdens rather than eliminating them.

As P+Rs grow in importance in both of these roles, the demand for space and supporting infrastructure at these locations also increases. This expectation is consistent with broader European mobility strategies, which advocate the development of multimodal hubs as part of the shift towards cleaner and more efficient transport systems (European Commission, 2021).

Despite their benefits, P+Rs currently produce several unintended effects. Many facilities in the Netherlands are free to use, which can encourage long-term parking or attract users seeking to avoid parking charges elsewhere in the city. As Mingardo (2013) argues, this undermines the intended purpose of P+Rs as transfer points and can reduce their effectiveness as instruments for managing traffic in urban centres. One way to address this is to integrate P+Rs into wider parking policies by introducing appropriate pricing mechanisms (Mingardo, 2013). Doing so provides a financial incentive for users to combine car travel with PT or other services, as intended, while discouraging misuse of the facilities, and reinforcing their role within a multimodal system.

In this way, P+Rs occupy a critical position in the broader functioning of the ZEZ. When they are well connected to PT and mobility services, and are supported by appropriate pricing and management strategies, they serve as effective nodes for modal interchange, strengthen the accessibility of the system and help distribute the benefits of the ZEZ more evenly. Conversely, if left unmanaged, they may introduce new spatial pressures or inefficiencies.

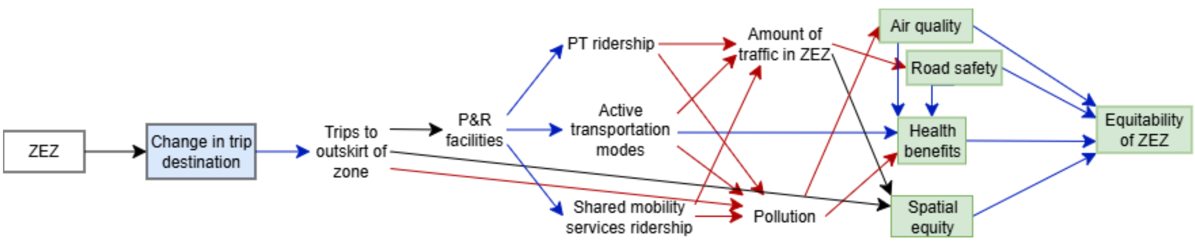

Figure 4.7: Pathway from the conceptual model showing how the introduction of a ZEZ increases the strategic importance of Park-and-Ride facilities at different stages of the journey.

4.6.6. External Variables

As outlined earlier, the implementation of a ZEZ may lead some individuals to experience a reduction in accessibility, particularly when they are no longer able to use their ICEV and no suitable alternative mode is available to them. From a sufficientarian perspective, maintaining a minimum acceptable level of accessibility is essential. Therefore, in order to understand where accessibility may fall and for whom, it is necessary to examine the factors that shape the use of alternative modes such as ZEVs, PT, active transport and shared mobility services.

For reasons of clarity, the external variables influencing these modal choices are not integrated directly into the main conceptual model in Figure 4.4. Including them explicitly would significantly increase the visual density of the model and reduce its readability. Instead, they are discussed separately in this section. These external variables are not influenced by the system itself, but rather form the conditions under which the system operates. Many of them can, however, be steered to some extent through policy or public investment, which is why they are particularly relevant for the later analysis in Chapter 5.

This section therefore provides a structured overview of the key external variables shaping each modality. The variables presented are those most consistently supported by empirical evidence and identified in the literature as significant determinants of mode choice. In doing so, the section offers the basis needed to understand who may be affected by the ZEZ, why certain alternatives may or may not be feasible for different population groups, and where targeted policy interventions might be required to avoid unequal accessibility outcomes.

Number of ICEVs

Vehicle choice in the context of the ZEZ is shaped by a combination of economic, technological and practical considerations. In general, consumers assess both ICEVs and ZEVs on purchase and operating costs, driving performance and range, charging or refuelling convenience and the availability of suitable models on the market (Liao, 2019). Within this research, purchase cost of ICEVs is not emphasised, as the baseline assumes an existing stock of ICEVs, and by 2035 the sale of new ICEVs will be prohibited under EU regulation (European Parliament, 2024). Brand diversity is also not considered here as it relates more to individual preference rather than to the system-level patterns relevant to this model.

For ICEVs, several factors influence the extent to which households maintain or dispose of their vehicle. These include the price of petrol, the cost and ease of parking, and personal attitudes towards car ownership. In Amsterdam in particular, rising parking costs and limited parking availability have increasingly influenced residents' decisions regarding car ownership, particularly where high-quality alternatives exist (Ostermeijer et al., 2019). In this context, energy prices also play a role, as they reflect the relative operating cost of ICEVs and ZEVs.

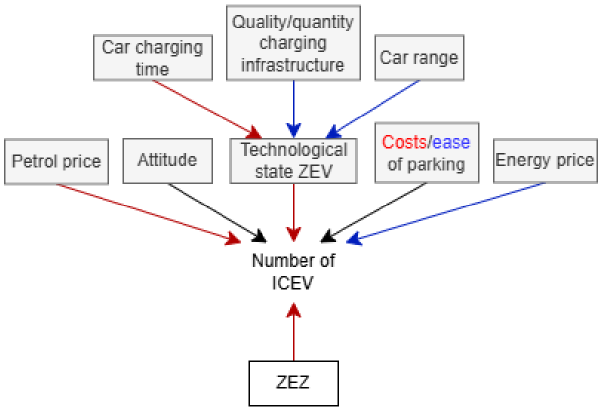

Figure 4.8: External factors influencing the number of ICEVs.

Adoption of ZEVs

For ZEVs, many of the same considerations apply, but additional perceived barriers come into play. Common concerns include limited driving range, long charging times and insufficient charging infrastructure. When these concerns are reduced through either technological improvements or infrastructure expansion, the willingness to adopt ZEVs increases. One distinguishing factor in ZEV adoption, compared with ICEVs, is the ability to charge at home. Access to private charging significantly increases convenience and reduces reliance on public charging infrastructure, which is a key determinant of purchase decisions (ANWB, 2021).

Overall, the number of ICEVs and the rate of ZEV adoption are closely related: barriers to ZEV adoption indirectly reinforce ICEV retention, while improvements in ZEV availability and affordability encourage substitution. Both vehicle types are also influenced by broader urban mobility conditions, particularly the perceived availability and quality of alternatives such as PT, active modes, and shared mobility.

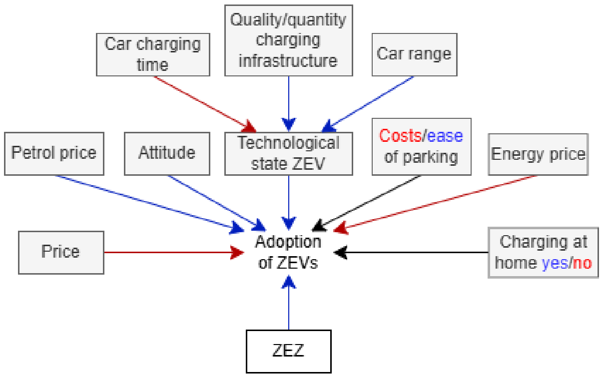

Figure 4.9: External factors influencing the adoption of ZEVs.

PT ridership

PT ridership is shaped by a combination of spatial, service-related and practical factors. One of the most important determinants is the spatial availability of PT services: if services are accessible within a reasonable distance, the likelihood of use increases. For example, Liotta (2025) show that in Marseille the relatively good spatial coverage of PT in low-income neighbourhoods contributes to higher usage among these groups, whereas in other cities with poorer spatial coverage PT use among similar groups was noticeably lower.

Service-related characteristics also play a central role. Fares, route structures, service frequency and reliability all influence whether PT is perceived as a convenient and viable option (Taylor & Fink, 2013). In this context, service quantity refers to the frequency and headways of services, while service quality concerns reliability and consistency. The more predictable and frequent the service, the more attractive PT becomes.

Integration with other modes further affects PT ridership. Research indicates that improving the quality of cycling routes and bicycle parking facilities can substantially increase train ridership and expand the number of jobs reachable by PT users (Geurs et al., 2016). Moreover, multi-modal coordination between shared mobility services and PT can increase the attractiveness of using PT, particularly for first- and last-mile travel (Montes et al., 2023). Earlier work by Martens (2007) similarly demonstrates that encouraging bicycle-train and bicycle-bus combinations can increase use of both bicycles and PT.

Ultimately, people are more likely to choose PT when it is accessible, affordable, reliable, and well-connected to other transport modes. These factors are illustrated in Figure 4.10 and collectively shape PT ridership levels.

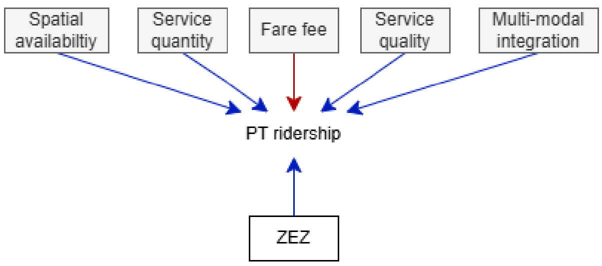

Figure 4.10: External factors influencing PT ridership.

Active transportation modes

Evidence shows that the built environment plays a substantial role in shaping decisions to walk or cycle. Osmënaj et al. (2023) demonstrate that the quality of pedestrian infrastructure around workplaces can strongly influence the likelihood of commuting on foot. However, in the context of this research, cycling is generally a closer functional substitute for the private car than walking, as walking tends to be associated with shorter travel distances.

A large body of literature has shown that improvements in cycling infrastructure such as the provision of dedicated cycle lanes, safer junctions and well-connected networks lead to increased cycling rates (Buehler & Pucher, 2010; Goel et al., 2022; Hull & O'Holleran, 2014; Marqués et al., 2015; Pucher & Buehler, 2008). The relationship between cycling and PT is also relevant here. As van Ommeren et al. (2017) argue, these modes are not competitors but rather complements: better integration of bicycle networks with PT facilities (e.g. secure bicycle parking at stations) encourages use of both.

The distance to key destinations and the perceived safety and comfort of available routes also play an important role. Ek et al. (2021) find that travel distance is negatively associated with walking and cycling for commuting, while the presence of safe, accessible routes increases the likelihood of choosing these modes. Moreover, several studies highlight that subjective safety, which has been described as the level of safety that an individual feels when cycling, can be as influential as actual infrastructure provision (Dill & McNeil, 2016; Gössling & McRae, 2022; von Stülpnagel & Binnig, 2022; Yang et al., 2019). Perceived risk linked to traffic speed, road design, or social safety can therefore either encourage or discourage cycling, even when infrastructure technically exists.

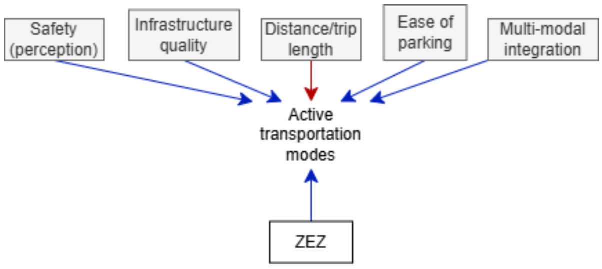

Figure 4.11: External factors influencing active transportation modes.

Shared mobility services ridership

Ridership of shared mobility services is influenced by a range of service-related, spatial and economic factors. A key determinant is the degree to which shared mobility services are integrated with PT. Montes et al. (2023) and Ghasri et al. (2024) show that when shared modes are linked effectively to PT networks, the overall attractiveness of PT increases, thereby making shared mobility services more convenient as part of multi-modal travel. Similarly, Wang et al. (2024) find that connectivity to PT stations is an important factor in shared bike uptake, highlighting the role of network integration.

Service quality also plays a central role. Guo and Gao (2025) identify safety, ease of use, and transit connectivity as important determinants of shared mobility adoption. In this context, ease of use and transit connectivity can be understood as dimensions of service quality, reflecting whether shared mobility is straightforward to access and compatible with onward travel. Infrastructure quality also matters. For example, Dias et al. (2024) report that dedicated cycling infrastructure and designated micromobility parking facilities encourage greater use, while the absence of safe routes deters potential users, as 80% of their respondents indicated that they do not use shared e-scooters primarily due to safety concerns.

Spatial availability is another crucial factor. Dias et al. (2024) show that shared mobility usage is substantially higher in dense urban areas where services are widely available, while peripheral areas with limited availability exhibit much lower uptake. This uneven spatial distribution shapes who is able to use shared mobility services in practice. Correspondingly, studies by Buehler et al. (2023), Meng et al. (2025) and Berg Wincent et al. (2023) suggest that the density and placement of micromobility parking stations influence both compliance and ridership, with neighbourhood-level planning being essential to minimise nuisance and ensure accessibility. Brown et al. (2025) emphasise the importance of such planning for system effectiveness and community acceptance.

Lastly, economic considerations also affect ridership, as Manout et al. (2024) demonstrate that pricing strategies shape market share in shared micromobility, as lower user costs encourage broader uptake.

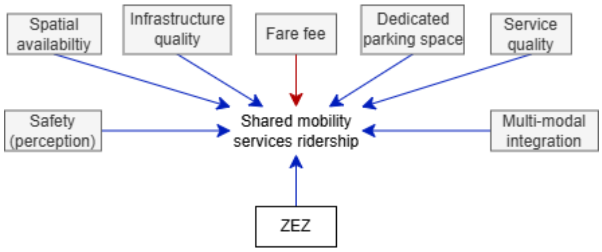

Figure 4.12: External factors influencing shared mobility services ridership.

4.7. Conclusion

This chapter set out to examine how the system surrounding a ZEZ can be conceptualised and how such a system gives rise to equity impacts. In doing so, it addressed the second research question concerning how the effects of a ZEZ can be visualised and which dynamics matter when assessing the fairness of the policy. The chapter brought together insights from systems thinking, causal analysis, and the equity literature to develop a structured representation of the pathways through which a ZEZ influences travel behaviour, system conditions, and, ultimately, the distribution of mobility outcomes.

The discussion began with the aggregated model, which offers a simplified view of the core processes set in motion by the introduction of the zone. This high-level representation clarifies how changes in mode choice and trip patterns feed into the wider system and how these changes relate to the equity dimensions considered in this research. The disaggregated model then expanded this foundation by presenting a far more detailed picture of the specific variables and mechanisms involved. By distinguishing socio-demographic characteristics, behavioural responses, internal system variables, external influences, and equity outcomes, the disaggregated model shows in a more granular way how people with different needs or constraints may experience unequal effects.

The chapter subsequently illustrated three example pathways that emerge from the detailed model. The first pathway showed how the ZEZ can deliver improvements in air quality, public health, and road safety when a reduction in ICEV use is accompanied by the uptake of ZEVs, PT, shared mobility, and active modes. The second pathway outlined a contrasting concern: the risk that some individuals lose access to essential destinations when they cannot replace their ICEV with a feasible alternative. This mechanism highlights the potential for accessibility loss and social exclusion, particularly among low-income households or those with specific mobility needs. The third pathway focused on the growing relevance of P+R locations, showing both the opportunities they provide for cleaner travel and the spatial pressures that may arise at the edges of the zone or at the start of people's journeys. Together, these examples demonstrate that the same policy can generate both positive and negative outcomes, depending on the circumstances under which people travel and the alternatives realistically available to them.

A central contribution of the conceptual model is its separation of variable types. Socio-demographic variables identify the groups that may be more or less able to adapt, behavioural variables reflect the choices people make in response to the ZEZ, and internal variables describe the system dynamics that follow from these choices. Equity variables represent the outcomes that are ultimately of interest, such as accessibility, air quality and road safety. External variables, such as fuel prices, parking policies or the quality of PT, set the broader context within which decisions are made. These external elements lie outside the system's immediate boundaries, yet they shape the feasibility of adopting alternative modes and indicate where policy measures may be required to avoid inequitable outcomes. The interaction between these different types of variables, rather than any single factor, is what produces equity effects.

As the chapter showed, these interactions also give rise to a series of tensions. Cleaner air and safer streets may be achieved at the same time that certain groups lose accessibility. Reduced traffic in the city centre may coincide with increased pressure on areas around the boundary of the zone. These tensions form the core challenge addressed in this thesis: ensuring that the transition to zero-emission mobility does not cause some groups to fall below an acceptable level of accessibility while others benefit. The conceptual model helps to identify where these tensions arise, for whom they are most pressing and which mechanisms underpin them.

Finally, the conceptual model serves as the analytical lens through which the results in the next chapter are interpreted. It provides the structure needed to examine who is likely to lose accessibility, who is better positioned to adapt, and which external factors or policy instruments are most relevant for supporting equitable outcomes. In this way, the model developed in this chapter forms the foundation for evaluating how a ZEZ may contribute to, or jeopardise, a fair and inclusive transition towards cleaner urban mobility.

5
Results

This chapter presents the empirical results derived from the survey conducted by the Municipality of Amsterdam, which forms the basis for addressing the third research question. As the survey data are recent, they have not yet been analysed in depth within existing academic research. Section 5.1 therefore provides a first systematic examination of the findings, with a particular focus on how residents perceive the ZEZ and the extent to which different groups experience opportunities or constraints in adapting to it.

Building on these findings, Section 5.2 identifies a set of necessary conditions for a socially just transition towards a ZEZ. These conditions relate to both egalitarian and sufficientarian considerations and highlight where additional policy measures may be required to prevent unequal accessibility outcomes.

Finally, Section 5.3 situates the Amsterdam case within a broader policy context by examining how other Dutch cities approach the implementation of ZEZs. By comparing policy ambitions, timelines, and contextual conditions across cities, this section reflects on the likelihood of successful implementation elsewhere and explores what lessons can be drawn from these different approaches.

5.1. Survey Results

This section presents the results of the survey analysis and addresses the third research question: In what ways do mobility alternatives, socio-economic barriers and supportive policy measures influence how different socio-demographic groups in Amsterdam experience and adapt to the transition towards a ZEZ? The findings are organised to highlight differences between socio-demographic and spatial groups, as these distinctions provide the clearest insight into how the introduction of a ZEZ may affect residents in unequal ways. Where relevant, results are disaggregated by city district, age category, and educational level, as these variables are available in the dataset and closely relate to the equity dimensions discussed earlier in the thesis.

The analysis proceeds in two main steps. First, Subsection 5.1.1 examines patterns of car dependence, focusing on which groups rely most heavily on the private car and the underlying reasons for this dependence. Second, Subsection 5.1.2 explores the extent to which respondents perceive viable alternatives to car use, thereby identifying who is able to adapt to the proposed changes and who faces constraints in doing so.

A distinction is made in this section between the O&S panel dataset and the City Pass panel dataset. The O&S panel allows for comparisons across spatial and socio-demographic characteristics but does not include direct information on respondents' income levels. As a result, it is not possible to identify all low-income individuals within this dataset, even though such individuals are likely to be included. The City Pass panel dataset, by contrast, consists exclusively of residents with a lower socio-economic background. This group is therefore analysed separately in Subsection 5.1.3.

This separate treatment is justified for two reasons. First, respondents in the City Pass panel face structurally different constraints, particularly in financial terms, which are highly relevant given that the transition towards zero-emission mobility currently involves substantial costs. Second, the City Pass panel contains a smaller number of respondents, which calls for a more careful and targeted interpretation of the results. By analysing this group separately, the specific experiences of lower-income residents can be examined more clearly, without being obscured by patterns that dominate in the broader sample.

5.1.1. Car Dependence

Car dependence constitutes one of the central concerns identified in the conceptual model, particularly because individuals who rely heavily on the private car may face difficulties adapting to the introduction of a ZEZ. Where such adaptation is not possible, a decline in accessibility may occur, increasing the risk of social exclusion. Understanding patterns of car ownership therefore provides an important first indication of where car dependence is most prevalent.

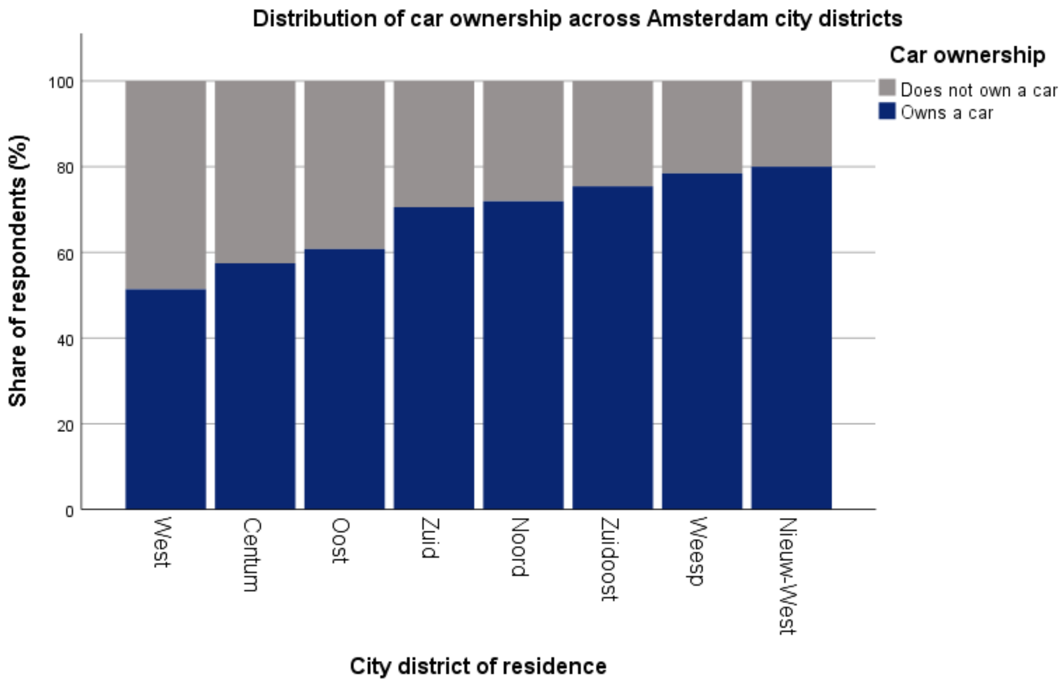

Figure 5.1: Percentage of respondents with ($N = 813$) and without a car by city district (O&S panel, $N = 1,218$).

Figure 5.1 presents the distribution of car ownership across city districts, where clear spatial differences are evident. Car ownership varies significantly by district ($\chi^2(7) = 53.06$, $p < .001$). Respondents living in Nieuw-West, Weesp, and Zuidoost are more likely to own a car than those residing in West or Centrum. These findings align with earlier research by the Municipality of Amsterdam, which reports relatively high levels of car ownership in Noord, Zuidoost, and Nieuw-West compared to other parts of the city (Gemeente Amsterdam, 2019, 2023a). Weesp was not included in this earlier analysis, as it was not yet part of the municipality at the time.

The observed pattern is also consistent with broader research on urban mobility. Witte et al. (2022) show that the degree of urbanity is an important determinant of car ownership, with residents in more urbanised areas generally being less likely to own a car. This relationship is also reflected in the conceptual framework developed in this thesis, where the degree of urbanity is included as a factor influencing vehicle dependence (see Figure 4.6).

By contrast, no statistically significant differences in car ownership were found across educational levels or age categories (Appendix Tables A.4 and A.5). This suggests that, within this sample, spatial factors are more strongly associated with car ownership than individual socio-demographic characteristics such as age or educational attainment.

Importance of car use

Following the analysis of car ownership, this subsection examines how important the car is perceived to be in everyday life and for which activities respondents consider it indispensable. Perceived importance is analysed across educational levels, age categories, and city districts. Descriptive results for these comparisons are presented in Tables A.6, A.7, and A.8.

Across these dimensions, some patterns emerge. A higher perceived importance of car use is reported more often among lower-educated respondents, among respondents aged 30–49 and those aged 80 or older, and among residents of Zuidoost compared to those living in the city centre. However, none of these differences are statistically significant. These findings should therefore be interpreted as descriptive tendencies rather than robust group effects.

What can be stated with greater confidence is the overall level of perceived importance. Across the full sample, car use is considered highly important by a substantial share of respondents. In total, 60% report that the car plays an important role in their daily lives, indicating that reliance on the private vehicle remains widespread.

To better understand this reliance, respondents were also asked for which activities they use the car and which trips they would be unable to make without it. Table 5.1 presents the distribution of reported car use purposes alongside the share of respondents indicating that a given trip cannot be made without a car.

Table 5.1: Car use purposes and trips that cannot be made without a car (multiple responses were allowed)

Trip purpose	Used for this purpose (%)	Cannot be made without a car (%)
Visiting family and friends	67.4	47.9
Grocery shopping	35.9	17.9
Transporting goods	27.6	23.8
Leisure, sports, hobbies	29.0	16.6
Commuting (home–work)	26.2	16.3
Care duties / medical visits	20.5	16.1
Bringing / picking up children	6.8	3.8
Other	14.6	12.9
Can make all trips without a car	–	11.4
Don’t know / no answer	–	0.5

Note. Percentages represent the share of respondents selecting each option. Multiple responses were allowed; percentages therefore do not sum to 100%. Car use purposes are based on respondents who own a car ($N = 813$). Car necessity is based on respondents who answered the follow-up question ($N = 808$).

The results reveal a clear distinction between car use and car dependence. Visiting friends and family stands out as the most frequently reported purpose of car use and is also the activity for which dependence on the car is highest. While 67.4% of respondents use their car for social visits, nearly half (47.9%) indicate that they would be unable to make these trips without a car.

For other activities, the gap between use and necessity is more pronounced. Commuting, leisure trips, and grocery shopping are relatively common reasons for using the car, yet a considerably smaller share of respondents report that these trips cannot be made without it. This suggests that, for many respondents, car use is not strictly necessary in a functional sense, although perceived convenience, reliability, or comfort may still play an important role. Transporting goods forms a partial exception, as the difference between use and necessity is smaller, suggesting a higher degree of dependence for this activity.

Finally, it is noteworthy that 11.4% of respondents state that they can make all trips without a car. Although this result should be interpreted with caution, it indicates that for a minority of car owners the vehicle does not appear to be essential for meeting daily mobility needs.

To further explore the relationship between car dependence and attitudes towards car use, the perceived importance of car use is compared with reported functional car dependence. Table 5.2 presents the distribution of respondents who report being unable to make at least one regular trip without a car, distinguished by whether they consider car use to be of high or low importance in their daily lives.

Table 5.2: Relationship between perceived importance of car use and inability to travel without a car

	Car need		
Importance of car use	Can do without car (%)	Cannot do without car (%)	N
Low importance of car use	21.9	78.1	319
High importance of car use	5.3	94.7	488
Total	11.9	88.1	807

Note. Percentages are row percentages. Car need indicates whether respondents report being unable to make at least one regular trip without a car. Pearson $\chi^2(1) = 50.81$, $p < .001$.

The results show a clear and statistically significant association between the perceived importance of car use and reported car dependence. Among respondents who consider car use to be highly important, almost all (94.7%) indicate that they cannot make at least one regular trip without a car. By contrast, this share is lower, though still substantial, among respondents who assign a lower importance to car use (78.1%).

This pattern can be interpreted as an internally consistency pattern: respondents who perceive their car as essential in everyday life also tend to report concrete mobility constraints when the car is unavailable. At the same time, the findings indicate that car dependence is not limited to those with strong pro-car attitudes. A large majority of respondents who report low importance of car use nevertheless experience functional dependence for certain trips.

This apparent discrepancy can be partly explained by the nature and frequency of the trips involved. As shown in the previous section, visits to friends or family are often reported as trips that cannot be made without a car, yet such trips do not necessarily occur daily. Because the survey measures the overall importance of car use in daily life (rather than importance by trip purpose), respondents may report a lower overall importance while still relying on the car for specific journeys that are less frequent but can still be essential or highly valued.

The association between the perceived importance of car use and car dependence is statistically significant, confirming that higher perceived importance is linked to a greater likelihood of functional dependence. However, the high level of dependency observed even among respondents who attach relatively little importance to car use suggests that dependency is shaped not only by preferences or attitudes, but also by structural and practical constraints.

These constraints are likely related to factors such as the lack of viable alternatives for certain destinations, spatial and temporal limitations of PT, caregiving responsibilities, or the need to transport goods. This finding reinforces the conclusion that reducing car dependence in the context of a zero-emission transition requires more than changing attitudes alone. Instead, it points to the importance of improving the availability, reliability, and suitability of alternative transport options for trips that currently cannot be substituted.

5.1.2. Viable Alternatives

To build on the analysis of car dependence, it is necessary to examine the extent to which travellers perceive viable alternatives to their personal ICEVs. This subsection therefore focuses on the availability and perceived suitability of alternative transport options, particularly for respondents who currently rely on conventional cars. It also considers the extent to which people are willing and able to shift towards more sustainable modes. The subsequent subsections will examine groups that face more limited options due to financial, practical, or contextual constraints, before distinguishing levels of adaptive capacity across respondent groups.

Perceived availability of alternatives

A first step in assessing the broader adaptive capacity of travellers is to examine how respondents perceive the availability of alternative transport options in Amsterdam. Respondents were asked to evaluate the general suitability of different modes as substitutes for polluting private cars, not in relation to their own personal circumstances. Table 5.3 summarises their assessments.

Table 5.3: Perceived suitability of transport alternatives as substitutes for polluting private cars in Amsterdam

	Not suitable (%)	Somewhat suitable (%)	Highly suitable (%)	Don't know (%)
Public transport	7.5	26.0	64.9	1.6
Electric bicycle	16.7	38.3	41.6	3.4
Shared mobility	20.0	45.6	27.8	6.5
Electric microcar	25.8	44.3	21.8	8.0

Note. Respondents ($N = 1218$) were asked to what extent they perceive different transport modes as suitable substitutes for polluting private cars in Amsterdam in general, not for their own personal situation. The option "electric scooter" was not included in this question in the main survey.

The results show that PT is widely perceived as a highly suitable alternative, with almost two thirds of respondents rating it as such. Electric bicycles are also viewed positively, with a substantial share of respondents identifying them as a viable substitute.

Shared mobility is perceived more cautiously. Although many respondents recognise its potential, attitudes towards convenience, trust, and ease of use appear to limit its perceived suitability, echoing earlier findings that behavioural and perceptual barriers can constrain uptake of shared mobility services (Frankx, 2017; Geržinič et al., 2025).

Willingness and capacity to adapt

This section explores respondents' willingness and perceived ability to adapt to a shift away from fossil-fuel vehicles. It begins by examining expectations among current petrol and hybrid car owners regarding a future switch to EVs, before turning to patterns of current use and openness to alternative transport modes.

Table 5.4: Expected timeline for switching to electric driving among non-electric car owners

Expected year of transition	N	Share of respondents (%)
By 2030	210	33.1
By 2035	123	19.4
By 2040	33	5.2
After 2040	31	4.9
Not feasible in the foreseeable future	164	25.8
Don't know / no answer / not applicable	74	11.7
Total	635	100.0

Note. This question was asked only to respondents who indicated that they currently own a fossil-fuel car or a hybrid vehicle (i.e., non–fully electric cars). Percentages are calculated based on valid responses ($N = 635$).

Table 5.4 indicates that just over half of the respondents who currently own a fossil-fuel or hybrid vehicle expect to transition to electric driving by 2035. Almost one third anticipate making this shift by 2030. At the same time, a substantial minority (25.8%) report that switching to an EV is not feasible for them in the foreseeable future. Overall, 62.6% of respondents who expressed any willingness to switch expect to own an electric car at some point in the future. Further qualitative insights into perceived barriers to EV adoption are presented later.

Beyond vehicle replacement, respondents were asked about both their current use of alternative transport modes and their willingness to adopt them.

Table 5.5: Current use and willingness to use transport alternatives in the future

	Already in use (%)	Willing among non-users (%)	Not willing among non-users (%)
Electric bicycle	32.1	29.6	70.4
Electric scooter	3.0	5.9	94.1
Electric microcar	6.7	13.5	86.5
Shared car	20.2	18.4	81.6
Shared scooter	3.3	1.7	98.3
Shared bicycle	11.9	5.9	94.1
Shared cargo bike	3.9	4.4	95.6

Note. "Already in use" is the share of the full sample ($N = 1{,}218$) for whom the mode was not asked in V9a because it was already owned or used (based on filters from V1a/V8). "Willing" and "Not willing" percentages are calculated among respondents who did not yet use the mode; the eligible sample size therefore differs by mode.

Table 5.5 presents both the current use of alternative transport modes and the willingness of non-users to adopt them in the future. Electric bicycles appear to be the most widely used option, with nearly one third of the respondents already reporting regular use. Among those who do not currently use an e-bike, 29.6% indicate that they would be willing to adopt one. This suggests that the electric bicycle represents the most feasible alternative for a considerable share of respondents.

For most other modes, however, both current use and willingness to adopt remain limited. Interest in electric scooters, shared scooters and shared cargo bikes is particularly low, with fewer than 10% of non-users indicating that they would consider using these options in the future. Shared cars display somewhat higher levels of both current use and willingness, yet even in this case the majority of non-users report that they would not be willing to adopt the mode.

Generally, the table reveals limited willingness among respondents to switch to alternative transport modes. For every option presented, the share of non-users who report that they are not willing to adopt the mode is substantially larger than the share that expresses openness to using it. This pattern suggests that many respondents are reluctant to transition to shared mobility services or smaller EVs when they do not already use or own such options.

Groups facing limited adaptation options

To better understand why some respondents struggle to transition to more sustainable travel behaviour, this section examines the specific barriers and support needs reported by current fossil-fuel car users (ICEV & (P)HEV). The focus is on identifying which measures respondents believe would help them reduce car use, how these preferences differ across groups, and what prevents some individuals from switching to electric driving.

Table 5.6 summarises measures that respondents believe could support a reduction in car use. Improving PT emerges as the most widely supported intervention. Both cheaper fares and more frequent, faster or better-connected services are mentioned by a substantial share of respondents. Investment in cycling infrastructure also receives notable support. At the same time, nearly one-third of respondents indicate that none of the listed measures would help them reduce car use.

Table 5.6: Measures that could help respondents reduce car use (multiple responses possible)

	Share of respondents (%)
More frequent, faster or more extensive public transport	42.7
Cheaper public transport	38.1
Improved cycling infrastructure	27.4
Other measures	22.8
None of the above	29.1
Employer compensation for alternative travel	4.4
More information about alternatives (e.g. shared mobility and public transport)	3.1
Don't know / no answer	2.5

Note. Percentages represent the share of respondents selecting each option ($N = 635$). Multiple responses were allowed; percentages therefore do not sum to 100%. Only respondents who indicated that reducing car use could be relevant to them were included in this question.

Open responses categorised as "other measures" largely expand on existing themes. Many respondents emphasise the need for better PT connections beyond Amsterdam or more fine-grained local networks. Smaller groups mention free PT (1.3%), work-related car dependence (0.6%), physical mobility limitations (1.3%), or the need for improvements in shared mobility (2.0%). Some respondents report already making minimal use of a car (2.8%), limiting further reductions.

To assess whether support for PT measures differs spatially, Figure 5.2 presents the share of respondents favouring lower PT fares by city district. Support for this measure varies significantly across districts in statistical terms, with the highest levels observed in Zuidoost and Weesp. Differences by age and educational level are less pronounced and in the case of age categories, not statistically significant (Appendix A.9).

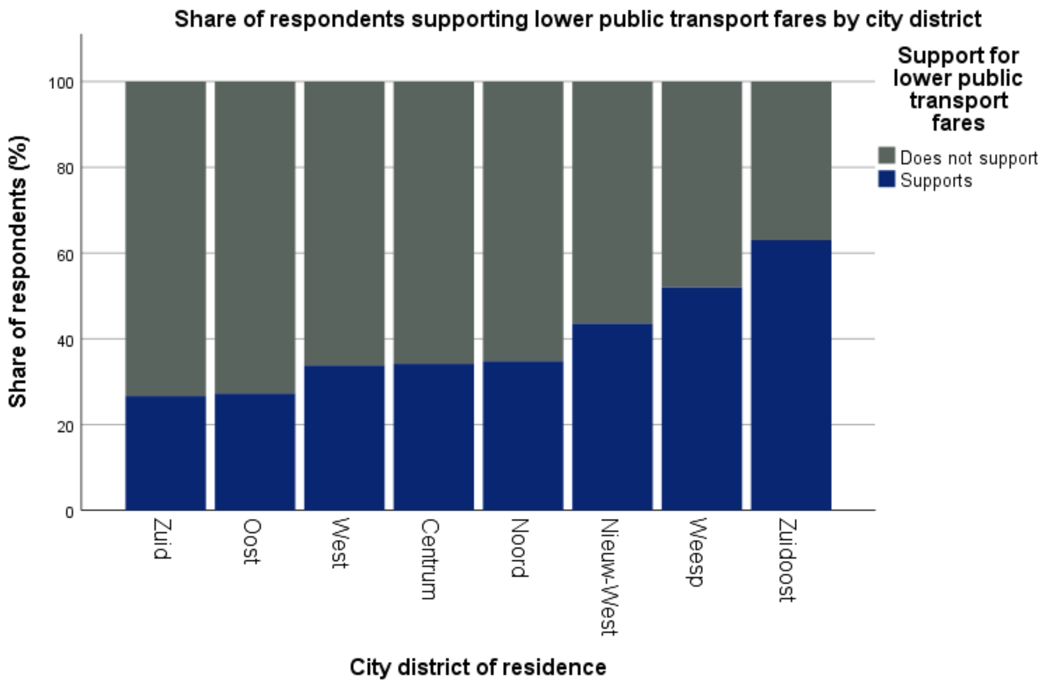

Figure 5.2: Support for making public transport more affordable by city district. The figure shows the percentage of respondents within each city district who support lowering public transport fares as a measure to reduce car use. Differences between city districts are statistically significant. Pearson $\chi^2(7) = 33.66$, $p < .001$, $N = 635$.

A similar pattern emerges when support for improving PT service levels is examined. As shown in Figure 5.3, respondents in Zuidoost and Weesp again express stronger support than those in central districts such as Centrum and Zuid. While overall support for improved PT is high across the sample, these findings highlight spatial inequalities in perceived transport needs. Differences by age and educational level are less pronounced and not statistically significant (Appendix A.9).

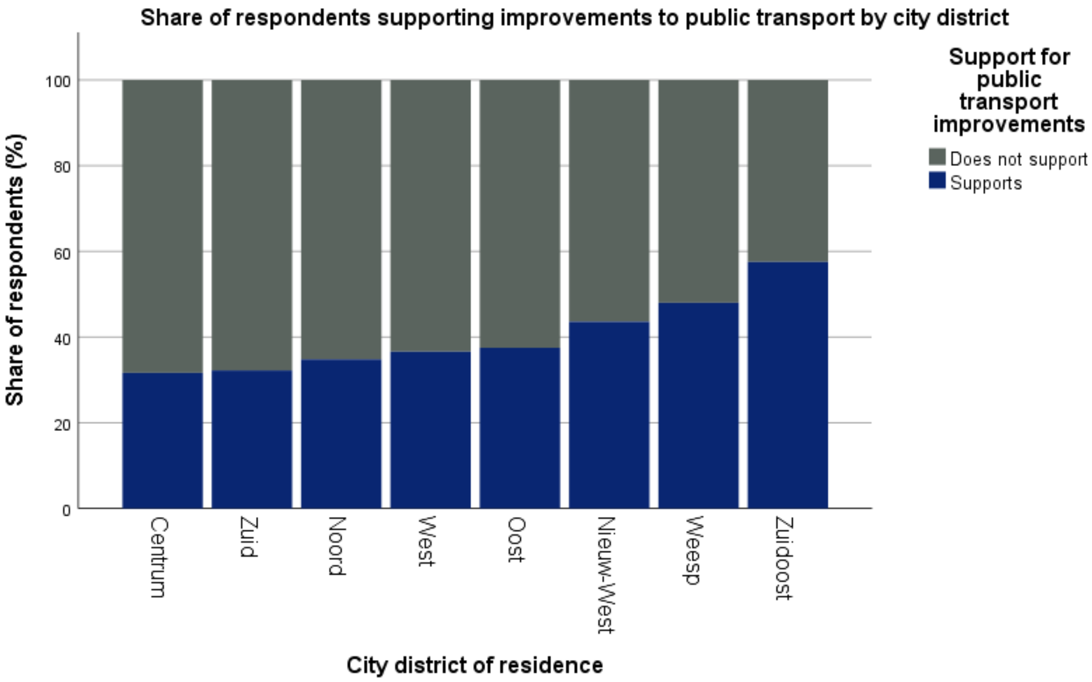

Figure 5.3: Support for improving public transport by city district. The figure shows the percentage of respondents within each city district who support making public transport more frequent, faster, or available in more locations. Differences across districts are statistically significant. Pearson $\chi^2(7) = 16.81$, $p = .019$, $N = 635$.

Beyond reducing car use, respondents were also asked which measures might enable them to switch to electric driving. Table 5.7 shows that government subsidies are the most frequently cited support mechanism. Alongside financial assistance, many respondents raise practical and technical barriers, particularly related to charging availability, driving range and vehicle suitability for specific uses such as long-distance travel or towing. More than a quarter of respondents indicate that no support measure would make electric driving feasible for them.

Table 5.7: Support measures that could facilitate switching to electric driving

	Share of respondents (%)
Government subsidy for purchasing an EV	44.7
Lease contract or temporary scheme to gain experience with EVs	7.4
More information about purchasing an EV	9.0
More information about using and charging an EV	12.9
Support from employer (e.g. charging at work)	3.5
None of the above	26.8
Other	27.2
Don't know / no answer	5.8

Note. Percentages represent the share of respondents selecting each option ($N = 635$). Multiple responses were allowed; percentages therefore do not sum to 100%. The category "Other" includes practical and technical barriers identified through qualitative coding of open responses ($N = 82$, 12.9%), such as the need for more charging infrastructure, faster charging, charging near or at home (including garages and on-street parking), greater driving range, and vehicle suitability for long-distance travel or towing (e.g. caravans).

To explore constraints in greater depth, Table 5.8 presents coded responses from individuals who, in

Table 5.4, stated that switching to an EV is not feasible in the foreseeable future. Financial barriers dominate, followed by technical and practical limitations such as insufficient charging infrastructure or concerns about vehicle range. Age-related considerations also feature prominently, with some older respondents expressing reluctance to invest in a new vehicle at their stage of life. These responses suggest that both economic capacity and everyday usability shape the perceived feasibility of electric driving. In particular, the prominence of financial and practical barriers supports the external factor section and confirms the relevance of the factors identified in Figure 4.9. In this way, the survey findings also reinforce the patterns identified in the literature.

Table 5.8: Reasons for perceiving a transition to electric driving as not feasible

Reason category	Share of responses (%)
Financial constraints	48.0
Technical or practical barriers	31.8
Age-related considerations	23.3
Uncertainty about future developments	6.1

Note. Based on a qualitative content analysis of open-ended responses ($N = 148$) from respondents who indicated that switching to electric driving is not feasible for them in the future. Responses were coded into thematic categories; multiple categories could be assigned to a single response. Percentages therefore do not sum to 100%.

Finally, Table 5.9 compares whether respondents believe any policy measures could influence their behaviour, either by reducing car use or encouraging a switch to EVs. In both cases, roughly seven in ten respondents indicate that at least one measure could help. However, a persistent minority report that no intervention would affect their behaviour, pointing to a group with structurally limited adaptation capacity.

Table 5.9: Perceived effectiveness of policy measures

	Share of respondents (%)
At least one measure would help (less car use)	70.1
No measure would help (less car use)	29.9
At least one measure would help (EV transition)	71.6
No measure would help (EV transition)	28.4

Note. Percentages calculated among respondents who answered the respective question. Missing answers were considered as SYSMIS in SPSS. EV transition: $N = 598$. Reducing car use: $N = 619$.

Taken together, these findings suggest that while many respondents see potential pathways towards more sustainable mobility, a substantial share face financial, technical or situational barriers that restrict their ability to change.

Adaptation typology

To better understand differences in respondents' ability to adjust to a reduction in car access, an adaptation typology was developed to capture perceived feasibility, reliance on policy support, and functional car dependence. This typology distinguishes three groups that differ in both their capacity to adapt and their vulnerability to accessibility loss.

The first group, potentially adaptable under supportive conditions, consists of respondents who indicate that switching to an EV is feasible at some point in the future or express willingness to adopt at least one alternative transport mode (see Table 5.5) provided they are not classified as structurally constrained. For this group, barriers tend to be transitional rather than structural. Adaptation is mainly a matter of time, habit change, or the availability of enabling conditions rather than requiring substantial compensation or exemptions to maintain accessibility. These respondents are therefore considered to be at relatively low risk of falling below an acceptable accessibility threshold.

The second group, highly policy-dependent, includes respondents whose ability to adapt depends strongly on external support. These individuals indicate that at least one policy intervention could help them either reduce car use or transition to electric driving. Common barriers include the affordability and quality of PT, cycling safety, access to charging infrastructure, and the financial costs of EVs. For this group, targeted policy measures are likely to be necessary to prevent uneven or inequitable impacts.

The third group, structurally insufficient, consists of respondents for whom adaptation appears fundamentally unfeasible. These individuals perceive a switch to electric driving as unrealistic, report that no policy measures would help, and indicate that at least one regular trip cannot be made without a car. Constraints in this group are often structural, including financial hardship, age- or health-related limitations, and practical mobility needs. Without exemptions or targeted interventions, this group faces a high risk of accessibility loss.

Table 5.10 summarises the typology, classification criteria, and key barriers associated with each group.

Table 5.10: Adaptation typology for transition away from car dependence

Typology group	Classification criteria	Key barriers and policy implications
Potentially adaptable under supportive conditions (low risk)	Switching to an electric vehicle is perceived as feasible or respondents express willingness to adopt at least one alternative transport mode is considered acceptable, provided respondents are not classified as structurally insufficient.	Barriers are mainly transitional (time, habit, enabling conditions). Limited policy intervention required.
Highly policy-dependent (medium risk)	Respondents who do not fall into the other groups but indicate that at least one policy measure could help reduce car use or enable an electric vehicle transition.	Barriers relate to affordability, public transport quality, cycling safety, charging access, or financial incentives. Targeted policy support is required to prevent inequitable burdens.
Structurally insufficient (high risk)	Switching to an electric vehicle is perceived as not feasible, no policy measures are perceived as helpful (to switch to EV or drive less), and at least one regular trip cannot be made without a car.	Structural constraints such as financial hardship, age or health limitations, and practical mobility needs. High risk of accessibility loss without exemptions or targeted support.

Note. Respondents were classified into three groups using a stepwise procedure. First, respondents were classified as potentially adaptable if they perceived EV adoption as feasible or expressed willingness to adopt at least one alternative transport mode. Second, remaining respondents were classified as highly policy-dependent if they indicated that at least one policy measure could help reduce car use or enable an EV transition. Finally, respondents were classified as structurally insufficient if EV adoption was perceived as infeasible, no policy measures were considered helpful, and functional car dependence was present.

After defining the typology, respondents were classified to assess how adaptation capacity is distributed among individuals with fossil-fuel or hybrid vehicles. Table 5.11 presents the distribution of these groups.

Table 5.11: Distribution of adaptation typology groups

Adaptation group	N	Share of respondents (%)
Potentially adaptable under supportive conditions	493	74.5
Highly policy-dependent	73	11.0
Structurally insufficient	96	14.5
Total	662	100.0

Note. Percentages refer to valid responses ($N = 662$). An additional 83 respondents (11.1%) could not be classified due to missing data.

The results indicate that roughly three quarters of respondents with polluting vehicles fall into the potentially adaptable category, suggesting that most car-owning residents perceive at least some capacity to adapt to the zero-emission transition. Nevertheless, a meaningful minority faces constraints. 11% are classified as highly policy-dependent, while 14.5% are structurally insufficient. Taken together, this implies that around one quarter of affected respondents may face an elevated risk of reduced accessibility.

To explore whether adaptation capacity varies spatially, Table 5.12 presents the typology by city district.

Table 5.12: Adaptation typology by city district

City district	Adaptable (%)	Policy-dependent (%)	Structurally insufficient (%)	N
Centrum	75.9	10.8	13.3	83
West	80.8	12.3	6.8	73
Nieuw-West	66.1	9.9	24.0	121
Zuid	68.4	17.9	13.7	95
Oost	82.0	9.0	9.0	89
Noord	75.8	6.3	17.9	95
Weesp	76.7	13.3	10.0	30
Zuidoost	76.3	10.5	13.2	76
Total	74.5	11.0	14.5	662

Note. Percentages are row percentages ($N = 662$). Differences across districts approach statistical significance: Pearson $\chi^2(14) = 23.19$, $p = .057$.

Although differences across districts do not reach conventional levels of statistical significance, some spatial patterns are visible. Respondents in Nieuw-West and Noord show comparatively higher shares of structurally insufficient individuals, whereas West and Oost display lower vulnerability levels. These trends suggest that adaptation risks may be unevenly distributed across the city, reinforcing concerns about geographically differentiated impact.

These patterns can be interpreted in light of earlier descriptive results presented in this thesis. Table 1.1 indicates that average household incomes are comparatively lower in districts such as Noord and Nieuw-West, while Figure 5.1 shows that car ownership levels are relatively high in these same areas. This combination suggests that residents in these districts may face a more challenging transition as they are more likely to rely on private vehicles while simultaneously having fewer financial resources to switch to a ZEV or alternative modes.

Spatial characteristics may further contribute to this pattern. Both districts are located further from the centre, and in the case of Noord physical separation by the IJ river adds an additional barrier in terms of connectivity, which could influence mobility behaviour and car dependence. Comparative research across European cities shows that increased distance from the city centre is associated with higher levels of car ownership and car use (Berrill et al., 2024; Witte et al., 2022). In this sense, the observed patterns in Amsterdam appear consistent with broader urban mobility dynamics, where peripheral districts with lower incomes and higher car dependence may face greater adaptation challenges under access-restrictive policies.

Age-related differences in adaptation capacity were examined next (Table 5.13).

Table 5.13: Adaptation typology by age group

Age group	Adaptable (%)	Policy-dependent (%)	Structurally insufficient (%)	N
30–39	100.0	0.0	0.0	12
40–49	88.7	3.8	7.5	53
50–59	85.0	7.8	7.2	153
60–69	71.6	12.3	16.1	211
70–79	68.8	12.9	18.3	202
80+	45.2	22.6	32.3	31
Total	74.5	11.0	14.5	662

Note. Percentages are row percentages. Differences across age groups are statistically significant: Pearson $\chi^2(10) = 37.68$, $p < .001$.

Age is strongly associated with adaptation capacity. Younger respondents are overwhelmingly classified as potentially adaptable, whereas vulnerability increases markedly with age. Among respondents aged 80 and above, fewer than half fall into the potentially adaptable group, while nearly one third are structurally insufficient. This pattern indicates that older residents may face disproportionate challenges in adjusting to reduced car access.

These findings are consistent with previous research on EV adoption. Several studies show that younger and middle-aged individuals are generally more likely to adopt EVs, whereas adoption rates decline with increasing age (Chen et al., 2020; Nayum et al., 2016; Plötz et al., 2014; Sovacool et al., 2018). In addition, younger adults tend to display more multimodal travel behaviour and greater flexibility in their transport choices, which may further increase their capacity to adapt to changes in mobility systems (Jamal & Newbold, 2020).

Differences by educational attainment are shown in Table 5.14.

Table 5.14: Adaptation typology by education level

Education level	Adaptable (%)	Policy-dependent (%)	Structurally insufficient (%)	N
Low	42.3	23.1	34.6	26
Middle	63.8	15.5	20.7	116
High	79.1	9.3	11.6	508
Other / unknown	50.0	16.7	33.3	12
Total	74.5	11.0	14.5	662

Note. Percentages are row percentages. Differences across education levels are statistically significant: Pearson $\chi^2(6) = 31.35$, $p < .001$.

Educational level is also strongly linked to adaptation capacity. Respondents with lower educational attainment are substantially more likely to fall into the structurally insufficient category, while higher-educated respondents are predominantly classified as potentially adaptable. Although the lower-educated respondents represents a smaller share of the sample, the observed differences are large and statistically significant. Similarly, while some age categories contain fewer respondents, the age gradient in adaptation capacity is consistent and pronounced.

These results are consistent with previous research on EV adoption. Several studies find that higher levels of education are associated with a greater likelihood of adopting EVs, while lower-educated groups are less likely to do so (X. Liu et al., 2017; Nayum et al., 2016; Plötz et al., 2014; Sovacool et al., 2018).

Conclusion

Overall, the findings suggest that the introduction of a ZEZ may have uneven consequences across Amsterdam's population. While a majority of residents appear able to adjust to the policy, particularly younger and higher-educated groups, a smaller but important share of the population faces constraints that could translate into reduced accessibility and, in turn, a risk of social exclusion. In particular, older residents and respondents with lower levels of education are more likely to encounter difficulties in adapting to the transition towards zero-emission mobility. Spatial patterns also suggest that residents living further from the city centre may face greater challenges, although these differences are less conclusive.

First, car dependence remains widespread. A large share of respondents report functional dependence on the car for at least one type of trip, implying that the ZEZ may have tangible implications for everyday mobility and social participation rather than representing a purely symbolic policy change. At the same time, respondents often identify alternatives in a more general sense as viable. However, when it comes to their own situation and travel behaviour, this perceived viability appears to be lower. This pattern is particularly visible in relation to the e-bike, which is more often recognised as a possible alternative in general than as a realistic substitute in respondents' own daily mobility.

Second, the stated barriers highlight where policy design matters. Among fossil-fuel and hybrid drivers, the most frequently cited conditions for reducing car use relate to the quality and affordability of PT and, to a lesser extent, to cycling infrastructure. For switching to electric driving, financial constraints (including purchase costs and subsidies) and practical considerations (notably charging availability and usability) are central. Importantly, around three in ten respondents indicate that none of the proposed measures would help them either drive less or switch to an EV, suggesting that policy instruments alone may not reach everyone affected.

These patterns are reflected in the adaptation typology. While roughly three quarters of fossil-fuel and hybrid drivers fall into the "potentially adaptable" group, around one quarter are classified as either policy-dependent or structurally insufficient. The policy-dependent group could adapt their mobility behaviour if supportive policy measures were introduced, whereas the structurally insufficient group consists of respondents who perceive switching to an EV as infeasible, report that no policy measures would help them adapt, and indicate that at least one regular trip cannot be made without a car. This latter segment therefore represents a clear equity concern, as their ability to maintain acceptable accessibility appears contingent on additional support or exemptions.

Finally, vulnerability is not evenly distributed. Adaptation capacity declines markedly with age, with older residents far more likely to fall into the higher-risk categories. Educational differences are similarly pronounced: lower-educated respondents are disproportionately represented among the policy-dependent and structurally insufficient groups, whereas higher-educated respondents are predominantly adaptable. Spatial patterns are suggestive rather than conclusive. Some districts show higher shares of structurally insufficient respondents, most notably Nieuw-West and Noord. These areas are generally located further from the city centre and are characterised by relatively higher levels of car dependence and lower average socio-economic indicators, which may help explain why residents there appear more vulnerable to the constraints associated with the ZEZ. In relation to the conceptual model, these findings indicate that lower educational attainment should also be treated as a marker of disadvantage, alongside disability, older age, low income, and degree of urbanity, in Figure 4.4 and Figure 4.6. In this respect, the analysis strengthens the expectation that restrictive policies such as the ZEZ may produce adverse accessibility outcomes for these groups. However, these spatial differences fall just short of conventional statistical significance and should therefore be interpreted with caution.

Taken together, the results indicate that implementing the ZEZ without complementary measures, potentially including carefully designed exemptions and targeted support, risks placing disproportionate burdens on older residents, lower-educated groups, and certain areas of the city, which raises concerns in relation to both sufficientarian and egalitarian conceptions of justice.

5.1.3. City Pass Panel

This subsection turns to the City Pass panel, which contains responses from Amsterdam residents with lower income. The panel includes 140 respondents. Given the modest sample size and the fact that several questions apply only to car owners or ICEV drivers, the analysis in this section is primarily descriptive. Results are therefore presented mainly as frequencies and percentages.

The structure broadly follows the same sequence as the analysis in the previous section: car ownership and the perceived importance of car use; reported trip purposes and functional dependence; perceived suitability of alternatives; willingness and capacity to adapt; perceived helpful measures for reducing car use or enabling an EV transition; and, finally, the adaptation typology.

Car ownership and perceived importance of car use

The first step is to establish the extent of car ownership within the City Pass panel, and to assess how important car use is among those who do own a vehicle.

Table 5.15: Car ownership and perceived importance of car use (City Pass panel)

	N	%
Car ownership (total sample, N = 140)		
Car owner	36	25.7
High perceived importance among car owners (N = 35)		
Car use	30	85.7

Note. Perceived importance of car use is reported only for respondents who own a car. The original three-point scale ("of little importance", "of some importance", "of great importance") was recoded into low importance (little/some importance) and high importance (great importance).

Around a quarter of respondents in this group report owning a car. This share is considerably lower than in the broader O&S panel dataset, where 66.7% of respondents owned a car, and also below the average level of car ownership in Amsterdam, which is approximately 0.4 cars per household (Oomen & Heijnen, 2024). However, among those who do own a car, perceived importance is high. Most car-owning respondents indicate that using the car is of great importance in their daily lives, suggesting that car ownership in this group is more closely linked to necessity rather than convenience.

Trip purposes and functional car dependence

The next step is to examine what City Pass car owners use their cars for, and which trips they report being unable to make without a car.

Table 5.16: Car use purposes and trips that cannot be made without a car (City Pass panel)

	Used for this purpose (%)	Cannot be made without a car (%)
Commuting (home–work)	33.3	25.0
Leisure, sports, hobbies	38.9	22.2
Visiting family and friends	69.4	50.0
Grocery shopping	72.2	47.2
Care duties / medical visits	58.3	50.0
Bringing / picking up children	36.1	22.2
Transporting goods	47.2	44.4
Other	2.8	2.8
Can make all trips without a car	–	0.0
Don't know / no answer	–	2.8

Note. Percentages represent the share of car owners in the City Pass panel ($N = 36$). Multiple responses were allowed; percentages therefore do not sum to 100%. "Used for this purpose" refers to trips respondents currently make by car. "Cannot be made without a car" indicates trips respondents report they cannot undertake without a car. No respondents indicated that all listed trips could be made without a car.

The results indicate a high degree of functional dependence. No respondents indicated that they could make all listed trips without a car. The car is most commonly used for visiting family and friends, grocery shopping, and care-related journeys. These same purposes also show particularly high reported dependency. Grocery shopping and care duties stand out, with half of car owners indicating that these trips cannot be made without a car. Transporting goods shows a similarly high level of reliance. Commuting plays a comparatively smaller role: about one third report using the car for commuting, and around one quarter report being unable to commute without it.

A short descriptive check is also included to illustrate how perceived importance aligns with this reported dependency.

Table 5.17: Perceived importance of car use (City Pass panel)

Perceived importance of car use	Share of respondents (%)
Low importance	14.3
High importance	85.7

Note. Table reports descriptive results only. No statistical test was conducted because all respondents ($N = 35$) in this subsample reported that they cannot do without a car.

As expected, the vast majority of respondents in this subsample report that car use is of high importance. Since all respondents in this group already report being unable to do without a car, the table is descriptive rather than inferential, but it reinforces the close link between perceived importance and practical necessity.

Perceived availability of alternatives

Respondents were also asked to assess how suitable different transport options would be as replacements for polluting passenger cars in Amsterdam in general, rather than for their own personal situation.

Table 5.18: Perceived suitability of transport alternatives as substitutes for polluting private cars in Amsterdam (City Pass panel)

	Not at all (%)	To some extent (%)	To a large extent (%)	Don't know (%)
Public transport	17.1	25.0	50.7	7.1
Electric bicycle	21.4	35.0	32.1	11.4
Electric scooter	28.6	35.7	24.3	11.4
Shared mobility	23.6	35.0	31.4	10.0
Electric microcar	25.7	32.1	30.7	11.4

Note. Percentages refer to City Pass holders' ($N = 140$) assessment of each transport mode as a replacement for polluting passenger cars in Amsterdam as a whole, not their personal situation.

PT is viewed most positively, with a majority indicating that it could substitute for polluting cars to a large extent. Other options, such as electric bicycles, shared mobility, electric microcars, and electric scooters, are more often viewed as suitable "to some extent" than "to a large extent". Across all modes, a non-trivial share of respondents either reject the option as unsuitable or report that they do not know.

Willingness and capacity to adapt

To understand whether respondents feel able to adapt in practice, ICEV and hybrid-vehicle drivers were asked whether switching to electric driving is feasible for them.

Table 5.19: Expected timeline for switching to electric driving among non-electric car owners (City Pass panel)

	Share of respondents (%)
Before 2030	6.3
By 2035	6.3
By 2040	3.1
After 2040	6.3
Not feasible in the future	59.4
Don't know / no answer / not applicable	18.8
Total	100.0

Note. Percentages are calculated among respondents who answered this question ($n = 32$), a subset of the City Pass panel ($N = 140$). The question was only asked to respondents who indicated that they currently drive a fossil-fuel or hybrid vehicle.

The results indicate very low perceived feasibility. Most respondents in this subgroup state that switching to electric driving is not feasible for them in the future. Only a small minority expects to be able to switch at some point in the future, and uncertainty remains relatively high as reflected in the share of ”don’t know / no answer” responses.

Respondents were also asked about their current use of several alternatives, and, if they were not already users, whether they would be willing to use these modes in the future.

Table 5.20: Current use and willingness to use transport alternatives in the future (City Pass panel)

	Already in use (%)	Willing among non-users (%)	Not willing among non-users (%)
Electric bicycle	25.7	32.7	67.3
Electric scooter	6.4	13.7	86.3
Electric microcar	12.9	23.8	76.2
Shared car	24.3	15.1	84.9
Shared scooter	10.7	9.6	90.4
Shared bicycle	20.0	11.6	88.4
Shared cargo bike	12.1	12.2	87.8

Note. “Already in use” refers to the share of City Pass holders ($N = 140$) who already owned or used the transport mode and therefore did not receive the willingness question. “Willing” and “Not willing” percentages are calculated among respondents who did not yet use the mode; the eligible sample size therefore differs by transport mode.

Across modes, willingness among non-users is generally low. Even where some respondents already use certain alternatives (such as e-bikes or shared cars), most non-users indicate that they are not willing to adopt the mode in the future. The electric bicycle is the most notable exception, showing both higher existing use and comparatively higher openness among those who do not yet use one. Overall, stated willingness suggests that many respondents do not perceive alternatives as realistic substitutes in their own lives, even when they acknowledge their general suitability at the city level.

Measures to support adaptation

The survey also asked ICEV and (P)HEV drivers what measures could help them reduce car use. The results are shown in Table 5.21.

Table 5.21: Measures that could help respondents reduce car use (City Pass panel)

	Share of respondents (%)
Cheaper public transport	46.9
More frequent, faster or better-connected public transport	31.3
Improved cycling infrastructure	15.6
Financial compensation from employer for alternative travel	12.5
More shared bikes or shared scooters nearby	12.5
More knowledge about alternative travel options	9.4
Other	25.0
None of the above	25.0
Don’t know / no answer	6.3

Note. Percentages refer to City Pass holders with a car who answered this question ($N = 32$). Multiple responses were allowed; percentages therefore do not sum to 100%. The remaining respondents in the City Pass panel ($N = 108$) did not receive this question.

Cheaper PT stands out as the most frequently supported measure, followed by improvements to service quality and connectivity. Compared with the earlier results, the emphasis on affordability is particularly pronounced here, which is consistent with the panel’s lower-income composition. A substantial share also selects ”other” or ”none of the above”, suggesting that standard policy options do not fully match the constraints experienced by part of this group. The open responses in ”other” largely expand on existing options (for example, calls for free PT or stronger versions of the measures already listed).

Next, fossil-fuel car owners were also asked what could help them to switch to electric driving.

Table 5.22: Measures that could facilitate switching to electric driving (City Pass panel)

	Share of respondents (%)
Government subsidy for purchasing an EV	40.6
More or faster charging points nearby	18.8
More knowledge about purchasing an EV	12.5
More knowledge about using and charging an EV	9.4
Support from employer (e.g. workplace charging)	9.4
Other	15.6
None of the above	46.9
Don't know / no answer	6.3

Note. Percentages refer to City Pass holders who answered this question ($N = 32$). Multiple responses were allowed; percentages therefore do not sum to 100%. The remaining respondents in the City Pass panel ($N = 108$) did not receive this question.

Government subsidies are the most frequently cited enabling measure. At the same time, nearly half indicate that none of the proposed measures would be helpful to them, which aligns with earlier findings that many respondents do not view electric driving as feasible. This points to a group for whom affordability, feasibility, or broader life circumstances may prevent adaptation even under supportive conditions.

To understand the reasons behind perceived infeasibility, open responses were coded into categories in Table 5.23.

Table 5.23: Reasons for perceiving a transition to electric driving as not feasible (City Pass panel)

Reason (coded categories)	N	Share of respondents (%)
Financial constraints (e.g. purchase costs)	11	64.7
Age-related or physical limitations	6	35.3
Practical / technical barriers (e.g. lack of charging)	3	17.6

Note. Based on qualitative coding of open-ended responses from respondents who indicated that switching to electric driving is not feasible ($n = 19$). Multiple reasons could be mentioned per respondent; percentages therefore do not sum to 100%.

Financial barriers dominate these explanations. A majority refer to affordability constraints, while age-related or physical limitations are also frequently mentioned. Practical and technical barriers, such as charging access, appear as well, but less often in this subgroup. Given the small number of coded responses, these findings should be interpreted cautiously, but they nonetheless indicate the central role of financial limitations.

Adaptation typology

Finally, the same adaptation typology was applied to the City Pass panel to provide an indicative comparison with the broader sample.

Table 5.24: Distribution of adaptation typology groups (City Pass panel)

Adaptation typology	Share of respondents (%)	N
Potentially adaptable under supportive conditions	46.7	14
Highly policy-dependent	10.0	3
Structurally insufficient	43.3	13
Total	100.0	30

Note. Percentages are based on valid responses ($N = 30$). Five respondents (14.3%) had missing values and were excluded.

Despite the small number of valid cases, the distribution is pronounced. A large share of respondents fall into the structurally insufficient category. In other words, within this low-income group, many respondents appear unable to adapt even under supportive policy conditions. This pattern reinforces the broader equity concern that lower-income residents may face greater constraints in the transition to zero-emission mobility. Previous research similarly finds that the adoption of EVs is closely associated with income levels, with higher-income households being significantly more likely to adopt or already own EVs (Axsen et al., 2016; X. Liu et al., 2017; Morton et al., 2017; Nayum et al., 2016). In this sense, the results are also consistent with the conceptual framework presented earlier, in which affordability and income levels shape the feasibility of adopting zero-emission vehicles. Given the limited sample size, these figures should be interpreted as indicative rather than representative, but they nevertheless align with the wider patterns observed earlier in the chapter.

Conclusion

Overall, the City Pass panel suggests a combination of lower car ownership and higher dependence among those who do own a car. Car use is closely linked to essential activities such as shopping, care duties, and transporting goods, and many respondents report having no workable alternatives for at least some of these journeys. In line with this, switching to electric driving is widely perceived as infeasible, primarily for financial reasons. While respondents frequently support measures such as cheaper and better PT, a substantial minority indicate that even supportive measures would not enable them to adapt. Taken together, the findings reinforce the view that lower-income residents may face disproportionate risks of accessibility loss in the transition to a ZEZ unless targeted and realistic support measures are in place. This analysis may, however, still underestimate the extent of these challenges, as car ownership within the City Pass panel is lower than the city average. The scale of the problem may therefore prove greater in practice than is captured in this analysis.

5.2. Necessary Conditions

This section builds on the survey results by translating the observed distributional risks into concrete requirements for policy design. The previous section showed who is most likely to face difficulties under a ZEZ, where the risks are concentrated, and which mechanisms sit behind them (for instance, high functional car dependence combined with limited adaptation options). The purpose here is to identify the minimum conditions under which a future ZEZ can be implemented in a way that is defensible from both a sufficientarian and an egalitarian perspective.

A sufficientarian approach implies that the policy should not push residents below a basic minimum level of accessibility. In practical terms, this means safeguarding residents' baseline accessibility: the ZEZ should not make people worse off in terms of their ability to conduct daily life using the transport system. The sufficientarian threshold is therefore anchored in the pre-policy situation rather than a universal minimum standard. An egalitarian approach adds that the burdens of the transition should not fall disproportionately on those with fewer resources or fewer realistic alternatives, such as lower-income households, lower-educated respondents, and older residents. Because the survey results show that a non-negligible minority may struggle to adapt, an assessment of a ZEZ cannot rest on aggregate environmental benefits alone. Implementation is only justified if enabling and protective measures are in place to reduce avoidable accessibility loss among vulnerable groups.

This section addresses the fourth research question by examining the conditions under which the implementation of a ZEZ in Amsterdam can be pursued without disproportionately disadvantaging specific groups. Rather than proposing a full implementation plan, the section sets out the minimum fairness requirements that should guide such a policy. The discussion follows six elements. It begins with the legal and governance requirements that determine whether a ZEZ can be implemented at all. It then turns to the spatial design of the zone, the timeline and transition architecture, and the exemption and permit system. The final two parts consider the complementary policy package needed to support adaptation, and the monitoring and adaptive governance required to identify and correct unintended impacts over time.

5.2.1. Legal and Governance Feasibility

Legal feasibility is a fundamental precondition for the implementation of a ZEZ for passenger vehicles. At present, the expansion of municipal emission zones beyond existing low-emission frameworks depends on authorisation at the national level. A clear legal mandate is required to enable municipalities to restrict access for fossil-fuel passenger cars. Without such a statutory basis, a full ZEZ for private vehicles cannot be introduced. Given the current legal and institutional uncertainties, any move towards implementation by 2030 would likely require a phased rollout, a geographically limited zone, or a robust package of complementary measures to mitigate inequitable effects.

Beyond the legal framework, governance capacity plays a critical role in determining whether residents are able to adapt to the transition. From sufficientarian and egalitarian perspectives, local authorities carry responsibility not only for enforcing restrictions but also for enabling residents to maintain an acceptable level of accessibility. This includes investing in PT, enhancing service coverage and reliability, and expanding charging infrastructure to support the uptake of EVs. In addition, governance arrangements should incorporate protective mechanisms such as exemptions, targeted support schemes, and compensatory measures for groups at risk of being disproportionately affected.

Operational implementation also requires reliable enforcement systems. This includes the use of automatic number plate recognition cameras and the technical capacity to identify vehicle drivetrain types. Such systems are already in place for existing low-emission zones in the Netherlands, indicating that the technological requirements for enforcement are feasible.

Finally, the transition should incorporate a graduated enforcement strategy. An initial period focused on warnings and public information can provide residents with time to adjust and explore alternative travel options. Once an adaptation period has elapsed, financial penalties can be introduced to ensure compliance, while exemptions may be granted for specific groups where immediate compliance is not feasible. Structuring enforcement in this way supports both fairness and policy effectiveness by balancing behavioural incentives with reasonable transition time.

5.2.2. Spatial Design

Public opinion and equity considerations both indicate that the geographic scope of a ZEZ is a critical design decision. Survey results from Table 5.25 show that respondents are more supportive of a ZEZ limited to the city centre (S100) than of one extending to the A10 ring or the entire municipality. From a sufficientarian perspective, this matters because a smaller zone reduces the number of residents directly affected, thereby lowering the risk that individuals fall below a minimum accessibility threshold.

Table 5.25: Public support for banning petrol and diesel cars from 2030 by geographic scope

	City centre (S100) (%)	Within Ring A10 (%)	Entire city (%)
Very good idea	34.2	20.9	16.1
Good idea	25.5	24.4	19.3
Neither good nor bad idea	15.1	18.0	18.9
Bad idea	9.6	16.4	17.3
Very bad idea	12.6	17.7	25.5
Don't know / no answer	3.0	2.7	2.9
Total positive (good/very good)	59.8	45.2	35.4
Total negative (bad/very bad)	22.2	34.1	42.8

Note. Percentages are based on the full sample ($N = 1{,}218$). Respondents were asked how they would feel about banning petrol and diesel passenger cars from 2030 at three spatial scales.

Support declines as the proposed boundary expands, suggesting that perimeter choice is not only a technical or environmental decision but also a matter of political legitimacy. Given the sensitivity surrounding car restrictions, higher public acceptance may facilitate smoother implementation and greater compliance. Nevertheless, legitimacy alone is insufficient: from a normative standpoint, any ZEZ must also safeguard minimum accessibility for vulnerable groups.

A centre-based zone can therefore be defended as a cautious and lower-risk initial step. Restricting the ZEZ to the city centre increases the likelihood that residents can maintain their existing level of accessibility, partly because car use in this area is already limited. Travel behaviour data support this interpretation. Trips to the city centre are predominantly made by PT, while private car use plays a comparatively modest role. According to Gemeente Amsterdam (2019), the dominance of PT is likely reinforced by strong service provision, limited parking availability, and relatively high parking costs.

Beyond travel mode choice, Table 5.26 shows that car dependence remains comparatively low for movements between city districts and the centre of Amsterdam, while increasing for trips to the peripheral districts or beyond the metropolitan region (Gemeente Amsterdam, 2025a).

Table 5.26: Share of car use for trips between the city centre and other areas

Area pair (Centrum ↔ …)	Car use share (%)
Centrum (within Centrum)	1
Noord	10
West	3
Nieuw-West	9
Zuid	5
Oost	3
Zuidoost	12
Weesp	36
Other MRA municipalities	27
Other parts of the Netherlands	34

Note. Percentages indicate the share of trips made by car for all movements between two areas (both directions combined; e.g., Centrum ↔ Noord includes trips from Amsterdam-Centrum to Amsterdam-Noord and from Amsterdam-Noord to Amsterdam-Centrum). Derived from Gemeente Amsterdam (2025a).

These patterns indicate that a centre-focused ZEZ would affect fewer car-dependent journeys, whereas a broader perimeter would impose greater disruption on residents in outer districts, where reliance on private vehicles is more pronounced.

At the same time, this thesis has also explored the potential case for an expansion of the ZEZ inside the A10 ring. Such an expansion yields greater environmental benefits but carries higher sufficientarian risk, particularly for residents in outer districts who face fewer viable alternatives. The choice between a smaller and a larger perimeter therefore represents a fundamental trade-off between environmental ambition and the risk of accessibility loss. A comparison between the two perimeters for various dimensions is given in Table 5.27.

Table 5.27: Comparison of ZEZ impacts by geographic scope

Dimension	City Centre (S100)	A10 Ring
Environmental impact	Gradual emission reductions and smaller absolute air quality gains	Larger net reductions in emissions and population exposure
Sufficientarian risk (minimum accessibility)	Fewer residents at risk of falling below accessibility thresholds	Greater share of residents exposed to potential accessibility loss
Adaptation feasibility	Higher likelihood of adaptation without structural harm	Greater need for exemptions, subsidies, and targeted support
Implementation and infrastructure burden	Lower short-term pressure on EV charging rollout, but continued constraints in EV availability, second-hand market supply, driving range, and resolution of practical user barriers	Requires rapid expansion of charging infrastructure, accelerated development of EV market supply (including second-hand options), improved driving range, and faster removal of practical adoption barriers
Boundary effects	Localised parking pressure and congestion at zone edge	Boundary congestion spread across a larger perimeter, increasing pressure on P+Rs and PT
Expected traffic displacement	Redistribution of car trips towards adjacent inner-city districts (Oost, West, Zuid, Noord), potentially shifting congestion rather than eliminating it	Traffic may re-route to peripheral districts and adjacent municipalities, such as Zuidoost, Nieuw-West, Diemen, Amstelveen, Westpoort, Zaandam, and Landsmeer, potentially shifting burdens spatially
Alignment with existing policy	Aligns with the current ZEZ for logistics in the city centre, creating consistency between freight and passenger vehicle regulation within the same area	Aligns with the existing LEZ for passenger cars within the A10 ring, meaning that a passenger vehicle ZEZ would build on the current regulatory framework rather than introducing a completely new spatial boundary
Policy learning and governance	Serves as pilot enabling iterative learning; slower realisation of system-wide benefits	Faster systemic transformation, but higher risk if design flaws occur at scale
Overall equity profile	Lower risk of exclusion; easier to maintain minimum accessibility, but limited environmental and transformative potential	Greater environmental and transformative potential, but higher equity risk without complementary policy

A city-centre ZEZ offers a lower-risk entry point: it limits immediate equity concerns, allows for gradual policy learning, and reduces infrastructure and enforcement pressure. It would also align with the existing ZEZ for logistics already in place in the city centre. However, its environmental benefits would be more modest. A zone covering the A10 ring would generate larger emission reductions and broader environmental gains, but it would also expose more car-dependent residents to potential hardship unless strong supporting policies are in place. In this case, the spatial scope would remain broadly consistent with the current environmental zone that already applies within the A10 ring.

Ultimately, this research does not prescribe a single ”correct” perimeter. Instead, it demonstrates that perimeter choice is an inherent trade-off. Expanding the zone increases environmental impact but also amplifies equity risks, requiring more extensive compensation, stronger PT provision, and more robust exemption frameworks. Beginning with a smaller zone may allow policymakers to refine implementation, monitor unintended consequences, and scale up over time while preserving fairness.

5.2.3. Timeline and Transition Architecture

A phased introduction of a ZEZ is essential to ensure a fair and manageable transition. Staggering restrictions over time gives residents the opportunity to adapt, reduces sudden accessibility losses, and aligns with both sufficientarian and egalitarian principles.

From a protective and transitional perspective, the most defensible approach is to restrict the most polluting vehicles first and progressively tighten standards over time. Older vehicles tend to emit the highest levels of pollutants and are, on average, closer to the end of their functional lifespan. Prioritising these vehicles therefore balances collective environmental benefits against individual mobility costs. In contrast, newer and cleaner vehicles generally have a longer remaining lifespan and impose lower environmental harm, making it more reasonable to allow their continued use for a longer period.

Predictability is a central condition for fairness. Residents should be able to anticipate when their vehicle will no longer comply with access rules, allowing them to plan financially and behaviourally. Clear timelines give households time to adjust, whether by delaying vehicle replacement, transitioning to alternative modes, or waiting for improvements in EV affordability, driving range, second-hand market supply, and charging infrastructure. At the same time, a longer transition window provides municipalities with the opportunity to expand PT, scale charging networks, and strengthen supporting policies.

The pace of implementation remains a political and ethical trade-off. It would be unrealistic to assume that all residents can adapt immediately, given the presence of policy-dependent and structurally insufficient groups identified in the survey analysis. A gradual rollout therefore serves as a key equity safeguard, limiting harm to those who have recently invested in a vehicle, those requiring additional time to adjust, and those whose capacity to transition depends on future technological and market developments.

Practically, this implies a stepwise tightening of access criteria based on established European emission standards. Diesel and petrol vehicles could be restricted in successive stages, beginning with the most polluting categories and moving towards a full zero-emission requirement. Comparable transition pathways already exist in other cities, such as Brussels, where older Euro standards are progressively phased out while newer vehicles retain access for longer periods (Appendix C.1 and C.2). This model illustrates how clear deadlines, long lead times, and gradual escalation can provide both certainty and fairness.

5.2.4. Exemptions and Permits System

An equitable ZEZ requires an exemptions and permits framework that recognises that some individuals cannot reasonably adapt within the policy timeframe. While the objective should always be to support transition rather than entrench car dependence, exemptions remain necessary where the personal burden of compliance would otherwise result in serious accessibility loss or social exclusion.

Exemptions should be targeted, proportionate, and where possible, temporary. They function as a safeguard for residents whose mobility needs cannot be met through available alternatives, particularly during the early phases of implementation. Rather than serving as permanent opt-outs, exemptions should be periodically reviewed to reflect technological progress, infrastructure expansion, and improvements in viable alternatives.

Several exemption mechanisms can be considered. One approach is a fixed eligibility list for clearly defined groups, such as individuals with medical or disability-related mobility constraints. Another option is a time-based or conditional exemption model, for instance allowing access during night-time hours where PT coverage remains insufficient. A third approach involves permit-based access, whereby residents or visitors receive a limited number of entry days per year. Systems of this kind, already used in cities such as Brussels, provide flexibility while still discouraging routine car use (Brussel Herademt, n.d.-b). However, pricing structures must be designed carefully, as high permit fees risk reinforcing income-based inequalities.

Survey findings indicate that car dependence is often linked to trips that are occasional rather than daily, such as visiting family, transporting goods, grocery shopping, or attending medical appointments. This suggests that a limited-entry permit system could be a pragmatic compromise: preserving access for essential or irregular trips while maintaining incentives to reduce habitual car use.

Examples of relevant permit categories can be found in existing European low- and zero-emission zones. These include exemptions for disability-related travel, care professionals and essential medical trips, night-time workers affected by limited PT availability, and historic vehicles (Gemeente Amsterdam, n.d.-d; Miljoezoner Denmark, n.d.; Stockholms Stad, 2024). City Pass holders could be included in recognition of the heightened risk of exclusion faced by lower-income residents, as identified earlier in this study, which points to the potential need for income-sensitive exemptions or targeted permit schemes during the transition period.

Exemption policy must also remain sensitive to timing. Faster implementation increases the need for transitional permits, whereas longer lead times strengthen the case for limiting exemptions as alternatives become more accessible. For this reason, exemptions should be accompanied by clear sunset clauses and reassessment mechanisms. In this way, exemptions serve not as a permanent exception from regulation, but as a structured bridge towards a fair and achievable transition.

5.2.5. Complementary Policy Package

This section builds on earlier discussions of implementation by focusing specifically on the complementary measures needed to ensure that a ZEZ does not disproportionately disadvantage particular groups. Rather than addressing administrative feasibility, the emphasis here is on equity: what policy interventions are required to support residents in adapting to the transition, and how these measures align with the sufficientarian and egalitarian principles outlined earlier. Some interventions follow the logic of the conceptual framework, while others reflect broader governance responsibilities necessary for a fair transition.

Public Transport Adequacy

Given that PT is widely seen as the most viable alternative to private car use (Table 5.3), ensuring adequate service quality is a key condition for an equitable ZEZ. Survey findings indicate that residents in districts such as Nieuw-West, Weesp, and Zuidoost are more likely to state that they would reduce their car use if PT were more affordable and offered better service. This suggests a conditional willingness to shift modes, rather than conclusive evidence that current PT provision is objectively insufficient.

Two policy directions emerge from this. The first concerns service improvements, particularly better connectivity and reliability in districts where residents report fewer viable alternatives (Figure C.4). The second concerns affordability. Cheaper PT (or targeted fare differentiation) could reduce barriers for groups that face greater financial constraints, such as City Pass holders, older residents, and lower-educated groups (Figure C.5). Fare differentiation can therefore function as an egalitarian measure that limits the share of household income spent on mobility.

Existing Dutch policies already provide discounted or free travel for specific groups, including children, students, and older residents with low incomes (9292, n.d.; Gemeente Amsterdam, n.d.-b). Extending similar benefits to City Pass holders could further reduce inequitable burdens during the transition to a ZEZ. However, such measures require careful design. Lower fares may unintentionally shift trips away from walking and cycling rather than from car use, potentially increasing PT demand without meaningfully reducing car dependence and, in some cases, raising overall emissions (de Haas et al., 2022). Any expansion of fare reductions should therefore be targeted and monitored to ensure that it supports a shift away from private car travel rather than substituting already sustainable modes.

These findings should, however, be interpreted with caution. Perceptions of inadequate PT do not necessarily imply objective poor service, and stated willingness to change travel behaviour does not always translate into actual mode shift. Moreover, as discussed earlier in Subsection 4.6.6, PT ridership is shaped by a wider set of external variables, including service frequency, travel time, reliability, accessibility, and cost. Improvements in affordability alone are unlikely to substantially reduce car dependence unless they are accompanied by stronger service quality, broader network coverage, and better integration with shared and flexible mobility options. As highlighted in the literature, PT is most effective when embedded within a wider multimodal system rather than treated as a stand-alone solution (Lucas, 2012).

Active Mobility

A transition towards active mobility depends on a built environment that supports both actual and perceived safety. Safe cycling infrastructure, including protected bike lanes, well-designed intersections, and continuous networks, is essential to make cycling a realistic alternative for a wider range of residents. In the conceptual model, this relationship is illustrated in Figure C.6.

Although this argument remains general at a citywide level, improvements are likely to be most effective when targeted at specific local problem areas. Certain streets, junctions, and routes in Amsterdam could be experienced as unsafe, which can discourage people from cycling even when distances are suitable. Decisions about where investments should be prioritised therefore require municipal judgement, informed by both safety data and local mobility needs.

Survey results indicate that a substantial share of respondents already view active mobility, particularly e-biking, as a viable alternative to private car use (Tables 5.3 & 5.18), or express willingness to adopt it in the future (Tables 5.5 & 5.20). This suggests that improvements in cycling infrastructure could unlock additional mode shift, especially among individuals who are not structurally dependent on cars but require safer or more comfortable conditions to change travel behaviour. As discussed earlier in Subsection 4.6.6, the uptake of active mobility is shaped by a broader set of external variables, including infrastructure quality, distance, and (perceived) safety. Strengthening active mobility can therefore support a zero-emission transition while also contributing to public health, affordability, and more inclusive access to urban opportunities.

Although active mobility is a realistic and sustainable option for many residents, it is not feasible for everyone. Research shows that older adults and people with mobility impairments face specific barriers to cycling, and that universal cycling-oriented mobility policies risk excluding vulnerable groups. When policy is treated as a one-size-fits-all solution, there is a risk of reinforcing existing transport inequities (Brüchert et al., 2022; CBS, 2023b; Damvakari et al., 2025).

Shared Mobility

For shared mobility to function as a realistic alternative to private car use, it must be accessible, affordable, and easy to use. In principle, shared cars and other shared modes could play a significant role in Amsterdam's mobility transition, particularly because many residents use cars for occasional rather than daily activities, such as grocery shopping, transporting goods, or visiting friends and family (Table 5.1 & 5.16). In these cases, access to a vehicle may be more important than ownership, making shared mobility a potentially efficient substitute.

At present, however, public perceptions and stated willingness to adopt shared mobility remain limited (Tables 5.5 & 5.18). This suggests that shared mobility is not yet widely regarded as a viable replacement for private cars. Expanding its role would therefore require broader rollout, more competitive pricing, and clearer information and communication campaigns explaining how shared mobility functions in practice.

Spatial availability also remains uneven. Shared car provision is concentrated in central districts such as Centrum, Zuid, West, and Oost, while availability is considerably lower in districts with higher car ownership, including Nieuw-West, Zuidoost, and Weesp (see Figure C.3) (Gemeente Amsterdam, n.d.-a). This mismatch implies that shared mobility currently offers fewer alternatives precisely in areas where residents are more car dependent. Expanding shared vehicle coverage in these districts could help reduce reliance on private car ownership, although existing figures should be interpreted as indicative rather than definitive evidence.

Affordability may further influence uptake. Fare differentiation or reduced pricing (for lower-income users) could increase accessibility, which is also reflected in the conceptual model in Figure C.5. As discussed earlier in Subsection 4.6.6, however, the use of shared mobility services is shaped by a broader set of external variables, including spatial availability, pricing, service quality and integration with other modes. Lower prices alone are unlikely to generate large-scale behavioural change without parallel improvement in service reliability, availability, and integration with other modes.

One longer term strategy is the development of Mobility as a Service (MaaS), which aims to integrate PT, cycling, and shared mobility into a single digital platform. MaaS has been associated with reductions in private car use in contexts such as Helsinki and Utrecht Leidsche Rijn, where users reported increased use of shared mobility and PT and fewer car trips (Rijkswaterstaat, n.d.-a). At the same time, evidence from Amsterdam suggests that MaaS adoption is complex and that behavioural change remains gradual and uneven across demographic groups (Nelemans, 2024; van 't Veer et al., 2023). Its strongest potential appears to lie in long-term change, particularly when combined with supportive regulation, strong PT networks, and car-restrictive urban policies.

Overall, shared mobility represents a promising but currently underutilised component of an equitable transition. Its effectiveness will depend not only on technological innovation, but also on spatial equity, affordability, and sustained public policy support.

EV Transition Support

Supporting a transition to EVs requires both infrastructural expansion and targeted policy design. As outlined earlier in Subsection 4.6.6, the adoption of ZEVs is shaped not only by price, but also by practical and perceived barriers such as charging access, range concerns, and charging time. A key condition is the continued rollout of charging infrastructure, including public on-street chargers, residential charging options, and facilities in parking garages. Perceived limitations in charging access remain a barrier for many prospective EV users, whether due to actual scarcity or uncertainty about availability. Expanding visible, reliable charging provision is therefore essential to reducing both practical and psychological adoption barriers.

However, infrastructure alone will not ensure an equitable transition. Access to affordable EVs remains uneven, particularly in the second-hand market. The Netherlands is predominantly a used-car market, yet the supply of second-hand EVs remains misaligned with consumer demand: most affordable EV models are scarce, while incoming ex-lease vehicles often remain too expensive for lower-income buyers (BOVAG, 2025; Mulder et al., 2024). Although the number of lower-priced EV models is increasing and average prices are declining, EVs still exceed average willingness-to-pay levels, especially among financially constrained households (ANWB, 2025). This reflects the broader set of external factors influencing ZEV adoption, where both affordability and charging possibilities shape the feasibility of a transition away from ICEVs (Subsection 4.6.6). Policy attention should therefore extend beyond new-car incentives to stimulating a more accessible second-hand EV market.

From an equity perspective, broad purchase subsidies have historically benefited higher-income households disproportionately. Previous schemes primarily supported buyers in higher-end EV segments, while lower-income groups remained underrepresented (Mulder et al., 2024). Targeted incentives aimed specifically at low-income households are more defensible and empirically supported, as these groups show greater responsiveness to financial support when barriers are reduced (Bauer et al., 2021; Jenn et al., 2020; Muehlegger & Rapson, 2018). Recent policy approaches, such as Sweden's Social Climate Fund measures, further illustrate how income-focused support can assist vulnerable households in accessing electric mobility (European Commission, 2025).

Therefore, EV subsidies must be carefully designed to avoid unintended substitution effects, such as encouraging shifts from walking, cycling or PT to electric car use. An equitable and environmentally effective subsidy framework should prioritise households with demonstrated car dependence and limited financial capacity, ensuring that support facilitates meaningful reductions in fossil-fuel car use rather than merely expanding private vehicle ownership.

In sum, effective EV transition support requires a combined strategy: expanding charging infrastructure, improving the affordability and availability of used EVs, and implementing tightly targeted financial incentives that prioritise equity, behavioural impact, and environmental integrity.

Other policy incentives

Beyond infrastructure and regulatory measures, several additional policy incentives have been implemented in other cities to encourage a transition away from ICEVs. International examples suggest that financial instruments can be designed in a progressive manner, ensuring that lower-income households receive greater support during the transition.

Wappelhorst et al. (2023) describes initiatives in Brussels and Paris that link vehicle scrappage schemes to income levels. In Paris, a progressive scrappage subsidy offers higher bonuses to lower-income households, thereby increasing affordability and strengthening equity considerations. Conceptually, this mechanism aligns with the model illustrated in Figure C.9. Brussels has introduced a mobility budget system in which residents receive a 'mobility budget' for surrendering their ICEV (Figure C.10). This budget can then be allocated to PT (Figure C.11), active mobility such as cycling (Figure C.12), or shared mobility services (Figure C.13). An expanded version of this system could also support transitions towards EVs, as depicted in Figure C.14. These approaches directly reduce ICEV ownership while incentivising shift towards more sustainable transport modes and thereby supporting the implementation of a more equitable ZEZ.

Amsterdam already operates a scrappage subsidy scheme (Gemeente Amsterdam, n.d.-h), yet a more progressive structure where higher benefits are offered to lower-income households could strengthen its distributive fairness, particularly if aligned with the introduction of a ZEZ. Such a design could accelerate the phase-out of ICEVs while mitigating regressive financial impacts.

The role of employers also represents a potential lever for behavioural change. Although commuting accounts for only a limited share of overall car use (Tables 5.1 & 5.16), workplace mobility policies can influence broader travel habits. Employers could be encouraged to promote sustainable travel options, including cycling, PT, and shared mobility. This pathway is conceptually represented in Figure C.15 and may complement municipal-level efforts to reduce car dependence.

Finally, Amsterdam's parking policy already functions as an indirect behavioural incentive. EVs receive preferential treatment in the allocation of parking permits (Gemeente Amsterdam, n.d.-g). While this framework is already comparatively progressive, it could be further strengthened over time by gradually restricting parking access for ICEVs. At present, however, the existing system provides a meaningful contribution to discouraging continued reliance on high-emission vehicles.

5.2.6. Monitoring and Adaptive Governance

Designing an equitable ZEZ requires ongoing oversight rather than fixed, once-and-for-all benchmarks. From sufficientarian and egalitarian perspectives, it is difficult to define rigid performance thresholds in advance, as acceptable outcomes depend on evolving social conditions, behavioural response, and differential impacts across population groups. Instead, emphasis should be placed on continuous monitoring, early detection of unintended effects, and the capacity to adjust policy in response to emerging risks.

A central requirement is systematic data collection. Repeated surveys, such as those used in this research, can help track changes in mobility behaviour, perceived fairness, and adaptation capacity over time. Monitoring should not only assess objective indicators, such as travel patterns, accessibility levels, and car dependence, but also subjective experiences, including perceptions of exclusion, burden, and legitimacy. Understanding both measured and perceived impacts is essential to evaluating whether the ZEZ remains socially acceptable and normatively defensible.

Special attention should be given to car dependence, including when, why, and for which activities individuals remain reliant on private vehicles. This allows policymakers to distinguish between avoidable and structurally constrained car use and to identify groups that may require targeted support. Ongoing monitoring is also necessary to anticipate secondary effects, such as rising parking pressure around zone boundaries, displacement of traffic to neighbouring districts, or emerging accessibility gaps among vulnerable populations.

In practice, adaptive governance means treating the ZEZ as a learning-oriented policy intervention rather than a static regulatory instrument. Continuous feedback loops, transparent reporting, and willingness to revise exemptions, support measures, or enforcement practices are necessary to ensure that environmental objectives are pursued without producing avoidable social harm.

5.2.7. Conclusion

This section translated the empirically observed distributional risks identified in the Amsterdam survey into a set of minimum fairness conditions for the implementation of a ZEZ. It did not aim to provide a full implementation strategy or an optimisation exercise, but rather to answer the fourth research question by identifying the minimum institutional, spatial, and policy requirements under which a ZEZ can be considered normatively defensible. The central finding is that the fairness of a ZEZ depends on whether adequate protective and enabling conditions are in place.

From a sufficientarian perspective, the primary requirement is the protection of minimum accessibility. A ZEZ is only defensible if it does not push residents below a baseline level of accessibility relative to the pre-policy situation. From an egalitarian perspective, the burdens of the transition should not fall disproportionately on those with fewer financial resources, weaker adaptation capacity or limited transport alternatives. Together, these principles imply that environmental effectiveness alone is insufficient. A policy that improves air quality but generates avoidable accessibility loss among vulnerable groups cannot be considered fair. The empirical results show that a non-negligible minority faces limited adaptive capacity, particularly among lower-income households, lower-educated respondents, older residents and some spatial contexts. Risks are not evenly distributed but are concentrated among groups with higher functional car dependence, and fewer viable alternatives. These findings make fairness safeguards a necessary condition rather than an optional design feature.

Several minimum conditions follow from this. First, legal and governance feasibility is a fundamental prerequisite. A clear national legal mandate is required to allow municipalities to implement a ZEZ for passenger vehicles. At the same time, procedural fairness, transparency and predictable enforcement must be ensured. Governance responsibility extends beyond restricting access; it also involves enabling residents to adapt through investments in PT, charging infrastructure and targeted support measures.

Second, the spatial scope of the zone must be proportionate to the strength of complementary policies and to the structural characteristics of the area. Larger zones generate greater environmental benefits but also expose more residents to potential accessibility risks. Perimeter choice is therefore inherently distributional rather than purely technical. A smaller zone reduces immediate equity risks and allows gradual policy learning, but yields more modest environmental gains. A larger zone produces stronger emission reductions but increases exposure to accessibility loss and therefore requires more substantial complementary measures. The choice between these options reflects a trade-off between environmental ambition and distributional risks.

Third, a predictable and gradual transition is essential. A phased rollout with clear timelines allows behavioural, financial and technological adaptation and reduces uncertainty for households and markets. Gradual tightening of access standards protects groups with limited short-term adaptation capacity and provides time for improvements in infrastructure, vehicle affordability and performance, and alternative transport options. However, such a gradual approach also entails a trade-off. While it may support behavioural adaptation and reduce short-term equity concerns, it may simultaneously delay environmental benefits by slowing the pace at which emission reductions are achieved. Governing bodies must therefore balance these considerations, weighing social equity and adaptation capacity against the urgency of environmental improvements.

Fourth, an exemption framework is required as a protective safeguard for individuals who cannot reasonably comply with the policy. Its purpose is to preserve accessibility where mobility needs cannot be met through available alternatives, particularly in cases where the personal consequences of compliance would be disproportionate to the societal objective, such as disability-related mobility or essential healthcare access. The exemption list therefore functions as a minimum protection mechanism for structurally constrained groups. Exemptions should be targeted, proportionate and periodically reassessed as conditions evolve. Permit-based instruments may provide limited transitional flexibility, but they are not a substitute for structural protection and must be designed carefully to avoid reinforcing income-based inequalities.

Fifth, adequate alternatives must be available. PT must ensure minimum accessibility in terms of travel time, reliability, network coverage and first- and last-mile connectivity. Active mobility requires safe infrastructure and inclusive access, including for older residents. Shared mobility must be spatially available, affordable and accessible to diverse user groups. The transition to EVs requires sufficient charging infrastructure, grid capacity and equitable financial access, particularly through improvements in the second-hand market. Without adequate alternatives, restrictive policy risks generating avoidable accessibility loss.

Finally, continuous monitoring and adaptive governance are necessary. Because mobility systems and behavioural responses evolve over time, policy must remain responsive to unintended consequences and emerging inequalities. Monitoring should track both objective mobility patterns and perceived fairness, allowing adjustments to exemptions, support measures and implementation design where necessary. A ZEZ should therefore be treated as a dynamic policy process rather than a fixed regulatory intervention.

Taken together, these findings show that a ZEZ can only be considered socially defensible when implemented within a framework that safeguards minimum accessibility, distributes burdens fairly and remains responsive to changing conditions. Without these conditions, the risk of disproportionate disadvantage for specific groups remains substantial.

5.3. Perspectives from Other Cities

This section addresses the fifth research question by placing the findings from Amsterdam in a broader policy context. Rather than offering a systematic comparison, it explores how other cities approach ZEZs for passenger cars, and what this reveals about feasibility, equity concerns, and policy readiness.

Drawing on interviews with policymakers from several Dutch municipalities, alongside an explorative review of the ZEZ in Oxford (UK), the section highlights how different cities interpret the challenges and opportunities associated with restricting car access. Attention is given to how municipalities weigh environmental objectives against concerns about accessibility, public support, and the availability of alternatives.

In municipalities where a passenger-car ZEZ is actively being considered or tested, discussions centre on design choices, public acceptance, and distributional effects. In cities where such a policy is not currently on the agenda, experience with freight-related ZEZs provides insight into governance challenges, enforcement issues, and potential unintended effects that may also be relevant for passenger cars.

Rather than identifying best practices or ranking cities by ambition, this section highlights recurring themes, contrasts, and points of tension across cases. In doing so, it helps to assess whether Amsterdam's approach is exceptional or aligned with wider developments, and whether the challenges identified earlier should be understood as local implementation issues or as more structural features of ZEZ policies.

5.3.1. Oxford

Oxford provides an instructive example of a cautious and incremental approach to implementing a ZEZ. Unlike the Dutch context, where municipalities currently face legal uncertainty regarding the introduction of passenger-car ZEZs, the regulatory framework in the United Kingdom provides local authorities with greater discretion to introduce such access restrictions. This institutional difference allowed Oxford to implement a pilot scheme without the legal constraints that currently limit similar initiatives in the Netherlands.

The Oxford scheme was introduced as a pilot in a limited number of streets within the historic city centre, primarily in areas characterised by retail and hospitality activity. Two of these streets were already partially pedestrianised during the day, meaning that traffic volumes were low and largely commercial in nature prior to implementation. The zone operates on a time-limited basis, from 07:00 to 19:00, rather than as a full 24-hour restriction.

The decision to start with a small, central zone was deliberate. According to the interviewee, the primary objective was to minimise political and social risk while testing new enforcement systems and technologies:

> "We chose a very small zone because it was the first of its kind and we wanted to test the systems without affecting too many people."

By limiting the spatial and temporal scope, the local authority was able to trial automatic number plate recognition, exemption handling, and enforcement procedures before considering wider expansion. Importantly, most residents were not directly affected, and the majority of traffic in the pilot area originated from outside the city. Estimates suggest that around 95% of vehicles entering the future expansion area are driven by non-residents, allowing the policy to target incoming traffic while largely protecting those living within the zone.

Oxford's existing mobility context also played a crucial enabling role. The city has a relatively high PT mode share, with buses accounting for roughly half of trips to the city centre, alongside a strong cycling culture of approximately 20%. In addition, Oxford benefits from extensive P+R facilities at the city's edge, with further capacity expansion planned. These conditions meant that viable alternatives to private car use were already in place when the ZEZ was introduced.

Equity considerations were explicitly incorporated in the design of the scheme. Exemptions were granted for people with disabilities, and residents living within the zone received substantial discounts. This reflected a broader policy aim to protect residents while discouraging polluting vehicles that enter from outside the city, rather than penalising those already living within the restricted area.

In practice, public response to the pilot was relatively muted. The limited scope of the zone meant that few people were directly affected, and extensive warning letters were issued before fines were introduced. Businesses that regularly entered the zone quickly became familiar with the rules, further reducing friction during the early stages of implementation. Operational challenges were minimal and largely confined to practical issues such as improving signage, ensuring that drivers received warnings in time, and smoothing the transition from warnings to enforcement.

One of the most significant challenges identified was communication. The interviewee emphasised that public debate was strongly shaped by social media, partial information, and in some cases, misinformation. Objections to the scheme often focused on isolated elements while overlooking exemptions or the limited scope of the pilot:

> "Communication is difficult. People often only hear parts of the story, and misinformation spreads quickly."

As a result, the interviewee stressed the importance of collecting detailed data on traffic composition and emissions, anticipating misinterpretation, and developing clear and proactive communication strategies. They also highlighted that schemes of this kind should be expected to evolve over time, shaped by iterative feedback, political negotiation, and gradual expansion once initial systems have proven effective.

Overall, the Oxford case illustrates how a narrowly defined, time-limited pilot can reduce political risk, safeguard accessibility, and allow for policy learning before scaling up. Rather than delivering immediate large-scale emission reductions, the approach prioritised institutional learning, public acceptability, and the gradual alignment of enforcement capacity with longer-term environmental ambitions.

5.3.2. Eindhoven

Eindhoven shares several structural characteristics with Amsterdam, including ambitions to reduce urban emissions and explore the feasibility of a ZEZ for passenger vehicles. While Eindhoven has not conducted the same depth of socio-economic and accessibility analysis as Amsterdam, the interviewee emphasised that this does not reflect a lack of interest or commitment. Rather, policy development is currently shaped by legal uncertainty and a preference for coordinated national action.

A central theme was the importance of national alignment. Drawing on experience with the ZEZ for freight transport, the interviewee stressed that the success of the logistics ZEZ depended heavily on joint legislation, shared design principles, unified communication, central vehicle registers, and harmonised exemption frameworks. Introducing passenger-car ZEZs in a fragmented or city-specific manner was seen as likely to generate confusion and resistance:

> "If cities move too far ahead of national and European policy, you quickly run into limits of what is socially and politically acceptable."

For this reason, the interviewee argued that any future passenger-car ZEZ should ideally follow a nationally coordinated approach, similar to the freight ZEZ, rather than being developed independently by individual cities.

Within these constraints, Eindhoven has nonetheless pursued a range of supportive measures that could underpin a future transition. These include a relatively extensive rollout of charging infrastructure, scrappage schemes targeting older vehicles, and employer-focused programmes aimed at electrifying company fleets. The municipality is also exploring broader scrappage models that would not only encourage residents to remove older fossil-fuel vehicles, but also discourage replacement with another ICEV. Instead, these schemes could support alternatives such as bicycles, PT subscriptions, or shared mobility options.

When discussing the potential distributional effects of a passenger-car ZEZ, it was highlighted that there would be a clear asymmetry between residents living inside the zone and those outside it. Inner-zone residents would face the most direct impact, as non-compliant vehicles could no longer access their homes. This would effectively force households to dispose of or replace vehicles that may still be economically viable. By contrast, residents outside the zone would retain car access for most trips, but would be required to switch modes or transfer at P+R facilities when travelling into the restricted area. As a result, the burden of adjustment would fall disproportionately on those living within the zone and could therefore be seen as a key equity challenge, implying the need for longer transition periods, targeted exemptions, or financial support for inner-zone residents.

At the same time, it was cautioned against overcomplicating the policy framework. Excessive differentiation, such as multiple exemption categories, finely graduated emission classes, or highly specific income-based rules, could undermine transparency and public trust:

> "We must avoid making the framework so complex that no one understands it."

Spatial differences within the city were also analysed. Peripheral areas, particularly at the urban edge, were described as having limited PT alternatives, especially during evenings and off-peak hours. In these areas, car access remains essential for reaching work and other daily activities.

> "Some areas, especially at the edge of the city, have very poor alternatives. For many people, the car is essential for reaching work."

This reinforces the importance of complementary measures such as P+R facilities, which were seen as offering a more realistic transition pathway for peripheral residents than outright car exclusion.

Overall, the Eindhoven case highlights a cautious and coordination-oriented stance. The municipality recognises both the environmental rationale for a passenger-car ZEZ and the significant equity risks involved. Rather than advancing independently, Eindhoven views national alignment, phased implementation, and institutional simplicity as preconditions for a socially and politically viable transition:

> "For a successful ZEZ you must do it together—cities, national government, and sector organisations."

5.3.3. Utrecht

Utrecht has long pursued an ambitious air quality and climate agenda and already operates an environmental zone that restricts older diesel passenger cars (emission classes 0-4), alongside a ZEZ for freight transport. Historically, there has been political ambition to extend these restrictions to passenger cars and move towards a zero-emission inner city by 2030. At present, however, this ambition is not being actively developed, primarily because national legislation does not provide a legal basis for implementing a passenger-car ZEZ. As a result, no concrete implementation plan currently exists, despite long-term strategic aspirations.

Within these legal constraints, Utrecht continues to explore incremental tightening of its existing environmental zone. The municipality has conducted several SCBAs to assess scenarios such as banning petrol vehicles or imposing stricter emission standards. It was noted that while SCBAs are useful for structuring debate, they also have clear limitations:

> "A societal cost–benefit analysis flattens everything into euros, which makes it very difficult to capture transport poverty, car dependence, or social inequality."

This concern reflects a broader tension between technocratic evaluation tools and the lived impacts of mobility restrictions, particularly for lower-income and car-dependent households. Equity considerations play a central role in Utrecht's approach. It was emphasised that environmental policy is explicitly linked to public health, noting that exposure to poor air quality is unevenly distributed across the population.

> "Lower-income residents suffer most from poor air quality; improving health is a key driver of our environmental zone."

At the same time, the municipality recognises that tightening access restrictions can create new burdens. Lessons drawn from the freight ZEZ have strongly shaped thinking around passenger cars. Three principals are therefore critical: feasibility, fairness, and proportionality. Exemptions are seen as unavoidable, but they must remain limited in scope and duration:

> "Exemptions are necessary, but they must be temporary and targeted at the people who genuinely cannot comply."

In practice, Utrecht combines stricter rules with supportive measures. When the environmental zone is tightened in 2027, low-income residents will be supported through targeted subsidies. Importantly, these subsidies are not limited to vehicle replacement but may also be used for non-car alternatives, such as PT subscriptions or shared mobility options:

> "When we tighten the environmental zone in 2027, we will support low-income residents with subsidies so they can switch to cleaner alternatives."

This reflects a broader policy preference for reducing car dependence rather than simply replacing ICEVs with EVs.

Looking ahead, several challenges were identified. Grid congestion poses a growing constraint on electrification, while progress remains heavily dependent on national regulation and the development of the second-hand EV market. These factors lie largely outside municipal control, reinforcing the limits of local action.

Finally, it was stressed that there is a need for inter-municipal coordination. If passenger-car ZEZs are introduced, fragmented local rules would be politically and socially untenable. The logistics ZEZ succeeded precisely because cities aligned their timelines, exemption categories, enforcement systems, and communication strategies. A similar level of harmonisation would be essential for passenger vehicles to avoid confusion and resistance.

5.3.4. Rotterdam

At present, Rotterdam has not taken a political decision to introduce a ZEZ for passenger cars. While the municipality acknowledges that such a measure could contribute to improved air quality, no formal ambition, timeline, or design trajectory has been established.

> "Politically, nothing has been decided about a passenger-car ZEZ."

A key reason for this cautious stance is that, under the current national legal framework, municipalities do not yet have a clear legal basis to introduce a ZEZ for passenger cars. In addition, the composition of the vehicle fleet poses practical challenges. Fewer than 10% of passenger cars in Rotterdam are electric, leading the municipality to conclude that an immediate or near-term ban on ICEVs would be neither socially acceptable nor practically workable. In this context, a passenger-car ZEZ is seen as premature.

Moreover, the city has a strong spatial gradient in car dependence. As distance from the city centre increases, the reliance on private vehicles rises sharply. This pattern has intensified in recent years, as higher parking costs and reduced parking supply in central areas have displaced car ownership towards outer neighbourhoods. For specific groups, such as care workers, shift workers in the port, and older residents, PT is often not a realistic alternative, particularly outside peak hours. For these groups, the car remains structurally essential.

Rather than pursuing access restrictions, Rotterdam currently focuses on reducing car dominance through urban design and behavioural interventions. The inner city is being reshaped by reallocating road space from cars to cycling infrastructure and green space, with the aim of discouraging car use without outright bans. Complementary measures include mobility coaches and neighbourhood-level programmes that support residents in reducing private car ownership.

Equity considerations feature prominently in Rotterdam's assessment of any future passenger-car ZEZ. Lower-income households face significant barriers in the second-hand EV market, making a forced transition financially unrealistic for many. Any future scheme would therefore require exemptions, financial hardship assessments, and a strong package of complementary policies. Crucially, alternatives such as PT and cycling must not only exist but be affordable, reliable, and usable in practice.

Lessons drawn from Rotterdam's experience with the logistics ZEZ further inform this cautious approach. Maintaining stable timelines is essential, as delays or changing deadlines undermine actors who have already invested in electrification. Exemptions are necessary to ensure feasibility, but they must remain temporary to preserve policy credibility.

Looking ahead, several structural challenges were identified. These include the need for a massive expansion of charging infrastructure, growing grid congestion, and competition for scarce street space. Social equity remains a central concern, particularly the risk that lower-income households or residents with limited mobility could be excluded or pushed into carlessness without adequate alternatives. Finally, behavioural resistance, especially negative attitudes towards EVs, is a significant barrier to acceptance of a ZEZ.

Overall, Rotterdam's position illustrates a governance pathway that prioritises incremental change and car reduction over access restrictions. While the municipality does not reject the idea of a passenger-car ZEZ in principle, it currently views the social, infrastructural, and political conditions as insufficiently developed to support such a measure in an equitable way.

5.3.5. The Hague

The Hague is characterised by relatively high car ownership and a spatial structure that supports car use. The city's urban form, combined with travel patterns oriented towards employment locations beyond the city centre, has contributed to a long-standing reputation as a "car city". This context shapes both policy priorities and political expectations.

At present, The Hague has no plan to introduce a ZEZ for passenger cars. Such a policy is not politically feasible under the current city council, nor under the existing national legal framework. Proposals to further restrict polluting vehicles encounter strong resistance, and the municipality is considered to be well behind cities such as Amsterdam and Rotterdam in terms of ambition.

> "A ZEZ for passenger cars is politically impossible for us right now."

Equity concerns play a central role in this assessment. A transition to EVs remains financially out of reach for many residents, particularly those relying on older second-hand cars. Several neighbourhoods in The Hague experience high levels of social vulnerability, and car ownership in these areas is often linked to necessity rather than choice. A rapid tightening of vehicle access rules would therefore disproportionately affect lower-income households. As the interviewee explained:

> "Low-income residents rely on older cars; they simply cannot afford an electric vehicle."

In addition, many residents depend on the car to reach destinations where PT alternatives are limited or slow, such as industrial areas or neighbouring municipalities. This travel pattern further constrains the feasibility of car-restrictive policies. While PT provision in the city centre is generally strong, service quality and coverage decline in outer areas, reinforcing car dependence:

> "Our public transport is good in the centre, but once you go outward it becomes much weaker."

Compared to Amsterdam and Rotterdam, The Hague also faces structural limitations in its PT system. The absence of a metro network reduces the range and capacity of high-quality alternatives available to residents, particularly for longer or cross-city trips. This limits the municipality's ability to offset car restrictions with credible, city-wide substitutes.

Overall, the position of The Hague reflects a combination of political caution, structural constraints, and equity concerns. While the municipality recognises the environmental rationale behind ZEZs, current conditions are seen as insufficient to support a passenger-car ZEZ without significant social and political costs. As a result, The Hague prioritises incremental improvements to mobility and environmental quality rather than pursuing access-based restrictions on private vehicles.

5.3.6. Conclusion

Across the cases examined, several shared perspectives can be identified. A consistent theme is the role of national legislation and legal clarity as a key enabling condition. Many respondents indicated that the development of a passenger-car ZEZ is closely tied to national policy frameworks and inter-municipal alignment. In the absence of such coordination, some municipalities remain in an exploratory or preparatory stage rather than actively pursuing implementation.

Another recurring observation concerns the tension between environmental ambition and social equity. While improving air quality and reducing emissions are widely supported objectives, respondents frequently expressed concern about the potential exclusion of vulnerable groups, particularly lower-income households and those with a strong dependence on the private car. In this context, the availability of viable alternatives was consistently regarded as a necessary condition for a socially acceptable transition.

Several participants also emphasised the importance of distinguishing between residents and non-residents. Individuals living within a potential zone may face different constraints compared to visitors or commuters and may therefore require differentiated treatment. At the same time, respondents cautioned against excessive policy complexity, noting that numerous exemptions or highly differentiated rules between residents and visitors could undermine clarity, public understanding, and overall support.

Despite these commonalities, important differences between cities were evident. Municipalities vary considerably in their mobility systems, spatial structure, and degree of car dependence. In some cities, particularly those with more dispersed urban forms or weaker PT provision in outer areas, reliance on the private car remains relatively high. Political feasibility and institutional context also differ, with some municipalities demonstrating cautious openness towards future implementation, while others emphasise legal constraints or limited readiness of current conditions. Differences were also visible in policy pathways: several cities appear to favour incremental measures, such as tightening existing environmental zones or strengthening alternatives to car use, whereas others are primarily focused on longer-term preparation.

In terms of transferability, several elements appear broadly applicable. A commonly emphasised starting point is the need to understand who is affected by potential restrictions, including differences between residents and visitors, patterns of car dependence, and spatial or temporal travel needs. Phased implementation and early policy signalling were frequently highlighted as important for allowing households and businesses to adapt through natural vehicle replacement cycles. Complementary measures, such as improvements in PT and cycling, P+R facilities, targeted financial support, and carefully designed exemptions, were also regarded as essential components of a socially balanced approach. Effective communication was similarly identified as a key factor in managing expectations and maintaining public trust.

Overall, the Amsterdam case should not be interpreted as a universal model, but rather as a source of potentially transferable design principles. The extent to which such insights can be applied elsewhere appears conditional upon local factors, including the quality of alternative transport options, political and institutional capacity, implementation resources, charging infrastructure, grid constraints, and the broader legal framework. In many municipalities, developments currently focus on establishing these preconditions rather than pursuing immediate implementation of a passenger-car ZEZ.

6
Discussion

This chapter presents the discussion of the research. Section 6.1 interprets the results and provides an overall reflection on the findings, including their meaning, relevance, and points of attention. Section 6.2 discusses the implications of the results, particularly for policy and practice. Section 6.3 outlines the main limitations of the study, and Section 6.4 concludes the chapter by identifying directions for further research.

6.1. Interpretation

6.1.1. Car Dependence

Table 5.1 indicates that car use among respondents is associated with occasional rather than daily activities, such as visiting friends and family, grocery shopping, and transporting goods. In contrast, routine activities such as commuting are less frequently cited as car-dependent. This suggests that, for a substantial share of respondents, access to a car is required intermittently rather than continuously. This distinction is relevant when interpreting car dependence in the context of a ZEZ. Commuting-related car use may be considered more structurally embedded, as it is often directly linked to employment and income generation and typically involves trips that occur frequently as part of daily routines. Occasional uses, while still legitimate and meaningful, tend to be less time-critical and may allow for a wider range of adaptive responses. The findings therefore point towards a form of dependency that is episodic rather than structural. This pattern is noteworthy, as it is not always assumed that leisure-related activities account for a substantial share of car use. However, similar findings have been reported elsewhere. For example, Tomasdotter et al. (2023) show that in Sweden the share of passenger kilometres travelled by car is greater for leisure activities than for commuting.

From a sufficientarian perspective, the legitimacy of car use is not determined by the purpose of the trip. All reported uses can be considered justified at the individual level. However, when sufficientarianism is applied at the system level, the key question becomes whether access to a car is indispensable for maintaining a minimum acceptable level of accessibility. The results suggest that, while many respondents value access to a car, this access is not always critical in the sense that no functional alternatives could exist. This aligns with the pathway illustrated in the conceptual model (Figure 4.4), where the availability of alternative modes such as PT may influence the extent to which individuals remain dependent on private car use (Figure 4.6). Car dependence is therefore not interpreted here as a binary condition, but rather as a spectrum shaped by the availability of alternatives, the nature of activities, and the temporal context in which travel takes place. This layered understanding of dependency is essential for assessing how different groups may be affected by access-restrictive policies such as a ZEZ.

6.1.2. Size of the Affected Group

Table 5.10 shows that, among car-owning respondents, 14.5% are prone to accessibility loss, while a further 11.0% are considered highly policy-dependent. These categories represent individuals who are most likely to experience an accessibility gap if access to ICEVs is restricted.

At the same time, it is important to acknowledge that the respondent group is not fully representative of the Amsterdam population. The sample is characterised by an overrepresentation of older and higher-educated individuals, and car ownership within the sample is higher than the city average. When the figures are expressed as a share of the full respondent sample, rather than only car owners, the proportions are smaller in absolute terms: 7.9% (96 out of 1,218 respondents) are classified as structurally insufficient and 6.0% (73 out of 1,218) as highly policy-dependent. Taken together, this indicates that up to 13.9% of respondents in the dataset may face accessibility challenges under a scenario in which access to ICEVs or (P)HEVs is restricted.

This difference reflects the fact that the typology focuses specifically on car-owning respondents, under the assumption that non-car owners are less likely to experience a direct loss of accessibility as a result of vehicle access restrictions. Moreover, car owners are overrepresented in the dataset relative to Amsterdam as a whole, where the average car-to-household ratio (0.4) is lower than the 0.7 observed in the sample (Oomen & Heijnen, 2024). As a result, the size of the affected group is likely to be overestimated in absolute terms.

However, the limited size of this group does not diminish its normative relevance. From an equity perspective, the concentration of accessibility risks among a clearly identifiable subset of the population is precisely what warrants attention. Even if only a relatively small share of residents is affected, the concentration of impacts among specific groups remains highly relevant within a sufficientarian framework, which focuses on preventing individuals from falling below a minimum acceptable level of accessibility.

6.1.3. Vulnerable Groups

The results indicate that the transition towards a ZEZ is likely to place a disproportionate burden on specific groups of car-owning residents, particularly older individuals, lower-educated respondents, and City Pass holders. This pattern is evident in Tables 5.12, 5.13, and 5.14, which show that these groups are overrepresented among respondents classified as structurally insufficient or highly policy-dependent. These classifications reflect different forms of vulnerability. Structural insufficiency indicates that respondents perceive no feasible pathway to adaptation, even under supportive policy conditions, while policy dependence suggests that adaptation is only possible if substantial external support is provided. Importantly, these outcomes do not necessarily reflect resistance to change. Instead, they point to constraints related to financial capacity, life stage, and the availability of realistic alternatives.

Older respondents form a particularly vulnerable group partly because they are more likely to own a car in the first place. In the Netherlands, more than a quarter of all passenger cars are owned by individuals aged 65 and over (CBS, 2025b), which increases their exposure to access-restrictive policies such as ZEZs. At the same time, survey responses indicate that many older respondents perceive a transition to a new vehicle as unfeasible. As shown in Tables 5.8 and 5.23, this reluctance is primarily related to age and life-stage considerations, including the expected remaining period of car use and the perceived lack of return on a large financial investment at their stage of life. This suggests that vulnerability among older respondents is driven less by unwillingness to adapt and more by a mismatch between policy timelines and individual investment horizons. Even respondents who may be supportive of environmental objectives can therefore face adaptation pressure when the timing of a zero-emission transition conflicts with their life-course considerations.

Educational differences further structure vulnerability. Previous research shows that higher educational attainment is associated with earlier adoption of EVs, while lower-educated groups remain underrepresented among EV owners (Peters et al., 2018; Sovacool et al., 2018; Zhang et al., 2025). These findings are consistent with the results of earlier studies, suggesting that disparities in resources, information and perceived feasibility contribute to unequal adaptation capacity across educational groups.

For City Pass holders, financial constraints emerge as the dominant barrier. Survey responses indicate that affordability concerns strongly shape perceptions of infeasibility, particularly with regard to vehicle replacement. This aligns with earlier research showing that lower-income households with ICEVs are particularly vulnerable in car-restrictive transitions (Geilenkirchen et al., 2024; Mulder et al., 2024). Evidence from LEZs further suggests that such policies tend to disproportionately affect low-income car owners, who are more likely to rely on older vehicles (De Vrij & Vanoutrive, 2022; Stefaniec et al., 2025). The findings of this research point in a similar direction for ZEZs, suggesting that the transition towards ZEZs may likewise place a disproportionate burden on lower-income car owners.

Clear spatial patterns emerge from both the survey and the interviews, indicating that car ownership and car dependence tend to increase with distance from the city centre (Witte et al., 2022). This finding is consistent with earlier comparative research across European cities, which identifies distance to the city centre as one of the strongest predictors of car ownership and mode choice (Berrill et al., 2024). The literature suggests that this relationship is primarily driven by higher concentrations of employment, services, and amenities in central urban areas, which reduce travel distances and lower the need for car use. In addition, peripheral districts typically offer greater parking availability and lower residential parking costs, further reinforcing car ownership outside dense city centres (Ostermeijer et al., 2019). This spatial pattern is also reflected, albeit cautiously, in the district-level results of this study. Table 5.12 shows comparatively higher shares of structurally insufficient respondents in districts such as Nieuw-West and Noord, while lower vulnerability levels are observed in West and Oost. Although these differences are not statistically significant, they suggest that adaptation risks may be unevenly distributed across the city. These findings indicate that spatial context plays an important role in shaping vulnerability to access-restrictive policies. Residents in peripheral districts may face structurally fewer alternatives to private car use, increasing their exposure to accessibility risks under a ZEZ. This reinforces concerns about geographically differentiated impacts and highlights the importance of considering spatial equity in the design and implementation of such policies.

Taken together, the empirical findings also correspond with the pathways outlined in the conceptual model (Figure 4.4). In particular, the analysis confirms heightened vulnerability among older residents, lower-income groups, and residents living further from the city centre, while additionally indicating that lower-educated groups also form a vulnerable category within this framework.

6.1.4. Perception and Actual Feasibility

Assessing car dependence involves an element of subjectivity, as it relies on respondents' own assessments of whether certain activities can be undertaken without a private vehicle. Tables 5.1 and 5.17 show that many respondents report that specific activities cannot be performed without the use of a car. These self-reported assessments form an important part of the analysis, as they reflect how individuals experience their own accessibility constraints. Simultaneously, the results raise the question of whether perceived car dependence always corresponds to an objective absence of feasible alternatives. Previous research suggests that such perceptions may be shaped not only by structural constraints, but also by knowledge, habits, and preferences. For example, respondents may be unfamiliar with available alternatives, may underestimate their feasibility, or may place a high value on flexibility, autonomy, and comfort associated with car use. This does not invalidate their responses, but it does indicate that car dependence should be understood as a socially and contextually shaped phenomenon rather than a purely technical one. This interpretation is supported by Van Eenoo and Boussauw (2023), who find that car dependence often relates to occasional practices rather than daily routines and is particularly pronounced outside dense urban contexts. Their work highlights the role of predispositions towards car use, even in situations where alternatives are technically available. Such predispositions can influence how individuals evaluate their options, independent of actual service provision or infrastructure quality.

Further evidence of this distinction between general acceptability and personal feasibility emerges when comparing perceived alternatives and stated willingness to use them. Table 5.3 reflects respondents' views on whether certain modes could function as alternatives in general, whereas Table 5.5 focuses on respondents' willingness to adopt these modes in their own situation. The results show that while many respondents express support for sustainable mobility solutions at a societal level, this support does not consistently translate into personal willingness to change behaviour. This divergence aligns with the well-documented attitude-behaviour gap in travel behaviour, whereby positive attitudes towards sustainable transport do not necessarily result in corresponding behavioural change (Fu, 2025). Importantly, classification as potentially adaptable in this research does not imply that respondents will change their behaviour in practice. Rather, it indicates the absence of self-reported structural barriers combined with a stated openness to adaptation. As previous studies have shown, such stated willingness should be interpreted cautiously, particularly in mobility contexts where habitual behaviour and contextual factors play a strong role (Fu, 2025).

6.1.5. Trade-offs and Tensions of the ZEZ

Access-restrictive policies such as ZEZs inevitably involve trade-offs between environmental objectives and accessibility outcomes. By limiting access for certain vehicles, these policies may generate exclusionary effects for specific groups, even when they deliver collective benefits such as improved air quality or public health. The key normative question is therefore not whether exclusion occurs at all, but whether any resulting accessibility losses remain within acceptable bounds from a sufficientarian and egalitarian perspective. These tensions were already reflected in the conceptual model developed earlier in this research (Figure 4.4). The model illustrates that several potential pathways may emerge simultaneously following the introduction of a ZEZ. While some pathways lead to environmental improvements (Figure 4.5), others involve behavioural adaptation through alternative transport modes such as PT or P+R facilities (Figures 4.6 and 4.7). Although individual travellers may follow only one pathway, these processes occur concurrently at the aggregate level, highlighting how environmental gains and accessibility challenges can arise at the same time.

Empirical evidence supports the existence of such tensions. Research by De Vrij and Vanoutrive (2022) shows that residents living within LEZs may experience forms of social exclusion, including feelings of dependence on visitors from outside the zone and disproportionate impacts on lower-income households with older vehicles. These findings underline that access restrictions can have social consequences that extend beyond personal mobility alone.

The results of this thesis suggest that, in practice, it is not always possible to fully guarantee the sufficientarian condition for all individuals affected by a ZEZ with 14.5% of car-owning respondents at risk of accessibility loss. This does not imply that the sufficientarian norm is invalid. Rather, it functions as a guiding benchmark against which policy outcomes can be assessed, highlighting where risks of unacceptable accessibility loss are most likely to occur. From this perspective, the presence of some negative impacts does not automatically delegitimise a ZEZ. Instead, it emphasises the importance of complementary measures aimed at mitigating accessibility losses and preventing disproportionate burdens on specific groups. Egalitarian considerations therefore play a supporting role, guiding the design of targeted interventions that seek to uphold sufficientarian thresholds as far as reasonably possible within the constraints of access-restrictive policy.

6.2. Implications

6.2.1. Defensibility of a ZEZ

Although the absolute number of individuals directly affected by a ZEZ appears limited, the results show that accessibility risks are concentrated among specific socio-demographic groups. From a sufficientarian perspective, this concentration is normatively significant, as it raises concerns about individuals potentially falling below a minimum acceptable level of accessibility. On this basis, the introduction of a ZEZ in Amsterdam can be considered defensible only under clearly defined conditions. The findings suggest that such a policy is more justifiable when implemented alongside adequate alternatives and support measures that enable affected groups to adapt. Survey results indicate that, particularly in central areas, a substantial share of respondents perceive themselves as capable of adapting to the policy, which strengthens the case for conditional implementation (Table 5.12).

The analysis also confirms that no single measure can fully guarantee an equitable outcome. Even if a wide range of mitigating policies is introduced, it is unlikely that accessibility losses can be entirely avoided for all individuals. This does not invalidate the policy itself, but it highlights the limits of municipal capacity to prevent all negative effects within an access-restrictive framework. Rather than presenting an all-or-nothing judgement, this thesis therefore treats the ZEZ as a policy that is conditionally defensible. Its legitimacy depends on the extent to which accompanying measures reduce accessibility losses and prevent disproportionate burdens on already vulnerable groups. In this sense, the findings do not argue for the unconditional adoption of a ZEZ, but for a carefully designed and phased approach that explicitly acknowledges and addresses its equity implications.

6.2.2. Spatial Scope

From Subsection 5.2.2 it became evident that a more limited initial scope may be preferable from a sufficientarian perspective. Introducing a smaller zone first reduces the immediate number of individuals affected and allows households more time to adapt, thereby lowering the risk of abrupt accessibility losses. This phased approach is particularly relevant in light of the sufficientarian and egalitarian principles applied in this research, which emphasise limiting disproportionate burdens on vulnerable groups. Experiences from other cities, such as Oxford, indicate that starting with a more contained zone can facilitate implementation and public acceptance, while still delivering environmental benefits. By contrast, introducing a large and ambitious zone at an early stage may maximise environmental gains, but risks placing a disproportionate burden on groups that already face difficulties in adapting to mobility transitions. If such an approach is pursued, it becomes particularly important to identify which groups are most affected and to implement targeted support or compensatory measures to mitigate these impacts. From an equity perspective, a gradual expansion strategy therefore appears more defensible than an immediate city-wide approach. For residents living within the initial zone, temporary support measures such as exemptions or reduced permit costs may be justified during the early stages of implementation. Such measures can help mitigate short-term impacts while maintaining the long-term objective of transitioning towards emission-free urban mobility. Framing the policy as a sequence of incremental steps, rather than a single large intervention, aligns with the principle of allowing sufficient time and opportunity for adaptation.

A related spatial implication concerns the role of P+R facilities. As illustrated in the conceptual model (Figure 4.4) and the pathway shown in Figure 4.7, travellers who are unable or unwilling to enter the zone with their vehicle may increasingly rely on P+R locations at or near the zone boundary once access restrictions are introduced. This suggests that P+R facilities are likely to gain strategic importance as part of the wider mobility system surrounding a ZEZ. However, this expectation could not be empirically assessed using the survey data, as P+R use was not explicitly included. As such, the growing role of P+R should be understood as a plausible implication derived from the conceptual model and interviews, rather than a direct empirical finding.

6.2.3. Support Measures

A central policy implication of this research is the need to accelerate the transition of the vehicle fleet towards ZEVs, including within the second-hand market. At present, the composition of the car fleet suggests that a ZEZ would be difficult to implement in an equitable manner, as EVs remain financially inaccessible for a substantial share of households (Bauer et al., 2021; Caulfield et al., 2022; De Vrij & Vanoutrive, 2022; Geilenkirchen et al., 2024; Mulder et al., 2024). High purchase prices continue to be perceived as a major barrier, particularly among lower-income car owners (Bauer et al., 2021).

A range of policy instruments may contribute to addressing this challenge. Financial measures include targeted purchase subsidies (Figure C.8), local scrappage schemes for ICEVs (Figure C.9), and mobility budget schemes (Figure C.10) that allow residents to exchange private car ownership for access to alternative mobility options (Figures C.11, C.12, C.14, C.13).

In addition, behavioural and system-oriented measures may support adaptation. These include employer-based policies that encourage the use of ZEVs as well as alternative transport options such as PT and cycling (Figure C.15), wider adoption of MaaS systems (Figure C.7), fare differentiation for PT and shared mobility services (Figure C.5), improvements to cycling infrastructure (Figure C.6), and improved PT service levels (Figure C.4).

Furthermore, as stated in Subsection 5.2.5, closer alignment between the characteristics of vehicles entering the second-hand market and the financial capacities of lower-income households may be required. At present, many EVs entering the second-hand market originate from lease arrangements and remain relatively large and expensive, even after their first ownership period. As a result, these vehicles often remain out of reach for households that rely on the second-hand market due to budget constraints, limiting the role that second-hand EVs can play in supporting an equitable transition.

From an equity perspective, it is also important to consider how financial support is distributed. General purchase subsidies for EVs (Figure C.8) tend to have uneven distributive effects, as higher-income households are more likely to benefit from them (Caulfield et al., 2022; Israel et al., 2024). A stronger case can therefore be made for targeting subsidies more explicitly towards lower-income households, for whom affordability constraints are most binding. Such targeted approaches are more defensible within an egalitarian framework and are supported by empirical evidence showing that low-income households respond more strongly to financial support when barriers are reduced (Bauer et al., 2021; Jenn et al., 2020; Muehlegger & Rapson, 2018).

Beyond vehicle-related measures, PT provision (Figure C.4) plays a crucial supporting role in enabling equitable adaptation. While several findings in this research point towards a potentially important role for PT in outer districts such as Nieuw-West, Weesp and Zuidoost (Figures 5.2 & 5.3), the available evidence does not allow firm conclusions to be drawn about the adequacy of current service levels. This uncertainty is nonetheless policy-relevant. If access-restrictive measures are introduced without reliable and attractive PT alternatives, particularly in peripheral areas, the risk of accessibility loss increases. Further spatially targeted analysis of PT connectivity in relation to proposed zone boundaries therefore appears necessary prior to implementation. Existing research suggests that improving spatial availability and service coverage can significantly influence PT usage. As discussed in Subsection 4.6.6, higher levels of service provision are generally associated with increased ridership (Taylor & Fink, 2013), while relatively good PT coverage in lower-income neighbourhoods has been shown to contribute to higher usage among these groups (Liotta, 2025).

Finally, fare differentiation in PT (Figure C.5) may support modal shift, but its effects should not be assumed to be uniformly positive. In some scenarios, lower fares may encourage substitution from walking or cycling rather than from car use, potentially resulting in higher overall emissions (de Haas et al., 2022). This highlights the need for careful coordination between pricing policies and broader mobility objectives, ensuring that fare measures contribute to car reduction rather than unintended modal shifts.

6.2.4. Shared Mobility Options

The results indicate that private cars in Amsterdam are primarily used for activities that occur on an occasional rather than a daily basis, such as visiting friends and family, grocery shopping, transporting goods, and leisure-related trips (Table 5.1). This suggests that the functional value of the car often lies in intermittent availability rather than continuous ownership. From a policy perspective, this distinction is important, as it implies that access to a car may be more relevant than owning one.

This pattern creates clear opportunities for shared mobility solutions. If car use is largely episodic, shared vehicles may substitute private car ownership for a substantial share of users, provided that such services are accessible, reliable, and affordable. Existing literature supports this potential. Singh et al. (2025) argue that shared electric car options must be widely available and competitively priced in order to outweigh the perceived benefits of private ownership, while also identifying barriers to adoption such as limited awareness, negative attitudes, and low confidence, particularly among older car users.

Availability appears to be a particularly important determinant. As discussed in Subsection 4.6.6, Dias et al. (2024) show that shared mobility ridership is substantially higher in areas where services are widely available, while usage remains low where service coverage is limited. This pattern is also visible in the Amsterdam context. Figure C.3 shows that shared vehicles are concentrated in dense central districts, while availability decreases considerably in areas located further from the city centre.

Economic evidence further strengthens this argument. Kunsmann and Letmathe (2025) show that for individuals driving up to 200 kilometres per week, car sharing is cheaper than owning a private car across most user profiles. The competitiveness of car sharing increases as residential parking costs rise, a condition that is especially relevant in dense urban contexts such as Amsterdam.

Survey results suggest that there is moderate openness towards shared mobility, with a majority of respondents considering it either somewhat or highly suitable as an alternative (Tables 5.3 & 5.18). Nevertheless, the relatively high share of “somewhat suitable” responses points to remaining uncertainty. This may reflect a knowledge gap regarding how shared mobility could function in practice, or practical limitations related to availability, usability, vehicle choice or pricing. As noted by Singh et al. (2025), closer collaboration between local authorities and shared mobility providers is likely to be necessary to lower these barriers and increase confidence in shared alternatives.

Overall, shared mobility appears to offer a meaningful contribution to a more equitable transition under a ZEZ, particularly for residents who rely on a car for occasional rather than daily activities. Its effectiveness, however, depends on whether services are aligned with actual use patterns and whether informational and practical barriers can be adequately addressed.

6.2.5. Spillover Effects

The spatial scope of a ZEZ influences how environmental and mobility impacts are distributed. While emission reductions are expected within the restricted area, these benefits may be accompanied by negative spillover effects in surrounding neighbourhoods. Traffic and environmental burdens can therefore shift rather than disappear. Evidence from existing LEZs supports this concern. Research on the Madrid LEZ shows that traffic intensity declined within the zone but increased along its boundaries, indicating displacement of conventional vehicles to adjacent areas (Moral-Carcedo, 2024; Tassinari, 2024). This displacement can lead to higher traffic volumes, increased parking pressure, and potentially higher emissions in peripheral zones, as the diverted traffic mainly consists of ICEVs.

Similar spillover effects have been observed in German cities, where pollutant concentrations increased in areas bordering LEZs (Sarmiento et al., 2021). From an equity perspective, this raises concerns about spatial justice, as residents in boundary areas may experience additional environmental burdens without directly benefiting from improved air quality. These trade-offs, also reflected in the conceptual model (Figure 4.4 and 4.7), highlight the need for accompanying measures to manage and mitigate spillover effects.

6.2.6. Role of Coordination versus Municipal Autonomy

Interviews with municipal officials highlight differing views on the role of inter-municipal coordination in implementing a ZEZ. Representatives from Eindhoven and Utrecht emphasised that acceptance and effective implementation would be more likely if municipalities acted collectively, similar to the coordinated rollout of the freight ZEZ. According to these interviewees, fragmented implementation risks creating confusion among users and may undermine public support. This concern primarily relates to administrative coherence and practical implementation rather than to the normative legitimacy of city-level action. From a governance perspective, coordination can indeed reduce transaction costs, streamline communication and ensure consistency in key elements such as timelines, exemptions and enforcement rules. In this sense, cooperation between municipalities offers clear practical advantages.

A lack of national or regional alignment does not necessarily preclude individual cities from acting. Amsterdam operates within its own policy framework and, provided that national legislation allows it, retains the authority to pursue more ambitious mobility policies independently. Waiting for consensus among all major Dutch cities could significantly delay implementation, particularly given that municipalities differ in political priorities and levels of ambition.

International experiences suggest that unilateral action by pioneering cities is feasible. Zero-emission or access-restrictive zones have been introduced in cities such as Paris, Brussels and Oxford without full national alignment, and continue to operate. While coordinated implementation may be preferable from an efficiency perspective, municipal autonomy can play an important role in advancing policy innovation and accelerating transition where political will exists.

Ultimately, the balance between coordination and autonomy will depend on the regulatory framework adopted at the national level. Whether the Dutch government opts for a centrally defined model, as with the freight ZEZ, or allows greater local discretion will shape the extent to which cities can independently define the scope and timing of passenger car ZEZs.

6.3. Limitations

First of all, the conceptual model has some limitations. Accessibility inequality is represented in aggregated form and does not capture differences between transport modes or highly individualised accessibility changes. Consequently, mode-specific accessibility effects cannot be assessed in detail (by the conceptual model). Moreover, the model represents a simplified abstraction of reality, and additional contextual factors may influence outcomes beyond those included in the framework.

A further important limitation of this study concerns the representativeness of the dataset. As shown in

Tables 2.2 and 2.4, the sample is skewed towards older and higher-educated respondents, which limits direct comparability with the broader population of Amsterdam. Nevertheless, the dataset remains analytically valuable for examining differences between groups within the sample. Given that structural insufficiency increases with age in the observed data, it is plausible that the overall share of structurally insufficient individuals would be lower in a more age-representative population. Previous research indicates that younger adults tend to display greater flexibility in travel behaviour, higher familiarity with shared mobility, and stronger intentions to adopt EVs (Anastasiadou & Gavanas, 2022; Chen et al., 2020; Kumar & Alok, 2020; Sovacool et al., 2018). While this cannot be verified empirically within the present dataset, the reported level of vulnerability may therefore represent an upper-bound estimate. This pattern is consistent with a degree of self-selection, whereby older and/or higher-educated respondents are more engaged and more likely to participate in population surveys (Bovens & Wille, 2010; Kong et al., 2025).

A related limitation concerns the relatively small number of City Pass holders who reported owning a car within the sample (n = 32). While descriptive patterns derived from this subgroup provide useful indicative insights, the limited sample size reduces statistical robustness, and the results should therefore be interpreted with caution, as small subsamples may produce unstable or exaggerated estimates.

A further limitation relates to the cross-sectional nature of the data. The study captures perceptions and expected behaviour at a single point in time, whereas adaptation to a ZEZ is inherently dynamic. Consequently, the analysis reflects anticipated rather than realised adaptation and does not allow causal inference regarding long-term behavioural change or accessibility outcomes.

Another limitation concerns the measurement of the adaptation typology. The classification of respondents into the categories of potentially adaptable, policy-dependent, and structurally insufficient is based on self-reported expectations within a hypothetical scenario rather than observed behaviour. Respondents' assessments of their future situation may therefore deviate from actual outcomes, introducing uncertainty into estimates of vulnerability and adaptive capacity. This limitation is reinforced by the presence of hypothetical bias, whereby stated intentions and expectations do not necessarily correspond to real-world behaviour (Hensher, 2010).

Finally, the survey design did not include detailed questions on the substitutability of car use by alternative modes such as PT, nor on the use or perceived role of P+R facilities. More detailed information on these aspects, including spatial differences, socio-economic variation, and perceptions of PT substitutability and current usage, would have strengthened the analysis of behavioural adaptation pathways.

6.4. Future Research

Future research could extend the spatial scope of this study beyond Amsterdam residents. A substantial share of car movements into and out of the city originates from surrounding municipalities and other parts of the Netherlands (Table 5.26), yet the present survey captures the perspectives of Amsterdam residents. Understanding the adaptive and behavioural responses of commuters and visitors from outside the municipality would provide a more complete picture of the broader mobility impacts of access-restrictive policies.

A second area for future research concerns behavioural dynamics over time. The present study captures expectations at a single point, while adaptation to mobility transitions unfolds gradually and may differ across cohorts. In particular, it remains uncertain how current age groups will adapt in the longer term, and whether younger cohorts will display similar vulnerability patterns as they age. Further research could therefore examine how accessibility, adaptation, and mobility behaviour evolve in response to changing technologies, policies and market conditions. This would also make it possible to assess the extent to which the attitude-behaviour gap manifests in the Amsterdam context, by examining whether stated openness towards alternative modes translates into actual behavioural change over time.

More detailed empirical insight into car use intensity would be valuable. Existing evidence suggests that car sharing becomes financially advantageous for drivers with relatively low annual mileage (Kunsmann & Letmathe, 2025), yet the distribution of driving intensity across socio-demographic groups in Amsterdam remains unclear. Future research could examine travel purposes, the frequency of car use among different groups, and their annual driving distances, and assess how these patterns relate to the potential uptake of shared mobility. Such insights would support more targeted policy and help identify where shared mobility services could realistically substitute private car use.

Current evidence shows that shared mobility availability varies across districts (Figure C.3), with relatively limited provision in areas further from the city centre, such as Noord, Nieuw-West, Zuidoost and Weesp. At the same time, private car use remains relatively common for trips between these areas and the centre. For example, 36% of movements between Weesp and the centre are made by car (Table 5.26). However, the motivations behind these trips remain unclear. If they are primarily commuting-related, substitution potential may be limited due to the regularity of such journeys. In contrast, if a substantial share consists of occasional trips, such as visiting friends, family, or leisure activities, shared mobility may represent a more viable alternative. Future research could therefore examine not only these travel motives and spatial mobility patterns, but also how shared mobility services could be more effectively integrated into such areas and what conditions would be required for wider adoption. This would provide important insight into where shared mobility services could realistically be expanded and under what circumstances they could help reduce private car ownership.

Another promising direction concerns the quantitative modelling of modal change. While the present study evaluates expected behavioural response and equity implications, future work could estimate the actual magnitude of modal shifts following the introduction of access-restrictive policies. Simulation-based approaches, such as agent-based modelling, could provide more precise estimates of changes in mode share, PT demand, private vehicle use, and environmental benefits under different policy scenarios.

Finally, this study focuses primarily on car users, yet indirect accessibility effects may also affect non-car owners. Changes in social visits, care arrangements or service provision could influence accessibility and social inclusion among individuals who are not directly subject to vehicle access restrictions. Further research into these indirect and spillover effects would deepen understanding of the broader equity implications of mobility transitions.

7 Conclusion

This thesis set out to answer the following research question: Under what conditions can zero-emission zones for passenger cars be implemented in a socially equitable manner in Amsterdam, and what lessons can be drawn for other Dutch cities? To address this question, the research combined normative and empirical perspectives. Drawing on the principles of sufficientarianism and egalitarianism, the study examined survey data on mobility behaviour and perceptions among Amsterdam residents to identify patterns of adaptive capacity and accessibility risk. By linking these empirical findings to policy design considerations, the research identifies the conditions under which a ZEZ could be implemented without causing unacceptable accessibility losses.

A key contribution of this thesis is the use of accessibility as the central metric for evaluating equity outcomes. While much of the literature on emission zones focuses on indicators such as car ownership, emissions or modal share, this research instead examines whether individuals can still reach the activities that structure daily life. Framing the analysis in terms of accessibility therefore provides a more direct assessment of whether residents risk falling below an acceptable level of participation in urban life.

To better understand adaptation capacity in the context of a ZEZ, this research introduced an adaptation typology that moves beyond the binary distinction between those who can and cannot adapt to access restrictions. Instead, the typology distinguishes between varying degrees of adaptive capacity and connects behavioural willingness to structural constraints. The analysis identifies three groups: individuals who are potentially adaptable, those who are highly policy-dependent, and those who are structurally insufficient. Within the group of car-owning respondents, 74.5% were classified as potentially adaptable, 11.0% as policy-dependent, and 14.5% as structurally insufficient and therefore at risk of accessibility loss.

The empirical findings show that accessibility risks are unevenly distributed and concentrated among specific socio-demographic groups, particularly older people, those with lower levels of education or income, and those living further from the city centre. Roughly one in seven respondents (13.9%) may face accessibility challenges if access to ICEVs or (P)HEVs were restricted. The findings therefore indicate that a substantial group of residents could face genuine accessibility challenges under a ZEZ.

Even if the affected share of the population remains relatively limited in absolute terms, this concentration of impacts remains normatively significant. From both sufficientarian and egalitarian perspectives, the existence of identifiable groups at risk of accessibility loss requires policy attention. The findings therefore underline an important broader insight: distributive burdens are inherent to restrictive access policies. Policies such as ZEZs may generate collective environmental benefits, but they can simultaneously produce unequal accessibility impacts. As a result, such policies require deliberate policy steering to prevent accessibility gaps from widening and to ensure that the transition towards cleaner mobility remains socially inclusive.

The findings highlight that the transition towards zero-emission mobility has clear distributional implications. Existing inequalities in vehicle ownership and EV adoption already shape potential accessibility patterns, meaning that policies restricting access to ICEVs alone may risk creating accessibility gaps if implemented without supporting measures. In the Dutch context, where systematic empirical analysis of the social equity implications of passenger-car ZEZs remains limited, this research provides an initial indication of how accessibility risks may be distributed across the population. Recognising these patterns is essential for designing policy approaches that prevent the transition towards cleaner mobility from reinforcing existing inequalities.

With regard to the question of under what conditions a ZEZ can be introduced in a socially equitable manner, the findings suggest that such policies cannot be considered equitable by default. Access-restrictive measures inevitably create distributional tensions and therefore require a set of accompanying conditions to preserve accessibility for affected groups. The analysis identifies five main conditions for the socially equitable implementation of a ZEZ in Amsterdam.

First, a gradual and transparent implementation strategy is essential. A phased ZEZ reduces the number of individuals affected at once, allows households time to adapt, and lowers the risk of sudden accessibility loss. A phased timeline also makes it possible to first exclude the oldest and most polluting vehicles, while allowing lower-emission vehicles to continue entering the zone for a longer period before they too are phased out. Clear timelines should be communicated well in advance, so that residents can anticipate when their vehicle will no longer comply with the regulations and adjust accordingly.

Second, the spatial scope of the initial zone should remain limited before any wider implementation, preferably focusing on the city centre. In the Amsterdam context, a smaller zone is likely to enjoy greater public acceptance and can build on existing mobility conditions, as alternatives such as PT already account for a large share of movements to and from the city centre. From a sufficientarian perspective, a limited spatial scope also reduces the number of individuals whose accessibility may be put at risk, thereby lowering the likelihood of immediate accessibility loss. However, a smaller zone may also result in more modest environmental benefits and carries the risk of spillover effects, as traffic pressures and environmental burdens may shift towards surrounding neighbourhoods. This highlights a fundamental trade-off in the spatial design of the zone. Expanding the perimeter can increase environmental benefits but may simultaneously increase the risk of accessibility loss for a larger share of residents. Careful policy design and monitoring are therefore required to manage these spillovers and prevent the displacement of inequities.

Third, targeted support measures are necessary for groups identified as most vulnerable to accessibility loss, including older residents, lower-educated groups, lower-income households and residents living further from the city centre. Possible measures include targeted EV purchase subsidies, temporary exemptions, scrappage schemes for ICEVs and mobility budgets that provide access to alternative transport options. However, these measures alone cannot fully address the structural challenges of the current vehicle market. EVs remain financially inaccessible for many households, particularly within the second-hand market that is most relevant for lower-income groups. Nationally strengthening the supply of affordable second-hand EVs therefore requires greater policy attention to support a more equitable transition towards zero-emission mobility.

Fourth, viable alternatives to private car use should be in place before implementation. PT must function as a credible substitute, as it represents one of the most important alternatives to private vehicle use. In addition, high-quality cycling infrastructure can provide a viable alternative for many trips in the Amsterdam context. The findings further indicate that car use in Amsterdam is often occasional rather than structurally embedded in daily routines, suggesting potential for shared mobility services to substitute private car ownership for certain trips. However, the availability of shared mobility remains spatially uneven and is limited in areas where car use is relatively more common. A wider and more spatially balanced provision of these services is therefore important to support adaptation.

Fifth, monitoring and mitigation measures are necessary to prevent uneven impacts during implementation. The policy should incorporate continuous monitoring of impacts across socio-demographic characteristics such as income, age, education and city district. This allows policymakers to identify emerging accessibility gaps and adjust the policy where widening accessibility inequalities become visible.

Ultimately, the transition towards zero-emission mobility cannot be assessed solely in environmental terms. Ensuring that such policies remain socially equitable requires explicit attention to accessibility, targeted support for vulnerable groups and continuous policy adaptation as the transition unfolds.

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A

Supplementary Tables

This chapter presents supplementary tables that provide additional contextual information and statistical details supporting the analyses presented in the main chapters of the thesis. These tables include socio-economic indicators for selected Dutch cities and districts, as well as additional statistical results related to the survey analysis.

Socio-economic context

The following tables provide contextual socio-economic indicators for The Hague and Rotterdam, including average disposable household income and housing prices across city districts.

Table A.1: Average household income and housing price (WOZ) in The Hague and its districts, retrieved from Gemeente Den Haag (2023a, 2023b)

Indicator	Year	The Hague	Centre	Loosduinen	Escamp	Segbroek	Scheveningen	Laak	Haagse Hout	Leischenveen-Ypenburg
Average disposable household income	2023	48,700	47,958	41,597	51,469	60,920	43,156	37,846	57,492	65,979
Average housing price (WOZ)	2023	363,571	361,608	270,380	403,267	505,620	334,608	246,369	431,795	474,812

Table A.2: Average household income and housing price (WOZ) in Rotterdam and its districts, retrieved from CBS (2023c)

Indicator	Year	Rotterdam	Centre	Delfshaven	Overschie	Noord	Hillegersberg-Schiebroek	Kralingen-Crooswijk	Feijenoord	Ijsselmonde	Prins Alexander	Charlois	Hoogvliet
Average disposable household income	2023	34,400	38,500	31,000	38,000	34,200	45,800	35,400	31,700	31,700	36,400	28,800	34,200
Average housing price (WOZ)	2023	320,000	407,000	300,000	364,000	344,000	472,000	370,000	289,000	247,000	341,000	217,000	271,000

Conceptual model justification

The following table presents the causal relationships included in the conceptual model, together with the supporting sources and a brief explanation of the empirical evidence for each link.

Table A.3: Justification of the causal links in the conceptual model (scientific evidence)

Variable A	Sign	Variable B	Source	Explanation
Accessibility inequality	⟶	Social exclusion	(Lucas, 2012)	Figure in the research done by Lucas (2012) shows that inaccessibility leads to social exclusion

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Variable A	Sign	Variable B	Source	Explanation
Active transportation modes	→	Health benefits	(Rojas-Rueda et al., 2016)	Policies that stimulate active transportation modes generate health benefits for people in general.
Adoption of ZEVs	→	Accessibility inequality	(Liotta, 2025)	Income disparities create unequal accessibility: wealthier groups maintain mobility via ZEV, whereas lower-income groups are more restricted.
Air quality	→	Health benefits	(Malina & Scheffler, 2015; Pestel & Wozny, 2021)	Reduced levels of air pollution in Germany due to the implementation of LEZs have improved the air quality and therefore resulted in population health benefits by lowering the share of diagnoses related to air pollution.
Amount of traffic in ZEZ	→	Road safety	(Høye & Hesjevoll, 2020)	"Crashes increase with increasing volumes" (Høye & Hesjevoll, 2020).
Degree of urbanity	→	Dependence on a vehicle	(Witte et al., 2022)	The more suburban people are, the more they are 'dependent' on their car. "Urbanisation is an excellent determinant in explaining differences in car ownership." (Witte et al., 2022)
Degree of urbanity	→	Shared mobility services ridership	(Ghaffar et al., 2023)	Population density is an indicator of increasing shared mobility services ridership.
Disabled persons	→	Dependence on a vehicle	(Tarriño-Ortiz et al., 2022)	Disabled persons are more likely to continue using their private vehicles in the Madrid Central case.
Elderly	→	Dependence on a vehicle	(Tarriño-Ortiz et al., 2022)	Elderly are more likely to continue using their private vehicles in the Madrid Central case.
Individual accessibility	→	Social exclusion	(Lucas, 2012)	Inaccessibility leads to social exclusion. Therefore an increase in individual accessibility leads to less social exclusion.

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Variable A	Sign	Variable B	Source	Explanation
Level of income/affordability	→	Adoption of ZEVs	(Tang & Sun, 2019; Tarriño-Ortiz et al., 2022)	Disposable income positively affects the sale of New-energy vehicles (Tang & Sun, 2019). Populations with high income levels have less propensity to leave and substitute their cars for another mode to get to Madrid central as they can afford private parking rates within the LEZ and/or buy a low pollution vehicle (Tarriño-Ortiz et al., 2022).
Pollution	→	Air quality	(Malina & Scheffler, 2015; Pestel & Wozny, 2021)	Reduced levels of air pollution in Germany due to the implementation of LEZs have improved the air quality and therefore resulted in population health benefits by lowering the share of diagnoses related to air pollution.
Pollution	→	Health benefits	(Broster & Terzano, 2025)	"The results show that there is statistically significant evidence of LEZs curbing pollution levels, which in turn contributes to long-term health benefits" (Broster & Terzano, 2025).
PT ridership	→	Amount of traffic in ZEZ	(Tarriño-Ortiz et al., 2022)	In Madrid's LEZ, public transport use increased while overall car traffic decreased, indicating a substitution effect.
Social exclusion	→	Health benefits	(van Bergen et al., 2019)	Evidence is found for the association between high social exclusion and adverse health outcomes.
ZEZ	→	Active transportation modes	(Tarriño-Ortiz et al., 2022)	Evidence from the Madrid LEZ shows a shift towards more sustainable transport modes.

Continued on next page

Variable A	Sign	Variable B	Source	Explanation
ZEZ	⟶	Adoption of ZEVs	(Tarriño-Ortiz et al., 2022)	Evidence from the Madrid LEZ shows a shift towards more sustainable transport modes, encouraging adoption of zero-emission vehicles.
ZEZ	⟶	PT ridership	(Tarriño-Ortiz et al., 2022)	Evidence from the Madrid LEZ shows a shift towards more sustainable transport modes.
ZEZ	⟶	Shared mobility services ridership	(Tarriño-Ortiz et al., 2022)	Evidence from the Madrid LEZ shows a shift towards more sustainable transport modes.

Survey tables

The following tables present additional descriptive statistics from the survey that support the analyses reported in the results chapter.

Table A.4: Car ownership by educational level

Educational level	No car (%)	Car owner (%)	N
Low	48.3	51.7	60
Medium	33.2	66.8	208
High	32.3	67.7	924
Other / unknown	34.6	65.4	26
Total	33.3	66.7	1218

Note. Percentages are row percentages. Differences between educational levels are not statistically significant (Pearson $\chi^2(3) = 6.59,\ p = .086$).

Table A.5: Car ownership by age category

Age category	No car (%)	Car owner (%)	N
30–39	48.6	51.4	37
40–49	39.2	60.8	120
50–59	29.0	71.0	269
60–69	32.3	67.7	384
70–79	33.6	66.4	357
80 or older	34.0	66.0	50
Unknown	100.0	0.0	1
Total	33.3	66.7	1218

Note. Percentages are row percentages. Differences between age categories are not statistically significant (Pearson $\chi^2(6) = 10.24,\ p = .115$).

Table A.6: Perceived importance of car use by educational level

Educational level	High importance (%)	N
Low	67.7	31
Medium	64.0	139
High	58.6	626
Other / unknown	64.7	17
Total	60.0	813

Note. Percentages indicate the share of respondents reporting that car use is of great importance in daily life. Differences across educational levels are not statistically significant ($\chi^2(9) = 4.55$, $p = .87$).

Table A.7: Perceived importance of car use by age category

Age category	High importance (%)	N
30–39	73.7	19
40–49	65.8	73
50–59	62.3	191
60–69	55.0	260
70–79	59.9	237
80 or older	66.7	33
Total	60.0	813

Note. Percentages indicate the share of respondents reporting that car use is of great importance. Differences across age categories are not statistically significant ($\chi^2(15) = 10.81$, $p = .77$).

Table A.8: Perceived importance of car use by city district

City district	High importance (%)	N
Centrum	55.0	100
West	56.5	92
Nieuw-West	62.9	140
Zuid	60.0	115
Oost	55.8	113
Noord	61.0	118
Weesp	57.5	40
Zuidoost	69.5	95
Total	60.0	813

Note. Percentages indicate the share of respondents reporting that car use is of great importance. Differences across city districts are not statistically significant ($\chi^2(21) = 25.43$, $p = .23$).

Table A.9: Support for public transport measures by socio-demographic group

	Cheaper public transport (%)	Improved public transport (%)
City district		
Centre	34.2	35.4
West	33.8	38.0
New West	43.6	47.0
South	26.7	34.4
East	27.3	40.9
North	34.8	40.2
Weesp	52.0	56.0
Southeast	64.4	58.9
Age category		
30–39	50.0	60.0
40–49	37.7	45.3
50–59	42.0	42.0
60–69	42.2	44.6
70–79	32.3	39.2
80+	25.0	43.8
Educational level		
Low	53.8	50.0
Medium	45.6	43.9
High	35.1	42.8
Other/unknown	54.5	9.1

Note. Percentages indicate the share of respondents supporting each policy measure ($N = 635$). For cheaper public transport, differences are statistically significant across city districts ($\chi^2(7) = 33.66$, $p < .001$) and educational levels ($\chi^2(3) = 8.81$, $p = .032$), but not across age categories ($\chi^2(5) = 7.70$, $p = .174$). For improving public transport, differences are statistically significant across city districts ($\chi^2(7) = 15.72$, $p = .028$), but not across age ($\chi^2(5) = 4.90$, $p = .428$) or education ($\chi^2(3) = 4.68$, $p = .197$).

B

Survey

This chapter contains the full questionnaire used for the Municipality of Amsterdam survey, distributed via the O&S Panel, City Pass panel and an open link. The questions cover current mobility behaviour, perceived necessity of car use, views on potential policy measures, and respondents' expectations regarding a future shift towards zero-emission mobility. The questionnaire is reproduced here to provide transparency regarding the data underlying the empirical analysis.

Het autoverkeer in Amsterdam vervuilt de lucht. Schone lucht is belangrijk voor de gezondheid van de inwoners. Ook neemt verkeer veel ruimte in. De gemeente Amsterdam wil het verkeer verminderen en schoner en stiller maken. Dit vraagt om veranderingen in het autobezit van Amsterdammers. Ook vraagt dit dat bezoekers en forenzen het gebruik van de auto in Amsterdam veranderen.

Graag stellen wij u enkele vragen hierover, bijvoorbeeld over wat u van de maatregelen vindt en welke effecten u verwacht op uw eigen situatie. Het invullen van de vragenlijst kost ongeveer 10 minuten.

V1a. Welke vervoermiddelen heeft uw huishouden? Meerdere antwoorden mogelijk.

- auto op benzine, diesel, CNG of LPG
- hybride auto
- elektrische auto
- kleine elektrische auto (microcar)
- niet-elektrische fiets
- elektrische fiets
- bromfiets, snorfiets of scooter op benzine
- elektrische bromfiets, snorfiets of scooter
- motor
- gehandicaptenvoertuig
- anders, namelijk
- geen van bovenstaande
- weet ik niet, geen antwoord

Indien van toepassing op basis van V1a:

V1b. Hoe laadt u uw kleine elektrische auto nu meestal?

- thuis, buiten aan de gevel, op eigen oprit of in eigen garage
- op het werk, buiten aan de gevel of bij een laadpaal
- bij een openbare laadpaal (bij een parkeerplek)

- weet ik niet, geen antwoord

Indien van toepassing op basis van V1a:

V1c. Hoe laadt u uw elektrische bromfiets, snorfiets of scooter nu meestal?

- thuis, binnen aan het stopcontact
- thuis, buiten aan de gevel, op eigen oprit of in eigen garage
- op het werk, binnen aan het stopcontact
- op het werk, buiten aan de gevel of bij een laadpaal
- bij een openbare laadpaal (bij een parkeerplek)
- weet ik niet, geen antwoord

V2. Hoe vaak gebruikt u de volgende vervoermiddelen? (telkens met de antwoordopties: dagelijks; meerdere keren per maand; meerdere keren per jaar; één keer per jaar of minder; weet ik niet, geen antwoord. Los van 'openbaar vervoer' alleen de bij V1a gekozen vervoermiddelen voorleggen)

- auto op benzine, diesel, CNG of LPG
- hybride auto
- elektrische auto
- kleine elektrische auto (microcar)
- niet-elektrische fiets
- elektrische fiets
- bromfiets, snorfiets of scooter op benzine
- elektrische bromfiets, snorfiets of scooter
- motor
- gehandicaptenvoertuig
- openbaar vervoer
- anders, namelijk

V3a. Waarvoor gebruikt u uw auto momenteel het meest? (alleen vragen als bij V1a een personenauto gekozen is)

- ritten van en naar werk
- ritten tijdens werk
- uitgaan, sport, vrijetijdsbesteding, hobby
- bezoek aan familie en vrienden
- boodschappen doen
- mantelzorg, bezoek arts of ziekenhuis
- kinderen wegbrengen en ophalen
- vervoeren van spullen
- anders, namelijk
- geen van bovenstaande
- weet ik niet, geen antwoord

V3b. Welke verplaatsingen kunt u niet zonder auto doen? Meerdere antwoorden mogelijk. (alleen vragen naar bij V3a gekozen antwoorden)

- ritten van en naar werk
- ritten tijdens werk
- uitgaan, sport, vrijetijdsbesteding, hobby

- bezoek aan familie en vrienden
- boodschappen doen
- mantelzorg, bezoek arts of ziekenhuis
- kinderen wegbrengen en ophalen
- vervoeren van spullen
- anders, namelijk
- ik kan de bovenstaande verplaatsingen ook zonder auto doen
- weet ik niet, geen antwoord

V4. Wanneer gebruikt u uw auto meestal? Meerdere antwoorden mogelijk. (alleen vragen als bij V1a een personenauto gekozen is)

- op maandag tot en met vrijdag
- op zaterdag en zondag
- weet ik niet, geen antwoord

V5. Waar rijdt u meestal met uw auto? (alleen vragen als bij V1a een personenauto gekozen is)

- ik blijf meestal in Amsterdam
- ik ga meestal Amsterdam uit
- ik rij (ongeveer) evenveel in Amsterdam als buiten Amsterdam
- weet ik niet, geen antwoord

V6. Hoe belangrijk is voor u... (telkens met de antwoordopties: van weinig belang; van enig belang; van groot belang; weet ik niet, geen antwoord. Alleen vragen als bij V1a een personenauto gekozen is)

- het bezit van een auto in uw dagelijkse leven?
- het gebruik van een auto in uw dagelijkse leven?

V7. Hoe tevreden bent u over uw elektrische auto op de volgende punten? (telkens met de antwoordopties: zeer tevreden; tevreden; niet tevreden en niet ontevreden; ontevreden; zeer ontevreden; weet ik niet, geen antwoord. Alleen vragen als bij V1a een elektrische auto gekozen is)

- laden in Amsterdam
- laden buiten Amsterdam
- langere afstanden afleggen, zoals op vakantie gaan
- woon-werkverkeer
- de kosten
- het gebruiksgemak en onderhoud

V8. Maakt u gebruik van deelvervoer? (telkens met de antwoordopties: niet; soms; regelmatig; weet ik niet, geen antwoord)

- deelauto (zoals Greenwheels, MyWheels of SnappCar)
- deelscooter (zoals Check of Felyx)
- deelfiets (zoals Donkey Republic of OV fiets)
- deelbakfiets (zoals BAQME)

V9a. Zou u overwegen in de toekomst gebruik te gaan maken van... (telkens met de antwoordopties: nee, zeker niet; nee, waarschijnlijk niet; ja, waarschijnlijk wel; ja, zeker wel; weet ik niet, geen antwoord. Alleen de vervoermiddelen tonen die niet in bezit of gebruik zijn bij V1a of V8)

- een elektrische fiets
- een elektrische bromfiets, snorfiets of scooter

- een kleine elektrische auto (microcar)
- deelauto (zoals Greenwheels, MyWheels of SnappCar)
- deelscooter (zoals Check of Go Sharing)
- deelfiets (zoals Donkey Republic of OV fiets)
- deelbakfiets (zoals BAQME)

V9b. Een kleine elektrische auto kan worden opgeladen aan een laadpaal en aan een normaal stopcontact, maar heeft geen uitneembare accu. Bij het laden moet het voertuig dus worden geparkeerd bij een laadpunt of stopcontact. (alleen vragen wanneer bij V9a is gekozen voor een kleine elektrische auto)

Waar denkt u vooral te gaan laden wanneer u een kleine elektrische auto koopt?

- thuis, buiten aan de gevel, op eigen oprit of in eigen garage
- werk, buiten aan de gevel of een laadpaal
- openbare laadpaal (bij een parkeerplek)
- weet ik niet, geen antwoord

V9c. Een elektrische bromfiets, snorfiets of scooter heeft meestal een uitneembare accu van 4 tot 10 kilo die op te laden is aan een gewoon stopcontact. (alleen vragen wanneer bij V9a is gekozen voor een elektrische bromfiets, snorfiets of scooter)

Waar denkt u vooral te gaan laden wanneer u een elektrische brommer, snorfiets of scooter koopt?

- thuis, binnen aan het stopcontact
- thuis, buiten aan de gevel, op eigen oprit of in eigen garage
- werk, binnen aan het stopcontact
- werk, buiten aan de gevel of een laadpaal
- weet ik niet, geen antwoord

V10. Van de volgende vervoermiddelen verwacht u mogelijk in de toekomst gebruik te maken: (hier de bij V9a gekozen vervoermiddelen tonen) Als u deze zou gebruiken, van welke andere vervoermiddelen verwacht u daardoor minder gebruik te maken? Meerdere antwoorden mogelijk (los van 'openbaar vervoer' en 'lopen' alleen de vervoermiddelen tonen die in bezit of gebruik zijn bij V1a of V8)

- auto op benzine, diesel, CNG of LPG
- hybride auto
- elektrische auto
- kleine elektrische auto (microcar)
- niet-elektrische fiets
- elektrische fiets
- bromfiets, snorfiets of scooter op benzine
- elektrische bromfiets, snorfiets of scooter
- motor
- anders, namelijk
- lopen
- openbaar vervoer
- deelauto (zoals Greenwheels, MyWheels of SnappCar)
- deelscooter (zoals Check of Go Sharing)
- deelfiets (zoals Donkey Republic of OV fiets)
- deelbakfiets (zoals BAQME)
- geen van bovenstaande

- weet ik niet, geen antwoord

V11. Ziet u de volgende vervoermiddelen in het algemeen als vervanging voor het gebruik van personenauto's die de lucht vervuilen in Amsterdam? Het gaat dus niet om uw eigen situatie, maar voor Amsterdam als geheel. (telkens met de antwoordopties: niet; in enige mate; in sterke mate; weet ik niet, geen antwoord)

- openbaar vervoer
- elektrische fiets
- elektrische scooter
- deelvervoer
- kleine elektrische auto

Omdat verkeer de lucht vervuilt, wil de gemeente, naast het verminderen van het verkeer, ook dat het verkeer dat rondrijdt schoner wordt. Om het verkeer schoner te maken is er een Milieuzone (een gebied) voor auto's die op diesel rijden. Dit betekent dat vervuilende dieselauto's niet binnen dit gebied mogen komen.

V12a. Was u bekend met de Milieuzone voor dieselauto's in Amsterdam?

- ja
- voor een deel
- nee
- weet niet, geen antwoord

Ook werkt de gemeente aan de overgang naar het gebruik van elektrische auto's. Een plan van de gemeente is om een zone (gebied) te maken waar helemaal geen vervuilende auto's mogen komen. Dit betekent dat er geen toegang is binnen dit gebied voor dieselauto's, maar ook niet voor auto's die rijden op benzine of gas of voor hybride auto's. Het plan is dat er zo'n gebied komt na 2030. Hoe dit gebied er precies uitziet is nog onduidelijk.

V12b. Was u bekend met dit plan van de gemeente Amsterdam?

- ja
- voor een deel
- nee
- weet niet, geen antwoord

V13a. In de toekomst wil de gemeente dat alle auto's in Amsterdam elektrisch zijn, of op een andere manier uitstootvrij. Hoe denkt u hierover?

- zeer positief
- positief
- niet positief en niet negatief
- negatief
- zeer negatief
- weet ik niet, geen antwoord

V13b. Kunt u uw antwoord toelichten? (open vraag met optie 'weet ik niet, geen antwoord', niet vragen als bij V13a 'weet ik niet, geen antwoord' is geantwoord)

V14a. Hoeveel invloed zou het hebben op uw persoonlijke situatie als alle auto's in Amsterdam elektrisch moeten zijn, of op een andere manier uitstootvrij?

- geen of weinig invloed
- enige invloed
- veel invloed

- weet ik niet, geen antwoord

V14b. Kunt u uw antwoord toelichten? (open vraag met optie 'weet ik niet, geen antwoord', niet vragen als bij V14a 'niet of weinig' of 'weet ik niet, geen antwoord' is geantwoord)

V15. Wat zou u ervan vinden wanneer er op deze locaties vanaf 2030 geen personenauto's meer mogen rijden op brandstof, zoals benzine of diesel? (telkens met de antwoordopties: een zeer goed idee; een goed idee; geen goed idee en geen slecht idee; een slecht idee; een zeer slecht idee; weet ik niet, geen antwoord)

- in uw buurt
- in het centrum van Amsterdam (binnen de centrumring S100)
- binnen de Ring A10 (waar nu de Milieuzone is)
- in heel Amsterdam (binnen de bebouwde kom)

V16. In hoeverre bent u het eens met de volgende stellingen? (telkens met de antwoordopties: helemaal mee eens; mee eens; niet mee eens en niet mee oneens; mee oneens; helemaal mee oneens; weet ik niet, geen antwoord)

- De bewoners en bezoekers van Amsterdam zijn zelf verantwoordelijk voor de overstap naar vervoermiddelen zonder uitstoot.
- De gemeente Amsterdam is ervoor verantwoordelijk dat de bewoners en bezoekers van Amsterdam de overstap naar vervoermiddelen zonder uitstoot maken.
- De landelijke overheid is ervoor verantwoordelijk dat de bewoners en bezoekers van Amsterdam de overstap naar vervoermiddelen zonder uitstoot maken.

V17. Denkt u binnen tien jaar een personenauto te kopen? Als u al een auto bezit dan kan het gaan om een vervangende auto of een extra auto.

- nee, zeker niet
- nee, waarschijnlijk niet
- ja, waarschijnlijk wel
- ja, zeker wel
- weet ik niet, geen antwoord

V18a. Welk type brandstof zou uw voorkeur hebben wanneer u een andere auto koopt? (alleen vragen als bij V17 'ja, waarschijnlijk wel' of 'ja, zeker wel' is geantwoord)

- benzine
- diesel
- hybride
- elektriciteit
- geen voorkeur
- weet ik niet, geen antwoord

V18b. Kunt u uw voorkeur toelichten? (open vraag met optie 'weet ik niet, geen antwoord', niet vragen als bij V18a 'geen voorkeur' of 'weet ik niet, geen antwoord' is geantwoord)

V19. Zou u een elektrische auto overwegen wanneer deze in kosten en in gebruik net zo duur zou zijn als een vergelijkbare auto die op benzine rijdt? (alleen vragen als bij vraag V18a 'benzine', 'diesel' of 'hybride' is geantwoord)

- nee, zeker niet
- nee, waarschijnlijk niet
- ja, waarschijnlijk wel
- ja, zeker wel

- weet ik niet, geen antwoord

V20a. Van welke van onderstaande maatregelen bent u voorstander? Meerdere antwoorden mogelijk.

- een gebied in Amsterdam waarin geen auto's mogen rijden
- een gebied in Amsterdam waarin geen auto's met uitstoot (vervuilende stoffen) mogen rijden
- strengere eisen aan de Milieuzone (gebied met regels voor dieselauto's) die Amsterdam al heeft
- alleen nog parkeervergunningen voor elektrische voertuigen
- hogere parkeertarieven voor auto's die vervuilende stoffen uitstoten
- geen van bovenstaande
- weet ik niet, geen antwoord

V20b. Wat zou u helpen om minder vaak de auto te gebruiken? Meerdere antwoorden mogelijk. (alleen vragen als bij V1a 'benzine, diesel of LPG rijdende auto' en/of 'hybride auto' is geantwoord en niet 'elektrische auto' is geantwoord)

- goedkoper maken van het openbaar vervoer
- het openbaar vervoer vaker, sneller of op meer plekken laten rijden
- fietspaden verbeteren, veiliger fietsverkeer
- vergoeding voor andere manieren om te reizen vanuit uw werkgever
- meer kennis over andere manieren om te reizen, zoals deelvervoer of openbaar vervoer
- meer deelfietsen of deelscooters in de buurt
- anders, namelijk
- geen van bovenstaande
- weet ik niet, geen antwoord

V20c. Wat zou u helpen om elektrisch te gaan rijden? Meerdere antwoorden mogelijk. (alleen vragen als bij V1a 'benzine, diesel of LPG rijdende auto' en/of 'hybride auto' is geantwoord en niet 'elektrische auto' is geantwoord)

- subsidie (geld vanuit de overheid) voor het kopen van een elektrisch voertuig
- een leasecontract of tijdelijke regeling om ervaring op te doen met elektrisch rijden
- meer kennis over het kopen van een elektrische auto
- meer kennis over het gebruiken en laden van een elektrische auto
- steun vanuit uw werkgever (zoals laadpalen op kantoor)
- meer of snellere laadpunten in uw buurt
- geen van bovenstaande
- anders, namelijk
- weet ik niet, geen antwoord

V21a. Voor welk jaar denkt u dat het voor u mogelijk is om over te stappen op elektrisch rijden? Dit is met de eventuele hulp die u bij de vorige vraag gekozen heeft. (alleen vragen als bij V1a 'benzine, diesel en/of LPG rijdende auto' of 'hybride auto' is geantwoord en niet 'elektrische auto' is geantwoord)

- voor 2030
- 2030
- 2035
- 2040
- na 2040
- ik denk niet dat overstappen op elektrisch vervoer voor mij haalbaar is in de toekomst
- weet ik niet, geen antwoord, niet van toepassing

V21b. U heeft aangegeven dat u niet denkt dat overstappen op elektrisch vervoer voor u haalbaar is in de toekomst. Kunt u aangeven waarom? (open vraag met optie ‘weet ik niet, geen antwoord’, alleen vragen als bij V21a geantwoord is ‘ik denk niet dat overstappen op elektrisch vervoer voor mij haalbaar is in de toekomst’)

V22. Welk rijbewijs heeft u? Meerdere antwoorden mogelijk.

- geen
- AM: rijbewijs voor bromfiets, scooter, speedpedelec, snorfiets en brommobiel
- A1/A2: motorrijbewijs
- B: autorijbewijs
- anders, namelijk
- weet ik niet, geen antwoord

V23a. Zijn er vervoermiddelen die u niet kunt gebruiken vanwege een fysieke of andere beperking? Meerdere antwoorden mogelijk.

- lopen
- fiets
- openbaar vervoer
- auto
- kleine elektrische auto (microcar)
- nee, niet van toepassing
- weet ik niet, geen antwoord

V23b. Heeft u een aangepaste auto? Een aangepaste auto is een auto die aangepast is, zodat iemand met een beperking erin kan rijden als passagier of als bestuurder. (alleen vragen als bij V1a een personenauto gekozen is)

- ja
- nee
- weet ik niet, geen antwoord

V24. Wilt u verder nog iets kwijt over de onderwerpen die in deze vragenlijst aan bod zijn gekomen? (open vraag met optie ‘weet ik niet, geen antwoord’)

V25. Mogelijk komt er in 2025 een vervolgonderzoek waarin verder verkend wordt met welk beleid de uitstoot van personenauto’s in Amsterdam verminderd kan worden. Zouden wij u daarvoor mogen benaderen? (open vraag met optie ‘weet ik niet, geen antwoord’)

Achtergrondvragen voor open link (voor stadspaspanel zijn deze gegevens al bekend):

Wat is uw leeftijd?

- ________________
- wil ik niet zeggen

Wat is uw geslacht?

- man
- vrouw
- anders
- wil ik niet zeggen

Wat is uw hoogst voltooide opleiding? Heeft u die opleiding in het buitenland gevolgd en ziet u deze niet in het rijtje staan? Kruis dan de opleiding aan die erop lijkt.

- geen opleiding afgerond
- lagere school, basisschool, speciaal (basis) onderwijs
- lager beroepsonderwijs (LBO, VBO, VSO, MBO niveau 1, praktijkonderwijs)
- VMBO
- MAVO, MULO, ULO
- middelbaar beroepsonderwijs (MBO 2, 3 of 4)
- HAVO, MMS
- VWO, Gymnasium, Atheneum, HBS
- hoger beroepsonderwijs (HBO)
- wetenschappelijk onderwijs (WO), PhD
- anders, namelijk:
- weet ik niet, geen antwoord

In welk stadsdeel woont u?

- Centrum
- Westpoort
- West
- Nieuw-West
- Zuid
- Oost
- Noord
- Zuidoost
- Weesp
- weet ik niet, geen antwoord

C

Supplementary Figures

This chapter presents supplementary figures that provide additional visual material supporting the analyses and conceptual discussions in the main chapters of the thesis. The figures include examples of policy instruments and regulatory frameworks, spatial contextual information, and conceptual pathway diagrams illustrating how specific policy measures may contribute to a socially equitable implementation of a ZEZ. These materials are included to enhance transparency and to further clarify the mechanisms discussed throughout the thesis.

Brussels LEZ standards

The following figures illustrate the emission standards and access requirements for passenger cars in the Brussels LEZ. The first figure shows the requirements for diesel vehicles, while the second presents the standards for petrol, hybrid, LPG, and CNG vehicles.

Diesel/hybride — 2036 zien ▸

Norm	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Euro 7	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 6d - Euro 6e	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 6d-TEMP	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 6 (b, c)	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 5	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 4	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 3	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 2	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 1	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Geen Euro	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘

Figure C.1: Emission standards and access requirements for diesel passenger cars (M1) in the Brussels LEZ. Retrieved from Brussel Heradem (n.d.-a)

Benzine/hybride/LPG/CNG 2036 zien ▸

Norm	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Euro 7	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊘	⊘
Euro 6d - Euro 6e	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊘	⊘
Euro 6d-TEMP	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 6 (b, c)	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 5	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 4	✓	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 3	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 2	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Euro 1	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Geen Euro	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘

Figure C.2: Emission standards and access requirements for petrol/hybrid/LPG/CNG passenger cars (M1) in the Brussels LEZ. Retrieved from Brussel Herademt (n.d.-a)

Shared mobility availability

The following figure illustrates the spatial distribution of shared car availability across the city districts of Amsterdam, providing contextual information on the accessibility of shared mobility services within the city.

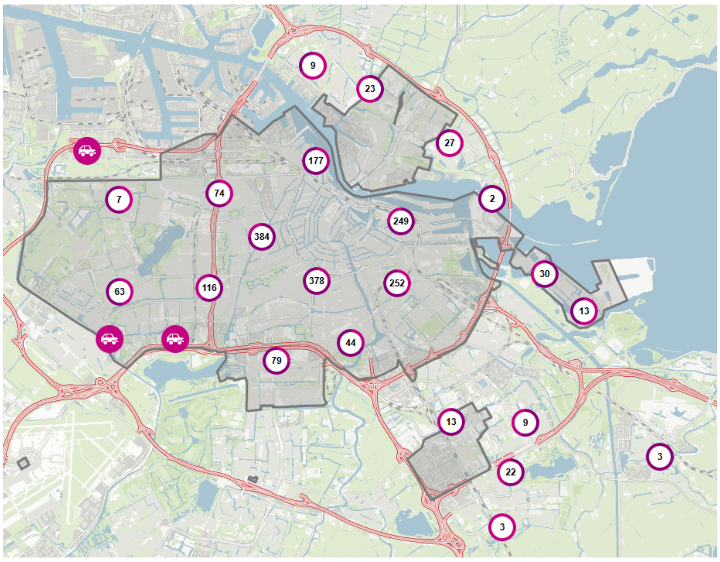

Figure C.3: Spatial availability of shared cars across the city district of Amsterdam. Retrieved from Gemeente Amsterdam (n.d.-a)

Conceptual policy pathways

This section of the appendix illustrates how selected policy measures relate to the conceptual model and may contribute to a socially equitable implementation of a ZEZ. The figures present simplified conceptual pathways linking policy instruments to the mechanisms described in Chapter 4.

These diagrams represent a simplified abstraction of reality. In practice, additional factors and potential trade-offs may influence these relationships. For the purposes of conceptual clarity and readability, the figures focus on the primary pathways identified in the conceptual model.

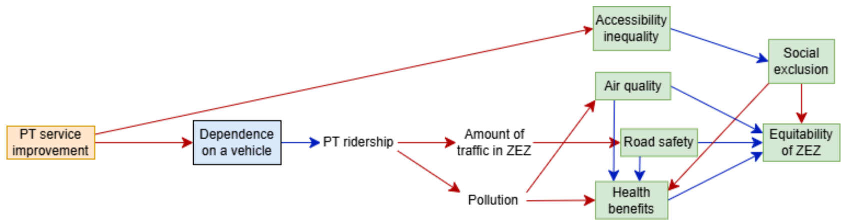

Figure C.4: Conceptual pathway illustrating how improvements in public transport service quality can enhance accessibility and support a more socially equitable implementation of a ZEZ.

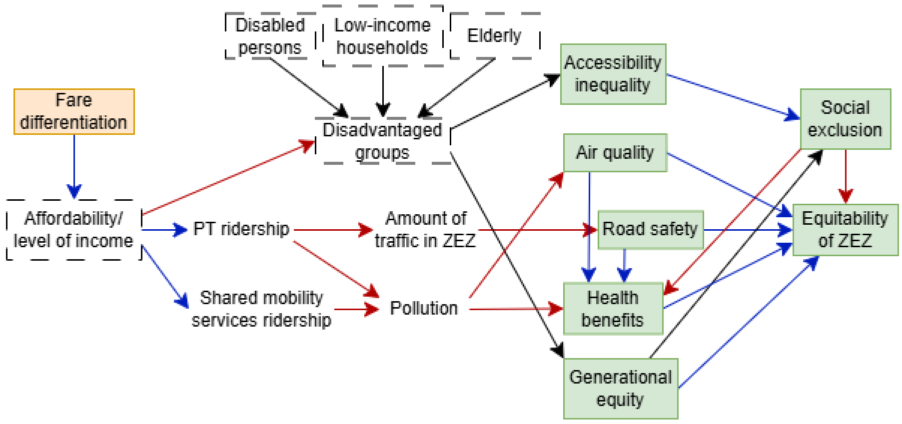

Figure C.5: Conceptual pathway illustrating how fare differentiation for public transport or shared mobility services can improve affordability and accessibility, thereby supporting a more socially equitable implementation of a ZEZ.

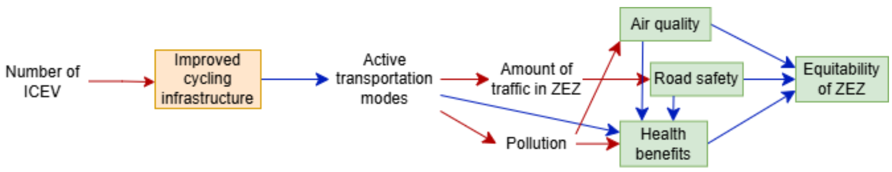

Figure C.6: Conceptual pathway illustrating how improvements in cycling infrastructure can increase the feasibility of cycling as an alternative to private car use, thereby supporting a more socially equitable implementation of a ZEZ.

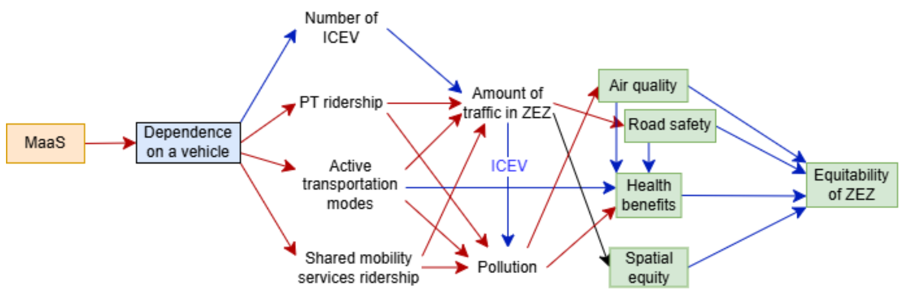

Figure C.7: Conceptual pathway illustrating how Mobility as a Service (MaaS) can improve access to multimodal transport alternatives, thereby supporting a more socially equitable implementation of a ZEZ.

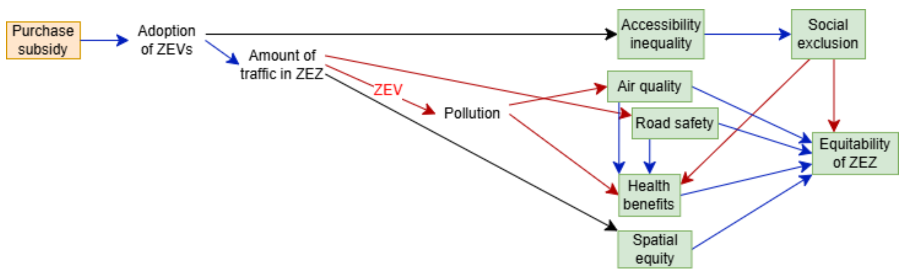

Figure C.8: Conceptual pathway illustrating how purchase subsidies for ZEVs can reduce financial barriers to adoption and support a more socially equitable implementation of a ZEZ.

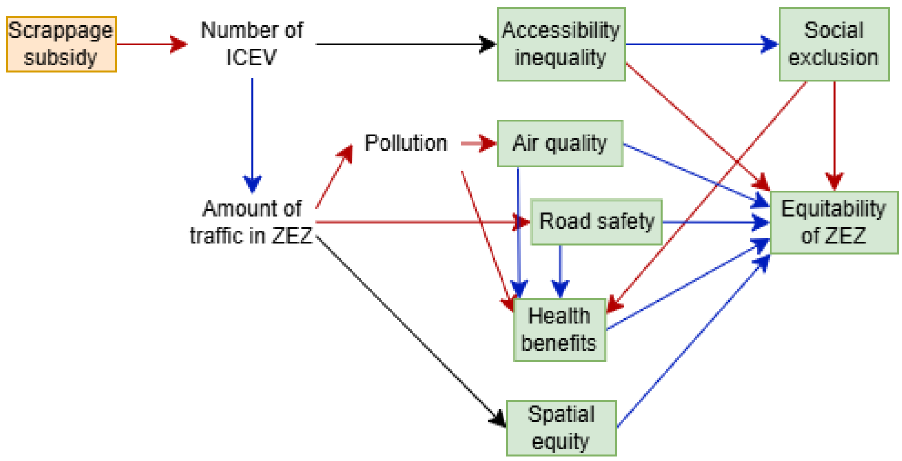

Figure C.9: Conceptual pathway illustrating how scrappage subsidies can support the replacement of older ICEVs, thereby supporting a more socially equitable implementation of a ZEZ.

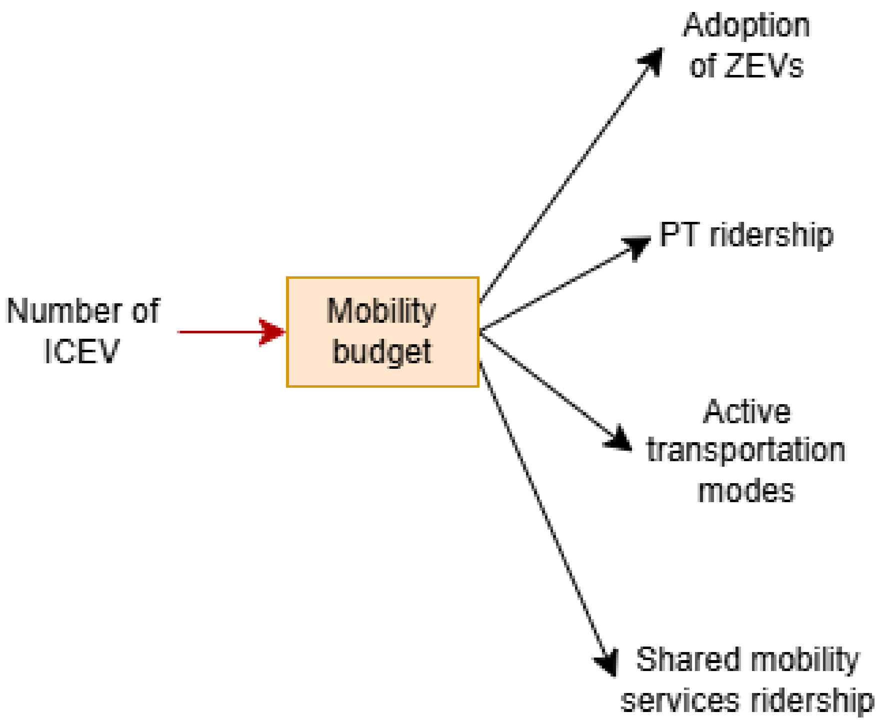

Figure C.10: Conceptual pathway showing the mechanism of a mobility budget scheme in which polluting private cars are replaced by a flexible mobility budget that can be spent on sustainable transport options.

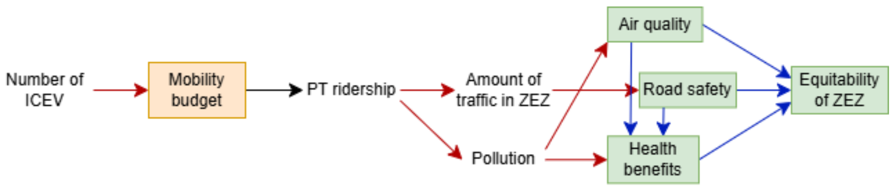

Figure C.11: Conceptual pathway illustrating how surrendering a private ICEV in exchange for a mobility budget can lead to increased public transport ridership.

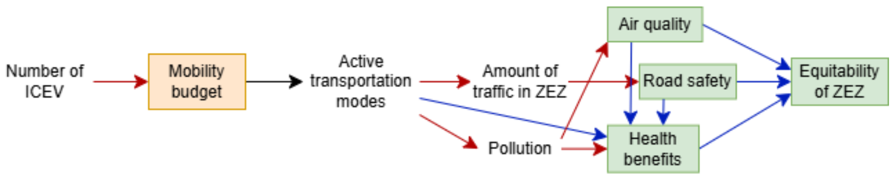

Figure C.12: Conceptual pathway illustrating how surrendering a private ICEV in exchange for a mobility budget can lead to increased use of active transportation modes such as cycling.

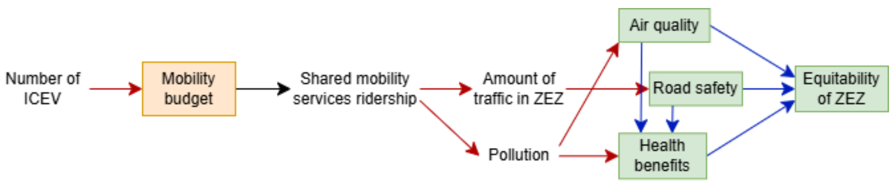

Figure C.13: Conceptual pathway illustrating how surrendering a private ICEV in exchange for a mobility budget can lead to increased use of shared mobility services.

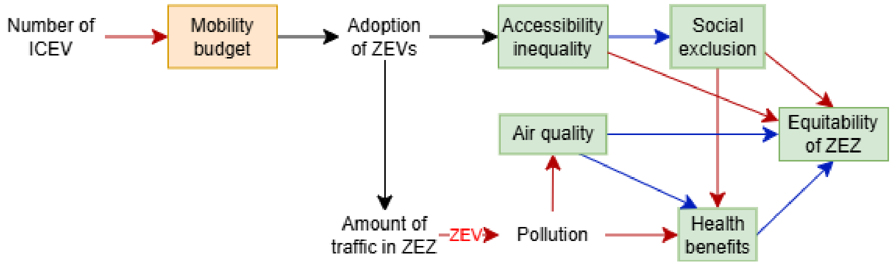

Figure C.14: Conceptual pathway illustrating how surrendering a private ICEV in exchange for a mobility budget can lead to adoption of a ZEV.

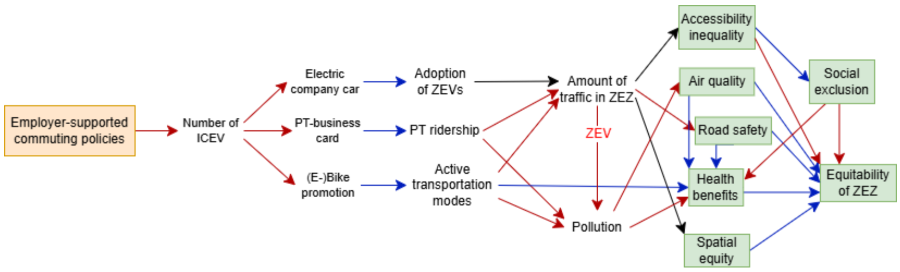

Figure C.15: Conceptual pathway illustrating how employer mobility policies can influence commuting behaviour and promote the use of sustainable transport modes, thereby supporting a more socially equitable implementation of a ZEZ.

D

Interviews

Oxford

Interview date: 3 December 2025
Interviewee: Transport policy officer, Oxfordshire County Council

This interview explored Oxford's experience with implementing a ZEZ, focusing on policy design, implementation challenges, and social considerations. The discussion centred on the ZEZ pilot introduced in Oxford in 2022 and the broader policy context in which it operates.

Policy background and objectives

The interviewee explained that Oxford's ZEZ was introduced as a small-scale pilot in the historic city centre, covering only a limited number of streets. The primary objective was not immediate large-scale emission reduction, but rather to test new systems and minimise risks during early implementation. As the interviewee stated:

> "It was the first zero-emission zone to be introduced and we were using completely new systems and processes, so we just wanted to try something on quite a small scale."

The pilot began in February 2022 and remains in place. Expansion is being considered but is dependent on other ongoing transport policies, including traffic filters and congestion charging. The sequencing of these policies is important, as overlapping schemes could distort monitoring and evaluation.

Public response and implementation experience

Because the pilot covered only a very small area with already limited traffic access, public reaction was relatively muted. Most residents were not directly affected, which helped reduce resistance. According to the interviewee, this limited impact was intentional:

> "Most people are not affected… we chose an area that didn't have a huge impact on a large number of people."

Implementation was generally smooth. Authorities introduced a warning period before issuing fines, allowing users to adapt to the system. Minor issues emerged, mainly related to signage and communication, but no major technical problems occurred. Communication was identified as a continuing challenge, particularly due to misinformation and partial understanding of the scheme.

Policy design and social considerations

The Oxford ZEZ operates as a charging scheme rather than a strict ban, allowing non-compliant vehicles to enter the zone by paying a fee. This design resulted from a long consultation process beginning around 2015. Social justice concerns played a central role in shaping exemptions and discounts, particularly for people with disabilities and residents.

The interviewee emphasised that consultations significantly shaped the final policy:

> "Consultation has changed the scheme more than anything else… it helps ensure the impacts don't fall more heavily on one group than another."

The policy primarily targets traffic entering the city from outside, rather than residents already living within the zone. Most traffic in the area originates from commuters, deliveries, and visitors, while residents generate only a small share of vehicle movements.

Mobility context and alternatives

Oxford's broader mobility system supports the ZEZ. The city has high levels of bus use and cycling, with approximately half of trips to the city centre made by bus and around one-fifth by bicycle. Car use in the centre is relatively low, and extensive park-and-ride facilities provide an alternative for incoming traffic.

The interviewee noted that viable alternatives are essential for such policies:

> "The alternatives are very much in place… if you don't have a bus service, you can drive to the park and ride and catch a bus in from there."

Electric vehicle charging infrastructure is still developing but improving, and future ZEZ revenue may be used to expand charging capacity.

Observed impacts and behavioural change

Monitoring data suggests the pilot has had measurable effects on traffic composition and vehicle behaviour. The interviewee explained that vehicle movements declined across several categories, including cars and delivery vehicles. Some behavioural adjustments were observed, such as more efficient delivery scheduling, where fewer trips were made but deliveries were consolidated.

The interviewee stressed the importance of collecting detailed traffic and emissions data before implementing such schemes. Understanding where traffic originates and which vehicle types contribute most to emissions helps design more effective and targeted policies.

Communication and public debate

Communication was identified as one of the most difficult aspects of implementation. The interviewee explained that complex transport schemes are difficult to convey clearly to the public, particularly in environments shaped by social media and simplified narratives. Misinformation and selective presentation of information were seen as common challenges, especially when exemptions and policy details were not widely understood.

Lessons for other cities

When asked for advice, the interviewee emphasised several key lessons. First, cities should collect detailed data on traffic patterns and emissions to understand likely behavioural responses. Second, extensive consultation is essential to address social concerns and adjust policy design. Finally, policymakers should expect gradual implementation and ongoing adjustment rather than immediate large-scale results.

Overall, the Oxford case illustrates a cautious and incremental approach to ZEZ implementation. The pilot prioritised institutional learning, public acceptability, and system testing, while broader expansion remains dependent on complementary policies and future evaluation.

Eindhoven

Interview date: 11 November 2025
Interviewee: Policy advisor for sustainable mobility, Municipality of Eindhoven

This interview explored Eindhoven's perspective on the potential introduction of a ZEZ for passenger cars, with particular attention to policy feasibility, national coordination, and social distributional effects. The discussion reflected on Eindhoven's broader transition towards cleaner mobility and the institutional constraints shaping current policy development.

Policy orientation and national coordination

The interviewee emphasised that Eindhoven shares similar ambitions to other large Dutch cities in reducing transport emissions and exploring the feasibility of a passenger-car ZEZ. However, the municipality has not yet conducted the same depth of socio-economic and accessibility analysis as some other cities. This was described not as a lack of commitment, but as a reflection of legal uncertainty and the importance of coordinated national action.

Drawing on experience with the ZEZ for freight transport, the interviewee stressed that successful implementation relied heavily on national alignment. Joint legislation, shared design standards, harmonised exemption frameworks, and coordinated communication were all seen as critical elements. Without such coordination, city-specific implementation could create confusion and resistance:

> "If cities move too far ahead of national and European policy, you quickly run into limits of what is socially and politically acceptable."

For this reason, the interviewee argued that a future passenger-car ZEZ should ideally follow a nationally coordinated model rather than being introduced independently by individual municipalities.

Supporting measures and transition policies

Despite these constraints, Eindhoven has implemented several supportive measures that could facilitate a future transition. These include continued expansion of charging infrastructure, scrappage schemes targeting older vehicles, and employer-oriented programmes aimed at accelerating fleet electrification.

The municipality is also exploring broader scrappage approaches that do not simply replace fossil-fuel vehicles with newer internal combustion vehicles. Instead, such schemes could encourage behavioural change by supporting alternatives such as bicycles, public transport subscriptions, or shared mobility options. This approach reflects a wider strategy aimed at reducing overall car dependency rather than focusing solely on vehicle technology.

Distributional impacts and equity considerations

A key theme in the interview was the uneven distribution of policy impacts between residents living inside and outside a potential ZEZ. The interviewee noted that households located within the zone would face the most direct consequences, as non-compliant vehicles would no longer be able to access their homes. This could effectively force residents to replace vehicles that are still economically viable.

In contrast, residents outside the zone would retain car access for most trips but might need to switch modes or use park-and-ride facilities when travelling into the restricted area. As a result, the burden of adjustment would fall disproportionately on inner-zone residents, raising important equity concerns. The interviewee suggested that longer transition periods, targeted exemptions, and financial support could help mitigate these effects.

Policy simplicity and governance

While acknowledging the need for targeted measures, the interviewee cautioned against excessive policy complexity. A highly differentiated system with numerous exemption categories or detailed eligibility rules could undermine transparency and reduce public trust:

> "We must avoid making the framework so complex that no one understands it."

Maintaining a balance between fairness and administrative simplicity was therefore seen as an important design challenge.

Spatial accessibility differences

The interview also highlighted spatial differences within the city. Peripheral areas, particularly at the urban edge, were described as having relatively limited public transport availability, especially during evenings and off-peak periods. In these areas, car use remains essential for accessing employment and daily activities:

> "Some areas, especially at the edge of the city, have very poor alternatives. For many people, the car is essential for reaching work."

This reinforces the importance of complementary measures, such as park-and-ride facilities and multimodal connections, which were seen as offering more realistic transition pathways than strict car exclusion.

Overall perspective

Overall, the Eindhoven perspective reflects a cautious and coordination-oriented approach. The municipality recognises both the environmental rationale for a passenger-car ZEZ and the significant equity risks associated with its implementation. Rather than advancing independently, Eindhoven emphasises national alignment, phased implementation, and institutional simplicity as key conditions for a socially and politically viable transition:

> "For a successful ZEZ you must do it together—cities, national government, and sector organisations."

Utrecht

Interview date: 14 November 2025
Interviewee: Project leader Zero-Emission Zone, Municipality of Utrecht

This interview explored Utrecht's perspective on tightening emission restrictions for passenger cars and the potential future development of a ZEZ. The discussion focused on legal feasibility, equity considerations, and lessons drawn from the implementation of the logistics ZEZ.

Policy context and legal constraints

The interviewee explained that Utrecht has long pursued an ambitious air quality and climate agenda. The city currently operates both an environmental zone targeting older diesel passenger cars and a ZEZ for freight transport. Historically, there has been political ambition to move towards a fully zero-emission inner city by 2030, including potential restrictions on passenger vehicles. However, this ambition is not currently being translated into concrete policy, primarily because national legislation does not yet provide a legal basis for implementing a passenger-car ZEZ.

As a result, while the long-term vision remains, no formal implementation plan is under development. Instead, the municipality is focusing on incremental strengthening of existing environmental measures.

Role and limits of policy evaluation

Within current legal constraints, Utrecht continues to explore the tightening of its environmental zone through scenario-based analysis. Several societal cost–benefit analyses (SCBAs) have been conducted to assess options such as banning petrol vehicles or introducing stricter emission standards. The interviewee emphasised that while SCBAs are useful for structuring debate, they have clear limitations when addressing social impacts:

> "A societal cost–benefit analysis flattens everything into euros, which makes it very difficult to capture transport poverty, car dependence, or social inequality."

This reflects a broader tension between technocratic policy evaluation and the lived realities of mobility restrictions, particularly for lower-income and car-dependent households.

Equity and public health considerations

Equity considerations play a central role in Utrecht's approach to emission policy. The interviewee emphasised that environmental regulation is closely linked to public health outcomes, noting that exposure to poor air quality is unevenly distributed across the population:

> "Lower-income residents suffer most from poor air quality; improving health is a key driver of our environmental zone."

At the same time, the municipality recognises that tightening access restrictions can create new burdens for vulnerable groups. Lessons from the logistics ZEZ have therefore shaped a set of guiding principles for any future passenger-car restrictions: feasibility, fairness, and proportionality.

Exemptions and supportive measures

The interviewee explained that exemptions are unavoidable in emission-based policies but should remain limited in scope and duration:

> "Exemptions are necessary, but they must be temporary and targeted at the people who genuinely cannot comply."

In practice, Utrecht combines stricter regulatory measures with supportive policies. When the environmental zone is tightened in 2027, targeted subsidies will be provided for low-income residents. Importantly, these subsidies are not limited to vehicle replacement but may also support alternative mobility options such as public transport subscriptions or shared mobility services:

> "When we tighten the environmental zone in 2027, we will support low-income residents with subsidies so they can switch to cleaner alternatives."

This reflects a broader policy preference for reducing car dependency rather than simply replacing internal combustion vehicles with electric vehicles.

Future challenges and structural constraints

Looking ahead, the interviewee identified several structural challenges. Electricity grid congestion is becoming an increasing constraint on large-scale electrification, while the pace of transition remains strongly dependent on national regulation and the development of the second-hand electric vehicle market. These factors lie largely outside municipal control, highlighting the limits of local policy action.

Inter-municipal coordination

Finally, the interviewee stressed the importance of coordination between municipalities. Fragmented local rules for passenger-car ZEZs would likely be politically and socially difficult to sustain. The logistics ZEZ was considered successful largely because cities aligned their timelines, exemption frameworks, enforcement systems, and communication strategies. A similar level of harmonisation would be necessary for passenger vehicles to avoid confusion, resistance, and administrative complexity.

Overall perspective

Overall, the Utrecht perspective reflects a cautious and incremental approach centred on legal feasibility, social fairness, and public health. While long-term ambitions for stricter emission restrictions remain, current policy focuses on gradual strengthening of existing measures, supportive transition policies, and coordination across governance levels.

Rotterdam

Interview date: 18 November 2025
Interviewee: Coordinator Zero-Emission Passenger Transport, Municipality of Rotterdam

This interview explored Rotterdam's perspective on the potential introduction of a ZEZ for passenger cars, with particular attention to policy feasibility, spatial inequality, and structural transition challenges.

Policy position and feasibility

The interviewee explained that Rotterdam has not taken a political decision to introduce a passenger-car ZEZ. While the municipality recognises that such a measure could contribute to improved air quality, no formal ambition, implementation timeline, or policy trajectory has been established:

> "Politically, nothing has been decided about a passenger-car zero-emission zone."

A key reason for this cautious stance is the current composition of the vehicle fleet. Fewer than ten percent of passenger cars in Rotterdam are electric, meaning that an immediate or near-term ban on internal combustion engine vehicles would be neither socially acceptable nor practically feasible. In this context, the introduction of a passenger-car ZEZ is considered premature.

Spatial car dependence

The interview highlighted strong spatial differences in car dependence across the city. Reliance on private vehicles increases with distance from the city centre, a pattern that has intensified in recent years. Higher parking costs and reduced parking availability in central areas have displaced car ownership towards outer neighbourhoods, where alternatives are more limited.

For certain groups, including care workers, shift workers in the port, and older residents, public transport is often not a realistic substitute, particularly outside peak hours. For these groups, the car remains structurally essential, raising concerns about accessibility and social inclusion under any restrictive policy.

Current policy focus

Rather than pursuing access restrictions, Rotterdam currently focuses on reducing car dominance through spatial and behavioural measures. The inner city is being reshaped by reallocating road space from cars to cycling infrastructure and green areas, with the aim of discouraging car use without introducing outright bans. Complementary initiatives include mobility coaching and neighbourhood-level programmes designed to support residents in reducing private car ownership.

Equity and social feasibility

Equity considerations play a central role in Rotterdam's assessment of any future passenger-car ZEZ. The interviewee emphasised that lower-income households face significant barriers in accessing the second-hand electric vehicle market, making a forced transition financially unrealistic for many. Any future scheme would therefore require exemptions, financial hardship assessments, and a comprehensive package of complementary policies.

Importantly, the availability of alternatives alone is not sufficient; public transport and cycling must also be affordable, reliable, and practically usable. Without this, emission restrictions risk excluding vulnerable groups or forcing involuntary carlessness.

Lessons from the logistics ZEZ

Rotterdam's experience with the logistics ZEZ has shaped its cautious approach. Stable policy timelines were identified as essential, as delays or changing deadlines undermine actors who have already invested in electrification. Exemptions are necessary to ensure feasibility, but must remain temporary to maintain policy credibility and avoid weakening long-term transition signals.

Structural challenges and future outlook

Looking ahead, several structural challenges were identified. These include the need for a substantial expansion of charging infrastructure, increasing electricity grid congestion, and growing competition for limited street space. Social equity remains a major concern, particularly the risk that lower-income households or residents with limited mobility could be excluded if alternatives remain insufficient.

Behavioural resistance was also highlighted as an important barrier, especially persistent negative attitudes towards electric vehicles, which may slow acceptance of stricter emission policies.

Overall perspective

Overall, the Rotterdam perspective reflects a governance pathway that prioritises incremental change and reduction of car dominance over immediate access restrictions. While the municipality does not reject the idea of a passenger-car ZEZ in principle, it currently considers the social, infrastructural, and political conditions insufficiently developed to support such a measure in an equitable and feasible manner.

The Hague

Interview date: 22 October 2025
Interviewee: Policy advisor, Municipality of The Hague

This interview explored The Hague's perspective on the potential introduction of a ZEZ for passenger cars, focusing on political feasibility, structural mobility conditions, and equity considerations.

Urban context and policy environment

The interviewee described The Hague as a city with relatively high car ownership and a spatial structure that supports car use. Employment and travel patterns are often oriented towards destinations outside the city centre, reinforcing reliance on private vehicles. This broader context shapes both mobility policy and political expectations, contributing to the city's longstanding reputation as a car-oriented urban environment.

Political feasibility

At present, the municipality has no plans to introduce a passenger-car ZEZ. According to the interviewee, such a policy is not politically feasible under the current city council, nor within the existing national legal framework. Efforts to further restrict polluting vehicles often encounter strong resistance, and the city is perceived as less ambitious than some other Dutch municipalities:

> "A zero-emission zone for passenger cars is politically impossible for us right now."

This political context significantly limits the scope for advancing access-based restrictions on private vehicles.

Equity and social considerations

Equity concerns were identified as central to the municipality's cautious stance. Many residents rely on older second-hand vehicles, and the financial barrier to electric vehicle adoption remains substantial. In several neighbourhoods, car ownership is closely linked to necessity rather than preference, making rapid tightening of access rules socially sensitive:

> "Low-income residents rely on older cars; they simply cannot afford an electric vehicle."

The interviewee emphasised that restrictive policies could disproportionately affect lower-income households, raising concerns about fairness and social inclusion.

Accessibility and mobility structure

Car dependency is further reinforced by spatial differences in transport accessibility. While public transport provision in the city centre is relatively strong, coverage and service quality decline in outer areas, where many residents rely on the car to reach employment locations, industrial zones, or neighbouring municipalities:

> "Our public transport is good in the centre, but once you go outward it becomes much weaker."

Compared to some other major Dutch cities, The Hague also faces structural limitations in its public transport system. The absence of a metro network reduces the availability of high-capacity, city-wide alternatives, particularly for longer or cross-city trips. This limits the municipality's ability to offset car restrictions with credible substitutes.

Overall perspective

Overall, The Hague's position reflects a combination of political caution, structural constraints, and equity concerns. While the municipality recognises the environmental rationale behind ZEZs, current social, infrastructural, and political conditions are considered insufficient to support a passenger-car ZEZ without significant costs. As a result, the city prioritises gradual improvements to mobility and environmental quality rather than pursuing access-based restrictions on private vehicles.

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Use of Artificial Intelligence

During the preparation of this thesis, artificial intelligence (AI) tools were used in a supportive role. AI was consulted primarily to improve clarity of expression, refine wording, and correct spelling and grammatical errors. It was also used occasionally as a feedback instrument for minor textual adjustments related to structure and readability. All substantive elements of the research, including the research design, conceptual framework, data analysis, interpretation of findings, and overall argumentation, were developed by the author. The use of AI was limited to editorial support and were carried out using ChatGPT. In addition, AI was used to assist with the transcription of the interviews conducted for this research. This transcription was performed using Microsoft Teams.